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Recovery Potential Assessment for Eastern Cape Breton Atlantic Salmon (*Salmo salar*): Habitat Requirements and Availability; and Threats to Populations

A.J.F. Gibson, T.L. Horsman, J.S. Ford, and E.A. Halfyard

Fisheries and Oceans Canada
Science Branch, Maritimes Region
P.O. Box 1006, Dartmouth, Nova Scotia
Canada, B2Y 4A2

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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

The purpose of this Research Document is to provide background information on the habitat characteristics required by Atlantic Salmon in eastern Cape Breton to complete their life-cycle, as well as the stressors and threats impacting those processes. The document includes information related to:

1. functional descriptions of habitat properties,
2. the spatial extent of areas in eastern Cape Breton having these properties,
3. identified threats to habitat, as well as threats to populations that are not habitat-related,
4. the extent to which threats have reduced habitat quality or quantity in eastern Cape Breton, and
5. the potential for mitigation of identified threats.

Each of these components was requested by the Terms of Reference for the Recovery Potential Assessment for eastern Cape Breton salmon. Information is presented for the fresh water and marine (and estuarine where appropriate) environments separately.

Habitat requirements of Atlantic Salmon in freshwater include properties, such as water quality, substrate composition, discharge characteristics, and accessibility. Several life stages (eggs, age-0, age-1 and age-2+ juveniles) have residences that individuals defend and that are required to support essential life-cycle processes. At the current low population sizes of eastern Cape Breton Atlantic Salmon, freshwater habitats are unlikely to be limiting recovery in rivers as there remains a large proportion of accessible area.

Habitat requirements in marine and estuarine environments have not been delineated spatially, but are thought to be primarily related to food availability and oceanographic conditions, as individuals require resources and water conditions that support rapid growth. As such, the areas occupied by Atlantic Salmon populations from eastern Cape Breton likely vary over time with oceanographic environments (currents, temperature, food availability). Tagging data are limited, however, eastern Cape Breton salmon are likely to use much of the northwest Atlantic, in particular the waters of coastal Cape Breton, the southern coast of Newfoundland, western Newfoundland, the Labrador sea and the West Greenland sea. There is no evidence for a residence in the marine environment. Research on population dynamics of Atlantic Salmon demonstrate that survival in the marine environment is not resource-limited, so the availability of habitat in marine environments is not limiting population size.

Threats have been identified that are likely to have an effect on Atlantic Salmon populations in eastern Cape Breton, either historically, currently or in the future. In general, the linkages between threats and changes to Atlantic Salmon populations have been established in the scientific literature, but have not been quantified for specific eastern Cape Breton rivers. Where possible, the relative magnitude of a specific threat has been quantified among watersheds in eastern Cape Breton using GIS (Geographic Information Systems) analyses. In freshwater environments, it is likely that these threats have resulted in an overall reduction in habitat quality. The feasibility of restoring habitats to higher values is likely greater in freshwater environments than in marine because it is possible to quantify the impact of a given threat on a population, and the threats are more localized and tractable to address in the short-term.

Évaluation du potentiel de rétablissement du saumon de l'Atlantique (*Salmo salar*) de l'est du Cap-Breton : besoins et disponibilité en matière d'habitat, et menaces sur les populations

RÉSUMÉ

L'objectif du présent document de recherche est de fournir des renseignements généraux sur les caractéristiques de l'habitat dont a besoin le saumon de l'Atlantique dans l'est du Cap-Breton pour compléter son cycle de vie, ainsi que sur les agents de stress et les menaces ayant des répercussions sur ces processus. Le document contient des renseignements relatifs :

1. aux descriptions fonctionnelles des propriétés de l'habitat;
2. à l'étendue spatiale des secteurs de l'est du Cap-Breton qui ont ces propriétés;
3. aux menaces pour l'habitat qui ont été déterminées ainsi qu'aux menaces sur les populations qui ne sont pas liées à l'habitat;
4. à la mesure dans laquelle les menaces ont diminué la qualité ou la quantité des habitats dans l'est du Cap-Breton;
5. aux possibilités d'atténuation des menaces déterminées.

Chacun de ces éléments était exigé dans le cadre de référence pour l'évaluation du potentiel de rétablissement du saumon de l'est du Cap-Breton. Les renseignements sont donnés séparément pour les milieux d'eau douce et les milieux marins (et estuariens, le cas échéant).

Les besoins du saumon de l'Atlantique en matière d'habitat d'eau douce comprennent des propriétés comme la qualité de l'eau, la composition du substrat, les caractéristiques d'écoulement de l'eau et l'accessibilité. Plusieurs stades biologiques (œufs, âge 0, âge 1 et âge 2+ et juvéniles) ont des résidences que les individus défendent et qui sont nécessaires pour soutenir les processus essentiels du cycle de vie. Les niveaux actuels des populations de saumons de l'Atlantique de l'est du Cap-Breton sont faibles, mais il est peu probable que les habitats d'eau douce limitent le rétablissement de l'espèce dans les rivières, car il reste une grande proportion de zone accessible.

Les besoins en matière d'habitat dans les milieux marins et estuariens n'ont pas été délimités géographiquement. Cependant, on pense que ces habitats sont essentiellement liés à la disponibilité de la nourriture et aux conditions océanographiques, puisque les individus ont besoin de ressources et de conditions aquatiques qui favorisent une croissance rapide. Ainsi, il est probable que les zones occupées par les populations de saumons de l'Atlantique de l'est du Cap-Breton changent avec le temps en fonction des milieux océanographiques (courants, température, disponibilité de la nourriture). Les données de marquage sont limitées. Toutefois, il est probable que le saumon de l'est du Cap-Breton utilise la plus grande partie de l'Atlantique Nord-Ouest, plus précisément les eaux côtières du Cap-Breton, les eaux de la côte sud et de l'ouest de Terre-Neuve, la mer du Labrador et les eaux de la côte ouest du Groenland. Il n'y a aucune preuve de résidence dans le milieu marin. Les recherches sur la dynamique des populations de saumons de l'Atlantique montrent que la survie dans le milieu marin n'est pas limitée par les ressources, ce qui fait que la disponibilité des habitats dans les milieux marins ne limite pas la taille de la population.

On a déterminé des menaces susceptibles d'avoir des incidences sur les populations de saumons de l'Atlantique à l'est du Cap-Breton, soit par le passé, à l'heure actuelle ou à l'avenir. En règle générale, les liens entre les menaces et les changements dans les populations de saumons de l'Atlantique ont été établis dans les documents scientifiques, mais ils n'ont pas été

quantifiés pour les rivières de l'est du Cap-Breton. Là où c'était possible, l'importance relative d'une menace particulière a été quantifiée dans des bassins versants de l'est du Cap-Breton en utilisant des analyses du SIG (système d'information géographique). Il est probable que ces menaces ont eu pour conséquence la réduction globale de la qualité de l'habitat dans les milieux d'eau douce. La faisabilité de la restauration des habitats à des niveaux supérieurs est probablement plus grande dans les milieux d'eau douce que dans les milieux marins, parce qu'il est possible de quantifier les incidences d'une menace donnée sur les populations et que les menaces sont plus localisées et plus faciles à traiter à court terme.

1.0 INTRODUCTION

Atlantic Salmon of the Eastern Cape Breton Designatable Unit (ECB DU) occupy rivers from the northern tip of Cape Breton (approximately 47° 02’ N, 60° 35’ W) along the Atlantic Coast to the Canso Causeway (approximately 45° 39’ N, 61° 25’ W), including all rivers in Victoria, Cape Breton, and Richmond counties, and rivers in Inverness County that drain into the Bras d’Or Lakes (Figure 1). It is one of 16 Atlantic Salmon DUs whose conservation status was assessed by the Committee on the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010), and is one of the five DUs whose status was determined to be “Endangered” during that assessment.

When COSEWIC has evaluated 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 which require scientific information about the species or DU. Formulation of this scientific ice has typically been developed through a Recovery Potential Assessment (RPA). This information is then used in *SARA* processes including consultations, listing decisions and recovery planning. In support of the RPA process, four research documents were prepared to provide information about eastern Cape Breton Atlantic Salmon populations. This research document is focused on habitat requirements, habitat availability, and status and threats to populations.

The Terms of Reference (TOR) developed to guide this RPA process contained a set of 27 objectives. The specific objectives addressed within this document are:

Assess current/recent species status

6. Evaluate residence requirements for the species, if any.

Assess the habitat use

7. Provide functional descriptions (as defined in DFO 2007) 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. 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.
18. 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.
19. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

The three other research documents contain information about:

1. abundance, trends and recovery targets for eastern Cape Breton salmon populations (Levy and Gibson 2014);
2. life history parameters, population dynamics and population viability (Gibson and Levy 2014), and
3. information about genetic structuring among salmon populations in eastern Cape Breton (O'Reilly et al. 2013).

Further information about the assessments and status of eastern Cape Breton Atlantic Salmon populations can be found in: DFO (2012), Gibson and Bowlby (2009) and Robichaud-Leblanc and Amiro (2004).

1.1 SALMON RIVERS IN EASTERN CAPE BRETON

Thirty rivers in the ECB DU have records of Atlantic Salmon catch in the recreational fishery between 1983 and 2008 (Gibson and Bowlby 2009). The North Atlantic Salmon Conservation Organization (NASCO) identified 45 watersheds in this DU that are thought to support or to have supported Atlantic Salmon (Figure 2). These 45 watersheds, plus Indian Brook in Cape Breton County, were used as the basis for the analysis of habitats and threats for eastern Cape Breton. However, there are a much larger number of smaller or unassessed watersheds draining into the Atlantic Coast or Bras d'Or Lakes in eastern Cape Breton, and it is likely that salmon use or would have used these habitats as well. There is no known minimum size of a river for occupancy. Additionally, wild Atlantic Salmon populations exhibit nearly precise homing behavior to natal rivers, to the extent that each river is thought to contain a more or less distinct population, and larger rivers may include more than one population.

Rivers in eastern Cape Breton are generally considered to have better water quality and to be less impacted by human activities than other rivers along Nova Scotia's Atlantic coast (Amiro et al. 2006). Rivers draining the Cape Breton Highlands and into the western Bras d'Or Lakes (watersheds 1-14 in Figure 2) are generally steeper than rivers east of the Lakes, especially the coastal rivers flowing directly into the Atlantic Ocean. Five of the six rivers in this DU for which adult salmon abundance has been assessed originate in the Cape Breton Highlands, and are characteristic of this area, with steep stream gradients and relatively good water quality (Gibson and Bowlby 2009, Davis and Browne 1996). Rivers entering into the Bras d'Or on the eastern side of the lake are mostly small, short systems with few lakes in their upper reaches. The sixth assessed river, the Grand River, drains an area of the Cape Breton Lowlands and entering the Atlantic Ocean near St. Peters in southern Cape Breton, is more typical of rivers in the Lowlands region, with a lower mean stream gradient, lower seasonal water flow and temperatures that are moderated by mid-reach lakes (Robichaud-LeBlanc and Amiro 2004).

A review of the conservation status of Atlantic Salmon populations in Canada suggested dividing the ECB DU into two segments or conservation units, to reflect the differences in the river types and life history east and west of the Lakes (DFO and MNRF 2008). Subsequently, Gibson and Bowlby (2009) analysed proportions of small (one sea-winter; 1SW) salmon in the recreational catch in 18 rivers in eastern Cape Breton. In all rivers west of the Bras d'Or Lakes, the majority of the catch was large salmon (means ranged from 20-40% small salmon), while most rivers east of the Bras d'Or Lakes had mainly small salmon in the catch (means ranged from 40-90% small salmon). Robichaud-LeBlanc and Amiro (2004) note that in the Grand River (east of the Bras d'Or), the large salmon that are found are principally repeat-spawning 1SW fish rather than 2SW (two sea-winters) as in many rivers west of the Bras d'Or Lakes.

These differences in the proportion of fish maturing after one winter at sea (1SW), as well as the habitat differences between the two areas (east and west) were the basis for separating the ECB DU into two conservation units in the conservation status report. COSEWIC (2010) concluded that “Differences in freshwater habitat (e.g. stream gradient) and divergent demographic trends suggest there is some structuring within the DU.”, but opted to group eastern Cape Breton rivers as one DU due to a lack of infomation about genetic structuring among populations in these two areas.

2.0 FUNCTIONAL DESCRIPTION OF HABITAT PROPERTIES (TOR 7)

The text in this section borrows heavily from the review provided in Bowbly et al. (2014), with minor adaptation for populations in eastern Cape Breton.

2.1 FRESHWATER ENVIRONMENT

Returning adults and spawning

Run timing of adult salmon in the ECB DU is population-specific. Adult Atlantic Salmon in some rivers are thought to return as early as May, but in many rivers the largest proportion of the population enters the rivers in late fall. As such, the length of time that adults remain in fresh water prior to spawning can vary from a few days or a couple of weeks up to 4-6 months. Particularly for populations with extended residency, the upstream migration of salmon can consist of two main phases: a migration phase with steady progress upriver interspersed with stationary resting periods, and a long residence period called the holding phase (Thorstad et al. 2011).

Bowlby et al. (2014) describe the habitat properties required for successful migration as follows:

> “Habitat properties required for the successful migration of adult salmon into rivers are:
>
> 1. appropriate river discharge,
> 2. pools of sufficient depth and proximity in which to hold, and
> 3. unimpeded access throughout the length of the river.
>
> The migration phase within rivers appears to be largely dependent on river discharge, with numerous studies reporting an increased tendency to move up rivers under higher water conditions. It has been suggested that upstream migration will initiate at a river discharge rate of >0.09 m^3/s per meter of river width (Power 1981). Once in the river, changes in discharge are likely important for stimulating upstream movement and allowing accessibility upstream of migration barriers (e.g. shallow riffle areas, small falls, fishways, etc.). However, responses of salmon to changes in discharge have been found to be extremely variable and there is no median flow or flow pattern that is consistently preferred (Thorstad et al. 2011). River discharge is a highly significant habitat property, given its influence on the age and size composition of returning adults

> (Jonsson et al. 1991), as well as the distribution of adult spawners in a river (Moir et al. 2004, Mitchell and Cunjak 2007), factors which ultimately dictate production in the system.
>
> While adult salmon are resident in fresh water, they typically occupy holding pools and may spend weeks to months in a single pool (Bardonnet and Bagliniere 2000). These pools:
>
> 1. dissipate hydraulic 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.
>
> Long duration, extreme low flows reduce pool depths and result in increased summer water temperatures, which can lead to increased stress on fish. High water temperatures have been linked to increased disease susceptibility and lower fecundity in adult salmon (McCullough 1999), as well as increased mortality following recreational angling (ICES 2009)."

Incubation and emergence

Atlantic Salmon in eastern Cape Breton spawn primarily in November, with eggs incubating in redds through the winter and hatching in April.

Bowlby et al. (2014) describe the habitat properties required for incubation and emergence:

> "Atlantic salmon in the Southern Upland spawn in late fall (October-November), with eggs incubating in redds through the winter and hatching in April (Scott and Crossman 1973). Successful incubation and emergence of juveniles depends on:
>
> 1. river discharge,
> 2. water depth and velocity,
> 3. substrate composition,
> 4. water temperature, and
> 5. water quality.
>
> Redds dug by female salmon are generally located in gravel riffles at the tails of pools where water depth is decreasing and current flow is accelerating (White 1949, Gibson 1993). Commonly used water depths for redd 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). 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). Steady, continuous water flow is necessary to ensure provision of fresh oxygen to the eggs, and removal of toxins and metabolites from the redd (Moir et al. 1998, LaPointe et al. 2004). Therefore, low to moderate river discharge, ideally without rapid transitions among water levels, is an important habitat variable for the incubating eggs and alevins.
>
> The substrate composition of Atlantic salmon redds must have sufficient permeability and porosity to allow delivery of well oxygenated water (>4.5 mg/L dissolved oxygen; Davis 1975) to the developing embryo, but also allow for sufficient flow to remove metabolic waste generated during development (Scrivener and Brownlee 1989). Coarse gravel and cobble with a median grain size between 15 and 30 mm forms the majority of the substrate, with fine sediments found at low concentrations (generally <12% (by volume); Moir et al. 1998, Crisp and Carling 1989). Selection of substrate

> size by the spawning female is, in part, size dependent, with larger salmonids selecting larger substrate. Similarly, the depth of redd excavation is dependent upon the size of the female digging (Crisp and Carling 1989, Gibson 1993), but is in the range of 14 cm (for a 1SW female) to 30 cm (for a MSW female) (Gibson 1993).
>
> In general, alevins remain in the gravel absorbing the yolk sac until spring when they emerge (Scott and Crossman 1973). Egg development time in the gravel is dependent upon temperature and the fines content of the streambed in which they are developing. Stable cold temperatures are the optimal habitat, while major temperature fluctuations or extreme cold periods may be problematic to incubating eggs (Crisp 1981, 1988, MacCrimmon and Gots 1986). In terms of water quality, developing salmon embryos and alevins require clean (uncontaminated) water with a pH >5.0 for appropriate development."

Juvenile development

Upon emergence from the gravel, juvenile Atlantic Salmon can remain in fresh water for one to more than four years, although in eastern Cape Breton, the majority of juveniles undergo smoltification and migrate to sea in their second or third year (Chaput et al. 2006, Levy and Gibson 2014). Juveniles in their first year (age 0) are termed fry, and older juveniles (age-1 and older) are termed parr.

Bowlby et al. (2014) describe the following important habitat characteristics for the successful rearing of juveniles:

> "Habitat characteristics that are important for the successful rearing of juveniles (fry and parr) include:
>
> 1. water depth and velocity,
> 2. substrate composition,
> 3. the presence of cover,
> 4. water temperature, and
> 5. water quality.
>
> Juvenile Atlantic salmon can be found in a wide range of habitat types in a watershed, including riffles, runs, pools, ponds, lakes, slow moving weedy stream segments, estuaries and small tributaries (DeGraaf and Bain 1986, Erkinaro and Gibson 1997). The potential for dispersal from spawning areas increases with juvenile size (Armstrong 2005), with fry exhibiting limited dispersal from hatching locations, while parr have greater potential for movement and thus habitat choice. Although preferred habitats (here defined as having the highest density of juveniles) vary according to juvenile abundance (density dependent habitat selection; Bult et al. 1999, Gibson et al. 2008a), juvenile salmon habitat is typified as riffle areas with gravel or cobble substrate (Gibson 1993). Optimal stream gradients are between 0.5 to 1.5% (Amiro 1993), however, a wider range of gradient categories are occupied when juvenile abundance is high (Gibson et al. 2008a). Occupied habitats also change seasonally, with juveniles moving from riffles in summer to pools and deeper riffles in autumn, as well as to protected areas (overhanging banks, among large rocks, under boulders) depending on water conditions and temperature (Saunders and Gee 1964). In winter, fry and parr seek out sheltered areas predominantly within the streambed itself (Heggenes 1990); possibly as protection from ice scour as well as to minimize energy expenditure.
>
> Water depth and velocity are two key determinants of the amount of energy required to occupy a given habitat for juvenile Atlantic salmon (Johansen et al. 2005). Preferred

> depths from habitat suitability curves suggest fry tend to occupy water 15-25 cm deep. Although older parr show a similar preferred depth range, they will occupy habitats in deeper water more frequently than fry (Heggenes 1990, Scruton and Gibson 1993). Salmon fry tend to be found in riffles with surface velocities >40 cm/s, while parr are found in a wider range of velocities with an optimum between 20-40 cm/s (Heggenes 1990). Juvenile Atlantic salmon are rarely found at water velocities <5 cm/s or >100 cm/s (Heggenes 1990). During winter, juveniles seek out lower velocity water, presumably to minimize energy expenditure (Rimmer et al. 1984).
>
> Substrate is considered to be one of the main habitat characteristics that determine the suitability of a riverine area for juvenile rearing (DeGraaf and Bain 1986, Cunjak 1988). Preferred substrate for age 0 salmon is in the range 16-256 mm diameter (gravel to cobble) and 64-512 mm diameter (cobble to boulder) for age 1 and older (Heggenes 1990, Heggenes et al. 1999). Within a given reach of river, juvenile salmon are territorial and occupy territories associated with home stones. These home stones provide eddies and spaces for juvenile salmon to shelter from currents, thus limiting the energy expenditure necessary to maintain position in a fluvial environment (Cutts et al. 1999a). In autumn, coarse substrate (>20 cm diameter) provides shelter for juveniles in the interstitial spaces among the rocks (Rimmer et al. 1984, Cunjak 1988, Heggenes 1990).
>
> Cover is an important habitat property which provides thermal refuge during summer, protects juveniles from predators (Gibson 1993), and limits the potential for inter- or intra-species competition through visual isolation (Grant et al. 1998). Cover types include large substrate (cobble and boulder), large woody debris and undercut banks, overhead vegetation, or broken water surfaces (riffles).
>
> Juvenile Atlantic salmon prefer freshwater environments with moderate water temperatures, typically between 15ºC and 25ºC (Gibson 2002). Such conditions are thought to maximize the potential for juvenile growth and survival. Juvenile Atlantic salmon will modify their behaviour in response to changes in water temperature, moving to deeper areas or those with groundwater upwelling at temperatures above 24ºC (Gibson 1993).
>
> The juvenile life stages of Atlantic salmon are more tolerant of low pH than developing eggs or alevins (Lacroix and Knox 2005a), but still require clean (uncontaminated) water of pH >5.4 for appropriate development."

Smolts

Bowlby et al. (2014) describe the important environmental characteristics for smolt migration as follows:

> "The process of smoltification includes all of the physiological, behavioural, and morphological adaptations that juvenile Atlantic salmon undergo to enable survival at sea (Duston et al. 1991, McCormick et al. 1998). Smolts do not have the same freshwater habitat requirements as parr, but rather require the environmental conditions necessary to trigger the changes associated with smoltification as well as to successfully emigrate to salt water. Environmental characteristics influencing the process of smoltification are:
>
> 1. photoperiod,
> 2. water temperature, and
> 3. river discharge.
>
> The main characteristics influencing successful emigration from the river are:

1. unimpeded access throughout the length of the river, and
2. sufficient river discharge.

> Juvenile Atlantic salmon are physiologically able to make the transition from fresh water to salt water for a limited period of time only, which appears to be dependent on water conditions and day length (McCormick et al. 1999). Several environmental factors are postulated to act together to initiate downstream migration and smoltification, including photoperiod, temperature and changes in water flow. Temperature is generally considered the proximate cue to migrate, with juveniles responding to a threshold temperature (approximately 10°C) in some systems (Power 1981, McCormick et al. 1998, Moore et al. 1995, Friedland et al. 2003), to the rate of change in temperature (i.e. degree-days) in others (McCormick et al. 1998, Zydlewski et al. 2005), and to a combination of actual temperature and temperature increase in others (Jonsson and Ruud-Hansen 1985). There is some evidence that smolt migration may be initiated by spring peak water discharge (Jonsson 1991) and that they migrate more rapidly at high water flow than low (McCormick et al. 1998).
>
> Behavioural changes by smolts during downstream migration include increased negative rheotaxis (i.e. moving downstream rather than holding position) and schooling, decreased agonistic and territorial behaviour, and increased salinity preference (McCormick et al. 1998). Individuals may passively drift or actively swim (Fangstam 1993), with the majority moving at night (Moore et al. 1995)."

The timing of smolt migrations for populations within the ECB DU is relatively unstudied, but based on monitoring programs in the Southern Upland and Gulf rivers in western Cape Breton, most smolts would be expected to migrate during May (although the smolt run may begin in late April and generally would extend into June).

Kelts

Relatively little is known about freshwater habitat use by post-spawning adult salmon (kelts) in eastern Cape Breton, and considerable variability may exist among river systems.

Bowlby et al. (2014) summarize freshwater habitat use by kelts as follows:

> "There is thought to be a component of the kelt population that exits the river relatively quickly after spawning; however, kelts have also been shown to overwinter in deep water habitats and descend the river in the spring (Bardonnet and Bagliniere 2000, Hubley et al. 2008), or to overwinter 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 stillwaters in the watershed (Bardonnet and Bagliniere 2000)."

2.2 ESTUARINE ENVIRONMENT

There is little to no information about the use of estuaries by salmon that is specific to eastern Cape Breton. As is the case in other areas, estuarine habitat use is likely variable depending on the characteristics of the estuary. Given its size and characterization as an "inland sea", the Bras d'Or Lakes may have an important role in the life-cycle of salmon for those rivers draining into the Bras d'Or Lakes.

Postsmolts

Bowlby et al. (2014) provided the following review of estuarine habitat use by postsmolts:

> "Once smolts enter estuaries, there does not appear to be a prolonged period of acclimation to salt water given that smolts are actively swimming and move continuously through the estuary (i.e. they do not spend periods resting above the

> substrate) (Lacroix and Knox 2005b, Moore 1998). Migration patterns are not necessarily directly toward the open ocean; a proportion of the population typically moves in various directions over short temporal and spatial scales (Thorstad et al. 2011), leading to various residency times in the estuary. This cyclical movement pattern has been exhibited by Southern Upland smolts (Halfyard et al. 2013). Research on four Southern Upland Atlantic salmon populations (LaHave, Gold and St. Mary's rivers, and West River, Sheet Harbour) suggest that mean swimming speeds increase once smolts enter the estuary, and can range from 0.55 body lengths per second in the Gold River to 1.15 body lengths per second in the St. Mary's River (Halfyard et al. 2012). Higher mortality rates were associated with extended residency in the estuary and with more frequent upstream movements, while lower mortality rates were associated with more unidirectional and rapid movements toward open ocean (Halfyard et al. 2013). These patterns were hypothesized to result from the degree of acidification among river systems, where multiple changes in swimming direction were potentially an acclimation strategy for fish with compromised osmoregulatory capacity associated with acidity (McCormick et al. 2009) and other contaminants (Fairchild et al. 1999).
>
> Residency patterns only suggest where and when smolts occupy estuaries, not the physical habitat characteristics that may be required. Given that smolts are thought to swim near the surface within the fastest flowing section of the water column, and use an ebb tide pattern of migration (Moore et al. 1995, Moore 1998), habitat choice is unlikely to be based on physical habitat characteristics (e.g. substrate type). It is more likely that the oceanographic conditions in estuaries and coastal areas influence movement and thus habitat choice in estuaries. Halfyard et al. (2013) hypothesized that short and wide estuaries with rapid mixing of fresh and salt water (e.g. Gold River) may pose a greater osmoregulatory demand on smolts than longer and narrower estuaries with gradual mixing (e.g. LaHave River) and may lead to longer residency times in the estuary near the river mouth."

Estuarine use by eastern Cape Breton salmon has not been studied. The summary above is focused on estuarine habitat use by postsmolts in the Southern Upland region of Nova Scotia, but the estuarine ecology of salmon by much of ECB DU is likely similar. However, the presence of the Bras d'Or Lakes (into which several eastern Cape Breton rivers drain) may lead to a potentially significant difference between estuary use in the ECB DU and elsewhere in the salmon's range.

The Bras d'Or Lakes are an inland sea located in the centre of Cape Breton Island (Figure 1). Parker et al. (2007) define the Bras d'Or Lakes as "a series of estuarine bodies linked together in a manner that forms a unique coastal ecosystem within the Nova Scotian coastline." The lakes cover a surface area of over 1080 km^2 and have a mean depth of approximately 30 m (max. >280 m), and embody a volume of approximately 32 billion m^3 (Petrie and Bugden 2002, Strain and Yeats 2002, Parker et al. 2007). Both tidal amplitude and tide-generated currents in the Bras d'Or Lakes are limited (e.g. <0.15 m and <0.1 m/s, respectively), with the exception of constriction points such as Great Bras d'Or Channel or Barra Strait, where currents can exceed 3 m/s (Petrie and Bugden 2002, Dupont et al. 2003). Non-tidal sea level fluctuations associated with barometric pressure changes can, however, be greater than 0.5 m (Parker et al. 2007).

The Bras d'Or Lakes are connected to the Atlantic Ocean at three locations (Great Bras d'Or channel, Little Bras d'Or, and St. Peters inlet), although the majority of water exchange occurs in the Great Bras d'Or channel (Parker et al. 2007). Similarly, the majority of fish movement likely also occurs through this channel, and it is considered the primary migration corridor for anadromous and migratory marine fishes (Parker et al. 2007).

Surface waters of the Bras d'Or Lakes are highly influenced by freshwater inputs, and salinity can range from approximately 20 in East Bay (Davis and Brown 1996), to less than 5 in enclosed areas, such as River Denys Basin (Parker et al. 2007). As such, the Bras d'Or Lakes may act as an extended estuary for eastern Cape Breton rivers draining into the lake. Freshwater inputs lead to substantial stratification of the lakes (commonly at 20 m depth in summer; Parker et al. 2007), with less saline waters dominating the upper water column and cold marine waters dominating the lower water column (Petrie and Bugden 2002, Strain and Yeats 2002). Dilute surface waters also influence surface currents in the lakes. Generally, surface waters exhibit a seaward outflow pattern while landward movement of saline marine water dominates the lowermost water column (Petrie and Bugden 2002). Sea surface temperatures in the Bras d'Or Lakes show considerable seasonal variability, with late summer high temperatures exceeding 20°C and ice covering much of the lake in the winter (Parker et al. 2007). Surface temperature in May (thought to coincide with the out-migration period for salmon smolts), is approximately 6°C (Parker et al. 2007).

Flora of the lakes is similar to coastal Cape Breton (MacLachlan and Edelstein 1971); however, the faunal community of the Bras d'Or Lakes is well developed and contains species of both boreal and arctic-relict origin (the latter in the cold water, more saline and deep basins of the lake; Parker et al. 2007).

Primary production in the Bras d'Or Lakes appears nutrient limited (Strain and Yeats 2002), and may exhibit a late winter / early spring peak, which differs from many coastal areas (Parker et al. 2007). The timing of phytoplankton blooms may have phenological implications on the availability of zooplankton prey to postsmolts during their spring emigration. Geen (1965, *in* MacLachlan and Edelstein 1971) estimated that annual primary production rates were approximately 55 mg C/m^3, which is lower than most coastal areas of Nova Scotia (e.g. Platt et al. 1971, 1972). The zooplankton communities in the Bras d'Or Lakes have been partially described (e.g. Shih et al. 1988), but the suitability of zooplankton in the Bras d'Or Lakes as salmon prey is unknown. The copepod, *Calanus finmarchicus,* has been considered an potentially important prey item of Atlantic Salmon at sea (e.g. Beaugrand and Reid 2003). While it is abundant in the nearby waters of the southern Gulf of St. Lawrence and Scotian Shelf (Shih et al. 1988), these are rare in the Bras d'Or Lakes (Shih et al. 1988).

The Bras d'Or Lakes are inhabited by several species of diadromous and marine fishes, and a total of 46 species have been surveyed (Lambert 2002). Atlantic Cod are the most abundant demersal fish in the lakes while Atlantic Mackerel and Atlantic Herring dominate the pelagic community (Parker et al. 2007). There was a small commercial fishery for herring in the Bras d'Or Lakes (Denny et al. 1998), however, rapid population declines triggered a fishery closure in 1999 (Parker et al. 2007). Many of the resident marine species, as well as many anadromous fishes, spawn in the Bras d'Or Lakes or its tributaries and, thus, provide larval fish (ichthyoplankton) upon which salmon postsmolts may prey.

Estuary use in other areas may be less extensive. Postsmolt residency from several Bay of Fundy rivers rarely exceeded 0.5 days/km (Lacroix 2008), and postsmolts from two Newfoundland rivers rarely averaged above 1.0 to 1.2 days/km (Dempson et al. 2011). However, there are examples where postsmolts utilize local habitats for longer periods. For example, Lacroix (2012) describes the behavior of Inner Bay of Fundy postsmolts that have a prolonged residency in the Bay of Fundy. How salmon of the ECB DU use the Bras d'Or Lakes is unknown; however, as a minimum, this area is likely important estuarine habitat for populations in rivers draining into the lakes.

Returning adults

Adult Atlantic Salmon return to rivers in eastern Cape Breton throughout the spring, summer, and fall months. Similar to postsmolt use of estuaries, residency times are not well known, and could range from several days to spending 4-6 months holding in an estuary before moving into the river. Studies elsewhere have shown that estuaries appear to be mainly staging areas, and movements within them are frequently slow (<0.2 body lengths per second), following the sinusoidal pattern of the tidal currents (Thorpe 1994).

Kelts

Bowlby et al. (2014) summarized the limited information about estuary use by kelts:

> "There is limited information on residency times or habitat use by kelts in estuaries, but the available evidence suggests that they are used predominantly as staging areas in the spring (Thorstad et al. 2011), or for overwintering if deep-water habitats are limiting in a particular watershed (Cunjak et al. 1998). In spring, kelts pass relatively quickly through estuaries on their way to open ocean (Thorstad et al. 2011). There has been one published study on acoustically tagged kelts in the Southern Upland, which found that kelts tagged in fresh water in April exited the estuary of the LaHave River within five weeks of release (Hubley et al. 2008). A typical migration pattern was not evident from these data, with one kelt exhibiting non-stop migration seaward and others interspersing periods of continuous movement with residence periods and backtracking (Hubley et al. 2008). Such movement patterns have been hypothesized to result from behavioural differences among individuals, which could be related to active feeding or predator avoidance (Lacroix and Knox 2005b), acclimation to seawater and other physiological stresses (Reddin et al. 2004, 2006), or differing bioenergetic costs associated with spawning (Bendall et al. 2005). However, survival rates of kelts moving through estuaries were high (Hubley et al. 2008, Thorstad et al. 2011), suggesting that entry into the marine environment is not a critical component of at-sea mortality for post-spawning adults."

Although there is no information about the use of estuaries by kelts specific to eastern Cape Breton, it is likely variable throughout the region due to the variability in the size of the estuaries in eastern Cape Breton, with larger estuaries playing a more important role in the life-cycle of salmon.

2.3 MARINE ENVIRONMENT

Postsmolts and immature adults

Bowlby et al. (2014) summarized the characteristics of marine habitat for immature salmon as follows:

> "Habitat use in the marine environment by immature Atlantic salmon (individuals that have undergone smoltification, migrated to the ocean, but have not yet returned to fresh water for the first time to spawn) has been mainly hypothesized based on physiological requirements and/or tolerances. At sea, salmon tend to be found in relatively cool (4^{o}C to 10^{o}C) water (Reddin and Friedland 1993), avoiding cold water (<2^{o}C; Power 1981), and modifying their migratory route in space and time in response to ocean temperature conditions (Reddin and Friedland 1993). For example, in years that coastal water temperatures are warmer, salmon arrive at home rivers earlier (Naryanan et al. 1995). Tagging studies suggest that immature salmon are pelagic, spending the majority of their time in the top few meters of the water column, following the dominant surface currents and remaining in the warmest thermocline (Thorstad et al. 2011). Although movement patterns and distribution have been correlated with water temperature (Friedland 1998, Holm et al. 2000) and other abiotic factors (e.g. Friedland et al. 2005), the availability of prey and potential for growth are assumed to determine distribution at sea (Rikardsen and Dempson 2011). As such, marine

> distribution patterns would be expected to vary in space and time, as well as among years, based primarily on the distribution of suitable prey items.
>
> Recent studies in the Northeast Atlantic demonstrate that immature salmon begin to feed extensively on marine fish larvae and to a lesser extent on high-energy crustaceans, experiencing a rapid increase in growth in the near-shore environment (Rikardsen et al. 2004). Atlantic salmon are opportunistic feeders, leading to geographical differences in the type and amount of prey consumed. There is some indication that salmon in the Northwest Atlantic have a larger proportion of insects and crustaceans in their diet than those in the Northeast Atlantic (Lacroix and Knox 2005b, Rikardsen and Dempson 2011), but gadoids, herring (*Clupea harengus*) and sand lance (*Ammodytes* spp.) are also important prey items (Hislop and Shelton 1993). Highest marine mortality rates are hypothesized to occur soon after immature salmon reach the open ocean while they are still in the near-shore environment (Hansen and Quinn 1998). One hypothesis is that faster growth and lower mortality of immature Atlantic salmon is associated with entry into the ocean at a time when larval fish prey are abundant and at a consumable size. Thus, the environmental factors controlling primary marine production (which would determine prey availability and size) may have a large impact on early marine survival and growth (Rikardsen and Dempson 2011) and likely largely dictate distribution and habitat use.
>
> [*Text omitted*]. A coastal or near-shore migration route along the North American continent is generally accepted (Thorstad et al. 2011). The predominant direction of movement is thought to be northward, along the near-shore environments of Nova Scotia, northern New Brunswick, the Gulf of St. Lawrence, Newfoundland and Labrador, until a proportion reach the Labrador Sea, Irminger Sea, or areas along the coast of West Greenland during the winter months (Montevecchi et al. 2002, Friedland et al. 2003). Analysis of the subsistence harvest of Atlantic salmon from the Greenland fishery demonstrates that the catch consists almost exclusively of immature salmon thought to be destined to return to natal rivers after two winters at sea (2SW) (ICES 2009). Information on the main feeding and staging grounds for immature salmon destined to return after one winter at sea (1SW) [*text omitted*] is less well known. It may include all near-shore areas along the North American coast with suitable surface temperatures, extending northward to the Labrador Sea, but is more likely to correspond to areas of high prey density within that broad range (Thorstad et al. 2011).”

Repeat-spawning adults

Bowlby et al. (2014) summarized the characteristics of marine habitat for repeat-spawning adults as follows:

> “After spawning, the majority of adult salmon exit rivers in the spring of the following year (Bardonnet and Bagliniere 2000, Hubley et al. 2008) for a period of reconditioning before spawning again. The length of time adults spend in the ocean between spawning events likely determines marine habitat use and distribution patterns for adults. Consecutive spawners return in the same year as their migration as kelts and have a relatively short ocean residence period (<6 months), while alternate spawners return the following year and can spend up to a year and a half in the marine environment. Tagging studies demonstrate that alternate spawners travel as far north as West Greenland during this time (Ritter 1989), and likely follow a similar migration route as immature salmon along the coastal or near-shore habitats of North America. The marine habitat use of consecutive spawning adults is less well known, but it is very unlikely that individuals would be able to reach the Labrador Sea or West Greenland in the time between spawning events. One acoustically tagged kelt from the LaHave

> River reconditioned over a period of 79 days before re-ascending the river, and spent this time outside of the estuary (Hubley et al. 2008). This very limited data suggests that estuarine environments are not as important for consecutive spawning adults as coastal habitats in the vicinity of their natal river when reconditioning.
>
> As with immature salmon, marine distribution and habitat use of adult salmon is thought to be determined primarily by the distribution and abundance of suitable prey. Fish form the majority of the diet of adult salmon (Hislop and Shelton 1993), and the species consumed include capelin (*Mallotus villosus*), sand lance, herring, lanternfishes and barracudina (Rikardsen and Dempson 2011). Amphipods, euphausids (krill) and other invertebrates are also consumed, and there is some indication that the proportion of invertebrates consumed increases in more southerly feeding areas (Lear 1980). Adult salmon are opportunistic feeders and prey on those organisms which are most available in the area (Thorstad et al. 2011), so marine habitat use is unlikely to be closely related to temporal or spatial changes in any particular prey (Hansen and Quinn 1998). However, major climate or oceanographic events altering the abundance and/or distribution of entire assemblages of suitable prey would have significant effects (Hislop and Shelton 1993)."

3.0 SPATIAL EXTENT OF HABITAT FOR EASTERN CAPE BRETON SALMON POPULATIONS (TOR 8)

3.1 FRESHWATER ENVIRONMENT

There is no information that suggests Atlantic Salmon did not utilize most or all accessible habitat in eastern Cape Breton at least intermittently in the past. As discussed in the introduction, information for 46 rivers that are considered salmon rivers is being provided, but there are several hundred other rivers and brooks that salmon may use as well. There is no known minimum size for occupancy.

Bowlby et al. (2014) describe spawning and juvenile rearing habitat as follows:

> "Within a given watershed, spawning locations, as well as juvenile rearing habitat, are distributed throughout the system, with habitat quality varying due to factors such as stream discharge, substrate type, temperature, and food availability (see Section 1.1 for details), all of which may be influenced by human activities. Comparing parr densities estimated by electrofishing with river gradient, Amiro (1993) and Amiro et al. (2003) found that stream gradient (average-weighted surface gradient) was a good general indicator of habitat quality, with optimal gradients ranging from 0.5% to 1.5%, although lower and higher gradient habitat becomes important when juvenile abundance is high (Gibson et al. 2008a)."

For many eastern Cape Breton rivers, orthophoto map measurements and aerial photographs have been used to classify stream reaches by gradient category (Amiro 1993, Korman et al. 1994), and all reaches with gradients greater than 0.12% and less than 25% are considered to be productive salmon habitat (Amiro 1993, O'Connell et al. 1997). Information on the amount of habitat contained in each gradient classification was available for 16 of the 46 watersheds (Amiro 2000; Table 1). The amount of productive area or rearing area for juvenile salmon in each watershed was estimated by summing the number of habitat units (a habitat unit is a unit used to quantify the amount of fluvial habitat: each unit has an area of 100 m^2) with gradients between 0.12% and 25% (Table 1). For the majority of watersheds, productive habitat was more abundant than low gradient habitat, (i.e. >66% in all but one of the rivers) ranging from 49% to 100% (mean=90%) of the total habitat area (Table 1).

For rivers in which gradient had not been classified (n=30), it was necessary to develop an alternate method for calculating the productive area in these watersheds. Following the approach in Bowlby et al. (2014), a linear regression was used to determine the functional relationship between total drainage area of a watershed and the number of productive habitat units, assuming a zero intercept (Figure 3). The slope estimate (25.731) from the regression multiplied by the drainage area (in km^2) becomes the approximate rearing area (in 100 m^2 habitat units) of the unclassified watershed. Total drainage area for all rivers in the ECB DU was obtained from the secondary watershed layer for Nova Scotia, a GIS (Geographic Information Systems) map product developed and maintained by the Nova Scotia Department of the Environment (NSDoE). The linear regression of all data from eastern Cape Breton watersheds had an R^2 value of 0.559 and was highly significant (p-value <0.001; Figure 3).

Combining information from all 46 watersheds, there is an estimated 4,545 km^2 of drainage area, which contains an estimated 179,429 habitat units of rearing area for Atlantic Salmon (Table 2). Excluding Indian Brook (because most the habitat is above an impassable waterfall), the five rivers with the most habitat are the Mira, Inhabitants, Middle, Baddeck and Framboise. These rivers contain more than half of the productive area for salmon in eastern Cape Breton (106,475 habitat units, Figure 4). Seventeen of the 46 watersheds have estimated rearing area less than 1,000 habitat units (Table 2). The median amount of rearing habitat contained in a single watershed is 1,268 habitat units (range=297 units in Wilkie Brook to 68,750 units in Indian Brook).

3.2 ESTUARINE ENVIRONMENT

The extent of estuarine habitat use by eastern Cape Breton salmon has not been assessed. In general, salmon smolts are not expected to reside in estuaries for more than 3-4 weeks. For example, recent research using acoustic tagging in the Southern Upland of Nova Scotia suggests that Atlantic Salmon postsmolts spent only 1-8 days per km of estuarine habitat (Halfyard et al. 2012), whereas kelts required between 3 and 32 days to migrate from their release site in the river to the open ocean (Hubley et al. 2008). Depth information from the tagged kelts indicated that they were located predominantly near the surface but made occasional forays to the bottom. It has been hypothesized that such behavior could be associated with feeding and searching for prey, or could be an adaptation to the physiological stresses of re-entering sea water (Hubley et al. 2008). Similarly, postsmolts are thought to migrate mainly in the upper water column (e.g. Davidsen et al. 2009).

In general, it is not known whether salmon in estuaries (postsmolts, adults and kelts) use habitat selectively (i.e. based on some physical criteria). This is particularly true for eastern Cape Breton salmon as there has been no directed study in this region. Habitat use may vary in association with life stage and individual fish behavior. If migration through estuaries is influenced by feeding behavior or coping strategies for physiological stresses (*see* Strand et al. 2011), habitat use may be dependent on prey distributions or hydrological features within estuaries. Further, because predation in estuaries can be substantial (e.g. Ward and Hvidsten 2011, Halfyard et al. 2012), the use of physical habitat structure and cover (e.g. kelp forests or intertidal *Fucus* spp.) may be important for predator avoidance, although this hypothesis has not been tested. Similarly, the use of estuaries by returning adults has not been studied in eastern Cape Breton (*see* Section 1.1), but they would presumably be concentrated in habitat types that minimize energy expenditure (e.g. minimal current) while waiting for appropriate river water levels to initiate upstream migration.

3.3 MARINE ENVIRONMENT

As detailed in Section 1.3, marine habitat use by immature and mature salmon is expected to vary spatially and temporally, partially in response to changes in prey availability or oceanographic conditions, and partially due to the life history strategy being employed by each individual (i.e. returning as 1SW versus 2SW, or returning as an alternate versus consecutive spawner). Both the challenges of sampling on a large scale, such as the near-shore marine environment, as well as the low recapture rates of tagged animals mean that predictive relationships among marine conditions and adult or immature abundance (akin to that between stream gradient and rearing habitat for parr) have yet to be developed. However, marine distribution patterns for eastern Cape Breton Atlantic Salmon can be assessed from historical tagging programs of smolts and adults combined with reported recaptures by commercial and recreational fisheries (Ritter 1989). Tagging data spans the years from 1966 to 1998 and only includes information from fish that were individually tagged (generally with numbered carlin or floy tags) and subsequently recaptured (i.e. releases with zero recaptures are not considered). Tags recovered in fisheries (or by people associated with the fishing industry such as fish plant workers) were returned for a monetary reward (Ritter 1989).

When interpreting these data, it is important to remember that sampling effort in the marine environment was non-random over space and time (i.e. the distribution of tag returns depends on the distribution of fishing effort, as well as the distribution of the fish). In the Maritime Provinces and much of Newfoundland, commercial trap nets for salmon were often at fixed locations accessible from shore (Dunfield 1974). For the commercial off-shore fisheries in Labrador and West Greenland, few of the tag recaptures were assigned a latitude and longitude when recovered (ICES 2008), therefore, recaptures were ascribed to the mid-point of each West Greenland fishing district or to locations or communities along the coast of Labrador. Therefore, it is not possible to determine the distance off-shore that Atlantic Salmon may frequent from these data and it is similarly difficult to correlate recapture locations with environmental or oceanographic variables. Furthermore, the scarcity of tag recaptures during specific months (e.g. December to March) is largely due to the lack of sampling effort (i.e. reduced or zero fishing effort) and may not reflect actual distribution patterns.

There were no tag returns from wild salmon (either immature or post-spawning) originating from eastern Cape Breton rivers. Therefore, the data presented is based entirely on recaptures of hatchery-origin smolts (Ritter 1989). Further, this analysis includes only hatchery-origin salmon where the strain (i.e. the stock of origin) matches the river into which they were released.

In total, there were only 17 recapture events of individuals tagged in eastern Cape Breton; representing only three release groups. Marine recapture rates were extremely low, ranging from 0.05% to 0.24%. Due to the relative scarcity of recapture information, marine distribution patterns of eastern Cape Breton salmon are presented as a group, although it is recognized that there are likely differences among populations in marine habitat use patterns. Recaptures are grouped using a 50 km^2 grid and totals for each grid cell (summarized by month) are plotted in ArcGIS (Appendix 1). Three time periods are considered: distribution in the year of release, distribution in the year following release, and distribution two years following release, although returns in each time period were low. All smolts were released in the spring, from late April to early June.

The majority of tagged smolts were released in fresh water in May and June, only two tags were returned as postsmolts (within 12 months of release). Both were captured in Fortune Bay, on the south coast of Newfoundland, two (end of July) and three months (end of August) after release (Figure 5). The spatial extent of recaptures extended dramatically during the second year at sea. In total, 14 tags were returned, six of which were released in Grand River and captured north of Neils Harbour, Nova Scotia, between late June and late September of the year following release (potentially during return migration). An additional tag return was reported from the south coast of Newfoundland in June, two from the north coast of Newfoundland (July-August), and the final five returns came from the west coast of Greenland (Figure 5). These Greenland recaptures occurred in the early fall (mid-August to late September) and, thus, potentially represent salmon that were destined to become 2SW spawners. Finally, a single tag was returned from the northern west Greenland Sea in late September and may potentially represent a salmon destined to return as a three sea-winter (3SW) spawner. Given the paucity of returns, it is difficult to formulate hypotheses regarding oceanic distribution or migration patterns of salmon from the ECB DU.

However, assuming that these data represent general distribution patterns in the marine environment, it is evident that eastern Cape Breton salmon use the oceanic and coastal waters of the south and west coasts of Newfoundland, as well as the Labrador Sea, at a minimum.

Although it is not possible to explicitly describe the movement patterns of the various life stages of eastern Cape Breton Atlantic Salmon from these data, the spatial extent of recapture locations highlight a crucial point when delineating important habitat in the marine environment. As discussed for Southern Upland salmon (Bowlby et al. 2014), different life stages may transiently occupy similar habitats and their overall direction of movement can be in opposite directions, potentially leading to a relatively ubiquitous distribution from Nova Scotia to the Labrador Sea and West Greenland throughout much of the year. Therefore, coastal areas of Nova Scotia do not cease to become salmon habitat during winter (for example), and although the southern Labrador Sea and southern Grand Banks are thought of as over-wintering areas (Reddin 2006), the tagging data demonstrates continued occupancy throughout the summer months as well. Given the variability expressed in run-timing, both within and among populations (O'Connell et al. 2006), similar variability is likely to exist in movement of eastern Cape Breton Atlantic Salmon along the near-shore environments of the northwest Atlantic, meaning that marine distribution (and therefore habitat use) will be difficult to delineate on a seasonal basis.

4.0 RESIDENCE REQUIREMENTS OF ATLANTIC SALMON (TOR 6)

Under *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). There are two guidance documents to aid in the identification of residences under *SARA*.

The draft *SARA* Policy (Environment Canada 2004) suggests three criteria:

1. Do individuals of the species use a dwelling place that is physically or functionally similar to a den or nest?
2. Are these places occupied or habitually occupied by the individual(s)?
3. Are these places crucially linked to the performance of a specific function?

DFO's draft (2011) Operational Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk uses the following four conditions to determine if an aquatic species uses residence:

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,
4. The dwelling place is occupied by one or more individuals at one or more parts of its life-cycle.

Here, four life stages of Atlantic Salmon (eggs, alevins, parr and adults) were evaluated to determine whether they use dwelling places that meet the criteria for being a residence. These life stages use three dwelling places:

1. redds (used by eggs and yolk-sac fry (called alevins)),
2. home stones (used by juvenile salmon in fresh water (called parr)), and
3. staging or holding pools (used by adults).

Each of these places is habitually occupied during part of the salmon's life-cycle, and is essential to the successful performance of specific, crucial functions of the salmon's life-cycle. Based on the rationales below, redds most closely match the criteria for being considered a residence under *SARA* because they are constructed. Home stones also match the criteria (they are not created, but are defended or protected). However, an individual home stone may be less essential for a life-cycle process than a redd because parr may potentially occupy a different home stone (if it is not already occupied) in the event that their original home stone is no longer available. Holding pools do not closely match the criteria because they are not created, modified or defended.

4.1 REDDS

Atlantic Salmon deposit their eggs in depressions excavated by the female in the substrate of streams and rivers; these excavations (nests) are called redds (Gaudemar et al. 2000; Wedemeyer 2001). The redd is excavated, eggs are deposited and fertilized, and then the eggs are actively buried by the female dislodging material upstream, which infills the hole. Redds are typically between 2.3 and 5.7 m^2 in area, and 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 (Gaudemar et al. 2000). Redds are typically constructed in water depths of 17 to 76 cm and velocities between 26 to 90 cm/s^2 (Beland et al. 1982). Eggs are deposited in redds from late October to early December and remain there more than six months until spring (roughly mid-May or June) when the fry emerge and begin feeding (Danie et al. 1984).

The function of the redd is to protect eggs and alevins from disturbance, currents and predators. Disturbance of salmon eggs after water hardening and prior to the eye stage can kill the eggs (Wedemeyer 2001). Salmon in rivers live in a fluvial environment and currents can displace eggs or alevins into unfavourable habitat if not sheltered from the currents. Redds fill this function by providing hydraulic eddies that capture expressed eggs and, after being covered over with gravel by the adult salmon, provide interstitial space for water flow and oxygen for the incubation of the eggs and development of alevins prior to emergence from the redd as early-feeding fry (Beland et al. 1982). Redds also provide protection for eggs and alevins from predators.

Disturbance or damage to the redd may result in high mortality due to the high density of eggs in a localized area. Examples of such damage may be winter floods causing scour of the redds (Cunjak and Therrien 1998), sedimentation forming a layer across the surface entombing the alevins, siltation of the redd interstices reducing percolation of water interfering with oxygen delivery and waste metabolite removale (Soulsby et al. 2001), or physical crushing by vehicles (e.g. ATVs) in stream running over redds.

Redds meet the following criteria for consideration as a residence:

Environment Canada Guidelines

Criterion 1: The dwelling place is physically and functionally a nest.
Criterion 2: These places are occupied by individuals (for more than 5-6 months of the year).

Criterion 3: These places are crucially linked to the performance of a specific function (successful egg incubation and alevin development).

DFO Guidelines

Condition 1: The dwelling-place (redd) is a nest.
Condition 2: The female salmon has made an energy investment in the creation of the redd.
Condition 3: The dwelling-place has the functional capacity to support the successful performance of the essential life-cycle process of spawning, breeding, incubation, and alevin development.
Condition 4: The dwelling place is occupied by one or more individuals at two parts of the salmon's life-cycle (egg and alevin).

4.2 HOME STONES

Atlantic Salmon parr are found in riffle-run areas typically with cobble and boulder substrate, are often stationary and occupy territories associated with home stones (Heggenes 1990). Home stones act as cover and break up the hydraulic forces acting on the fish, providing energetically beneficial shelter. Salmon parr use eddies and spaces around rocks (home stones) or in-stream debris as shelter from currents, with the size of these home stones being typically less than 20 cm diameter in summer and less than 40 cm in autumn (Rimmer et al. 1984). These areas are used for feeding, growth, shelter from currents and as cover for predator avoidance. Salmon parr are territorial and defend these spaces from other salmon parr (Cutts et al. 1999a,b, Keeley and Grant 1995), suggesting acquisition and defense of this resource is important. Occupancy (prior residency) is a key determinant for successful defense (Cutts et al. 1999a).

Home stones are used throughout the summer and fall. Although salmon may change home stones intermittently, movement may be limited in this period. For example, in a study of movement of young-of-the-year salmon during July and August, 61.8% of the fish moved less than one meter during the study period (Steingrimsson and Grant 2003). Ability to obtain and defend a territory has been linked to age-of-smoltification via growth (Cutts et al. 1999a), and hence age-at-maturity, a key life history parameter.

The effect of disturbance or damage to home stones (e.g. displacement or removal of stones) is likely dependent upon the prevalence of such material within the territory. That these areas are actively defended suggest that specific stones are preferred and so loss of them would affect the individual.

Home stones meet the following criteria for being considered as a residence:

Environment Canada Criteria

Criterion 1: The dwelling place is physically and functionally a den (offering cover and protection from environment, allowing energetic conservation).
Criterion 2: These places are occupied, and defended (by individuals for more than two months of the year).
Criterion 3: These places are crucially linked to the performance of a specific function (feeding and growth of parr, and subsequent smoltification).

DFO Conditions

Condition 1: The dwelling place is physically and functionally a den (offering cover and protection from environment, allowing energetic conservation).
Condition 2: An individual of the species has made an investment in the protection of the dwelling-place (protection of the location),
Condition 3: The dwelling-place has the functional capacity to support the successful performance of the essential life-cycle process of rearing,

Condition 4: The dwelling place is occupied by one or more individuals at one or more parts of its life-cycle (parr stage).

4.3 STAGING POOLS

Although spawning does not occur until late fall, adult Atlantic Salmon may enter the rivers in either the spring, summer or fall, and then typically remain in fresh water until they spawn. Ascension of rivers typically occurs in three phases, the second being a relatively long residency period (Bardonnet and Bagliniere 2000) that can range from about one month to more than six months. During this time, adult salmon stage in pools and these pools are used routinely year after year. Individuals use more than a single pool and may move among various pools within a river system in response to hydrological, temperature or other conditions. Adults may stay as long as two to three months in a single pool (Webb 1989). These pools dissipate hydraulic energy, provide cover and shelter from predators, provide low-flow areas that enable salmon to remain in fresh water without a large energy expenditure, and can also provide thermal refuges if the pools are fed by ground water. Holding pools are well documented for many rivers because they are the favored location for salmon anglers, and many are identified on the 1:50,000 National Topographic Series maps. Low numbers of holding pools has been considered a limiting factor for some salmon populations (Frenette et al. 1975).

Staging pools meet the following criteria for being considered as a residence:

Environment Canada Criteria

Criterion 2: These places are occupied by individuals.
Criterion 3: These places are crucially linked to the performance of a specific function (providing protection from predators and extreme environmental conditions while adults remain in river prior to spawning, and allowing energy conservation so adults are fit at the time of spawning).

DFO Criteria

Condition 3: The dwelling-place has the functional capacity to support the successful performance of the essential life-cycle processes of staging in fresh water prior to spawning, and possibly over-wintering by kelts.
Condition 4: The dwelling place is occupied by one or more individuals at one or more parts of its life-cycle. (These pools are occupied during summer and autumn prior to spawning, and possibly during winter by kelts).

5.0 SUPPLY OF SUITABLE HABITAT

In Section 2.1, the amount of rearing area in 46 rivers was calculated from previously collected gradient information (Amiro 2000) or estimated from linear regression (values listed in Table 2). This sums to a total of 179,429 units (100 m^2) of productive freshwater habitat for eastern Cape Breton Atlantic Salmon. Given that these calculations do not take into account factors such as accessibility or habitat quality (other than gradient), the true amount of salmon habitat available in a given watershed could be substantially less than that estimated from gradient alone. If a salmon population is prevented from accessing, or is unable to use, the rearing area thought to be contained in a given watershed, the supply of suitable habitat for that population is effectively zero.

5.1 INFLUENCE OF BARRIERS ON HABITAT ACCESSIBILITY (TOR 11)

Physical barriers

Assessing the impact of physical barriers on the amount of habitat in a watershed is difficult given that different structures can be completely or seasonally impassable, dependent on life stage and/or flow conditions. However, in this section, the focus is on barriers thought to prevent access of Atlantic Salmon to upstream habitats (i.e. total barriers). The issue of barriers is revisited in Section Bras 5.3, because other structures with different characteristics (e.g. other dams, water diversion, and culverts) exist in eastern Cape Breton watersheds. Unfortunately, there is insufficient information at present to quantify the full extent of partial barriers to Atlantic Salmon.

An ArcGIS layer detailing available information on barriers in Nova Scotia watersheds was compiled jointly by the NSDoE and the former Habitat Protection and Sustainable Development Division (Maritimes) of DFO (hereafter called the DFO Habitat Division). This layer contains the characteristics of known barriers, including fish passage capabilities (e.g. classified as passable to fish or not). Here, the data from barriers listed as having no fish passage is analysed, which is assumed to represent a total barrier to Atlantic Salmon movement, either upstream as adults or downstream as smolts (*see also* Appendix 1). In the absence of a detailed survey of the impacts of barriers seasonally in eastern Cape Breton watersheds, a more comprehensive analysis of total versus partial barriers is not possible. It is important to keep in mind that these data represent the most current regional survey of barriers in eastern Cape Breton rivers, but that the information has been collected over multiple years. The most recent updates to specific records span the years 2007 to 2010 (a total of 37 out of 586 records do not list a date). However, any changes that have taken place more recently would not have been captured in the database and, thus, would not be accounted for in these analyses.

There are 11 watersheds identified that contain man-made barriers (Table 3). Of these, Indian Brook, Sydney River, and Northwest Brook have significant amounts of habitat above the dams. In some cases, the impact of these total barriers may be significantly reduced; either because fish passage facilities have been constructed (e.g. Sydney River and Northwest Brook), or because the barriers are located above impassable natural barriers, such as waterfalls (Indian Brook).

5.2 ABILITY OF HABITAT TO MEET DEMANDS AT PRESENT (TOR 12)

Freshwater habitat supply is not thought to be limiting salmon abundance in eastern Cape Breton rivers at present. As described by Levy and Gibson (2014), adult counts and recreational fishery catches suggest that adult abundance is low within the DU, with the expectation that juvenile abundance would be similarly low. This expectation is consistent with estimates of juvenile density obtained by electrofishing, although data collections are sporadic and no juvenile data are available for the majority of rivers. Juvenile density estimates are highly variable (Gibson and Bowlby 2009). During an electrofishing survey in 2006 and 2007 (including 32 sites in 11 rivers), Gibson and Bowlby (2009) found that fry and parr densities were generally low relative to the indices of normal abundance (29 fry per 100 m^2 and 38 parr per 100 m^2, as developed by Elson (1967, 1975)). In contrast, juvenile density estimates from other areas (where Atlantic Salmon populations are thought to be meeting or close to conservation requirements) regularly report values that exceed Elson’s norm for all juvenile age classes (e.g. Cameron et al. 2009, Breau et al. 2009). Based on these data, it is likely that juvenile production is currently below what could be supported in the available freshwater habitat.

5.3 ABILITY TO MEET HABITAT DEMANDS IN THE FUTURE (TOR 13)

In contrast with the review of habitat availability for Southern Upland Atlantic Salmon (Bowlby et al. 2014), in which habitat loss due to barriers, acidification and other factors was estimated to be at least 40%, this review of habitat availability for eastern Cape Breton Atlantic Salmon has not found evidence of significant habitat loss for this DU. Additionally, the river specific conservation requirements being proposed as recovery targets are based primarily on the amount of habitat thought to be available in each river. The conservation requirement is consistent with a limit reference point (and is well below the observed abundances in some rivers in other regions now, as well as estimated carrying capacities of some rivers in the DFO Maritimes Region in the past (Gibson and Claytor 2012). Given the lack of evidence of significant habitat loss together with the evidence that rivers can support populations at sizes well above their conservation requirements, the quantity and quality of habitat currently available in the majority of eastern Cape Breton rivers are considered capable of supporting salmon populations at sizes above their proposed recovery targets.

Should adult population sizes begin to increase as a result of improved marine survival, freshwater habitat quality and quantity will ultimately determine maximum juvenile production in a watershed, which will determine whether or not habitat becomes limiting (Gibson et al. 2009). Therefore, the ability to reach recovery targets will be partially dependent on maintaining suitable freshwater habitats, including the mitigation of freshwater threats.

5.4 TRADE-OFFS ASSOCIATED WITH HABITAT ALLOCATION OPTIONS (TOR 15)

The functional characteristics of freshwater and marine habitats required to ensure the successful completion of the eastern Cape Breton salmon life-cycle are detailed in Section 1.1. Failure to consider all of these components when identifying priority habitats for allocation could lead to discrepancies between that which is protected and what is necessary from a population-level perspective. Maintaining connectivity between marine and freshwater habitats is essential, and habitat allocation in freshwater, estuarine, and marine environments should be directed at minimizing extinction risk. Further details are provided in Section 1.2.

Freshwater habitats

Allocation of freshwater habitat can occur on at least two scales. On the watershed scale, watersheds can be prioritized based on the populations selected for the distribution targets using the criteria provided by Levy and Gibson (2014). At a smaller, within-watershed scale, adult Atlantic Salmon require appropriate river discharge conditions and unimpeded access upstream to facilitate spawning migrations, 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 and temperature generally <23°C 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.

Estuarine habitats

Estuaries are a spatially explicit marine habitat known to be used by eastern Cape Breton Atlantic Salmon on an annual basis. By this, it is meant that the boundaries of the estuary can be clearly delineated (i.e. using coastlines). Although there is little evidence to support the idea of extended estuarine residency periods for either postsmolts or adults in the ECB DU (*see* Section 1.2), habitat allocation of estuaries should be considered important for the following reasons:

1. individuals are known to be within or passing through a defined area during the spring, summer and fall,
2. successful migration through this area is critical to salmon life history in eastern Cape Breton,
3. salmon likely come into direct contact with human activities taking place within estuaries, and
4. estuaries are areas where significant physiological demands occur as salmon transition between the freshwater/ marine environment.

In terms of increasing the potential for connectivity among the marine and freshwater environments, the estuaries of the watersheds identified above would be high priorities for habitat allocation in the marine environment. Emigrating postsmolts and kelts, as well as adult salmon returning to natal rivers to spawn, require unimpeded access to traverse the estuary, and estuarine water of quality (e.g. temperature, contaminants) amenable to survival.

Marine habitats

Outside of estuarine areas, marine habitats used by Atlantic Salmon populations from the ECB DU cannot be delineated at a scale relevant to typical administrative boundaries. Based on tagging data, marine habitats encompass coastal areas from coastal Cape Breton to Greenland, and are seasonally and annually variable, likely depending on factors such as oceanographic conditions or prey distributions (*see* Sections 1.3 and 2.3). Available tagging data provides only minor insight on the seasonal location of salmon from the ECB DU, and it does not capture annual variability or the true extent of potential movement (e.g. into off-shore areas) due to sampling limitations. Further research into marine distribution patterns is unlikely to reveal distinct areas that should be considered for marine habitat allocation because of similar logistical limitations (related to the number of animals that can be tagged and spatial coverage of recapture effort), as well as the aforementioned variability in marine conditions over time. Immature and mature Atlantic Salmon from the ECB DU 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, as well as sea surface temperatures conducive to growth and survival.

6.0 MAGNITUDE, EXTENT AND SOURCE OF THREATS TO EASTERN CAPE BRETON ATLANTIC SALMON IN FRESHWATER ENVIRONMENTS (TOR 9, 16, 20)

This section uses the approach for categorizing threats developed by Bowlby et al. (2014) for Southern Upland Atlantic Salmon.

In this section, as well as in Section 6, the definition of a threat is taken from the Draft Guidelines on Identifying and Mitigating Threats to Species at Risk (Environment Canada 2007), where a threat is defined as: "*an activity or process (both natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioral changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur*". As such, some threats may act on the population by degrading habitat, while others may affect population viability directly by increasing mortality (e.g. fishing), yet others may affect the life history characteristics of populations (e.g. stocking).

Threats occurring in fresh water are grouped into six categories (Water Quality and Quantity; Changes to Biological Communities; Physical Obstructions; Habitat Alteration; Directed Salmon Fishing; and By-Catch in Other Fisheries). Within each category, specific threats (e.g. barriers, non-native species, etc.) are discussed. Information is provided about each threat based first on what is known about the threat in general, followed by information about its extent in eastern Cape Breton.

Human activities may impact upon Atlantic Salmon populations via several pathways that can be considered discrete threats or may be considered in aggregate (Tables 4 and 5). For example, infrastructure (roads) as a threat may impact ecological (e.g. altered hydrology), demographic (e.g. reduced survival of eggs due to sedimentation) or behavioral (e.g. movement patterns due to barriers) attributes of populations leading to reduced viability and consequently reduced abundance (Gucinski et al. 2001).

Information on threats is presented relative to two sources:

1. how the threat has been shown to affect habitat or Atlantic Salmon populations in general, and
2. research that explicitly relates to eastern Cape Breton Atlantic Salmon populations or habitats (where available).

As such, the text attempts to be inclusive of the potential for impacts from a given threat (i.e. to represent the current state of knowledge). It is expected that the threats would act on eastern Cape Breton populations in a similar manner, but it is recognized that local conditions such as management regulations, environmental guidelines or operating policies could result in differences in the expected severity of impact in the ECB DU. This information, including the overall level of concern, is assessed based on criteria outlined in Table 6 for threats in fresh water and in Table 7 for threats in estuarine and marine environments.

Bowlby et al. (2014) provide the following guidance when prioritizing threats for Southern Upland Atlantic salmon in fresh water:

> “River systems function in a spatial hierarchy, with regional climatic or human land-use patterns affecting processes at the watershed scale, which in turn influence the reaches, and then localized in-stream habitats. Therefore, large-scale factors often have greater influence on salmon production than processes at smaller scales (Ugedal and Finstad 2011). Water movement has important implications on how threats influence populations in fresh water. For example, excessive input of fine sediment due to land use in the headwaters of a river system will be transported downstream and affect habitat conditions and productivity in downstream reaches (Ugedal and Finstad 2011). Therefore, a threat can have important implications in the system a considerable distance away from its source, and addressing these types of threats (i.e. those that impact a large proportion of the watershed) would be expected to have the greatest benefit to salmon populations.”

6.1 WATER QUALITY AND QUANTITY

Acidification

Low pH can affect the survival of all freshwater stages of Atlantic Salmon and river acidification can partially or completely eliminate suitable habitat within a watershed (Lacroix and Knox 2005a). Farmer (2000) lists Atlantic Salmon life stage sensitivity (in decreasing order) as: Fry > Smolt > Small parr > Large parr > Alevin > Eggs. Mortality rates by life stage for pH values from 4.5 to 5.5 are provided by Gibson and Bowlby (2013) based on the toxicity functions of Korman et al. (1994). Many authors concur that fry are the most sensitive juvenile life stage to low environmental pH (Johnston et al. 1984, Lacroix 1985, Farmer 2000). Cumulative mortality curves estimate 50% age-0 mortality at a pH of 5.3, and 100% mortality at a pH ≤ 5.0 (Lacroix 1985). However, these values are thought to be conservative for wild populations given that weaker or impaired fish could be more susceptible to predation, disease, or effects of competition and, thus, exhibit higher mortality rates (Lacroix 1989b).

There is an extensive literature on the effects of acidification from the Southern Upland Region in Nova Scotia. Data from the Medway and LaHave rivers suggests that age-0 density was 70% lower when pH ranged from 4.7-5.4 seasonally than from 5.6-6.3. Over-wintering mortality was more than double, as seen in a Medway tributary where December-May pH decreased below 5.0 as opposed to the LaHave where this did not occur (Lacroix 1989a). From these results, Lacroix (1989a) hypothesized that pH levels of 4.6-4.7 (when duration exceeds 20 days) and pH 4.4 (for durations of five days or less) would severely reduce densities and could completely eliminate juvenile year classes. Furthermore, mean annual pH values <5.0 were considered insufficient for the continued maintenance of Atlantic Salmon populations.

Non-lethal impacts of acidification have been studied most extensively in smolts, where lower pH values resulted in reduced survival and growth, interference with the smoltification process, and reduced salinity tolerance (Saunders et al. 1983, Johnston et al. 1984).

The capacity of watersheds in Nova Scotia to buffer against acidification is highly variable, with the southwestern mainland, parts of the Eastern Shore and parts of the Cape Breton Highlands considered the most sensitive to the effects of acid rain (Clair et al. 1982). Although significant acid deposition occurs over much of eastern Cape Breton (Whitfield et al. 2007), the surficial geology of most of the region provides ample cations to surface waters, and, thus, the ability to neutralize acids prevents stream pH from declining. Alexander et al. (1986) investigated lake water chemistry in the four Nova Scotian counties within eastern Cape Breton and found that mean surface water pH was slightly below neutral to slightly above neutral, ranging from a mean (sd) pH of 6.3 (1.0) in Victoria County to 7.4 (0.7) in Inverness County. More recently, MacMillan et al. (2008) provided pH measurements for Middle River (4 brooks), Baddeck River (5 brooks) and River Denys (5 brooks) collected during the early 2000s: pH measurements ranged from 6.9 to 7.8.

For these reasons, acidification is not thought to be a factor limiting Atlantic Salmon production for the majority of populations within the ECB DU.

Extreme temperature events

Bowlby et al. (2014) summarize the effects of extreme temperature events as follows (*detailed in* Section 1.1):

> “Water temperature affects the behaviour, growth, and survival of all freshwater life stages of Atlantic salmon, and can limit the amount of useable habitat in a watershed. Extreme high temperatures can lead to direct mortality of juveniles if they cannot move to cold water refugia, or such temperatures can reduce survival indirectly through impacts on growth, predator avoidance responses, or individual susceptibility to disease and parasites. Extreme low temperatures during winter can result in direct mortality by freezing redds or physical disturbances from ice scour (Cunjak et al. 1998), in addition to reducing developmental rates of eggs and alevins (Crisp 1981, 1988).
>
> The activities most likely to increase the incidence of extreme temperature events in a watershed are associated with either direct thermal change (e.g. loss of riparian cover) or altered hydrology (e.g. water extraction). Removal of riparian vegetation or the maintenance of fields without riparian zones (e.g. agricultural fields, urban areas) tends to allow greater heating and cooling of water than streams which have intact riparian zones providing shading (Caissie 2006). Excessive groundwater extraction (e.g. wells) or substantial reduction to the baseflow of a river (e.g. in-stream extraction or impoundment) reduces the input of cool groundwater or overall water volume, leading to greater susceptibility to temperature extremes (Caissie 2006). In the case of reservoirs or other barriers, periodic spilling of warm surface waters may be problematic as this will increase temperatures downstream. With respect to altering flow volume, land use activities which have changed stream channel morphology from

> shaded riffle-run-pool types to exposed straight segments (i.e. increased channelization), homogenizes water depths and makes the shallower water more responsive to changes in air temperature (Caissie 2006). Small streams are more susceptible to thermal impacts as the volume of water is less than in larger systems. In addition, all of the preceding effects are expected to be exacerbated by the impacts of climate change."

Data on river temperatures in eastern Cape Breton are limited or inaccessible. One example of available data is provided by MacMillan et al. (2005), who used continuously recorded summer river temperatures between 2000 and 2002. They reported that warm-waters sites (mean summer temp >18.9°C) were rare in the River Denys watershed (3 of 11 sites), the Middle River watershed (0 of 10 sites), and the Baddeck River watershed (1 of 12 sites). Based on this limited sampling, extreme water temperatures in eastern Cape Breton may not be a prevalent concern, although warm water has evoked recreational fisheries closures (*see* Section 5.5), and, thus, may be a more widespread concern than suggested by these data. Further, significant inter-annual variability is likely, and the data provided by MacMillan et al. (2005) may not encompass the full range of temperatures experienced by salmon of the ECB DU.

Altered hydrology

Bowlby et al. (2014) summarize the general effects of altered hydrological regimes as follows:

> "The hydrological regime of a river system may be altered by a large variety of human activities. These include direct withdrawal of water for industrial, agricultural or municipal purposes, intensive land use affecting overland and groundwater flow and thus recharge to streams, water diversions for power generation, and an operating schedule of water release at power generating stations not consistent with the natural flow regime. These changes can have significant effects on Atlantic salmon spawning and rearing habitat when stream baseflows are substantially reduced (DFO and MRNF 2009, Fay et al. 2006). Extreme low flows can increase the incidence of temperature extremes (as discussed above) and reduce seasonal habitat availability in a watershed. As such, the survival of eggs, alevins and juveniles has been directly linked to stream discharge, with better survival in years with higher flows during the summer and winter months (Gibson 1993, Cunjak and Therrein 1998). Furthermore, returning adult spawners have been found to initiate spawning migrations as water levels rise, as well as to require sufficient water for distribution throughout the river system and to hold in pools (Thorstad et al. 2011, Mitchell and Cunjak 2007). Spring high water is potentially a trigger for smolt migration, and survival of smolts has been shown to be higher under years of high discharge than low in some systems (McCormick et al. 1998).
>
> "[*Text deleted*]…natural variability may be exacerbated by intensive land use (e.g. forestry, agriculture, urbanization) which can accelerate the rate of runoff from land and entrance into stream channels (Caissie 2006). This can make a river more prone to flooding and increase the frequency and duration of large freshets. Extremely high flows can cause large scale erosion and significant changes in channel and bed morphology. All of these processes influence the quality and quantity of habitat available in fresh water. Under extremely high flows, juvenile salmon tend to seek refuge in the substrate (DFO and MNRF 2009), but can experience increased mortality from physical displacement, turbulence, abrasion, and transportation of the substrate (Cunjak and Therrein 1998, Erman et al. 1988, Jensen and Johnsen 1999). Watershed characteristics, such as the presence of large lakes, can buffer extreme flow events, but it is expected that extensive land use in riparian areas will have a greater impact on the timing and magnitude of high flow events. Such effects will likely be exacerbated by the impacts of climate change, where the hydrology of freshwater environments is

> expected to change in terms of the timing and volume of seasonal discharge, and water quality (Bates et al. 2008)."

Water extraction

Excessive groundwater extraction (e.g. wells) or substantial reduction to the base flow of a river (e.g. in-stream extraction or impoundment) reduces the input of cool groundwater or overall water volume, leading to greater susceptibility to temperature extremes, as well as loss of habitat along the banks of rivers (Caissie 2006). With respect to altering flow volume, the effects of water extraction are expected to be exacerbated by land use activities, which alter stream channel morphology from shaded riffle-run-pool types to exposed straight segments (i.e. increased channelization). This homogenizes water depths and makes the shallower water more responsive to changes in air temperature (Caissie 2006). As such, the survival of eggs, alevins and juveniles has been directly linked to stream discharge, with better survival in years with higher flows during the summer and winter months (Gibson 1993, Cunjak and Therrein 1998). Furthermore, returning adult spawners have been found to initiate spawning migrations as water levels rise, as well as to require sufficient water for distribution throughout the river system and to hold in pools (Thorstad et al. 2011, Mitchell and Cunjak 2007). Spring high water is potentially a trigger for smolt migration, and survival of smolts has been shown to be higher under years of high discharge than low in some systems (McCormick et al. 1998).

Chemical contaminants

Bowlby et al. (2014) summarize some of the effects of contaminants as follows:

> "Nutrient (nitrogen and phosphorus) enrichment from intensive application of fertilizers on land adjacent to rivers can lead to eutrophication problems such as reduced oxygen concentrations and excessive algal or plant growth in fresh water (Huntsman 1948, Paul and Meyer 2001). Given that Atlantic salmon rely on dissolved oxygen concentrations >5.0 mg/L (Davis 1975) as well as interstitial spaces within the substrate for egg development and juvenile overwintering habitat, eutrophic conditions degrade habitat quantity and quality in a river. Nutrient run-off would be expected to be highest in areas where riparian vegetation has been removed (i.e. intensive land use), and its effects would be compounded by the warmer temperatures and increased solar exposure associated with lack of cover. In terms of the potential for impact, urbanized landscapes (e.g. residential areas, golf courses) are second only to agriculture as the major human causes of stream eutrophication (Paul and Meyer 2001).
>
> There are hundreds of compounds that are recognized as chemical contaminants in fresh water environments, including: heavy metals, organic compounds, petroleum products, and endocrine disruptors (Currie and Malley 1998). In instances where such compounds have been released into the environment (e.g. after spills or impoundment failures), acute toxicity (e.g. fish kills) has been observed at high concentrations of multiple chemicals. However, chronic exposure to sub-lethal concentrations have been found to have a range of behavioural and physiological impacts on Atlantic salmon that are thought to reduce survival and lifetime reproductive output (Fairchild et al. 2002). For example, at the smolt stage, it has been hypothesized that chemical-related impacts interfere with the development of salinity tolerance and with olfactory imprinting to natal rivers (McCormick et al. 1998). Of greatest concern are some of the organic compounds (e.g. PCBs, flame retardants, some pesticides) because they did not occur in nature until being synthesized for human use. Thus, the pathways for degradation of these synthetic compounds are limited. In many cases it is not possible to isolate the impact of an individual chemical on a fish population given the number of contaminants present as well as the potential synergistic effects among them (Currie and Malley 1998). Introduction of contaminants is more likely where human population

> density or land use is the greatest, including areas of intensive agriculture, forestry or urbanization, and areas of high road density."

Water quality and quantity is monitored by Environment Canada across Atlantic Canada. Specifically, the National Water Research Institute (Environment Canada) is assessing the impact from the dispersion of metals, such as cadmium, lead, and mercury, through stream discharges from abandoned mining sites in Cape Breton. Major ecosystem and human health concerns have led to a focus on discharges from abandoned mining and storage sites for coal, including priority metal sources, transport and retention mechanisms, and fate from selected areas of concern. A remediation program by the Cape Breton Development Corporation is in progress. In eastern Cape Breton historical mining operations are predominantly coal, as indicated by 892 of 1046 of abandoned mine openings, the surface component of abandoned mine workings resulting from past underground mining (Nova Scotia Department of Natural Resources (NSDNR) database). Of all records of abandoned mine openings within eastern Cape Breton, 164 (15.6%) occur in 24 of the 46 assessed watersheds. The remaining 882 abandoned mine openings occur outside of the 46 assessed watersheds. Mining in eastern Cape Breton occurs most frequently in lowland watersheds, many of which drain into the Bras d'Or Lakes. The Mira River watershed contains the most abandoned mine openings (n=48) followed by Middle River (=19) and MacAskills Brook (n=19). Mines in the Mira and MacAskills Brook watersheds were mostly directed at coal extraction, however, mines focused on iron (n=3), lead (n=3), manganese (n=9) and shale oil (n=9) extraction were also present in the Mira River watershed. Drainage from abandoned mines (particularly those associated with metal extraction) can contain elevated levels of heavy metals and also tend to be acidic (*see also* Section 5.4). In eastern Cape Breton gold mining activity was concentrated in the Middle River watershed (based on abandoned mine data, 18 of 31 gold mines in the ECB DU are recorded in Middle River) (Table 8).

Stewart et al. (2001) summarize contaminants in Sydney Harbour as follows:

> "Sydney Harbour on the northeast coast of Cape Breton Island has developed as an industrial, transportation and population center, probably second only to Halifax/Dartmouth on the Atlantic Coast in overall development and level of activity. In common with other industrial ports, the Harbour has been the depository of industrial and anthropogenic contamination, and its physical characteristics-a shallow, estuarine system in a drowned river valley where fine sediments, including those containing elevated levels of contaminants, accumulate- has added contamination problems. Contamination of Sydney Harbour has been dominated, however, by a case of massive industrial contamination-the release into Sydney Harbour of high concentrations of a range of hazardous substances, principally polycyclic aromatic hydrocarbons (PAHs) but including other organic contaminants as well as metals-from a steel smelter and coke ovens on its shores. Operation of the blast furnaces until the early 1980s (they have since been shut down) also resulted in toxic air emissions that became a health concern through suspected elevated cancer risk for residents, while the PAH contamination of harbour waters has led to closure of the lobster fishery in parts of the inlet. The clean-up of the Sydney Tar Ponds and Muggah Creek into which much of the contaminants from the smelter and associated facilities flowed and accumulated (acknowledged to be the most hazardous toxic waste site in Canada), has been one of the most expensive, long-term, and controversial environmental undertakings in Canadian history-and one that is far from being over.
>
> Sydney Harbour is an example of a coastal inlet impacted by a major uncontrolled pollution source, the Sydney Tar Ponds, but one also exposed to the range of contaminants typical of a major industrial, transportation and population center. Major impacts have occurred in the Harbour, including significant contamination of waters,

> sediments and biota in South Arm with anthropogenic contaminants such as organic carbon, trace metals, PAHs and PCBs; physical/chemical changes including the occurrence of decreased oxygen levels in South Arm and biological changes such as biochemical changes in fish, and changes in abundance and distribution of organisms (i.e. benthic animals). Contamination has also had a significant impact on an important commercial fishery for lobster, which is no longer carried out in South Arm. Despite the various impacts, the extent of contamination does not appear to extend beyond the Harbour, although the extent of current sampling does not allow the assessment of the full extent of its effects. Current efforts to remove the main source of PAHs through a clean-up of the Sydney Tar Ponds are likely to significantly improve conditions in Sydney Harbour, but a complete improvement will only come when changes are made which will reduce the levels of the full range of contaminants which currently enter it."

Parker et al. (2007) summarized the knowledge of contaminants in the Bras d'Or Lakes and watersheds flowing into the Lakes as follows:

> "Heavy metal contamination of the Bras d'Or's waters from the freshwater systems is not significant, although several hotspots have been noted and mapped (Young 1976). The freshwater runoff in the larger rivers is not sufficiently acidic to dissolve the naturally occurring heavy metals that are quite limited in the surficial geology (Kenchington and Carruthers 2001). Field surveys have confirmed heavy metal content of silt in the rivers flowing into Bras d'Or as being generally low, though somewhat higher in Baddeck and Middle rivers (Creamer et al. 1973; Young 1976). More recently, sediments in Denys Basin have been found to contain levels of cadmium, zinc, copper, and lead greater than threshold effects levels (but less than probable effects levels) (Yeats, pers. comm. 2005). An earlier study (Chou et al. 1999) reported that Denys Basin had the lowest ranking for metal concentrations in sediments of five basins evaluated in the Bras d'Or during 1997 over a wide range of metals examined. However, samples from this study were not corrected for grain size, likely resulting in an under reporting of metal concentrations in sediments. Limited sampling from East Bay sediment has shown localized copper and zinc above threshold effects levels and lead above probable effects levels (Yeats, pers. comm. 2005). Studies have shown some areas of the Bras d'Or as having high zinc in oysters (Young 1973) and in water (Strain et al. 2001). Most recently, in an as yet unreported study, zinc was found to be elevated in both oysters and water at the same location within the Bras d'Or (Yeats, pers. comm. 2005). Evaluation of the significance of these observations is ongoing."

Silt and sediment

Bowlby et al. (2014) provide the following summary of the effects of silt and sediment (*see also* Section 2):

> "Silt (particulate matter such as clays and fines; <0.063 mm diameter) and sediment (material such as sands and gravels; larger than silt) introduced into rivers can have negative impacts on fish and their habitat. Silt may be harmful through physical abrasion of skin, eyes and gills, but also can significantly impact habitat quality (O'Connor and Andrew 1998), by depositing and infilling spaces in the gravel/cobble substrate, smothering eggs, entombing alevins, and obstructing access to overwintering habitat under large cobble and boulders (Soulsby et al. 2001, Julien and Bergeron 2006). Excess sedimentation (erosion of sands and gravels in excess of the streams ability to transport it downstream) has been associated with reduced heterogeneity of channel morphology, where pools and riffles are replaced with homogenous run-type habitat. Rivers are particularly prone to such alteration during storm flows where the majority of substrate transport takes place (Lisle 1989). Sources of silt or sediment include urbanization, road systems and their maintenance, off-road

> vehicle use, timber harvesting, and agricultural practices. Of these threats, road systems are thought to be the most significant contributor to habitat changes resulting from siltation."

6.2 CHANGES TO BIOLOGICAL COMMUNITIES

Non-native species (fish)

Non-native fish species that have been introduced to the lakes and streams of Nova Scotia include the Goldfish (*Carassius auratus*), Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), Chain Pickerel (*Esox niger*), and Smallmouth Bass (*Micropterus dolomieu*). The impact of Rainbow Trout and Brown Trout stocking by the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) is considered in the section on stocking (below). There is currently no known occurrence of Goldfish in eastern Cape Breton. Chain Pickerel and Smallmouth Bass have only limited distribution in this region (Table 9), however, both species may negatively impact Atlantic Salmon when present.

Chain Pickerel are a lacustrine species, favouring shallow, weedy warm lakes and ponds (Raney 1942, Foote and Blake 1945). Warner et al. (1968) examined Chain Pickerel predation on stocked landlocked Atlantic Salmon (stocked directly into the lakes) in Maine and found pickerel predation to be the major form of fish predation. Studies in Nova Scotia suggest that pickerel presence in a lake substantially reduces the abundance and species richness of the native fish community (Mitchell et al. 2011). Significant competition between Chain Pickerel and Atlantic Salmon is unlikely given that there is little to no evidence of juvenile salmon using lacustrine environments for rearing in eastern Cape Breton, although they are documented to do so elsewhere (e.g. Newfoundland; DeGraaf and Bain 1986, Erkinaro and Gibson 1997). However, in rivers with lacustrine habitat through which salmon migrate, there is a high potential for direct predation on salmon smolts during spring out-migration.

Smallmouth Bass are well suited to lotic habitats (Scott and Crossman 1973, Edwards et al. 1983), including in the northern extent of their introduced range (Lasenby and Kerr 2000) although occupancy of riverine habitats in Nova Scotia is poorly understood. Preliminary data suggests that river use is limited by the presence of nearby lentic habitats (J. Leblanc, Biologist, NSDFA, pers. comm.). Relatively more is known about the impacts of introduced Smallmouth Bass on fish communities compared to Chain Pickerel. The presence of non-native Smallmouth Bass impacts native fishes in several ways, including; predation (van den Ende 1993), reduced abundance and diversity of small-bodied cyprinid species (Jackson 2002) competition for prey resources (Morbey et al. 2007), physical displacement from habitats (where native fishes are relegated to marginal or complex habitats; MacRae and Jackson 2001, Wathen et al. 2011), altered trophic interactions, and shifts in energy pathways (Vander Zanden et al. 2004, Weidel et al. 2007).

Specifically, regarding interactions between Atlantic Salmon and Smallmouth Bass, salmon juveniles may be consumed by bass (van den Ende 1993), and Smallmouth Bass may induce a temperature-dependant shift of habitat use by age-0 salmon, when in sympatry with age-0 / age-1 Smallmouth Bass in experimental stream reaches (Wathen et al. 2011). However, Walthen et al. (2012) suggest that the two species are likely to minimize interspecific competition by partitioning habitat through space and time, based on the minimal overlap of preferred habitat in mesocosm experiments, and contrasting diel activity patterns (salmon were primarily nocturnal feeders and smallmouth were primarily diurnal feeders).

Data on known locations of Smallmouth Bass and Chain Pickerel throughout Nova Scotia were obtained from the NSDFA. Locations were given in latitude and longitude with 1 minute arc resolution (i.e. low resolution). To create points for mapping in ArcGIS, geographical corrections of the latitude and longitude values were made manually from the references to lake names (using the NS Road Atlas 6th Edition), to ensure that: 1) points occur in the correct watershed and 2) points occur in the correct water body. The two species were considered separately to produce statistics on the presence and number of observations of each species within each watershed.

Chain Pickerel are currently found in two documented locations in eastern Cape Breton (both in the Sydney River watershed), and Smallmouth Bass are found in these same two locations, as well as in the downstream riverine habitats (Table 9; *see also* Leblanc 2010). Although a very small number of Smallmouth Bass introductions were authorized by the Province during the 1950s and 1960s, none of the introductions in eastern Cape Breton were authorized and are, thus, the result of illegal transport and release(s). Given that the distribution of Smallmouth Bass and Chain Pickerel in eastern Cape Breton is limited to the Sydney River watershed, the spatial extent for interactions with Atlantic Salmon is expected to be minimal. Within the Sydney River watershed, Smallmouth Bass and Chain Pickerel are likely to impact the Atlantic Salmon population through predation and competition.

Non-native species (other)

As summarized in Bowlby et al. (2014):

> “Didymo (*Didymosphenia geminata*), or “rocksnot”, is a freshwater alga indigenous to rivers and lakes in boreal and mountainous regions in the Northern Hemisphere (including Canada). In the last two decades, didymo has started appearing outside of its natural range (both within Canada and in other countries, notably New Zealand) and has the characteristics of an invasive species. Damage to freshwater habitats from the alga has been greatest in New Zealand where blooms have modified stream flow, reduced natural algal diversity, and altered the composition of invertebrate communities (Bothwell and Spaulding 2008). With the recent introduction of didymo into several rivers containing wild Atlantic salmon in Quebec and New Brunswick, there is concern that it will spread to other Maritime salmon rivers. Negative impacts to wild Atlantic salmon populations in Canada have not been found from preliminary research, although studies on this topic are limited and have not been published in peer reviewed journals. Preliminary research on blooms in Scandinavian and Icelandic rivers suggests that didymo has had no obvious negative effects on Atlantic salmon populations (Bothwell and Spaulding 2008, Jonsson et al. 2008). Similarly, for the three Pacific salmon species investigated (coho (*Oncorhynchus kisutch*), chum (*O. keta*), and steelhead (*O. mykiss*)), there were no significant negative effects on escapement or productivity associated with the presence of didymo (Bothwell et al. 2008). However, given the potential for substantial ecological change as seen in New Zealand, it would be prudent to prevent the spread of didymo into new areas to limit its overall potential for harm.”

At present, didymo blooms have not been reported in rivers in eastern Cape Breton.

The Spinycheek Crayfish has been discovered in Freshwater Lake, near Ingonish (within the Cape Breton Highlands National Park. The date and origin of this crayfish introduction is currently unknown. This lake borders the Ingonish River estuary and the potential for invasion into the river is likely high given the proximity of Freshwater Lake and the river, and the suitability of lotic habitats for Spinycheek Crayfish (Holdich and Black 2007). Introduced Spinycheek Crayfish are known to affect aquatic communities by altering habitat structure (i.e. as ecosystem engineers), affecting trophic structure, influencing energy flow, competing for resources and directly preying upon fish eggs and juvenile fishes (*see review by* Reynolds 2011).

Although the effects of the Spinycheek Crayfish on salmon populations in eastern Canada has not been evaluated, other species of non-native crayfishes have negatively impacted Atlantic

Salmon populations elsewhere. For example, Griffiths et al. (2004) reported that over-wintering Atlantic Salmon parr used shelter less frequently when in sympatry with non-native crayfish, and, thus, were more vulnerable to predation. In an English stream, where non-native crayfish had been introduced, the relative abundance of juvenile Atlantic Salmon and Brown Trout was reduced when in the presence of the non-native crayfish, relative to a native crayfish species (Peay et al. 2009).

Stocking for fisheries enhancement (Atlantic Salmon – using traditional methods)

Traditionally, captive breeding and rearing programs for salmon attempted to increase population size by capturing adults and raising juveniles (typically smolts) for fisheries enhancement purposes (Fraser 2008). Salmon populations of the ECB DU received the greatest hatchery intervention in the 1980s. However, as scientific literature about the genetic risks of supplementation to wild populations became available, federally-funded stocking programs were discontinued (DFO and MNRF 2009).

With the exception of Indian Brook (Cape Breton County), which was stocked with native strain, or hybrids, until 2007, nearly all federally-operated juvenile release programs were terminated by 1999, except for a few, relatively small operations. The Fish Friends educational program (operated by the Nova Scotia Salmon Association and the Atlantic Salmon Federation) has continued to release juvenile salmon since 1999, but releases have been small and isolated events, and the program has recently shifted to releasing mainly Brook Trout. Finally, a small enhancement program, using traditional methods (i.e. capture of pre-spawning wild adult salmon and rearing of progeny to parr or smolt stage) was initiated on the Middle and Baddeck rivers in 2009. Levy and Gibson (2014) detail this program as follows:

> "During 2009-2011, adult salmon were also collected from Middle [and Baddeck] River on an annual basis for use as broodstock as part of a program to offset catch-and-release mortality associated with recreational angling. Juvenile salmon stocked as part of this program commenced in 2010 and adult returns associated with these releases were expected in three to seven years thereafter (DFO 2011)."

Juvenile salmon stocked as a result of this program included both fry and young-of-year parr. The total numbers of salmon released into the Middle River were approximately 12,000 and 23,000 in 2010 and 2011, respectively while the Baddeck River received a total of approximately 22,000 and 16,700 in 2010 and 2011, respectively. This program removed nine, seven, and eight adult salmon from each the Middle and Baddeck rivers in 2009, 2010, and 2011, respectively. Relative to the adult population estimates for those years (Levy and Gibson 2014), the program involved a small portion of the Middle River population (1.7–3.8%) and the Baddeck River population (2.2–5.0%). Thus, the potential negative effects of these brood stock removals (broodstock were returned to the river immediately following egg/milt stripping), is unknown, but likely negligible. The magnitude of genetic impacts on wild populations resulting from hatchery rearing of these released juveniles is also unknown.

A summary, by decade, of the historical stocking programs in eastern Cape Breton rivers, including the total number of each life stage released and broodstock origin is provided in Table 10. Because the stocking database only includes information from 1979 to 2007, the values listed for the 1970s in Table 10 only include releases from 1979. Similarly, information for the 2000s on Indian Brook only includes data from eight years. Additionally, stocking not included in the database was summarized (years 2010-2012 on the Middle and Baddeck rivers). This variation in the number of years a river was stocked in a given decade means that the total numbers of fish released in each decade are not directly comparable. However, they do give a relative indication of the magnitude of stocking over time in eastern Cape Breton. All life stages released and broodstock origins are listed for a given decade, provided that they were released in at least one year. For example, smolt/parr/fry means that all three life stages were released during at least one stocking event in a particular decade. Similarly, native/local/hybrid means that broodstock from the natal river, from another river in eastern Cape Breton, or a crossbreed (either native x local or local x local) were used at various times to produce the juveniles released during a stocking event (Table 10).

Including the most recent program on the Middle and Baddeck rivers, a total of 907,424 salmon were reported stocked in eastern Cape Breton rivers (Table 10). Of these, 78.2% were stocked in four rivers: the Grand River (32.3% of total, 292,736 salmon stocked over the period of record), the Middle River (21.3% of total, 193,427 salmon), Indian Brook (Cape Breton County., 13.6% of total, 123,733 salmon), and the Mira River (11.0% of total, 100,056 salmon). Keeping the previous caveat regarding unequal number of years per decade included in the dataset, a total of 9,458 salmon were stocked into eastern Cape Breton rivers during the 1970s, 291,438 during the 1980s, 495,754 during the 1990s, 37,074 during the 2000s, and 73,700 thus far during the 2010s.

It is now accepted within the scientific community that salmon reared in captivity rapidly undergo significant changes in morphological, behavioral, and physiological traits in ways that reduce fitness in natural environments (Lynch and O'Hely 2001). The genetic consequences of captive breeding and rearing result from loss of genetic diversity, inbreeding depression, accumulation of deleterious alleles, and genetic adaptation to captivity (Frankham 2008), as well as relaxed selection for adaptation to wild conditions (Lynch and O'Hely 2001). Such processes lead to declines in fitness (reproductive potential or survival) and changes to fitness-related traits (e.g. growth and fecundity) of captive-reared animals relative to their wild counterparts (Araki et al. 2007, Small et al. 2009, Williams and Hoffman 2009), even when local wild fish are used as broodstock. Once captive animals are released, interbreeding among the captive and wild components of populations could lower the overall fitness of a supplemented population over time (Fraser 2008). Although there has been no formal analysis on the degree of interbreeding among fish of wild and hatchery origin for salmon populations from the ECB DU, the literature suggests that such interbreeding (and the resulting fitness loss) would be expected to have negatively impacted ECB DU salmon populations, and in some cases, contributed to population declines from the 1990s to present. However, the rate at which population-level fitness declines during the supplementation program, and how long it takes fitness to recover after supplementation is ended, are both relatively unknown for wild Atlantic Salmon populations (Bowlby and Gibson 2011).

In terms of the impact of historical stocking on populations, it is expected to be less from stocking events that used native broodstock and released younger age classes of juveniles (Fraser 2008). However, based on the 1979 to 2007 data, only three (North, Grand, and Mira rivers) of the stocked rivers within eastern Cape Breton were consistently stocked with fry or parr from native broodstock (Table 10). However, in the North River, there is evidence of stocking that used strains from several other eastern Canadian rivers, including the Miramichi, Saint John, Margaree, Morell rivers, as well as rivers from the Bay de Chaleur (Amiro and Marshall 1990). In many cases, the particular life stages stocked, as well as the broodstock origins, varied both within and among decades.

Current stocking practices

There has been only one federal stocking program for Atlantic Salmon in eastern Cape Breton since 2007. Unlike traditional enhancement methodology, this program captured wild juveniles and reared them in captivity until maturity, at which point they were released back into their natal rivers to spawn. This program took place concurrently with the adult broodstock collections and traditional captive rearing program for juveniles on the Middle and Baddeck rivers. Levy and Gibson (2014) detail this program as follows:

> “Beginning in 2009, DFO initiated a stocking program to offset anticipated future losses to the population from catch-and-release mortality (assumed to be 4% of fish angled) and to offset Aboriginal Food, Social, and Ceremonial (FSC) harvests from Middle River. In 2009, 40 parr were collected from Middle River [and Baddeck River] and taken to the Coldbrook Biodiversity Facility to rear to adults. DFO began stocking adults from this collection in 2011 with an aim to support Aboriginal FSC use.”

Considering the low reproductive value of parr removed from the system, and the low anticipated number of adults that will be restocked into these rivers, the potential negative effects of the parr removals, or genetic impacts associated with the supportively-reared adults are likely negligible, although unknown.

Other salmonid stocking

The potential for competitive interactions among juvenile Atlantic Salmon, stocked Brook Trout and non-native Brown or Rainbow Trout is high, given that all species have similar habitat requirements and can co-exist in freshwater environments (Hearn 1987, Gibson 1988). There is evidence that Brown Trout are both aggressive toward salmon, as well as socially dominant to salmon of similar size (Harwood et al. 2002). These characteristics would influence successful territorial defense and the acquisition of resources. Juvenile Atlantic Salmon alter their behavior and feeding patterns in the presence of Brown Trout (Harwood et al. 2002) and Rainbow Trout (Blanchet et al. 2006), in ways that would likely increase exposure to predation (i.e. increased daytime activity). The presence of non-native trout has substantially disrupted dominance hierarchies and behavioral strategies of juvenile salmon in laboratory and natural settings, resulting in reduced individual growth rates of salmon (Blanchet et al. 2007). However, the population-level impacts of the above competitive interactions (i.e. how Atlantic Salmon survival, growth and maturation changes in the presence of non-native trout) have not been well-quantified. Brown Trout are considered highly piscivorous and juvenile Atlantic Salmon have been reported in the diets of Brown Trout (e.g. Krueger and May 1991). Therefore, Brown Trout (and potentially Rainbow Trout) may represent a source of predation for juvenile salmon, although the population-level impact of such predation has been poorly quantified.

The NSDFA stocks rainbow (spring and fall) and Brown Trout (fall) into a small number of lakes in eastern Cape Breton. In 2011 (combining data from spring and fall distributions), Brown Trout were distributed into 5 locations (3 watersheds), and Rainbow Trout into 10 locations. (Table 10, Figure 6; refer also to Appendix 1). The distribution of Rainbow Trout stocking in eastern Cape Breton is largely focused on supporting a recreational fishery in the Bras d’Or Lakes, although Rainbow Trout are also stocked into four other locations, representing four watersheds (Table 11). Brown Trout releases only take place in systems, which currently have established (naturalized) populations of this species, originating from either historical introductions or invasion from nearby watersheds. There was no information available on the numbers of fish released during each stocking event for this review. The goal of this stocking program is to increase recreational fishing opportunities; thus, releases involve of Rainbow Trout of harvestable size, while Brown Trout releases include both harvestable size and young-of-year fish. Historically, all three species of trout stocked by the NSDFA were reproductively-viable diploid animals, however, stocking of Rainbow Trout over the last decade has involved all-female releases. In an effort to reduce the potential further establishment of wild-spawning populations, the NSDFA evaluated the use of triploid Rainbow Trout in 2010 and 2011. However, poor performance and low survivorship eventually led to their discontinued use (D. Murrant, Manager of Enhancement Program, NSDFA, pers. comm.).

Rainbow Trout is a non-native species that occurs in a large number of water bodies in Nova Scotia as a result of accidental and intentional introductions and invasion. The largest population in Nova Scotia is in the Bras d’Or Lakes (Madden et al. 2010). In general, reproduction of Rainbow Trout in Nova Scotia is considered to be limited:

> “Successful reproduction has been detected in a few Cape Breton stream systems; however, the ability of these populations to self-sustain is questionable. As a result the NS Rainbow Trout fishery is almost entirely supported through direct enhancement to the population or through aquaculture escapement. The rainbow fishery in the Bras d’Or Lakes was largely dependent on escapement of Rainbow Trout from aquaculture sites.” NSDFA (2005).

Possibly as a result of aquaculture escapes, Rainbow Trout seem to have established themselves in the Bras d’Or Lakes. Hurley Fisheries Consulting (1989) reports that: “A sizeable run occurs on the Skye River, while a few rainbow fry have been caught in the Middle River and some smaller brooks. Rainbows migrate up the Skye in the fall (September-October) apparently to spawn the following spring.” In an effort to confirm the presence of wild spawning Rainbow Trout, Madden et al. (2010) electrofished in seven watersheds surrounding the Bras d’Or Lakes in 2008 and 2009. Juvenile Rainbow Trout caught in these systems were presumed to be the progeny of wild spawning events “based on the timing of stocking occurrences and size and weight at age.” Of the seven watersheds investigated, wild juveniles were found in two systems (Skye and Baddeck rivers; R. Madden, Fisheries Technician, NSDFA, pers. comm.). The authors note that juvenile Rainbow Trout have previously been captured during electrofishing surveys in the Middle River (Robichaud-Leblanc and Amiro 2004), Skye River (Amiro et al. 2006), Gillis Lake Brook, Blues Brook, and Breac’s Brook (Sabean 1983). Additionally, “intensive” surveying of the River Denys was performed around the same time as this study (2008/2009) but wild juveniles were not observed (Madden et al. 2010). They also used scale analysis to determine whether age-1+ Rainbow Trout caught by anglers in and around the Bras d’Or Lakes were of hatchery or wild-spawned origin. Their result classified 71% of the trout caught as being hatchery-origin and 29% as wild origin.

A spring and fall stocking program of native Brook Trout, which also has the goal of increasing recreational fishing opportunities, is conducted annually by the NSDFA. This distribution program is much more widespread than that for Brown or Rainbow Trout, uses multiple life stages, and includes releasing both sexes. Not including permitted privately stocked facilities (e.g. commercial “u-fish” operations), there were a total of 46 stocking locations in 2011 (combining data from spring and fall distributions), which represents 12 watersheds, in eastern Cape Breton (Table 11, Figure 6; refer also to Appendix 1).

Although there is some evidence of habitat partitioning (Rodriguez 1995), the potential for competition between Atlantic Salmon and Brook Trout is high, given their co-existence in freshwater environments. In pool habitats, juvenile Brook Trout are able to exclude juvenile Atlantic Salmon through interference and exploitative competition (Gibson 1993, Rodriguez 1995). Larger Brook Trout are known predators of juvenile Atlantic Salmon (Henderson and Letcher 2003), and have a higher potential to impact populations when they are more numerous in the watershed than are Atlantic Salmon (Ward et al. 2008).

The stocking of all three species of trout represents a potential vector for disease transfer between the hatchery environment and wild stocks. To date, there have been no confirmed instances of pathogen outbreak in eastern Cape Breton salmon resulting from hatchery stocking of trout, although there has been very little assessment. Hatcheries are routinely monitored for the presence of pathogens, and animal health guidelines are applicable, however, monitoring programs are not failsafe. Overall, the widespread distribution of stocked trout the potential for competition with, and predation on, wild juvenile salmon, and the ongoing potential for disease transfer, the impact of trout stocking for fisheries enhancement may be considered a medium-level threat to wild Atlantic Salmon in the ECB DU.

Commercial salmonid aquaculture in fresh water

The potential influence of commercial salmonid aquaculture in freshwater environments was described by Bowlby et al. (2014) as follows:

> “Producing fish for stocking programs or commercial aquaculture operations necessitates a facility in which to rear individuals to the desired size. Scientific literature dealing exclusively with Canadian freshwater aquaculture facilities is extremely limited, so most information regarding the effects on freshwater ecosystems and fish communities comes from European studies (Podemski and Blanchfield 2006). The majority of contemporary freshwater hatcheries for salmonid species use flow-through systems, where water is pumped in and discharged continually (rather than re-circulated within the facility) and is subjected to varying levels of filtration (Michael 2003). The NSDoE has regulations regarding permitted concentrations of certain chemicals in wastewater (e.g. ammonium, phosphorus). Commonly recognized components of aquaculture wastewater include organic solids (feed remnants and feces), elevated levels of nitrogen and phosphorous, and chemical residues (e.g. antibiotics) (Camargo et al. 2011, Michael 2003). Wastewater is also characterized by lower dissolved oxygen concentrations and elevated concentrations of suspended solids that settle out of the water column downstream (Bonaventura et al. 1997, Camargo et al. 2011). Therefore, freshwater hatcheries are potentially sources of chemical contaminants and siltation to rivers (refer to Section 5.1), although the overall effect on freshwater ecosystems would vary with the productive capacity of the facility (i.e. the total number and pond density of the fish produced), the regulations on wastewater quality, the species cultured, and the downstream water velocities or flow rate (Bonaventura et al. 1997). In addition to concerns over water quality, freshwater hatcheries have been connected with disease outbreaks and fish escapes (see also Section 6.1 for details on disease outbreaks). Given the usual proximity of rearing ponds to a stream or river to allow for efficient water use, hatcheries have flooded during high water events, leading to the escape of thousands of juvenile salmonids. Escapes due to flooding have been reported at facilities both within and outside of the Southern Upland region, although such information is anecdotal. Escaped juveniles may affect the fish community immediately downstream of the hatchery by increasing competition for food and space, and potentially attracting predators to the area or spreading pathogens to wild fish (Krueger and May 1991).”

Changes in predator or prey abundance

The availability of quality prey is a major factor affecting habitat quality, and prey density may affect risk of predation, growth, survival, and the intensity of density-dependent processes (Slaney and Northcote 1974, Anholt and Werner 1995). In fresh water, the vast majority of Atlantic Salmon diet consists of aquatic invertebrates, although terrestrial invertebrates may also be important (Keeley and Grant 1995, Dineen et al. 2007).

Stream production of aquatic invertebrates, as well as community structure is directly affected by water quality, and indirectly by land use practices (Lenat and Crawford 1994, Quinn et al. 1997). Further, allochthonous inputs (terrestrial-derived organic nutrient input), nutrient turnover and nutrient cycling can be affected by land use practices, which influences stream productivity (Delong and Brusven 1994, Young and Huryn 1999). The availability of terrestrial invertebrates is likely impacted by land use practices within watersheds, in particular the riparian zone. For example, removal of riparian vegetation (historically a common effect of agriculture or forestry) can reduce the abundance of terrestrial insects falling into rivers (Edwards and Huryn 1996, Saunders and Fausch 2007).

There is no evidence specific to eastern Cape Breton linking changes in aquatic invertebrate communities with land use practices, and the is also little data on invertebrate community or trends in aquatic invertebrate communities through time. However, considering the links between land use and invertebrate communities described above, the abundance of prey and prey quality of salmon may represent a plausible mechanism of the impacts associated with land use.

The abundance of predators may also affect salmon in fresh water, and predation is widely reported for all life stages of Atlantic Salmon (*see review by* Ward and Hvidsten 2011). Of the known predators of Atlantic Salmon in eastern Cape Breton, avian predators and piscivorous fishes are the most likely to significantly contribute to mortalities in fresh water. Changes in fish communities and piscivorous fish predators in eastern Cape Breton have been altered in several ways, most notably the introduction of non-native fishes and the stocking of trout for fisheries enhancement (both described in the sections above). Both Chain Pickerel and Smallmouth Bass have the ability to prey upon all sizes of juvenile salmon in fresh water, however, given their limited distribution, these affects are likely to be localized. Conversely, stocked trout are widely distributed in eastern Cape Breton, however, these trout likely consume primarily small salmon (i.e. 0+) as only the largest trout incorporate fish in their diet (e.g. Grey 2001).

Avian predators have received a great deal of attention across much of the Atlantic Salmon’s range, however, avian predators in eastern Cape Breton are not widely surveyed. Double crested cormorants, belted kingfishers and merganser species have all been identified as predators of salmon in Nova Scotia (White 1936, Milton et al. 1995) and elsewhere in eastern Canada (*see review by* Cairns 2001).

The population-level impact of predation in fresh water is dependent on three criteria; the timing of predation (in particular relative to other density-dependent processes), the abundance trends predator populations, and the functional response of salmon predators (Ward and Hvidsten 2011). If predation occurs in conjunction with strong density-dependent mortality, then losses associated with predation may be offset via a compensatory response (likely the case with the majority of trout predation). Conversely, if predation occurs in later life stages, where salmon mortality is not density-dependent (e.g. older parr and smolts being predated by avian predators), then predation may manifest as multiplicative mortality and directly reduce the number of recruits from a watershed.

Genetic effects of small population size

As summarized by Bowlby et al. (2014):

> “Substantial declines in population abundance leading to reduced genetic variation have been associated with a reduction in fitness with respect to one or more phenotypic trait values (an effect termed inbreeding depression; Frankham 2005). Inbreeding depression arises either through an increased chance of sharing parental genes (leading to increased homozygosity and the potential expression of deleterious alleles) or a loss of alleles from random genetic drift (Wang et al. 2002). Despite well-established theory, direct empirical evidence documenting inbreeding in salmonids from historical abundance declines in natural populations is rare (Campton and Utter 1987).”

Although aboundance declines have been observed for some adult populations in the ECB DU (e.g. North, Clyburn), it is unknown if any populations are currently experiencing inbreeding depression. There is some evidence from genetic analyses that four of the seven populations investigated from eastern Cape Breton (North Aspy, Indian Brook, Grand and Inhabitants) may have undergone recent population bottlenecks (O’Reilly et al. 2013), which would result in reduced genetic variability (and substantial population decline), as well as increased susceptibility to inbreeding. However, levels of within-population genetic variability were not significantly lower from populations in eastern Cape Breton than those from large reference populations elsewhere in the Maritimes (O’Reilly et al. 2013).

Allee effects

As summarized in Bowlby et al. (2014):

> “Survival is density-dependent when survival rates change as a function of the number of individuals in a population (Rose et al. 2001). If survival rates decline as abundance declines, the process is depensatory and acts to reduce population growth rates when abundance is low and may accelerate population decline. This phenomenon is also known as an Allee effect, although Allee effects are typically defined as positive effects of increasing density on fitness (Kramer et al. 2009). Several ecological mechanisms have been hypothesized to result in Allee effects, including:
>
> 1. mate limitation, such as the inability to locate conspecifics, highly skewed sex ratios, or a lack of non-sibling partners,
> 2. cooperative defence, such as schooling behaviour,
> 3. predator satiation,
> 4. cooperative feeding,
> 5. effective dispersal, and
> 6. habitat modification, such as the ability to effectively exclude other species from preferred habitat types, or changes in abiotic or biotic conditions that benefit conspecifics (Kramer et al. 2009).”

Although few studies have demonstrated the existence of critical densities (i.e. a minimum population size) below which populations are adversely influenced by Allee effects (Kramer et al. 2009), the low abundance observed for eastern Cape Breton Atlantic Salmon relative to historical population sizes (Levy and Gibson 2014) suggests that Allee effects may have the potential to reduce population productivity.

Scientific activities

Direct sources of mortality to Atlantic Salmon populations from scientific research activities come from capturing, collecting, handling or holding fish (e.g. electrofishing, smolt wheels, seining and sampling for biological characteristics; weight, length, and scale samples). Other potential effects include displacement from territories, interruption of upstream or downstream movement, or small-scale habitat modification related to wadding. Annual population assessment activities for salmon in eastern Cape Breton are limited and typically involve passive methods (i.e. observing adult fish); however, electrofishing has been carried in the past. Deleterious effects on individual fish from electrofishing are well established (Snyder 2003), but influence a very small proportion of the population and take place at a point in the life-cycle where mortality can be offset by a compensatory response (Ward and Hvidsten 2011). All operations minimize handling as much as possible, avoid chemical anesthetics as much as possible, and cease operation and handling at physiological stressful water temperatures (DFO and MNRF 2009). Overall, mortality associated with scientific activities is thought to be low.

6.3 PHYSICAL OBSTRUCTIONS

Dams, water diversions and other permanent structures

Bowlby et al. (2014) provide the following summary of the effects of permanent structures:

> “Permanent structures are often placed in or along rivers for three main purposes:

> 1. water impoundment (reservoirs for hydro, municipal drinking water, or other industrial uses),
> 2. bank stabilization (to prevent movement of the stream channel), or
> 3. water diversion (for industrial and recreational uses or flood prevention).
>
> All of these structures disrupt the natural hydrological processes in a watershed and lead to a variety of impacts on fish and fish habitat. Bank stabilization is probably the most benign, provided it is carried out through a relatively small proportion of the total river length. However, preventing the natural meander of streams disrupts hydraulic energy dissipation and changes local channel morphology and flow patterns (i.e. the maintenance of various habitat types in a watershed). A substantial amount of research on the impact of logging roads on salmon habitat from the Pacific Northwest suggests that rapidly eroding banks and increased sedimentation can substantially increase mortality and alter species composition in rivers (Cedarholm et al. 1981, Gucinski et al. 2001). However, there has been comparatively little research on the impacts of erosion on Atlantic salmon populations. Surprisingly, rapidly eroding banks (which would be expected to require bank stabilization) were not associated with increased sedimentation or reduced habitat quality for Atlantic salmon in the Nouvelle River in Quebec (Payne and Lapointe 1997).
>
> The effects of water diversions (using dykes, ditches, small dams or artificial channels) are largely determined by the purpose and size of the installation, as water can be held back, diverted away from, or maintained in the main channel. Reducing flow downstream of the installation leads to reduced habitat availability and contributes to direct mortality of juvenile Atlantic salmon from extreme temperature events (Caissie 2006, DFO and MNRF 2009). Similarly, it can also contribute to habitat fragmentation in the watershed as individuals are prevented from moving due to low flow conditions, or are physically impeded by a dam (Thorstad et al. 2011). In contrast, substantially increasing flow in the main channel can accelerate erosion and lead to changes in channel morphology, both of which impact the quality, quantity and distribution of habitat available in fresh water."

The impacts of total barriers (i.e. structures listed as impassable to fish) in watersheds of eastern Cape Breton were provided in Section 4.1. Here, all types of structures listed in the barriers layer from the NSDoE and the Habitat Division are considered. These data indicate that there are a total of 20 dams or barrier structures within eastern Cape Breton, and that only 5 of them are considered to be passable to fish (Table 3, Figure 7). Visual assessment based on the location the barrier and the National Hydrographic Network (NHN) flow network data indicate that with the exception of the Wreck Cove Hydro project there are only two barriers known to be of significant impact (greater than 25% of the watershed): these are the Grand Lake Dam in Northwest Brook (watershed #34) and the Sydney River dam (watershed #35).

Reservoirs

Bowlby et al. (2014) provide the following summary of the effects of reservoirs:

> "The ecological impacts of reservoirs on fish populations and freshwater habitat can be substantial, particularly for rivers in temperate or northern climates (Rosenberg et al. 1997). Bioaccumulation of methylmercury in organisms is commonly associated with the creation of reservoirs, resulting from bacterial metabolism of the inorganic mercury naturally present in newly flooded sediment. High levels of mercury have been found to persist for 20 to 30 years in predatory fish populations, including salmonids (Rosenberg et al. 1997). Reservoirs (particularly those associated with hydroelectric generating facilities) tend to retain high spring flows for storage and release additional water

> during winter (Rosenberg et al. 1997), which is opposite to the natural hydrological regime of a river. Changes in discharge are important cues for smolts and adults to initiate movement, either upstream in the summer/fall or downstream in the spring (see Section 1.1 for more details). Furthermore, truncating flood flows and exacerbating low flow conditions during summer have multiple detrimental impacts on freshwater habitat and Atlantic salmon."

The specific issues related to reservoirs have not been studied in eastern Cape Breton, however, there is little reason to expect that the effects would be fundamentally different from those above. To identify the spatial extent to which reservoirs impact rivers in eastern Cape Breton, two spatial analysis methods were used to identify the location of reservoirs. The NHN data uses codes to identify water bodies as reservoirs and these were characterized (e.g. by area, or as counts in each watershed) in ArcGIS (refer also to Appendix 1). Additional spatial analyses was performed by intersecting known dams from the NSDoE and DFO Habitat Division barriers layer with the NHN stream network data to identify upstream water bodies (i.e. likely reservoirs) in watersheds. Due to the spatial accuracy of the barriers data, this intersection method is believed to have underestimated dammed water bodies (and therefore likely reservoirs) in eastern Cape Breton. However, trying to compensate for this error by increasing the search radius for the intersection analysis would have likely included water bodies that are not reservoirs (i.e. increased the misclassification rate of water bodies as reservoirs). Therefore, to avoid overestimating the numbers of reservoirs, only the upstream water body features that directly intersect dams were classified as "Likely Dam/Reservoir" and only in cases where the NHN had not already identified the water body as a reservoir.

Watersheds impacted by reservoirs (identified using either method above in addition to the reservoirs associated with the Wreck Cove Hydroelectric Project identified separately by the authors) are not widely distributed in the eastern Cape Breton region, affecting only 9 of the 46 watersheds (Figure 8). The total wetted area of all these reservoirs is approximately 21.6 km^2, with the most impacted watershed by area being Indian Brook, Victoria County (watershed #7) with approximately 9.2 km^2 of reservoir (the median amount of reservoir wetted area in the nine affected watersheds is 0.97 km^2; Table 12).

Culverts

Bowlby et al. (2014) provide the following summary of the effects of culverts for Southern Upland salmon:

> "Barriers to dispersal have recently been identified as a significant factor in fish population declines around the world (Poplar-Jeffers et al. 2009). Atlantic salmon depend on unobstructed movement in a watershed to access spawning and rearing areas, avoid predators, and respond to changing environmental conditions such as temperature, flow, or inter- and intra-species competition. [*Text deleted*] Culverts are recognized as the most significant contributor to barriers to fish passage in a watershed, where poor design, improper installation or inadequate maintenance reduce (or eliminate) passage at the majority of installations (Gibson et al. 2005, Blank et al. 2005). Recent surveys of culverts in Nova Scotia suggest that barriers to fish passage are prevalent, with 37% assessed as full barriers and 18% as partial barriers in the Annapolis watershed (Hicks and Sullivan 2008), and 61% assessed as full barriers from a random sample of 50 culverts in Colchester, Cumberland, Halifax and Hants counties (Langill and Zamora 2002). Of 62 culverts assessed on the St. Mary's River, Mitchell (2010) found that 40 did not meet criteria for water depth, 35 exceeded velocity criteria, and 24 had an outfall drop potentially preventing passage. Similar results have been obtained for watersheds containing Atlantic salmon in Newfoundland and the continental United States, as well watersheds containing Pacific salmon and other trout species in Alaska and British Columbia (Gibson et al. 2005).

> “[*Text deleted*]. Due to the ease of installation and low cost relative to bridges, culverts are installed at the majority of road crossings, particularly in tributaries or smaller headwater reaches. Activities such as timber harvesting, urbanization, road development, and other land development tend to increase the number of culvert installations in a watershed (Gibson et al. 2005). In eight counties of Nova Scotia, Langill and Zamora (2002) reported 215 notifications for installation of new culverts for the five year period between 1996 and 2000. If this rate is representative, there could have been as many as 600 new culverts installed in the last 15 years. Furthermore, research by Gibson et al. (2005) suggests that the age of the installation is not indicative of its effectiveness for fish passage, given that 53% of newly installed culverts in an upgraded section of the TransCanada Highway in Newfoundland were barriers to Atlantic salmon. Therefore, culverts are extremely likely to lead to significant habitat fragmentation.”

The presence of culverts could not be assessed directly from the data available because river-specific surveys are required, such as those in other regions of Nova Scotia (i.e. the Annapolis and St. Mary’s rivers; Hicks and Sullivan 2008, Mitchell 2010). Therefore, to assess the impact of culverts throughout the ECB DU, road crossings were used as a proxy. In ArcGIS, the NHN flow data, both known and inferred flow (e.g. arcs representing flow through rivers wide enough to be represented as a polygon) were intersected with the National Road Network (Edition 8) for Nova Scotia, combining data from paved and unpaved roads (refer also to Appendix 1) to calculate the total number of road crossings.

The total number of road crossings in a given watershed were expressed as a density (number of crossings per 10 km of stream length) to facilitate comparison among rivers. As expected, watersheds in more populated areas, as well as those impacted the most heavily by forestry or agriculture (*see* Section 5.4) had the highest road crossing densities (Figure 9; Table 13), and, thus, the greatest potential for impact from culverts. The mean and median number of road crossings per 10 km of the flow network is 2.8. Several of the smaller watersheds have road crossing densities greater than 5 and as high as 7.5 (McKinnons Brook #18). Nine watersheds (#s 1-6, 13, 14 and 41) have road crossing densities of less than 1 per 10 km of flow network.

6.4 HABITAT ALTERATION

Infrastructure (roads)

Bowlby et al. (2014) provided the following summary about the effects of roads on fish habitat:

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

> [*Text deleted*] In addition to roads, there are other types of corridors, such as power lines, natural gas pipe lines and railways, which would have similar types of effects and are often located adjacent to roads and watercourses. Similar to roads, these corridors are associated with land clearing (potentially including streamside vegetation) and are sources of increased sedimentation and chemical contamination."

In eastern Cape Breton, watersheds within the Cape Breton Highlands National Park (#s 1-6) and also Indian Brook, Cape Breton County (watershed #41) had the lowest road densities. The highest densities (with more the 1 km of road per square kilometer) occurred in more urban areas (watershed #s 17, 18, 22, 24, 34-38, 45, and 46), predominantly, but not exclusively, around Sydney and Port Hawkesbury (Figure 10; Table 13).

The total length of road contained in a specific watershed was approximately proportional to the size of the watershed (Linear regression, r^2=0.90, df=44, p <0.01). This road length may be expected to be related to the extent of human use of a watershed, in terms of the potential for agriculture, forestry, industry or urbanization.

Rivers in eastern Cape Breton tend to have a significantly greater amount (based on total length) of unpaved road versus paved road within a watershed (Table 13). In some instances, the amount of unpaved road is nearly two orders of magnitude greater than that of paved (e.g. Indian Brook, Victoria County, Middle River Framboise River), and is frequently one order of magnitude different. Unpaved roads are generally considered to contribute significantly greater quantities of sediment than paved surfaces so the large area of unpaved surfaces in eastern Cape Breton is likely a significant source of sediment to these systems.

Hydropower generation

Bowlby et al. (2014) provided the following summary about the effects of hydroelectric development on salmon populations:

> "Impacts to Atlantic salmon from hydropower development include direct mortality (e.g. from strike, shear, cavitation or extreme pressure changes during passage through turbines) as well as indirect effects from reduced habitat access (i.e. due to inefficiencies in fish passage structures or the lack thereof), changes to flow and temperature regimes, altered macroinvertebrate communities, or increased exposure to predators in impoundments (Carr 2001, Johnsen et al. 2011). Even in situations where the facility has been small (and thus considered minor), significant and substantial changes to the distribution of spawning redds, juvenile densities, and smolt production have been observed (Ugedal et al. 2008).
>
> In terms of the specific life stages impacted by hydropower generation, smolts and adults have the highest potential for direct mortality or reduced habitat access during upstream or downstream migrations. Mortality of smolts passing through turbines can be very high (e.g. estimated at 45% from the combined influence of three dams in the St. John River; Carr 2001), and adult upstream migration is often hindered by inefficient attraction to entrances or ineffective fish passage facilities (Johnsen et al. 2011). Juvenile life stages are more impacted by changes to hydrological conditions brought about by the operating schedule for power production than by the dam itself. Stranding (due to abrupt changes in water flow), increased feeding behaviour or movement during winter (caused by reduced ice cover), and changes to the chemical characteristics of water downstream of the dam (due to the combined effects of sedimentation and water impoundment) have all been found to negatively impact juvenile production (Johnsen et al. 2011)."

Within eastern Cape Breton, the only large hydroelectric development is the Wreck Cove Hydroelectric Project, which is also the largest hydroelectric facility in the province. The whole project includes 14 dams and/or spillways, and includes diversions of four rivers (the Cheticamp River, the Ingonish River, Indian Brook, and Wreck Cove Brook). While this is a major change to the hydrodynamics of the area, the effects on salmon habitat are less because of natural barriers in the area that precluded access to much of this area. The biggest change in habitat availability to salmon was likely in Wreck Cove Brook, a small watershed (25.4 km^2) that was noted to have salmon before the construction of the dams. Based on the available information, it does not appear that there is fish passage provided at any of the Wreck Cove project dams. The Ingonish River (watershed #6), which is a larger river and known to have salmon, has two dams on small water bodies near its headwaters. Indian Brook has two dams, one at the MacMillan Flowage and one at the Gisborne Flowage. However, most of Indian Brook, including these areas, is upstream from falls that are impassable to salmon, so no direct loss of access to salmon habitat results.

Pulp and paper mills

Bowlby et al. (2014) provided the following summary about the effects of pulp and paper mills:

> “Federal regulations passed in 2002 have improved the water quality of the receiving environment downstream from pulp and paper mills, although the results of environmental effects monitoring demonstrate that mill effluents are still degrading freshwater habitats at multiple locations across Canada (McMaster et al. 2006). Pulp mill effluent tends to be high in organic compounds and contains chemicals linked to endocrine disruption in fish (specifically sex steroid production), leading to decreased gonad size, altered secondary sexual characteristics, and decreased egg production (Hewitt et al. 2008). Such effects have been found in a wide range of freshwater fish taxa, although there is no recent research that has focused on Atlantic salmon (DFO and MNRF 2009). However, multiple endocrine-disrupting chemicals (predominantly from herbicides) have been found to have significant impacts on Atlantic salmon abundance (Fairchild et al. 1999), smolt growth rates (Arsenault et al. 2004), and survival upon entering salt water (Moore et al. 2003). Therefore, it is very likely that the endocrine active chemicals in pulp mill effluent would negatively influence Atlantic salmon populations, even though there is no definitive research linking pulp mill effluent with Atlantic salmon survival.”

There is one pulp mill, located at Point Tupper, near Port Hawkesbury in eastern Cape Breton. This area is not included in the assessed watersheds. The mill, ceased operating in September 2011, but resumed production in September of 2012.

Urbanization

Urbanization is a very general category of land use encompassing multiple types of land use related to human population growth, including: infrastructure development (e.g. roads and buildings) and residential, industrial, or commercial development. In terms of its effects on salmon populations, urbanization is strongly associated with activities such as clearing (deforestation), construction of roads, and increases in the amount of impervious surface (e.g. paved roads, parking lots), all of which can significantly alter or disrupt hydrological processes in a watershed and lead to declines in water and habitat quality (Booth et al. 2002). Increased erosion and sedimentation, changes to seasonal river discharge and temperature patterns, and increased nutrient or chemical concentrations have all been associated with urbanization in watersheds (DFO and MNRF 2009).

In the land classification data from the NSDNR Forest Inventory (see Appendix 1), any area that is used primarily as residential or industrial (including sidewalks, roads, and parking lots), as well as some house lots in wooded areas are classified as urban. The proportion of urban and industrialized areas within watersheds in eastern Cape Breton is provided in Table 14 and shown in Figure 11 (urban) and Figure 12 (industrial). Twenty-seven of the 46 watersheds have

<1% of their area classified as urban, and two watersheds have >5% of their area classified as urban. Similarly, 30 of the 46 watersheds have <1% of their area classified as industrial, with only one above 5% (Table 14). However, the available data on land use is not of sufficient resolution to identify all rural settlements (e.g. cabins or isolated properties with small cleared areas), and the values in Table 14 should be considered underestimates.

Agriculture and forestry

Bowlby et al. (2014) provided the following summary about the effects of forestry on salmon populations:

> “Agriculture and forestry practices are grouped together because of similarities in terms of their influence on Atlantic salmon populations, namely through large-scale land clearing affecting runoff patterns to streams, the removal of riparian vegetation and potential for sedimentation, as well as the application of chemicals to promote crop or stand growth and to control competition. Habitat deterioration associated with land clearing (e.g. stream widening, loss of pools, temperature extremes) is primarily due to changes in sediment input and hydrology (Gilvear et al. 2002). Impacts to Atlantic salmon populations from sedimentation, extreme temperature events, and changes to flow characteristics have previously been discussed in Section 5.1.
>
> Research in Britain suggests that the links between forest clearing and fish production are complex, and that restoration of forests is not necessarily going to lead to an increase in production. It has been suggested that young forests (early successional stages) are highly efficient filters for light, nutrients and sediments to the point that these properties can be reduced below those optimal for fish production (Nislow 2005). Other research on agricultural land from New Zealand suggests that land-use legacies (defined as in-stream habitat degradation associated with previous land-use; e.g. channelization) are much more important determinants of how an aquatic community will respond to increased riparian vegetation (Greenwood et al. 2012). Multiple studies on the West Coast of Canada have demonstrated negative impacts on salmonid populations related to forest clearing (e.g. Bilby and Mollot 2008), with the main effects coming from increased siltation (Waters 1995) or changes to hydrological patterns (Moore and Wondzell 2005). Research at Catamaran Brook in New Brunswick did not detect any hydrological change associated with forestry when 2% of a sub-basin drainage area was cut (Middle Reach), yet did detect increased peak flows and precipitation in the sub-basin subjected to 23% harvest (Upper Tributary) (Cassie et al. 2002). In the Nashwaak River in New Brunswick, a 59% increase in summer peak flow was measured the year after 90% of the basin was clear-cut (Dickison et al. 1981). In the Copper Lake watershed of Newfoundland, increased winter temperatures were detected even with a 20 meter no-harvest buffer zone (Cunjak et al. 2004). In Pockwock Lake and Five Mile Lake in central Nova Scotia, more substantial changes in stream chemistry were observed following timber harvesting with 20 m buffers (no cut or select cut) than with 30 m (select cut), demonstrating the importance of riparian vegetation for filtration and retention of minerals in riparian soil (Vaidya et al. 2008).
>
> Unlike Pacific salmon, studies on forestry interactions with Atlantic salmon are rare, but research in the Cascapedia River Basin (Deschenes et al. 2007) reported reduced density of salmon associated with land-clearing (again, timber harvest) at large spatial scales. In Catamaran Brook, New Brunswick, the relationship between mean winter discharge and egg survival for Atlantic salmon suggests lower than expected egg survivals in the years following timber harvest, although natural variability in juvenile survival was high and similar effects on the older age classes were not observed (Cunjak et al. 2004).

> Pesticides (insecticides, herbicides and fungicides) associated with forestry and agriculture may be introduced into aquatic environments by improper application practices (e.g. spraying too close to a watercourse) or through surface run-off. The impacts of pesticides on aquatic communities depend primarily on three factors:
>
> 1. the inherent toxicity of the chemical,
> 2. concentration of the chemical, and
> 3. duration of exposure.
>
> As such, different chemicals at different concentrations can have either acute (leading to immediate mortality) or chronic (leading to increased cumulative mortality) effects (DFO and MNRF 2009). Furthermore, chemical contaminants like pesticides can influence the behavioural or ecological processes of Atlantic salmon directly (see Section 5.1 for more details), or can modify the macroinvertebrate community of a river system, leading to indirect impacts. Toxicity of a given chemical in freshwater environments is influenced by many hydrological and water quality variables, including stream flow, pH, temperature, and conductivity (DFO and MNRF 2009)."

Land use data from the NSDNR Forest Inventory was used to quantify the amount of area classified as being used for forestry and agricultural activities (among other threats) in watersheds of the eastern Cape Breton (Table 14 and Appendix 1). Although alternate spatial datasets exist on land use in Nova Scotia (e.g. Land Cover circa 2000 from GeoBase, and the United States Geological Survey Global Land Cover Characteristics Database, versions 2 and 3), neither were of sufficient resolution to be comparable to the NHN used in these analyses. The land use data in the Forest Inventory was collected by aerial photography from 1995 to present and does not detail the order in which counties or areas were surveyed. Therefore, there is the potential for substantial changes in land use in an area since the survey was completed, but these changes would not be captured in the analyses presented here.

For the majority of watersheds in eastern Cape Breton, the proportion affected by agriculture is very low, with 29 of the 46 watersheds having less than 1% of their total area classified as agricultural use (Table 14, Figure 13). Agricultural activity is concentrated in the Aconi Brook (#39), McKinnons Brook (#18) and Skye River (#15) watersheds where agricultural land use ranges from 10.56 to 6.07% of the area. Conversely, forestry activities encompass a much greater proportion of total watershed area for the majority of rivers in the DU, with 16 rivers having between 10 to 30% of their total area used for silviculture or timber harvest (Table 14, Figure 14). An additional 20 rivers have between 5 and 10% of the watershed used for forestry. The remaining 10 watersheds are mostly protected from forestry operations, being within the boundaries of the National Park.

Mining

Bowlby et al. (2014) provided the following summary about the effects of mining on aquatic ecosystems:

> "Open pit mining operations (including gravel quarries) have several environmental effects within the mine site arising from activities such as land clearing, modification of soil profiles, and changes to topography and slope, all of which influence surface run-off and groundwater tables, and, thus, hydrology in a watershed. More distant effects include dust production, as well as increased sedimentation and mineral concentrations (including heavy metals) in mine drainage, which can have significant impacts on downstream aquatic ecosystems (Cavanagh et al. 2010a). Impacts to freshwater habitats related to increased sedimentation were discussed in Section 5.1. Because increases in suspended sediments are always expected from active open pit mining, mitigation measures are typically implemented concurrent with commencing

> operations, and may include diversion of surface-water, tailings management in settling ponds, and sediment traps (Cavanagh et al. 2010b). However, once active operations have ceased, waste rock and tailings are still present (particularly from historical mining techniques) and can increase sedimentation in watersheds for many years afterwards.
>
> Groundwater, surface water run-off and mine process water all have the potential to interact with mineralized rocks and thus are collectively referred to as ‘mine drainage’. Sulphide-rich, metamorphic slates or gold-bearing rocks have been associated with highly acidic run-off that can contain toxic levels of heavy metals, termed Acid Mine Drainage (Norton et al. 1998, Akcil and Koldas 2006). Such geologic features are common in the Southern Upland. The effects on aquatic ecosystems resulting from trace elements and metals in mine drainage (including Acid Mine Drainage) are among the most difficult mining-related environmental impacts to predict, mitigate, manage or remediate (Cavanagh et al. 2010a). Furthermore, there are no standardized methods for ranking, measuring or reducing the risk of Acid Mine Drainage, and the level of risk to freshwater ecosystems will vary considerably from site to site (Akcil and Koldas 2006). Depending on the underlying topography and the mineral being mined, mine drainage can range from a neutral pH to highly acidic (with elevated levels of dissolved iron and aluminum). Furthermore, various trace elements are found in mine drainage, where the specific elements tend to be characteristic of the mineral being mined. For example, gold mining is associated with elevated levels of arsenic or less commonly antimony (Cavanagh et al. 2010b). The biological impacts of mine drainage include direct toxicity associated with low pH or high metal concentrations, leading to immediate mortality or long-term sub-lethal effects such as endocrine disruption (e.g. reduced reproductive success). Also, heavy metals bioaccumulate in freshwater ecosystems, and tend to have higher concentrations in species or life stages (e.g. smolts) that feed at higher trophic levels (Beauchamp et al. 1997).”

Information on active mining operations was not collated for this review, but the locations of historic mines (as indicated by abandoned mine openings) was obtained from the NSDNR Abandoned Mines Database (*refer to* methods in Appendix 1). Of the 1046 openings listed for eastern Cape Breton, 892 were from historical coal mines (Table 8). The majority of these are not in watersheds under consideration here. Most of the abandoned mines are found in watersheds in the southeast portion of the region (Figure 15). Of the watersheds discussed in this document, the Mira watershed has the greatest number of abandoned mine openings, followed by MacAskills Brook and Middle River.

Within Middle River, nearly all the abandoned mine openings are old gold mines. Bowlby et al. (2014) provided the following summary of the effects of this activity on aquatic ecosystems:

> ”According to the Nova Scotia Department of the Environment, gold was extracted by crushing gold-bearing rocks and spreading the sediment over liquid mercury. Once the mercury was evaporated, the final products were gold and a sand-like tailings substance containing high concentrations of arsenic. In some locations, these tailing sites persist to present day and often resemble large inland beaches (NSDoE 2012). Elevated levels of mercury and arsenic have been found in freshwater fishes, leading to advisory warnings on the maximum frequency of consumption for Brook Trout and other freshwater sport fish (NSDoE 2012). Elevated metal concentrations, including arsenic, have been found to induce skeletal deformities in Atlantic Salmon (Silverstone and Hammell 2002), and may have other physiological or behavioral impacts.”

6.5 DIRECTED SALMON FISHING

Aboriginal salmon fisheries

In eastern Cape Breton (as elsewhere in Canada), Aboriginal food, social and ceremonial fisheries are prosecuted on specific rivers subject to negotiated agreements and licenses issued to individual groups. The licenses may stipulate gear, season and catch limits, as well as locations or other considerations related to the harvest (DFO and MNRF 2009). In some instances, fishing rights have been restricted to certain components of the salmon population (e.g. salmon <63 cm fork length; grilse, 1SW), foregone entirely, or reallocated to alternate rivers in situations where conservation of a particular salmon population has been a concern (DFO and MNRF 2009). Historically, estimates of salmon harvests under Aboriginal fishing agreements were low; less than 10% of the estimated retention from the recreational fishery (Anon. 1980).

Recreational salmon fisheries

Recreational fishery data have been collected for 31 of the watersheds in eastern Cape Breton (Figure 16). Conservation measures by fisheries management were originally implemented in 1984, which stipulated the live release of all fish >63 cm fork length (large, MSW salmon) and instituted a mandatory license-stub reporting system to record catch and effort data from individual fishermen (O'Neil et al. 1987). By 1998, catch-and-release angling was extended to include small salmon (<63 cm fork length) as well.

Since 2010, all rivers within SFA 19 were closed to recreational salmon angling with the exception of the Middle, Baddeck, North, and North Aspy rivers (DFO 2012). Across the 31 angling time series, two trends are obvious when describing catch and effort (*see* Levy and Gibson 2014). First, in rivers currently closed to angling in eastern Cape Breton, catch and effort declined dramatically, in most cases preceeding closure of the fishery. In the four rivers were angling remains permited, both effort and catch has remained relatively stable through time.

Recreational angling can threaten Atlantic Salmon populations through direct mortality of adults or sub-lethal effects, such as reduced spawning success (DFO 2011). Fly-fishing using barbless hooks (as opposed to using spinning gear) and educating individual fishermen on appropriate methods for live-release (e.g. minimizing exposure to air) have been shown to significantly reduce the mortality associated with recreational angling (ICES 2009). Mortality rates associated with recreational angling increase substantially with water temperature. Studies in water <10°C consistently reported zero mortality, while mortality ranged from zero to 22% in water temperatures from 12°C to 19°C, and 30% to 80% in water temperatures from 20°C to 23°C (*see review* by ICES 2009). However, it is important to note that only some of the studies estimated survival from release to spawning and all studies used experienced anglers, both of which could lead to underestimates of total mortality. Additionally, sub-lethal impacts (e.g. stress, injuries) on spawning success have not been studied (ICES 2009). Angler education, mandatory use of artificial flies, and warm-water season closures were all implemented for eastern Cape Breton in the years leading up to the closure of the recreational fishery.

Illegal fisheries (poaching)

There have been many anecdotal reports of illegal fishing activities (i.e. poaching) for Atlantic Salmon in eastern Cape Breton, using recreational fishing gear, by blocking the abandoned fishway on the Grand River and using gillnets. The magnitude of this threat to specific populations is not possible to quantify. Poaching would be expected to have the greatest impact when population sizes are small and when population growth rates are low; both of these conditions exist at present.

6.6 BY-CATCH IN OTHER FISHERIES

By-catch in Aboriginal or commercial fisheries

As summarized by Bowlby et al. (2014):

> “There has been no reported by-catch of Atlantic salmon in Aboriginal fisheries for other species taking place in fresh water (DFO and MNRF 2009). For commercial fisheries of other species (e.g. gaspereau (Alewife and blueback herring), shad, and American eel) in fresh water, fishing seasons and gear have been modified to reduce or eliminate the capture of Atlantic salmon (DFO and MNRF 2009). Therefore, incidental mortality to Atlantic salmon populations from commercial fisheries in fresh water is thought to be extremely low.”

By-catch in recreational fisheries

Recreational fishermen using the appropriate gear types and fishing in the appropriate habitats for their target species are unlikely to catch an adult Atlantic Salmon in fresh water. Fisheries for species co-existing with salmon are generally restricted by season, location and gear variation orders to prevent or minimize salmon by-catch (DFO and MNRF 2009). Atlantic Salmon parr may be captured incidentally while angling for Brook Trout, but they are unlikely to be targeted by anglers. Population level effects of this by-catch are likely minor given the abundance of this life stage and the suspected low by-catch. Mortality rates associated with hook and release of parr or smolts is unknown.

Illegal targeting of Atlantic Salmon while fishing under a general license

Conversely, in recent years there has been increasing concern regarding recreational anglers illegally targeting adult Atlantic Salmon while fishing under authority of a trout license (i.e. using artificial flies that target salmon and fishing in known salmon pools), particularly in areas where recreational salmon fisheries have been closed (DFO 2011). There is the potential for higher mortality rates from this type of catch and release angling as compared to a directed recreational fishery for Atlantic Salmon primarily because the fishing season for trout is longer and spans the summer (when water temperatures may be high). In the Nova Scotia Southern Upland, a variation order was announced in 2011 that prohibited all angling in several known salmon holding pools in several rivers (e.g. LaHave and St. Mary’s rivers) in an effort to stop such illegal fishing. There have been no similar management measures implemented in eastern Cape Breton to address this potential threat.

7.0 MAGNITUDE, EXTENT AND SOURCE OF THREATS TO EASTERN CAPE BRETON ATLANTIC SALMON IN MARINE ENVIRONMENTS (TOR 9, 16, 20)

Reduced marine survival has been implicated as contributing to population declines of Atlantic Salmon of the ECB DU. Historically, smolt-to-adult return rates for 1SW adults ranged from approximately 6% to 15% for rivers in Newfoundland and from 8% to 10% for Maritime rivers (Amiro 2000). Although there has not been assessment of marine return rates in eastern Cape Breton rivers, nearby index rivers may provide estimates of general trends, although the return rates for populations in western Cape Breton and around the Gulf of St. Lawrence are much higher than those of populations in the Southern Upland. Inferences from these surrounding regions may be problematic due to these differences.

At-sea or marine mortality does not imply that factors occurring at sea are solely responsible for subsequent adult returns. For example, threats like chemical contaminants or low pH in freshwater that interfere with the successful transition to the marine environment (e.g. those that reduce osmoregulatory capabilities, influence homing ability, or lower individual growth or condition factor) would lead to higher mortality rates in the marine environment and thus would become a component of at-sea mortality. The specific threats may occur in freshwater (sub-lethally), but their population-level impact on mortality rates may not be evident until after smolts enter the marine environment. It is not known how large the freshwater components of at-sea mortality may be relative to threats taking place exclusively in the marine environment.

7.1 CHANGES TO BIOLOGICAL COMMUNITIES

Non-native species

There have been several introductions of non-native marine species to the Maritime Provinces, including the green crab (*Carcinus maenus*), tunicates (*Ciona intestinalis*, *Botrylloides violaceus*, and *Botryllus schlosseri*), codium (*Codium fragile* spp.) and membranipora (*Membranipora membranacea*). Green crab (Klassen and Locke 2007, Breen and Metaxas 2008), and invasive tunicates (Sephton et al. 2011) have been found in the near-shore coastal environments of eastern Cape Breton, and have also been confirmed within the Bras d'Or Lakes. Therefore, these species have the potential to affect Atlantic Salmon and their marine habitats. It is unclear whether codium or membranipora are found in coastal waters of eastern Cape Breton.

The influence of non-native species on marine ecosystems was described by Bowlby et al. (2014) as follows:

> "Invasion by the green crab has been linked to significant changes in benthic communities (e.g. soft-shell clam (*Mya arena*) distribution and abundance in Nova Scotia; Breen and Metaxas 2008), and numerous studies have shown the potential for this crab to directly and indirectly affect many ecosystem components through predation, competition and habitat modification (Klassen and Locke 2007). In addition to changes in community structure, green crabs have been shown to decrease the diversity and biomass of entire estuarine communities, and to facilitate the spread of other invasives in the Gulf of St. Lawrence (Locke et al. 2007). Reduced productivity in estuaries, coupled with ecological shifts in species distribution or abundance, have the potential to impact prey availability and thus habitat quality in near-shore environments for Atlantic salmon (DFO and MNRF 2009), although invasion by the green crab has not been explicitly linked to salmon populations.
>
> Invasive marine tunicates (the three species listed above) are widely distributed along the coastal areas of Nova Scotia, and there is the potential for two additional tunicate species (*Styela clava* and *Didemnum vexillum*; found along Prince Edward Island coasts and in the Gulf of Maine) to establish (Sephton et al. 2011). The principle impact to marine ecosystems from tunicates is as a fouling agent, where they attach to available structures in the water column, such as boats, pontoons, docks, as well as aquaculture lines and cages. As such, tunicates represent a significant threat to the shellfish aquaculture industry by substantially increasing operating and equipment costs (Sephton et al. 2011). However, there is little evidence linking tunicates to changes in benthic communities or other marine ecosystems so their impact on wild Atlantic salmon populations is likely very low.
>
> Codium has significant and permanent effects on the structure of coastal habitats in Nova Scotia. Historically, these habitats have cycled between two forms of communities, one dominated by large kelps and the other by small algae that crust over rocks. This cycling is maintained by sea urchins grazing on kelp, reducing areas to 'urchin barrens' and these barrens then reverting to kelp forests as sea urchin populations move on or die off (Scheibling et al. 1999). Codium disrupts this cycle by establishing dense mats in barren areas, thus preventing kelp from re-establishing. The morphological structure of codium (low-lying dense mats) suggests that this species

> will trap transported sediment in near-shore areas, prevent benthic habitat use by large invertebrates (such as lobster (*Homarus americanus*) or clams), and eliminate three dimensional habitat for larger fish that typically shelter in the understory of a kelp forest. The use of kelp forests by immature Atlantic salmon has been hypothesized rather than directly observed (McCormick et al. 1998). However, it is logical to assume that Atlantic salmon would use kelp forests for feeding and protection from predators, given that kelp forests have traditionally been the dominant near-shore marine habitat type in Nova Scotia (Scheibling et al. 1999).
>
> The reduction in kelp forest habitats due to codium may be exacerbated by the presence of membranipora, a species found in the same areas as codium during dive surveys off Nova Scotia (Scheibling, unpublished data). This bryozoan forms dense mats on kelp fronds, making them significantly more prone to breakage during intense wave action (Lambert et al. 1992). Alone, the impacts of membranipora are transitory as kelp re-establishes when densities of the bryozoan decrease. However, its distribution in Nova Scotia overlaps with codium, which is then able to invade and prevent the re-establishment of kelp."

The brown algae *Fucus serratus* and red algae *N. harveyi* are two additional non-native species found in the Bras d'Or Lakes (Mathieson and Dawes 2011), although their ecological impacts are poorly understood.

While direct effects (e.g. predation or competition) of these non-native marine species on Atlantic Salmon are not expected, thier indirect effects on the productivity of marine ecosystems have not been investigated, consequently their potential to indirectly impact salmon populations of the ECB DU is unknown.

Salmonid aquaculture

Commercial aquaculture of salmonids in the marine environment takes place in net pens anchored in coastal estuaries or sheltered near-shore sites. With declines in wild fisheries resources, there is an immediate and growing interest in developing the aquaculture industry in Nova Scotia. There are currently nine finfish leases within eastern Cape Breton licensed to raise Rainbow Trout, eight of which are also licensed to raise Atlantic Salmon (Figure 17). Currently, none of these leases are actively raising Atlantic Salmon.

Detrimental effects on wild Atlantic Salmon populations from aquaculture may occur in both marine and freshwater habitats. Impacts in fresh water are largely a result of aquaculture escapes that migrate to fresh water and can introduce pathogens or disease to wild stocks, compete with wild fish for mates, and can reduce the genetic fitness of wild populations via inter-breeding between escapees and wild salmon. In the ocean, impacts include; disease and pathogen transfer, habitat degradation near aquaculture sites, contamination by pesticides and chemicals, and transfer of parasites, namely sea lice.

Several studies indicate that survival rates of net-pen escapes are lower than for wild salmon (summarized in Weir and Fleming 2006). However, appreciable numbers of farmed salmon have been found among wild salmon populations, including in rivers during the spawning period and in estuaries. For example, farmed salmon were found in 54 or 62 (87%) of all rivers investigated that lay within 300 km of aquaculture sites (Morris et al. 2008). Of the 4,624 salmon included in eastern Cape Breton rivers, a total of 580 farmed salmon were observed (approximately 12.5%; Table 15).

There have also been sizable escape events of Rainbow Trout. Rainbow Trout were commercially produced at aquaculture facilities from 1972 to 2002, and there are currently nine marine Rainbow Trout aquaculture leases. Large aquaculture escapement events occurred, totalling close to one million escaped Rainbow Trout in the lakes from 1974 to 1983 (Hurley Fisheries Consulting 1989).

Bowlby et al. (2014) further described the prevalence and potential genetic influence of farmed salmon escapes as follows:

> "Several studies indicate that survival rates of net-pen escapes are lower than for wild salmon (summarized in Weir and Fleming 2006). However, appreciable numbers of farmed salmon (relative to total wild population size) have been found entering rivers at spawning time in locations where aquaculture has been investigated. For example, research in Europe has demonstrated that the number of farmed salmon entering rivers is proportional to the number of farms (Lund et al. 1991, Fiske et al. 2006), and that escapes will enter multiple rivers in the vicinity of aquaculture sites (Webb et al. 1991). Morris et al. (2008) reviewed the prevalence of aquaculture escapes in North American rivers and found that escapes were reported in 54 of 62 (87%) of rivers investigated within a 300 km radius of the aquaculture industry since 1984. Aquaculture escapes made up an average of 9.2% (range: 0% to 100%) of the adult population in these rivers. On the Magaguadavic River in New Brunswick, Carr et al. (1997) found an increasing number of farmed salmon escapes contributing to spawning as the number of aquaculture sites increased. The prevalence of escapes suggests that farmed salmon pose a significant risk to the persistence of wild populations (Morris et al. 2008), and a recent meta-analysis has demonstrated that reduced survival and abundance of multiple salmonid species (including Atlantic salmon) are correlated with increases in aquaculture (Ford and Myers 2008).
>
> Interbreeding between wild populations and aquaculture escapes causes reduced fitness in the hybrids as they are less adapted to local conditions and thus exhibit lower survival rates and less resilience to environmental change (Fleming et al. 2000, Fraser 2008, McGinnity et al. 2003). The larger the genetic difference between wild and farmed populations, the greater these effects will be (e.g. when fish of European descent are used in aquaculture operations in Nova Scotia). Such changes can be permanent when genes from farmed fish become fixed in the wild genome, an effect called introgression (Leggatt et al. 2010). Despite poor reproductive success, the large number of escaped salmon in some areas of Canada has resulted in reports of significant numbers spawning. For example, 20% of redds in the Magaguadavic River, New Brunswick, were thought to belong to females of aquaculture origin in the 1992/93 spawning period (Carr et al. 1997). Extensive reproduction of escaped Atlantic salmon has also been found in Europe (e.g. 14 of 16 rivers examined in Scotland had emerging progeny that could be linked to adults of aquaculture origin, ranging from 0-17.8% of the population, Webb et al. 1993)."

Outbreaks of disease at aquaculture sites have the potential to negatively impact wild salmon, however in Canada, there is has not been a clear link between disease or sea-lice outbreaks in aquaculture sites and a subsequent impact on wild populations (Brooks and Jones 2008, Leggatt et al. 2010). The difficulty of assessing the health status and subsequent survival of wild salmon at sea makes evaluating such processed difficult, and research to date has been inconclusive. However, research in epidemiology demonstrates that exposure and the frequency of exposure are important contributing factors to the spread of disease.

Similarly, there has been significant concern and research regarding the impact of aquaculture-derived sea lice infestation of wild salmon. Again, because of the difficulties of assessing salmon at sea, "garden type" experiments are not easily conducted and evidence to date has largely been circumstantial (Hutchings et al. 2012). Alternative study design, such as meta-analytical techniques show promise, and in some cases suggest that aquaculture activity is negatively correlated with survival in wild salmon populations (Ford and Myers 2008), although the mechanisms underlying these trends remain unclear. Further analyses of marine return rates for hatchery-reared salmon treated with antibiotics designed to prohibit sea lice suggest that untreated smolts (i.e. susceptible to sea lice) demonstrate lower marine return rates (Jackson et al. 2013, Skilbrei et al. 2013 Torrissen et al. 2013), although the source of the sea lice is unknown. Additional discussion regarding sea lice is provided in the section concerning “Disease and parasites”.

In a review of potential impacts of open net-pen aquaculture on salmonids, the Royal Society of Canada (Hutchings et al. 2012) made the following statement, after considering the uncertainties of sea lice studies:

> “After a decade of study, it is generally accepted that open net-pen salmon farms can cause infections of the salmon louse (a type of sea lice), *Lepeophtheirus salmonis,* and contribute to infections of *Caligus clemensiin* native salmonids, and that these infections can increase juvenile salmonid mortality rates (directly and probably indirectly through increased predation).”

Considering the lack of active salmonid aquaculture operations in eastern Cape Breton, the present day impact of such open net-pen aquaculture is likely minimal. However, should these leases begin active salmon rearing, many of the issues detailed in this section would become more applicable. Further, given that all eastern Cape Breton salmon populations are considered quite small, escape events could produce sizable negative impacts through genetic introgression. The potential also exists that active salmon farming in the Southern Upland or south coast of Newfoundland may impact salmon from the ECB DU (given the potential dispersal range of escapees and potential eastern Cape Breton salmon migration routes near these sites), although the likelihood and magnitude of such effects is difficult to assess.

Aquaculture for other species

Non-salmonid aquaculture sites in eastern Cape Breton are licenses for bivalves, including: American Oyster, Blue Mussel, sea scallop and/or bay scallop shellfish aquaculture sites are distributed throughout the near-shore coastal regions of eastern Cape Breton and within the Bras d’Or Lakes (Figure 18; Appendix 1), with some of the highest concentrations occurring in St. Peters Inlet, the River Denys basin (River Denys estuary), St. Anns Harbour (North River estuary) and the estuaries of the North, Middle and South Aspy rivers. The area (number of hectares) licensed at a single site tends to be much higher than salmonid aquaculture licenses. The impact of non-salmonid aquaculture in eastern Cape Breton is not thought to be high as few sizeable direct or indirect linkages have been demonstrated.

Aquaculture permits for other species (non-salmonids) in Nova Scotia are predominantly for bivalves (i.e. mussels, oysters and clams); species that are cultured in estuaries on long vertical lines or socks in the water column. Bivalve aquaculture has the potential to modify near-shore marine environments in three principal ways: by changing nutrient dynamics due to filter-feeding activities and the production of wastes, through the addition of physical anchoring structures to the environment, and from mechanical disturbance to sediment or other species during harvest or maintenance (Dumbauld et al. 2009). Research on the impacts of mussel culture in a small bay near Lunenburg, Nova Scotia suggests that sedimentation rates (from feces) were higher, oxygen concentrations were reduced in the water column, and significantly more ammonium was released into the water at mussel culture lines relative to surrounding environments (Grant et al. 1995). These changes resulted in relatively minor shifts in benthic community structure. The interactions between bivalve culture and Atlantic Salmon have mainly been studied in the context of using bivalves to remediate the negative impacts of feed and feces accumulation under net-pens during salmon aquaculture (e.g. Brooks et al. 2003). Large-scale changes to estuarine productivity and species composition from bivalve aquaculture (that would be expected to influence the marine habitat of wild Atlantic Salmon) in eastern Cape Breton have not been empirically demonstrated.

Diseases and parasites

Diseases and parasites in the marine phase of the life-cycle of Atlantic Salmon are summarized by Bowlby et al. (2014) as follows:

> "Relatively little information exists on diseases and parasites in the marine phase of Atlantic salmon beyond species lists (e.g. Bakke and Harris 1998). Most freshwater parasites are lost shortly after entry into the sea, but others (e.g. myxosporidians) have been associated with outbreaks of Proliferative Kidney Disease in Chinook salmon (*Oncorhynchus tshawytscha*) when smolts reach the marine environment (Foott et al. 2007). Upon returning to spawn, some tapeworms and other parasites (e.g. sea lice) infecting adult salmon typically die because they cannot complete their life cycle in fresh water (Harris et al. 2011). In general, it has been hypothesized that the impact of diseases and parasites would be greater on smolt survival to maturity rather than on adult spawning success because immature salmon are particularly vulnerable to infectious diseases (Harris et al. 2011).
>
> Since 2005, several countries, including Canada, have reported salmon returning to rivers with swollen and/or bleeding vents. The condition, known as Red Vent Syndrome (RVS) has been linked to the presence of a nematode worm, *Anisakis simplex* (Beck et al. 2008). Although this is a relatively common internal parasite in marine fish, their presence in the muscle and connective tissue surrounding the vents of Atlantic salmon is unusual. There is no clear indication that RVS affects either the survival of the fish or their spawning success based on the condition of returning spawners (ICES 2011). However, if the condition does cause significant mortality, more heavily infected fish would be removed from the study population without the possibility of being sampled (i.e. would die at sea). In the Southern Upland, relatively severe *Anisakis* infestation has been found in returning adults on the LaHave River and less severe infestations have been recorded for adults returning to the St. Mary's River. Since there are no other adult monitoring programs in the Southern Upland, it is unknown how many populations, or which ones, may be impacted by *Anisakis*."

Bacterial kidney disease (BKD) is one of the most widely spread diseases in fish culture, and is prevalent in hatcheries throughout Canada, the US and most of Europe (Fryer and Sanders 1981). Most research on BKD in Cape Breton occurred though the 1970s and 1980s, and the prevalence of BKD in hatcheries in recent time is low (D. Murrant, pers. comm.). In eastern Cape Breton, BKD has been reported from the North River (Amiro and Marshall 1990), Middle and Baddeck rivers and St. Anns Bay (Paterson et al. 1979). In all cases, prevalence within samples ranged from 5.7 to 57.7%. Amiro and Marshall (1990) use data provided by Paterson et al. (1979) to estimate the impact of BKD on the marine survival of Margaree River salmon. Using the ratio of BKD-carrier smolts to BKD-free adults, they estimated an approximate 53% loss of smolt production as a result of the disease. There have been no recent surveys of BKD prevalence in eastern Cape Breton. If the estimates of BKD-induced mortalities are accurate, then the high prevalence of BKD in some eastern Cape Breton rivers may be negatively impacting populations.

Mortality associated with BKD appears to be affected by diet, environment and water temperature (Warren 1983). For example, outbreaks of BKD resulted in high mortality during seasonal temperature peaks or when stream water warms rapidly (Fryer and Sanders 1981). Transmission of BKD can occur from infected salmon or trout to other salmonids, and also from parents to offspring via the eggs (Fryer and Sanders 1981, Warren 1983). In addition to lethal effect in fresh water, BKD also reduces the marine survival of salmon. Using Margaree River and Restigouche River smolts, Frantsi et al. (1975) assessed the osmoregulatory ability of Atlantic Salmon, and their subsequent survival upon transfer to seawater and identified a negative relationship between survival approximately BKD prevalence, where control fish experienced 1.2% mortality, and heavily infected smolts experienced 40% mortality (28% if excluding infected fish that died as a result of handling, no uninfected fish died due to handling).

As summarized by Bowlby et al. (2014):

> “Sea lice (*Lepeophtheirus salmonis*) are external parasites that feed on the mucus, skin and body fluids of salmonid species. They were historically observed in low numbers on wild Atlantic salmon populations with few adverse impacts; however, since the late 1980s there have been epidemics reported in several European countries (Norway, Scotland and Ireland), as well as more recently in Canada (Finstad et al. 2011). Sea lice infestations have been associated with reduced swimming performance, lower growth and reproductive rates, impaired immunity, reduced osmoregulatory ability, and acute mortality in salmonid species (Atlantic salmon, sea trout (*Salmo trutta*), Arctic char (*Salvelinus alpinus*) and Pacific salmon (*Oncohynchus* spp.)) (Finstad et al. 2011). Linking these physiological effects with increased mortality rates in populations is inherently difficult due to the challenges of capturing wild infected fish. Sea lice epidemics were not reported prior to the widespread establishment of marine-based aquaculture, and have been linked to wild population declines in Norway, Scotland and Ireland (Finstad et al. 2011). On the east coast of Canada (including the Southern Upland region), sea lice infestations spread rapidly among aquaculture sites and have cost the industry approximately 20% of the market value of the fish (MacKinnon 1997). Although sea lice have been suggested as a potential contributor to the declines in wild Atlantic salmon populations in Canada (Cairns 2001), two recent studies in New Brunswick have not found a link between sea lice from aquaculture and wild population decline (Carr and Whorisky 2004, Lacroix and Knox 2005b).”

Anglers have reported sea lice on salmon captured in in eastern Cape Breton; however, the source and effect of these lice is unknown.”

7.2 CHANGES IN OCEANOGRAPHIC CONDITIONS

Marine ecosystem change

Bowlby et al. (2014) summarized shifts in oceanographic conditions as follows:

> “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 event 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 2009/10 was the lowest on record for both regions since the beginning of monitoring in 1968/69. This lack of ice resulted from early season storms breaking up and suppressing new ice growth in addition to being very closely correlated with temperatures (Canadian Ice Service 2010). 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 Current into the Nordic Seas."

Although there have been several negative winter North Atlantic Oscillation Index (NAOI) values in recent years (e.g. the winter of 2009/2010 was the lowest on record), the mean NAOI remains positive, and climatic models favor a shift in the mean state of atmospheric circulation towards positive NAOI conditions, likely due to anthropogenic impacts (Osborn 2011)."

Winter NAOI is strongly negatively correlated with sea-surface temperature (SST) and thus could influence Atlantic Salmon by; impacting the quantity of suitable ocean habitat, directly impacting growth rates, indirectly impacting growth by influencing marine productivity and prey abundance, altering the phenology of salmon migration and marine productivity blooms, shifting competitive advantages among species, altering predator fields and their relationship with salmon and changing migration patterns – all of which may influence salmon mortality rates at sea (Dickson and Turrell 2000, Jonsson and Jonsson 2004, Friedland et al. 2009a,b).

There is mounting evidence of a SST-growth-survival paradigm (i.e. bottom-up control) for the marine survival of European Atlantic Salmon postsmolts (e.g. Peyronnet et al. 2008, Friedland et al. 2009a). However, several directed studies did not identify a similar growth-survival relationship for North American postsmolt salmon (Friedland et al. 2005, 2009b, Hogan and Friedland 2010).

There is evidence of climate-driven survival of repeat spawning salmon in North America. For example, 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 the NAOI and survival in the second year for alternate-spawning Atlantic Salmon from the LaHave River (Hubley and Gibson 2011). However, the mechanism of climate impacts remains unknown.

Changes in predator or prey abundance

As summarized by Bowlby et al. (2014):

> "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."

If prey was limiting the marine survival of Atlantic Salmon, growth-mediated survival would be expected. However, as mentioned in the previous section, there is little evidence supporting this hypothesis for North American Atlantic Salmon postsmolts. However, there is emerging evidence for bottom-up control of survival to a second spawning event (i.e. postspawn kelts in the marine environment). Although they did not test for a growth-survival relationship, Chaput and Benoît (2012) used the time series of return rates to a second spawning for salmon kelts from the Miramichi River, New Brunswick, and an index of small-bodied fishes in the southern Gulf of St. Lawrence to show that survival was positively correlated with the abundance of small fishes, presumably representing prey availability.

The effect of predation was assessed by Friedland et al. (2012) who demonstrate that following the northest Atlantic Ocean ecosystem regime shift, predator fields and ocean currents in the Gulf of Maine shifted, resulting in altered migration routes, increased predation and decreased survival of Atlantic salmon postsmolts.

Given the mounting evidence of some interaction between climate, prey, predators and salmon, it is likely that the marine survival of salmon is impacted by changes in prey or predator fields. However, the magnitude of this impact, and the mechanism by which marine ecosystem regime shift has affected the marine ecology and survival of Atlantic Salmon from the ECB DU, remains unclear.

7.3 PHYSICAL OR ABIOTIC CHANGE

Contaminants and spills (land or water based)

As summarized by Bowlby et al. (2014):

> “Estuaries and other coastal areas are affected by any chemical contaminants flushed into the ocean from freshwater sources, in addition to direct inputs from municipal sewage treatment or industrial activities in harbours. These contaminants either precipitate out and influence bottom sediments, or remain suspended in the water column, to be absorbed by biota and bio-accumulated in the marine foodweb. The potential for distribution of contaminants in the marine environment is relatively high given the general connectivity of marine habitats as well as oceanic current patterns. Similar to the effects detailed in Section 5.1 for freshwater contaminants, those in the marine environment have been linked to eutrophication and harmful algal blooms (leading to anoxic conditions in estuaries), changes in species richness, abundance or distribution patterns, and acute mortality (Pierce et al. 1998).”

The potential for eutrophication in the near-shore coastal environments of the Scotian Shelf (within 12 nautical miles (22 km) of shore) was assessed as part of the Inshore Ecosystem Project run collaboratively by DFO and the Fishermen and Scientists Research Society (FSRS). The study area encompassed marine habitat from Cape Sable Island in Nova Scotia to Cape North in Cape Breton, and thus included all of coastal eastern Cape Breton, but not the Bras d’Or Lakes. The approach highlighted areas with a high potential for eutrophication and thus oxygen depletion relative to background levels (Yeats, unpublished data). Nutrient concentrations were found to be relatively consistent along the Atlantic coast of Nova Scotia in surface water (averaged over the entire year), but there was a higher potential for eutrophication of bottom waters in monitored estuaries in the fall (Figure 19). Within eastern Cape Breton, only the area near Sydney harbor was subject to particularly eutrophic conditions (Figure 19). Inputs of organic matter from sewage, fish plant wastes or other discharges can exacerbate an estuaries’ natural tendency toward eutrophication. Although the hypoxic (low oxygen) conditions associated with eutrophication have been found to be detrimental to many fish populations and species (e.g. Ludsin et al. 2009), there is no information linking eutrophication events to population decline for eastern Cape Breton Atlantic Salmon.

Shipping, transport and noise

As summarized by Bowlby et al. (2014):

> "Vessel noise is thought to cause avoidance behaviour in Atlantic salmon. This is based on observer data as well as recent trawling experiments, where catches of immature salmon increased when vessels towed in an arc such that the direction of the net was separate from that of the ship (DFO and MNRF 2009). Presumably, many species' distribution patterns (both predators and prey of Atlantic salmon) would be impacted by shipping lanes, altering the ecology of near-shore marine habitats. Shipping lanes are also sources of contaminants from petroleum products, bilge water, and waste, as well as having the potential for catastrophic spills or other accidents. Associated with shipping is dredging of navigational channels which re-suspends sediments and negatively impacts near-shore habitat, particularly during storms, freshets or large tidal flows (DFO and MNRF 2009). Finally, shipping has been directly linked to the spread of invasive species from ballast waters; species which can have significant impacts on near-shore marine ecosystems."

Data on ship traffic density was obtained from the most current version of the Human Use Atlas for the Scotian Shelf, compiled by the Oceans and Coastal Management Division of DFO (Maritimes). Considering the area, which includes a portion of the Gulf of St. Lawrence, the Atlantic coasts of Nova Scotia and New Brunswick, and up to the southern coast of Newfoundland, ship traffic is heaviest leaving the Gulf of St. Lawrence and moving eastward along the southern coast of Newfoundland (Figure 20). Thus, this traffic has a high potential to interact with immature or adult Atlantic Salmon from eastern Cape Breton.

7.4 DIRECTED SALMON FISHERIES

Three groups in Canada conducted directed fisheries for Atlantic Salmon in 2011: Aboriginal peoples, residents of Labrador fishing for food, and recreational fishermen. All commercial salmon fisheries in Canadian waters have been closed since 2000 (ICES 2012). The catch statistics from retention fisheries taking place in Atlantic Canada are aggregated estimates from both marine and freshwater fisheries, and estimates are reported in this section.

Aboriginal subsistence fisheries

Three Aboriginal groups participated in the Labrador subsistence food fishery in 2010. This fishery occurs in estuaries or coastal bays using multifilament gill nets (ICES 2012). Catch statistics are compiled from logbooks, and the reporting rate is thought to be over 85% (DFO and MNRF 2009). The total harvest estimate from all Aboriginal fisheries in 2010 (in which the majority of the catch was from the Labrador fishery) was 59.3 metric tonnes (t), and was 70.4 t in 2011 (ICES 2012). This represents a one-year increase of 18%, and an increase of 54% compared to harvest during the first five years (1998-2002) following the closure of the commercial fishery (mean 45.6 t, range=47.1–47.9 t; ICES 2012). The estimated 2011 Aboriginal harvest was the highest in the time series (since 1990). Although the Labrador food fishery is recognized as a mixed stock fishery, approximately 95% of the catch takes place in rivers or estuaries in an effort to minimize the number of salmon intercepted from non-local populations (ICES 2011). Overall, the Aboriginal fishery in Labrador is expected to have minimal impact on eastern Cape Breton Atlantic Salmon populations.

Non-Aboriginal residents of Labrador could also participate in the subsistence food fishery in 2010, and the same regulations of gear types, seasons, and logbook reporting applied. Regulations implemented in 2006 stipulate maximum mesh size and a monitoring program to initiate in-season closures during peak runs of large salmon (DFO and MNRF 2009). The Labrador fishery is a mixed stock fishery, so a proportion of those fish (mainly the 2SW component) may originate from rivers in eastern Cape Breton. However, recent changes to regulations were established in an effort to minimize the capture of large salmon by this fishery. Further, a lack of historical tag returns from the Labrador fishery indicate that captures of eastern Cape Breton Atlantic Salmon have not been numerous (Figure 5), although the tag return dataset is extremely data-poor, and this result may simply reflect tagging effort. In 2011, the estimated catch for this fishery was 2.1 t, the equivalent to about 800 fish, 37% of which were large (ICES 2012).

International fisheries (St. Pierre-Miquelon and Greenland)

There are no local salmon populations on the islands of St. Pierre and Miquelon, but France annually conducts a limited marine gillnet fishery. All adult age groups are harvested in the fishery (DFO and MNRF 2009). Nine professional and 56 recreational gillnet licenses were issued in 2011, where recreational licenses are restricted to one net of 180 meters while professional licenses can have three nets, each up to 360 m (ICES 2012). A total harvest of 3.8 t was reported in the professional and recreational fisheries in 2011, representing the largest catch in the time series (1990 – present; ICES 2012). Genetic analysis of the composition of the catches indicates that 96-98% of the fish are of Canadian origin (ICES 2011, 2012), although genetic sampling was limited. As this fishery occurs in an area adjacent to the south coast of Newfoundland (roughly 275–400 km ENE from the eastern Cape Breton rivers), it is likely to impact on eastern Cape Breton populations, based on marine distribution patterns inferred from tag returns. Specifically, tagged salmon from the ECB DU have been recovered in fisheries within regions of Newfoundland immediately adjacent to St. Pierre and Miquelon (*refer to* Section 2.3).

The current subsistence fishery for Atlantic Salmon in Greenland predominantly targets salmon destined to return to their natal rivers as 2SW spawners. Angling, fixed gillnets and driftnets are permitted within a fixed season throughout six divisions along West Greenland, as well as a single division in East Greenland. In 2010, the fishing season was August 1 to October 31 and catches were 38 t in West Greenland and 2 t in East Greenland (ICES 2011). This represents an increased catch of 53% relative to catches in 2009. Reporting by licensed fishermen has increased in recent years, as has the overall catch estimate (ICES 2011, 2012). Genetic analyses of the composition of the catches indicate that approximately 80% is of North American origin (ICES 2011). Atlantic Salmon from eastern Cape Breton likely contribute to catches in the given records of tag returns from Greenland.

The magnitude of removals (either at a population or DU level) related to either the St. Pierre and Miquelon or the Greenland fishery has not been assessed for the ECB DU.

Local commercial fisheries

Total retained catch from all fisheries in Canadian waters is estimated annually by the International Committee for Exploration of the Sea (ICES). This catch estimate was 153 t in 2010, and 179 t in 2011, with >90% of the catch taken in estuarine and river environments and the remainder in coastal habitats. Atlantic Salmon from eastern Cape Breton have essentially zero chance of being retained in (legal) recreational freshwater fisheries within eastern Cape Breton, and low probability of being retained in commercial or Aboriginal fisheries in rivers or estuaries outside of eastern Cape Breton. Thus, only coastal fisheries are a potential source for fisheries-induced losses. Given the limited marine tag return data (*refer to* Section 2.3), it is difficult to assess the likelihood of coastal fisheries intercepting salmon from the ECB DU, and the magnitude of these losses.

7.5 BY-CATCH IN OTHER COMMERCIAL FISHERIES

In Canada, there has been no reported by-catch of Atlantic Salmon in Aboriginal fisheries in the marine environment, except in Ungava Bay, Labrador where estuarine fisheries for Brook Trout (*Salvelinus fontinalis*), Arctic Char (*Salvelinus alpinus*), Lake Whitefish (*Coregonus clupeaformis*), Round Whitefish (*Prosopium cylindraceum*), Lake Trout (*Salvelinus namycush*) and Northern Pike (*Esox lucius*) also capture significant numbers of Atlantic Salmon (DFO and MNRF 2009). These fisheries are unlikely to catch salmon from eastern Cape Breton.

Other commercial fisheries have the potential to capture salmon incidentally, but there has been no evidence of significant by-catch in any of the fisheries surveyed (ICES 2004). In Canada, regulatory changes that would reduce the number of salmon caught as by-catch include the restrictions in fishing times, gear regulations or closures of bait, groundfish and pelagic fisheries that have been applied variously throughout eastern Canada. In Newfoundland, estimates of by-catch in herring and mackerel bait fisheries were estimated to be 0.3% of the catch (Reddin et al. 2002). The overall impact of by-catch in other commercial fisheries is thought to be low for eastern Cape Breton Atlantic Salmon.

There have been suggestions of unreported by-catch of Atlantic Salmon in offshore fisheries, those outside of Canada's 200 nautical mile Economic Exclusion Zone (Cairns 2001). Concerns centered on the extremely long driftnets fished and the potential to operate outside of any regulatory or monitoring system. Given the low market price for salmon, a targeted driftnet fishery would only be viable if catch rates were high, and based on demersal trawl fisheries in Newfoundland and Labrador, this is unlikely to be true (Dempson et al. 1998). However, the distribution of herring, mackerel and immature Atlantic Salmon overlap during parts of the year, so purse-seine and trawl fisheries for herring and mackerel have the potential to take significant numbers of Atlantic Salmon (ICES 2000). Salmon could be an undetected component of multiple North Atlantic trawl fisheries; although no monitoring data exists to support this hypothesis (DFO and MNRF 2009).

7.6 COMMERCIAL FISHERIES ON PREY SPECIES OF SALMON

Atlantic Salmon in the marine environment are generally opportunistic feeders, using a wide variety of potential prey. There is some evidence that certain prey items (e.g. fish larvae) are more energetically beneficial and, thus, would be preferred components of the diet (Rikardsen and Dempson 2011). Therefore, the availability of suitable prey resources may be important for Atlantic Salmon at sea (*see also* Section 1.3), and extensive fisheries on these species may have the potential to limit prey availability for immature Atlantic Salmon (particularly upon first entering the marine environment) or reconditioning post-spawn kelts. A shift in species composition in much of the northwest Atlantic Ocean toward smaller demersal fish species (*refer to* Section 6.1) and increased abundance of small pelagics does not lend substantial support for the hypothesis that prey abundance influences survival of postsmolts, however, it does support the theory of prey-limited growth and survival of salmon kelts at sea.

It is widely accepted that the collapse of Atlantic Cod stocks in much of the northwest Atlantic was the result of persistent overfishing and potentially concurrent climate-forcing (Myers et al. 1996). The dramatic collapse of cod, which were one of the most abundant demersal piscivores, reverberated through the food web via trophic cascades (Frank et al. 2005) and is likely responsible for widespread altered abundance of many species – many of which may influence Atlantic Salmon at sea. For example, the abundance of many small bodied fishes (e.g. sand lance), many of which are strictly pelagic (e.g. herring, capelin), has dramatically increased following ecosystem regime shift (Bundy et al. 2009, Frank et al. 2011). Many of these species are known to be important prey for salmon. Abundances of known salmon predators have had mixed trajectories following regime shift, where some fish predators (e.g. Atlantic Cod, Atlantic Pollock) experience significant declines (Frank et al. 2011, Swain and Mohn 2012), while grey seal abundance has increased, at times exponentially (Bowen et al. 2003).

8.0 EXTENT TO WHICH THREATS HAVE REDUCED HABITAT QUALITY AND QUANTITY (TOR 20)

Throughout this document, threats to the quality and quantity of habitat for salmon populations in the ECB DU in both the freshwater and marine environments are identified.

In fresh water, it was possible to determine the extent to which multiple activities occur in each watershed in eastern Cape Breton through an analysis of land use (e.g. forestry, agriculture, urbanization) and other threats (e.g. road crossings, reservoirs). Based on available data, there is little evidence to suggest that either the quality or quantity of freshwater habitat is limiting salmon populations of eastern Cape Breton. For example, of the three eastern Cape Breton watersheds where a significant portion of salmon habitat lies above barriers, two (Syndey River and Northwest Brook) have fish passage, and the third (Indian Brook) has dams that are above an impassable waterfall; areas that would not have historically been used by Atlantic Salmon.

Identification of the spatial extent of each freshwater threat provides an estimate of the relative degree of impact among watersheds and the regions as a whole. However, it was not possible to quantify the total human impact (from the sum of all threats) in the various watersheds relative to Atlantic Salmon abundance for several reasons, including variable spatial scales of impact (i.e. altered hydrology at the watershed scale versus culverts at specific locations), variable magnitude of impact, and discrepancies between the measurement units of each threat (i.e. counts of abandoned mine openings versus the density of road crossings). Thus, within the scope of this research document, it was not possible to calculate a total amount of human impact in eastern Cape Breton. Overall, there is substantial variation in the relative magnitude and the type of threats affecting eastern Cape Breton watersheds. In general, rivers located near the Cape Breton highlands (North Aspy River to Middle River) are less impacted by human activities, although forestry and road crossings remain prevalent for the more southern of these rivers, and mining activity is high within the Middle River watershed. However, there is little reason to believe that eastern Cape Breton salmon populations are currently limited by freshwater habitat availability.

Threats related to the marine environment were also identified, including an assessment of the potential mechanisms by which these threats may affect Atlantic Salmon. However, it was not possible to quantify the contribution of each threat to population viability.

9.0 FEASIBILITY OF RESTORING HABITATS TO HIGHER VALUES (TOR 14)

This review of habitat availability for eastern Cape Breton Atlantic Salmon has not found evidence of significant habitat loss for this DU and the habitat in the majority of rivers is thought to be able to support salmon populations at abundances above their proposed recovery targets. Feasibility of restoring habitats to higher values was not evaluated for this reason. With the exception of specific sites where localized threats exist, increasing freshwater habitat quality or quantity is not expected to result in substantial population increases.

10.0 SUMMARY

Considering the currently suspected low population sizes of many eastern Cape Breton salmon populations, neither the quantity or quality of freshwater habitat is likely limiting population abundance at present, although threats in fresh water may locally affect salmon. Additionally, because this review did not find evidence of significant habitat loss and salmon rivers are known to be able to support populations at levels well above their conservation requirements, freshwater habitat is not expected to become limiting as populations approach and exceed their recovery target.

Several threats were identified in freshwater, estuarine and marine environments, and all were subsequently ranked. Of the four highest ranked threats, one related directly to the survival of adult spawners (poaching), one related to marine ecosystem conditions presumed to be controlling the marine survival of salmon, and subsequently, adult returns, and the other two represent factors that may influence the survival of juveniles in fresh water, and salmon of various ages at sea. Both the threat of poaching, and of genetic introgression associated with salmon aquaculture escapees may disproportionately affect small populations.

Additional threats were identified as potentially important factors impacting salmon habitat (quantity and quality), prey availability, migration corridors or health, however, based on the localized nature of these impacts (i.e. small spatial scale), the level of causal uncertainty or the frequency of threat occurrence, these were not considered the primary threats for salmon populations of the ECB DU. Given the continuum of salmon life history and the connectivity of watersheds, it is likely that some threats are correlated and that their synergistic effects on salmon productivity compound to affect eastern Cape Breton salmon population. For many of these threats, there is substantial information regarding how threats may affect individual aspects of Atlantic Salmon populations (i.e. growth, juvenile survival or behavior), however, it is difficult to assess the impact of these threats in the context of population abundance or viability at the watershed level.

An obvious conclusion of this review is the paucity of data about salmon and other fish species for most rivers in the eastern Cape Breton, and as such, there exists some uncertainty regarding both Atlantic Salmon populations of eastern Cape Breton (as discussed in the abundance and trends working paper), as well as the statements about habitat quality. There is a need for river-specific data for the majority of the DU. Thus, a primary research recommendation focuses on the collection of additional data to: inventory the current state of salmon populations in those rivers without data, improve population parameter estimates for index rivers, including estimating egg-specific survival rates (by pairing adult counts/estimates with subsequent smolt production), and examine intra-population variability within the DU to assess the adequacy of using the selected index rivers to describe population trends across all of eastern Cape Breton.

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12.0 TABLES

Table 1. Area in rearing units (m^2 x 100) by percent orthogradient for 16 rivers in eastern Cape Breton (adapted from Robichaud-LeBlanc and Amiro 2004). Proportion of habitat greater than 0.12% grade is used as a measure of rearing habitat for salmon (Amiro 1993, O'Connell et al. 1997).

		%Grade												Proportion of Habitat >0.12% Grade
Watershed Number	River Name	0-0.12	0.121-0.249	0.25-0.49	0.5-0.99	1.0-1.49	1.5-1.99	2.0-2.49	2.5-2.99	3.0-3.49	3.5-5.0	>5.0	Total Area	
6	Ingonish	0	0	157	268	373	505	198	124	119	134	57	1935	1.00
8	Barachois	0	0	227	502	453	422	393	139	36	106	19	2297	1.00
10	North	0	0	391	1413	859	201	419	121	220	161	43	3828	1.00
11	Baddeck	0	494	2321	3387	873	616	374	155	68	75	0	8363	1.00
12	Middle	0	2538	1534	3530	539	331	85	62	27	0	0	8646	1.00
21	Tillard	0	279	329	330	139	43	0	4	0	3	2	1129	1.00
25	Grand	873	2352	1329	443	187	154	72	27	11	32	10	5490	0.84
27	Marie Joseph	565	1160	1392	1297	262	63	9	24	13	10	0	4795	0.88
28	Framboise	0	2154	2537	1317	324	175	54	51	68	13	7	6700	1.00
29	Gerratt	0	0	247	386	86	51	36	16	10	4	7	843	1.00
29	Lorraine	695	227	1215	957	138	27	27	8	3	3	5	3305	0.79
31	Catalone	0	2614	785	596	121	84	45	13	24	22	6	4310	1.00
32	Mira[1]	12246	5048	3655	2166	443	214	108	46	21	17	5	23969	0.49
35	Sydney	1135	1084	872	874	474	131	51	41	25	36	28	4751	0.76
37	Frenchvale	0	457	497	246	142	88	96	32	0	52	17	1627	1.00
39	Aconi	519	189	115	548	67	96	15	10	4	0	2	1565	0.67

[1] Areas for the Mira (#32) include the Mira River and its tributaries the Salmon River (Cape Breton County) and Gaspereau River to reflect the Mira Watershed.

Table 2. List of 46 major watersheds thought to support salmon populations (as determined from NASCO Rivers Database, assessment documents, and local knowledge) and their general characteristics in eastern Cape Breton. Drainage area is based on the Nova Scotia Environment (NSE) Secondary Watersheds Layer. Measured rearing areas are from Robichaud-LeBlanc and Amiro (2004). Estimated rearing areas are from the regression in Figure 3. Recognized barrier (dam) information comes from the NSE barrier layer (N=no, Y=yes). Full descriptions of datasets are provided in Appendix 1. Blank cells indicate values are not available.

Watershed Number	Watershed Name	Drainage Area (m^2)	No. of Habitat Units (100 m^2)		Estimated Conservation Egg Requirement	Recognized Barrier (Dam)	Evidence of Salmon Presence[1]
			Measured	Estimated			
1	Salmon R. (Vic. Co.)	48,123,499		1,238	297,185	N	
2	Wilkie Bk.	11,536,902		297	71,246	N	
3	North Aspy R.	141,699,393		3,646	875,057	N	RF, J
4	Middle, South Aspy R.	69,747,848		1,795	430,723	N	
5	Clyburn Bk.	70,484,612		1,814	435,274	N	RF, J
6	Ingonish R.	92,102,405	1,934		464160	Y	RF, J
7	Indian Bk.(Vic. Co.)	267,188,812		68,750[2]	16,500,101[2]	Y	RF
8	Barachois R.	113,565,678	2,297		551280	N	RF, J
9	River Bennett	23,270,991		599	143,710	N	RF
10	North R.	224,965,655	3,827		918,480	N	RF, J
11	Baddeck R.	269,390,230	8,363		2,007,120	Y	RF, J
12	Middle R.	348,714,810	8,646		2,075,040	Y	RF,J
13	Hume R.	48,641,773		1,252	300,384	N	J
14	MacPhersons (Lewis) Bk.	13,382,794		344	82,644	N	
15	Skye R.	113,387,274		2,918	700,217	N	RF, J
16	Blues Bk.	20,390,868		525	125,923	N	
17	Washabuck R.	23,574,260		607	145,582	N	
18	McKinnons Bk.	12,764,803		328	78,828	N	
19	River Denys	214,894,018		5,529	1,327,066	N	RF, J
20	Scott Bk.	27,472,093		707	169,651	N	
21	River Tillard	68,822,235	1,129		270,960	Y	RF, J
22	False Bay Bk.	20,912,586		538	129,144	N	
23	Black R.	49,930,124		1,285	308,340	N	J
24	River Inhabitants	349,482,474		8,993	2,158,207	N	RF, J
25	Grand R.	238,794,804	4,618		1,108,320	N	RF, J

Watershed Number	Watershed Name	Drainage Area (m^2)	No. of Habitat Units (100 m^2) Measured	Estimated	Estimated Conservation Egg Requirement	Recognized Barrier (Dam)	Evidence of Salmon Presence[1]
26	St. Esprit (Taylors) Bk.	12,927,251		333	79,831	N	RF, J
27	Marie Joseph Bk.	59,047,147	4,231		1,015,440	N	RF, J
28	Framboise R.	136,975,448	6,698		1,607,520	N	RF, J
29	Gerratt Bk./ Lorraine Bk.	69,040,922	3,453		828,720	N	RF, J
30	Little Lorraine Bk.	36,611,055		942	226,090	N	RF
31	Catalone R.	92,855,145	4,311		1,034,640	N	RF,J
32	Mira R.	605,344,471	11,723		2,813,520	Y	RF, J
33	MacAskills Bk.	55,469,334		1,427	342,547	Y	RF, J
34	Northwest Bk.	54,653,657		1,406	337,510	Y	RF
35	Sydney R.	184,887,618	3,615		867,600	Y	RF, J
36	Grantmire Bk.	23,009,179		592		Y	RF, J
37	Frenchvale Bk.	51,074,312	1,627		390,480	N	RF, J
38	Georges R.	17,979,715		463	111,034	N	
39	Aconi Bk.	44,676,425	1,045		250,800	Y	RF
40	Benacadie Bk.	43,528,689		1,120	268,810	N	
41	Indian Bk.(CB Co.)	43,298,805		1,114	267,389	N	J
42	MacIntosh Bk.	31,531,957		811	194,724	N	
43	Gillies Bk.	29,561,661		761	182,556	N	
44	Breac Bk.	33,680,252		867	207,991	N	
45	River Tom	21,150,415		544	130,613	N	
46	MacNabs Bk.	14,311,334		368	88,378	N	

1. Evidence of salmon presence: RF indicates a reported recreational fishing catch between 1983-2011; J indicates juvenile salmon observed in electrofishing surveys (1996-2007); blank cells indicate neither source has identified the presence of salmon.
2. Indian Brook (Victoria County) – most of watershed is above a waterfall inaccessible to salmon, accessible habitat value is much lower.

Table 3. Barriers on major watersheds in eastern Cape Breton included in the NSE barrier layer, plus four dams known to be part of the Wreck Cove Hydro Project, which were not included in the barrier layer. "Portion of watershed upstream" was determined visually based on the barrier location and the NHN hydrologic network, to provide a general idea of how much watershed area is upstream of each barrier. Roughly, proportions of watershed upstream are defined as: "very little"- <5% of the watershed is upstream of the barrier; "small area" – 5-25% is upstream; "significant area" – 25-75% is upstream, and "most" - >75% is upstream.

Watershed Number	Watershed Name	Barrier	Fish Passage	Portion of Watershed Upstream
6	Ingonish R.	Wreck Cove Hydro Project	No	Very little
6	Ingonish R.	Wreck Cove Hydro Project	No	Very little
7	Indian Bk. (Vic Co.)	Wreck Cove Hydro Project	No	Significant area
7	Indian Bk. (Vic Co.)	Wreck Cove Hydro Project	No	Significant area
7	Indian Bk. (Vic Co.)	*n/a*	No	Very little
11	Baddeck R.	Peters Brook Ducks Unlimited Project	Yes	Very little
12	Middle R.	Indian Brook	Yes	Very little
21	River Tillard	Long Lake Dam	No	Very little
32	Mira R.	*n/a*	No	Very little
33	MacAskills Bk.	Sand Lake	No	Small area
33	MacAskills Bk.	Sand Lake Brook Dam	No	Small area
33	MacAskills Bk.	MacAskill's Brook Dam	Yes	Most
33	MacAskills Bk.	Marconi Towers Dam	No	Unknown
34	Northwest Bk.	Power Lake	No	Very little
34	Northwest Bk.	Grand Lake Dam	Yes	Significant area
34	Northwest Bk.	Kehoe Brook Settling Pond	No	Very little
34	Northwest Bk.	Kehoe Brook Tailings Pond	No	Very little
35	Sydney R.	Sydney River Dam	Yes	All
36	Grantmire Bk.	*n/a*	No	Very little
39	Aconi Bk.	Prince Mine Dam	No	Small area

Table 4. The relationship between human activities affecting watersheds in the ECB DU (rows) and the functional changes to freshwater habitats (column headings) associated with those activities. Interactions are marked with an 'X'. Blank cells indicate no interaction.

Human Activity	Acidification	Extreme temperatures	Altered hydrology	Contaminants	Sedimentation	Invasive species	Dams/diversions	Culverts
Freshwater aquaculture				X	X		X	
Infrastructure (roads)		X	X	X	X	X		X
Hydropower		X	X		X		X	
Urbanization	X	X	X	X	X	X	X	X
Agriculture		X	X	X	X		X	
Forestry		X	X	X	X			X
Mining	X			X	X			
Pulp and paper				X	X			

Table 5. The relationship between human activities in the oceans (rows) and the functional changes to marine habitats (column headings) associated with those activities. Interactions are marked with an 'X'. Blank cells indicate no interaction.

Human Activity	Invasive species	Changed predator or prey abundance	Diseases/parasites	Contaminants
Pulp and paper mills				X
Aquaculture	X	X	X	X
Shipping/Transport	X	X		X
Fisheries on prey species		X		

Tables 6 and 7. Threats tables for the freshwater and marine environments, respectively, summarizing human activities or sources of environmental change that either negatively impact Atlantic Salmon populations (i.e. cause reduced abundance) or cause reduced quality and/or quantity of habitat in eastern Cape Breton.

Definition of table headings and column values

Threat Category: The general activity or process (natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioral changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur. Definition from the Draft Guidelines on Identifying and Mitigating Threats to Species at Risk (Environment Canada 2007).

Specific Threat: The specific activity or process causing stress to Atlantic Salmon populations in the ECB DU, where stress is defined as changes to ecological, demographic, or behavioral attributes of populations leading to reduced viability (Environment Canada 2007).

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

Location or Extent: The description of the spatial extent of the threat in the Southern Upland was largely based on the criteria developed for the Conservation Status Report Part II (DFO and MRNF 2009), where Low corresponds to <5% of populations affected, Medium is 5-30%, High is 30-70% and Very High is >70%. Where possible, the actual proportion of eastern Cape Breton Atlantic Salmon populations affected by a specific threat is given in brackets.

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

Severity: Describes the degree of impact a given threat may have or is having on individual Atlantic Salmon populations subjected to the threat given the nature and possible magnitude of population-level change. See table below for definitions of risk criteria.

Risk Criteria

Impact	Biological Risks:
Negligible	• Habitat alteration within acceptable guidelines that does not lead to a reduction in habitat quality or quantity. • No change in population productivity.
Low	• Minor or easily recoverable changes to fish habitat (e.g. seasonal or changes <1 year). • Little change in population productivity (<5% decline in spawner abundance).
Medium	• Moderate impact to fish habitat with medium term for habitat recovery (3-5 years). • Moderate loss of population productivity (5-30% decline in spawner abundance).
High	• Substantial damage to fish habitat such that the habitat will not recover for more than 5 years. • Substantial loss of population productivity (>30% decline in spawner abundance).
Extreme	• Permanent and spatially significant loss of fish habitat. • Severe population decline with the potential for extirpation.

Causal Certainty. Two-part definition. Part 1: Reflects the strength of the evidence linking the threat (i.e. the particular activity) to the stresses (e.g. changes in mortality rates) affecting populations of Atlantic Salmon in general. As such, evidence can come from studies on any Atlantic Salmon population. Part 2: Reflects the strength of the evidence linking the threat to changes in productivity for populations in the ECB DU specifically. See table below for definitions.

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

Rationale: Gives a brief overview of the main factors causing a specific threat, as well as the main stresses resulting from those threats to salmon populations in eastern Cape Breton (threat and stress are defined above). This information puts the threat in context and helps to designate overall concern and severity.

Table 6. Threats to eastern Cape Breton Atlantic Salmon populations occurring in freshwater (TOR 18).

Threat Category	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population Level Impacts**	**Causal Certainty**		**Rationale**
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
Water quality and quantity	Acidification	Low	Low	A (potential) Continuous	High	High	Low	Low pH has physiological effects on juveniles, as well as reduces juvenile survival. Few ECB drainages are affected by acid precipitation. The low extent in this DU results in a Low Level of Concern for this threat.
	Extreme temperature events	Low	Low	H, C and A Seasonal	Low	High	Low	Caused directly by altering cover, changing water flow patterns, and climate change. Affects behavior, growth and survival of freshwater life stages, reduces freshwater habitat, and exacerbates impacts of other threats. The low extent in this DU results in a Low Level of Concern for this threat.
	Altered hydrology	Medium	Low (or unknown)	H, C and A Recurrent	Negligible to High (dependent upon timing and magnitude of alteration)	High	Low	Due to development along rivers and significant forestry activity in some watersheds. Significantly reduced or increased flow decreases survival of juveniles, affects adult returns to rivers, as well as altering sedimentation rates and habitat availability. Low evidence of ECB-specific impacts, but extreme flow events are observed, resulting in a Medium Level of Concern.
	Water extraction	Low	Low	H, C and A Recurrent	Negligible to High (dependent upon timing and magnitude of extraction/alteration)	High	Low	Reduces flow which impacts survival. Low extent leads to a Low Level of Concern for the entire DU.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Chemical contaminants	Low	Low	H, C and A Seasonal	Negligible to High (dependent upon concentration (dose) and time of exposure (duration)	High	Low	Common agricultural and forestry chemicals are known to reduce survival in fresh water or cause physiological changes in juveniles. Nutrient enrichment degrades habitat quality. Occasional system failures in municipal wastewater treatment. The uncertain location and extent, low evidence of ECB-specific impacts, and ranges of severity result in a Low Level of Concern for the DU overall.
	Silt and sediment	Medium	High	H and C Continuous	Negligible to High (dependent upon concentration (dose) and time of exposure (duration)	High	Low	Road crossings, agricultural run-off and increased erosion due to forestry and other land use activities increase silt and sediment concentrations. Affects egg survival, juvenile physiology and survival, and reduces habitat quality. The very high location and extent, continuous occurrence and frequency, impact on physical habitat, as well as physiological impacts, and the influence on multiple life stages result in a Medium Level of Concern .
Changes to biological communities	Non-native species (fish)	Medium	Medium (15% of assessed populations with invasive fish documented)	H, C and A Continuous	Medium	High	Low	Rainbow and Brown Trout are most widespread invasives, with some potential for competition / predation with salmon. Chain Pickerel and Smallmouth Bass have been found in one watershed and are efficient predators leading to direct mortality of salmon.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty: Evidence linking the threat to stresses in general	Causal Certainty: Evidence for changes to viability of ECB salmon populations	Rationale
Freshwater environment								
	Non-native species (other)	Low	Low	A Continuous	Low to High	Medium	Very Low	*Didymo* forms dense mats that alter the composition of aquatic insect communities but has not yet been found in ECB. Spineycheek crayfish can alter aquatic communities and is present in a lake connected to the Ingonish River estuary. There is potential for unintentional introduction of didymo by river users or natural invasion by crayfish. However, the very low DU-specific causality, with limited observed impacts within Canada result in a Low Level of Concern relative to other threats.
	Stocking for fisheries enhancement (Atl. Salmon – using traditional methods)	Medium	Medium (two rivers currently stocked by NSDFA in 2010/2011.	H and C Continuous	Low to Extreme (dependent upon number of fish stocked and length of period of stocking)	High (rate of fitness recovery after stocking ends is unknown)	Low	Negative impacts associated with traditional stocking practices for fisheries enhancement are well established. There is a trade-off between short-term gain for population increase vs. long-term impact on population productivity. The Medium location or extent, high severity, and possible long-term detrimental fitness effects and potential spread of disease result in a Medium Level of Concern.
	Stocking (Atl. Salmon - current)	Low (two rivers stocked by DFO in 2010/ 2011.	Low (two rivers stocked by NSDFA in 2010; none recorded in 2011)	C and A Continuous	Low to High	High	Low	Current stocking activity is limited but given small size of receiving populations, potential for impacts on population productivity are unknown. Other risks include potential for disease transmission. The small scale of this activity results in a Low Level of Concern.

Threat Category	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population Level Impacts**	**Causal Certainty**		**Rationale**
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Other salmonid stocking (rainbow – including the Bras d'Or Lakes, brown, & Brook Trout)	Medium	Medium	H, C and A Continuous	Low to High (dependent upon number stocked and type of recipient waterbody (lake vs. river)	Medium	Low	Potential for increased competition, disease transfer, and direct predation. The medium ranking for severity plus the relatively widespread distribution of these fish results in a Medium Level of Concern for this threat.
	Salmonid aquaculture (commercial hatcheries)	Low	Low	H, C and A Continuous	Medium	High	Low	Potential impacts from escapes from commercial rearing sites, introduction of chemical contaminants, increased competition, potential for disease transfer, and reduced habitat quality. In the freshwater environment, the small scale (low location/extent), and medium ranking of severity, result in a Low Level of Concern currently.
	Changes in predator or prey abundance	Medium	High	C and A Seasonal	Low to High	Medium	Low	Multiple species prey on juvenile Atlantic Salmon and often target smolts. At this point in the life-cycle mortality is not compensatory so the potential to reduce the number of recruits is high. However, it is not known if native predator population sizes have increased and are causing increased mortality in fresh water. It is likely that the juvenile densities observed in fresh water reflect adult population sizes rather than prey limitation. Productivity of available freshwater habitats is thought to be good. The high extent of these changes coupled with potentially high severity lead to a Medium Level of Concern.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty: Evidence linking the threat to stresses in general	Causal Certainty: Evidence for changes to viability of ECB salmon populations	Rationale
Freshwater environment								
	Genetic effects of small population size	Medium	Medium (mostly focused in southwest area of DU)	H, C and A Continuous	Negligible to High (dependent upon length of time at small population size, stocking history, and site specific conditions)	High	Low	Reductions in genetic variation observed and expected to be associated with accumulation of inbreeding. Studies of salmonids indicate inbreeding usually associated with reduced performance, especially in the wild. The high causal certainty, potentially high and ongoing severity, and medium location/extent result in a Medium Level of Concern.
	Allee (small population size) Effects	Low	Medium (mostly focused in southwest area of DU	H, C and A Continuous	High	Medium	Low	Allee effects occur when survival or reproductive rates decrease as abundance decreases (e.g. too few fish to find a mate; too few fish to form a school). Many examples in the literature (including Pacific salmon) but not demonstrated for Atlantic Salmon. Uncertainty in the potential for Allee effects, as well as the restricted extent that they may occur in the DU lead to a Low Level of Concern.
	Scientific Activities	Low	Low (Five Rivers and occasional surveys/ sampling of other rivers)	H, C, A Seasonal	Low	Low	Low	Potential impacts from mortality during electrofishing, smolt or adult assessments, disruption of territory holding behavior, disruption of smolt migration. The very small spatial extent of this activity, sampling of only a small part of the population in most cases, and that the activity is designed to minimize risk to sampled organisms, results in a Low Level of Concern currently.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
Physical obstructions	Dams, water diversions and permanent structures	Low	Low	H, C and A Continuous	Medium to Extreme (Dependent upon design of structure and location within watershed)	Very High	Low	These form seasonal, partial or complete barriers to movement of juveniles, smolts and adults, reducing available habitat in the watershed. Structures alter habitat by affecting hydrological and sediment deposition processes. Relatively few ECB watersheds have a high proportion of habitat above dams, and many of those have fish passage, resulting in a Low Level of Concern.
	Reservoirs	Low	Low	H, C and A Continuous	Low to High (Dependent upon size of individual reservoirs and number in series on a system)	High	Low	Impacts of reservoirs inclide bioaccumulation of methylmercury, changes to hydrological patterns and altered freshwater habitat from impounding water. These may also delay smolt migration downstream and expose them to predation by bass and pickerel. The Low location/extent of this threat in the ECB DU results in a Low Level of Concern.
	Culverts	Medium	Very High	H, C and A Seasonal	Low to High (dependent upon design and condition of culvert, and location in watershed)	High	Low	Culverts are very common at road crossings and can form seasonal or complete barriers to upstream/downstream migration of juveniles and adults. Culverts can act to fragment habitat, reducing available habitat in the watershed. The very high location/extent, and large range of severity reflecting site- and discharge-specific conditions, result in a Medium Level of Concern for this threat.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
Habitat alteration	Infrastructure (roads)	Medium	Very High (all rivers)	H, C and A Continuous	Low to High (dependent upon road density within watershed or sub-watershed)	Medium	Low	Road crossings are point sources for pollution and sediment, as well as potential barriers to salmonid movement upstream and downstream. The very high location/extent, large range of severity reflecting site- and discharge-specific conditions, and low ECB-specific certainty result in a Medium Level of Concern.
	Hydro power generation	Low	Low	H, C and A Continuous	Low to Extreme (dependent upon facility design and operating schedule)	High	High	Impacts include channelization, habitat loss from impoundment, introduction of chemical contaminants, temperature changes, turbine mortality, fish passage issues, modified flow patterns. A small number of ECB salmon populations are affected by the Wreck Cove facility. The low location/extent results in a Low Level of Concern, despite potentially high severity in systems where hydro power generation exists.
	Pulp and paper mills	Low	Very low (one mill, currently)	H and C Continuous	Medium to High (Dependent upon process used and effluent discharge quality)	High	Low	Pulp mill effluent has been linked to endocrine disruption in fish populations and could similarly impact Atlantic Salmon. Remediation measures are not 100% effective. The very low location/extent, regulated effluent quality, and low ECB specific certainty result in a Low Level of Concern

Threat Category	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population Level Impacts**	**Causal Certainty**		**Rationale**
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Urbanization	Low	Medium	H, C and A Continuous	Low to High (dependent upon density and infrastructure development)	High	Medium	This is associated with multiple threats impacting populations, such as roads, contaminants, waste water, altered hydrology, silt/sediment, culverts, etc. The medium to high certainty and severity, and multiple impacts to habitat, is tempered by the relatively low number of urban centers in the DU, resulting in a Low Level of Concern.
	Agriculture	Low	Medium	H, C and A Seasonal	Low to High (dependent upon extent within watershed and practices used)	Medium	Low	Impacts include sedimentation and erosion, chemical run-off, and loss of cover (increasing water temperatures), causing habitat loss. Can reduce growth and survival of juveniles. The low to medium certainty and that most are subject to a fairly low amount agriculture result in a Low Level of Concern.
	Forestry	Medium	High	H, C and A Continuous	Low to High (dependent upon extent within watershed and practices used)	Medium	Low	Impacts include sedimentation and erosion, chemical run-off, and loss of cover (increasing water temperatures), causing habitat loss. Can reduce growth and survival of juveniles. The low to medium certainty and the fact that some watershed are under intensive forestry, while others are subject to lesser forestry result in a Medium Level of Concern.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Mining	Low	Unknown	H, C and A Continuous	Low to High (dependent upon type of mine, processes used, and susceptibility to Acid Rock Draiange)	Medium	Low	Impacts include sedimentation and erosion, chemical run-off, and loss of cover (increasing water temperatures); causing habitat loss. Can reduce growth and survival of juveniles. There is potential for significant impact from historical mines. While location/extent are unknown, the amount of mining historically is significant.
	Habitat alterations from fishing activities	Low	High	H, C and A Seasonal	Low (for current fisheries and fishing gears)	Medium	Low	Fisheries can have direct impacts on habitats. Existing fisheries have low severity because only angling fisheries are permitted. Historic fisheries using gillnets and other gears would have had higher impacts. The low severity results in a Low Level of Concern.
Directed salmon fishing (current)	Aboriginal fishery	Low	Low	H, C and A Seasonal	Negligible to Very High	Very High	High	Harvest of salmon for permitted food, social or ceremonial purposes is low in ECB rivers. The low location/extent and negligible severity result in a Low Level of Concern.
	Recreational fishery (angling)	Low	Low	H and A Seasonal	Negligible to High	Very High	High	Only four rivers open to recreational angling at present. If re-opened for catch and release, mortality rates associated with regulated gear types and seasons would be low. High mortality rates were associated with historical retention fisheries. The low location/extent and negligible severity result in a Low Level of Concern.

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Illegal fishery (poaching)	High	Unknown (but potentially high)	H, C and A Seasonal	Low to Very High (dependent on number of salmon removed and size of impacted population)	Very High	Medium	Impact is direct adult mortality. Population-level impact dependent on level of poaching and overall population size. Anecdotal reports of poaching are widespread. The potentially high location/extent, potentially high severity on some populations, and high risk that a few individual poachers could remove a large proportion of a small population result in a High Level of Concern.
By-catch in other fisheries	Aboriginal or commercial fisheries	Low	High	H, C and A Seasonal	Low	High	Low	Immature and adult mortality is low from permitted gear types and seasons. The low severity under current fishery conditions results in a Low Level of Concern.
	Recreational fisheries for other species	Low	High	H, C and A Seasonal	Low	High	Low	Recreational fisheries for other salmonids, striped bass, Smallmouth Bass, etc. can potentially capture adult salmon as by-catch. Other species can be targeted effectively with low rates of by-catch of salmon. The high location/extent but low severity result in a Low Level of Concern. True by-catch is low, in contrast to illegally targeting salmon while fishing for other species (see below).

Threat Category	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population Level Impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Freshwater environment								
	Recreational fishery: illegal targeting of Atlantic Salmon while fishing under a general license	Medium	High	H, C and A Seasonal	Low to High (dependent upon angling pressure)	High	Low	This impact leads to continued mortality in populations when abundance is low. Adult salmon mortality can be higher than in the regulated directed fishery given water temperatures and season length. The high location/extent, potentially high severity, and uncertainty regarding occurrence and frequency result in a Medium Level of Concern.

Table 7. Threats to eastern Cape Breton Atlantic Salmon populations occurring in marine or estuarine environments (TOR 18).

Threat	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population level impacts**	**Causal Certainty**		**Rationale**
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Marine and Estuarine environments								
Changes to biological communities	Non-native species	Low	High	C and A Continuous	Low	Low	Low	Example species. tunicates, green crab, *Codium*. Possibly indirectly impact salmon through changes in prey communities and near-shore ecosystem structure. The low severity and low causal certainty result in a Low Level of Concern.
	Salmonid aquaculture	High	Very High (because the spatial extent of potential impacts is very large, this can include salmon farms outside the DU)	H, C and A Continuous	Medium to High (dependent upon location of aquaculture facilities and operating practices)	High	Low	Impacts include near-shore habitat loss, possible disease transfer, predator attraction, and interbreeding; contributes to immature and adult mortality rates and lowers reproductive success. Specific sites have the potential to impact multiple populations. The high location/extent, medium-high severity, industry growth, and high general causal certainty result in a High Level of Concern.
	Other species aquaculture	Low	Very High (all populations)	H, C and A Seasonal	Negligible to Medium (dependent upon species under culture, location of fsaacility, and operating practices)	Low	Low	Impacts include near-shore habitat loss and changes in ecological communities. May contribute to immature and adult mortality rates. There are a large number of bivalve lease sites in ECB. The low severity and low causal certainty result in a Low Level of Concern.

Threat	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population level impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Marine and Estuarine environments								
	Diseases and parasites	High	Very High (all populations)	H, C and A Continuous	Low to High (dependent upon irruptive behavior of disease/parasites resulting in outbreaks)	High	Low	Examples. Bacterial kidney disease, *Anasakis*, sea lice. Introduces physiological stress on individuals and lowers overall condition, leading to increased mortality rates. The high to very high prevalence of some diseases/parasites (location/extent), potentially high severity, and low causal certainty result in a Medium Level of Concern relative to other threats.
Changes in oceanographic conditions	Marine ecosystem change (including shifts in oceano-graphic conditions and changes in predator/prey abundance)	High	Very High (all populations)	H, C and A Continuous	Low to Extreme (dependent upon magnitude of change and sensitivity of salmon to change)	High	Low	Climate change affecting sea temperatures, currents and ice cover, ecosystem shifts and changes in predator / prey abundance (possibly caused by humans). Influences mortality rates at sea for immature and adult salmon. At-sea survival has not been measured for any eCB salmon population. The high location/extent, potentially high severity, and low causal certainty result in a High Level of Concern.

Threat	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population level impacts**	**Causal Certainty**		**Rationale**
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Marine and Estuarine environments								
	Contaminants and spills (land- or water-based)	Low	Very High (all populations)	H, C, A Episodic	Low to Extreme (dependent upon identity and magnitude of contamination, and efficacy of cleanup)	Low	Low	Examples include catastrophic spill events (e.g. oil) or steady pollution sources (e.g. shipping lanes, drilling platforms). Has the potential to disrupt migration routes and to adversely impact marine habitats and prey distributions leading to increased marine mortality. The low severity, low causal certainty, and rare nature of such events result in a Low Level of Concern.
Physical or abiotic change	Shipping, transport, noise, seismic activity	Low	Very High (all populations)	H, C and A Seasonal	Uncertain; likely Negligible to Low (dependent upon proximity to source of noise / activity)	Low	Low	Near-shore shipping has the potential to disrupt migration routes and to adversely impact marine habitats and prey distributions. Population-level impacts are unstudied. The low severity and low causal certainty result in a Low Level of Concern.
	Pulp and paper mills	Low	Very low (one mill, currently inactive but may reopen)	H and C Continuous	Medium to High (Dependent upon process used and effluent discharge quality)	High	Low	Pulp mill effluent has been linked to endocrine disruption in fish populations and could similarly impact Atlantic Salmon. Remediation measures are not 100% effective. The very low location/extent, regulated effluent quality, and low ECB specific certainty result in a Low Level of Concern

Threat	**Specific Threat**	**Level of Concern for the DU as a Whole**	**Location or Extent of the Threat in the DU**	**Occurrence and Frequency of the Threat in the DU**	**Severity of Population level impacts**	**Causal Certainty** Evidence linking the threat to stresses in general	**Causal Certainty** Evidence for changes to viability of ECB salmon populations	**Rationale**
Marine and Estuarine environments								
	Subsistence fisheries (Aboriginal and Labrador residents)	Low	Low	H and A Seasonal	Negligible	High	High	Level of concern would be higher if more extensive fisheries were re-opened. The low location/extent and negligible severity result in a Low Level of Concern.
Directed salmon fisheries	International fisheries (Greenland, St. Pierre – Miquelon)	Medium	Very High (all populations)	H, C and A Seasonal	Negligible to High	High	Medium	Greenland fisheries have been reduced to a subsistence level from historical commercial fisheries. Exploitation rates remain high enough to warrant a Medium Level of Concern if ECB salmon are captured in proportion to other stocks.
	Commercial fisheries (Local)	Low	Low	H and A Seasonal	Low	High	Low	Commercial fisheries in eastern Cape Breton were closed by the mid-1980s, resulting in a Low Level of Concern
	Commercial fisheries	Medium	Very High (all populations)	H, C and A Seasonal	Low to High (dependent upon target species, gear and timing)	High	Low	Some fisheries in ECB have a high potential to catch Atlantic Salmon (smelt in the Bras d'Or; Gaspereau in the Mira). Is dependent on gear. The very high location/extent of this activity and potentially high severity is tempered by gear and season restrictions to minimize by-catch, resulting in a Medium Level of Concern.

Threat	Specific Threat	Level of Concern for the DU as a Whole	Location or Extent of the Threat in the DU	Occurrence and Frequency of the Threat in the DU	Severity of Population level impacts	Causal Certainty		Rationale
						Evidence linking the threat to stresses in general	Evidence for changes to viability of ECB salmon populations	
Marine and Estuarine environments								
By-catch in other fisheries	Commercial Fisheries	Low	Very High (all populations)	H, C and A Seasonal	Low to High (dependent upon reduction of prey species and availability of other forage species)	Low	Low	Reduced prey availability upon entry into the marine environment is hypothesized to cause significant mortality in Atlantic Salmon populations. The low to high severity and low casual certainty result in a Low Level of Concern relative to other threats.
Fisheries on prey species of salmon	Commercial Fisheries	Low	Very High (all populations)	H, C and A Seasonal	Low to High (dependent upon reduction of prey species and availability of other forage species)	Low	Low	Little to no evidence that prey species abundance have been reduced to levels that would affect survival of salmon

Table 8. The number and type of historical mine openings in major watersheds of eastern Cape Breton. Data are from the Nova Scotia Natural Resources Abandoned Mine Openings Database. Blank cells indicate that no mines of that type were identified.

Watershed Number	Watershed Name	Coal	Copper	Gold	Graphite	Iron	Lead	Manganese	Oil Shale	Silica Sand	Talc	Zinc	Total
5	Clyburn Brk.			6									6
8	Barachois R.			2									2
9	River Bennett											1	1
12	Middle R.	1		18									19
15	Skye R.		3	1							4		8
19	River Denys			1						3			4
20	Scott Brk.	1											1
23	Black R.					1							1
24	River Inhabitants	1		1	5								7
25	Grand R.						1	2					3
28	Framboise R.											4	4
32	Mira R.	30	1			3	3	9	2				48
33	MacAskills Bk.	19											19
34	Northwest Bk.	5											5
35	Sydney R.	2				1							3
36	Grantmire Bk.		8										8
37	Frenchvale Bk.						2						2
38	Georges R.		2										2
39	Aconi Bk.	1											1
40	Benacadie Bk.				1								1
41	Indian Bk. (CB Co.)					2							2
43	Gillies Bk.					2	2		1				5
44	Breac Bk.					5							5
45	River Tom					4		3					7
Other ECB watersheds		832	5	2		36	5				2		

Table 9. Known locations (and watersheds) where introduced (non-native) fish species in have been sampled in eastern Cape Breton.

Species	Watershed Number	Watershed Name	Waterbody	Year and Source
Chain Pickerel	35	Sydney River	Blacketts Lake	2010; NSDFA
			Gillis Lake	2009; NSDFA
Smallmouth Bass	35	Sydney River	Blacketts Lake	2009; NSDFA
			Gillis Lake	2009; NSDFA
			Sydney River	2009; NSDFA
Rainbow Trout (observations of juveniles)	12	Middle River	Middle River	1985; NSDLF in Hurley 1989; also Robichaud-LeBlanc and Amiro 2004
	15	Skye River	Skye River	1985; NSDLF in Hurley 1989
	16	Blues Brook	Blues Brook	1985; NSDLF in Hurley 1989
	35	Sydney River	Gillis Lake Brook	Sabean 1983 in Madden et al. 2010
	41	MacIntosh Brook	MacIntosh Brook	1985; NSDLF in Hurley 1989
	42	Gillies Brook	Gillies Brook	1985; NSDLF in Hurley 1989
	43	Breac Brook	Breac Brook	1985; NSDLF in Hurley 1989
Brown Trout	19	River Denys	River Denys	2010; NSDFA, unpublished data (adult observations only)
	25	Grand River	Grand River	Robichaud-LeBlanc and Amiro 2004
	32	Mira River	Mira River	2007; Gibson and Bowlby 2009
	41	Indian Brook	Indian Brook	2006; Gibson and Bowlby 2009

Table 10. Decadal summary of the juvenile Atlantic Salmon stocking programs operated in rivers of the ECB DU from 1976 to 2007 (all years in the distributions database), including the total number of each life stage stocked and the broodstock origin. Native is defined as broodstock from the river of origin, local is broodstock from another river in the ECB DU and hybrid is a crossbreeding of two different populations (either native x local or local x local). Where broodstock came from outside of eastern Cape Breton, the DU of origin is given. Watershed numbers correspond to those in Table 1. Data are from the hatchery distributions database maintained by DFO Science Branch.

Watershed Number	Watershed Name	Decade	Total	Life Stage	Stock origin
10	North R.	1980	21,432	smolt	native
		1990	55,062	smolt/parr	native
11	Baddeck R.	1970	2,700	smolt	Gulf DU
		1980	37,086	parr	local
		2010	38,700	parr/smolt	native
12	Middle R.	1970	6,758	smolt/parr	Gulf DU
		1980	151,669	smolt/parr	local / Gulf DU
		2010	35,000	parr/smolt	native
24	River Inhabitants	1980	13,079	smolt/parr	hybrid / Gulf DU / SU DU
		1990	1,026	smolt	Gulf DU
25	Grand R.	1980	56,658	smolt/parr	native
		1990	236,078	smolt/parr	native
32	Mira R.	1980	11,514	parr	native
		1990	88,542	smolt/parr	native
41	Indian Bk. (CB Co.)	1990	86,659	smolt/parr	hybrid / local
		2000	37,074	smolt/parr/fry	hybrid / local
0	other ECB watersheds	1990	28,387	smolt	local

Table 11. Number of locations stocked with trout species (Brook, Brown, and Rainbow Trout) in watersheds of eastern Cape Breton by the NSDFA during their spring and fall stocking distributions in 2010 and 2011. Seven "other" watersheds (not major watersheds) were also stocked for fishing derbies, but the species stocked were not specified. Blank cells indicate that no stocking events were identified in the watershed during 2010 or 2011.

Watershed Number	Watershed Name	Brook Trout	Brown Trout	Rainbow Trout
3	North Aspy R.	1		
12	Middle R.	1		
21	River Tillard	1		
23	Black R.	1		
24	River Inhabitants	2	1	
25	Grand R.	4		
29	Gerratt Bk./Lorraine Bk.	1		
32	Mira R.	1	1	
34	Northwest Bk.	2		
35	Sydney R.	3		
39	Aconi Bk.	1		
43	Gillies Bk.	2		
45	River Tom		1	
0	Other ECB watersheds	25	2	5
0	Bras d'Or Lakes			5

Table 12. Number and total area of water bodies identified as reservoirs from the NHN hydrographic network data or as possible reservoirs based on the NSE barriers layer. Reservoirs associated with the Wreck Cove Hydroelectric Project (possible reservoirs on Ingonish River and Indian Brook (Victoria Co.) were identified by the authors.

River No.	River Name	NHN identified reservoirs		Possible reservoirs		Total reservoirs	
		Number	*Area (m^2)*	*Number*	*Area (m^2)*	*Number*	*Area (m^2)*
6	Ingonish R.	n/a	n/a	n/a	n/a	2	350,308
7	Indian Bk. (Vic. Co.)	n/a	n/a	n/a	n/a	2	9,244,256
15	Skye R.	1	1,048	0	0	1	1,048
21	River Tillard	0	0	1	796,657	1	796,657
32	Mira R.	2	970,306	0	0	2	970,306
33	MacAskills Bk.	2	3,251,758	3	1,705,729	5	4,957,487
34	Northwest Bk.	3	5,312	3	1,799,696	6	1,805,008
35	Sydney R.	3	30,291	1	3,458,186	4	3,488,477
39	Aconi Bk.	1	26,880	0	0	1	26,880

Table 13. Summary of the analysis of number of road crossings in eastern Cape Breton watersheds. Information for paved and unpaved roads is presented separately for comparison, as well as the total number of crossings and crossing densities within watersheds. Information on roads is from the National Roads Network dataset (available from GeoBase). Blanks cells indicate values are not available.

Watershed Number	Watershed Name	Number of Unpaved (Paved) Road Crossings	Length of Unpaved Roads (km)	Length of Paved Roads (km)	Total Number of Crossings	Total Length of Roads (km)	Length of Flow Network (km)	Crossing Density (number/ 10 km)
1	Salmon R. (Vic. Co.)	0 (1)		0.83	1	0.83	50.35	0.20
2	Wilkie Brk.	1 (1)	0.09	0.42	1	0.50	12.27	0.82
3	North Aspy R.	5 (7)	9.97	17.62	12	27.6	184.9	0.65
4	Middle and South Aspy R.	2 (2)	11.99	8.93	4	20.92	80.82	0.49
5	Clyburn Brk.	4 (1)	9.27	1.14	5	10.41	88.36	0.57
6	Ingonish R.	7 (2)	13.86	0.76	9	14.62	105.93	0.85
7	Indian Brk.	33 (1)	132.67	1.53	34	134.2	289.19	1.18
8	Barachois R.	12 (6)	35.48	6.04	18	41.53	110.61	1.63
9	River Bennett	7 (4)	8.87	6.03	11	14.90	21	5.24
10	North R.	37 (7)	143.72	5.11	44	148.82	220.12	2.00
11	Baddeck/Middle R.	48 (11)	159.97	23.89	59	183.86	280.02	2.11
12	Middle R.	47 (29)	183.73	49.01	76	232.73	389.66	1.95
13	Hume R.	2 (1)	14.54	0.28	3	14.82	46.81	0.64
14	MacPhersons Brook (Lewis)	0 (1)	7.83	0.90	1	8.74	13.48	0.74
15	Skye R.	52 (19)	87.03	21.00	71	108.03	137.75	5.15
16	Blues	6 (6)	10.44	4.53	12	14.97	27.57	4.35
17	Washabuck R.	12 (3)	25.12	2.23	15	27.35	25.32	5.92
18	McKinnons Brook	8 (2)	12.56	2.27	10	14.83	13.32	7.51
19	River Denys	65 (30)	125.51	39.30	95	164.81	250.36	3.79
20	Scott Brk.	5 (1)	11.53	1.73	6	13.27	27.51	2.18
21	River Tillard	19 (1)	56.74	2.93	20	59.67	67.31	2.97
22	False Bay Brook	7 (4)	20.49	5.35	11	25.84	17.52	6.28
23	Black R.	13 (8)	29.35	8.61	21	37.96	64.82	3.24
24	River Inhabitants	103 (59)	267.92	90.60	162	358.52	386.27	4.19
25	Grand R.	77 (4)	194.54	12.06	81	206.61	288.64	2.81

Watershed Number	Watershed Name	Number of Unpaved (Paved) Road Crossings	Length of Unpaved Roads (km)	Length of Paved Roads (km)	Total Number of Crossings	Total Length of Roads (km)	Length of Flow Network (km)	Crossing Density (number/ 10 km)
26	St. Esprit (Taylors Brook)	4 (0)	4.36		4	4.36	20.35	1.97
27	Marie Joseph Brk.	20 (0)	30.33		20	30.33	91.75	2.18
28	Middle River Framboise	21 (0)	66.08	0.18	21	66.26	157.99	1.33
29	Gerratt Brk/ Lorraine Brk	15 (6)	26.46	7.58	21	34.03	77.83	2.70
30	Little Lorraine Brook	1 (11)	5.11	11.98	12	17.09	35.83	3.35
31	Catalone R.	19 (5)	51.05	12.55	24	63.60	84.93	2.83
32	Mira R.	144 (75)	334.47	136.76	219	471.24	656.08	3.34
33	McAskills Brk.	8 (8)	19.42	12.69	16	32.11	48.26	3.32
34	Northwest Brook	10 (6)	47.83	21.05	16	68.88	59.07	2.71
35	Sydney R.	47 (28)	135.59	73.61	75	209.20	202.21	3.71
36	Grantmire Brook	6 (7)	14.96	9.35	13	24.31	26.44	4.92
37	Frenchvale Brk.	12 (6)	39.99	29.49	18	69.48	60.3	2.99
38	Georges	3 (1)	10.09	10.16	4	20.24	17.78	2.25
39	Aconi Brook	15 (6)	23.03	20.96	21	43.99	39.39	5.33
40	Benacadie Bk.	14 (2)	26.11	1.98	16	28.10	43.11	3.71
41	Indian Bk (CB Co.)	1 (2)	6.31	1.82	3	8.13	48.49	0.62
42	MacIntosh Brk.	3 (2)	7.42	3.17	5	10.59	33.45	1.49
43	Gillies Brk.	10 (2)	20.42	1.99	12	22.41	32.99	3.64
44	Breac Brk.	8 (1)	29.94	1.06	9	31.00	27.78	3.24
45	River Tom	8 (1)	19.88	1.32	9	21.20	25.22	3.57
46	MacNabs	5 (1)	18.18	1.83	6	20.01	15.98	3.76

Table 14. The proportion of each watershed in the ECB DU that is used for agriculture, forestry activities, industrial sites (municipal landfills and gravel pits) and corridors (e.g. cut lines for power poles), and urban settlement. More detailed explanation of how land uses were classified is provided in Appendix 1. Data are from the NSDNR Forest Inventory (collected between 1995 and 2012).

Watershed Number	Watershed Name	Percent Forestry	Percent Agriculture	Percent Industrial Sites and Corridors	Percent Urban
1	Salmon R. (Vic. Co.)	0.04	0.00	0.03	0.06
2	Wilkie Bk.	0.00	0.00	0.07	0.33
3	North Aspy R.	0.03	0.65	0.28	0.06
4	Middle, South Aspy R.	0.11	0.67	0.32	0.80
5	Clyburn Bk.	0.00	0.00	0.03	0.50
6	Ingonish R.	0.58	0.00	0.10	0.25
7	Indian Bk. (Vic. Co.)	15.50	0.00	0.17	0.06
8	Barachois R.	6.21	0.04	0.32	0.12
9	River Bennett	2.39	0.09	0.52	2.56
10	North R.	29.42	0.17	0.22	0.22
11	Baddeck R.	21.39	1.96	0.46	0.81
12	Middle R.	15.71	2.32	0.46	0.77
13	Hume R.	12.58	0.00	0.10	0.10
14	MacPhersons (Lewis) Bk.	6.03	0.45	0.92	0.03
15	Skye R.	9.93	6.07	0.85	1.23
16	Blues Bk.	9.14	0.98	2.26	0.69
17	Washabuck R.	8.18	1.58	1.80	0.24
18	McKinnons Bk.	18.17	7.46	0.67	4.68
19	River Denys	9.55	2.27	3.02	1.14
20	Scott Bk.	5.02	1.33	0.42	0.84
21	River Tillard	6.49	1.36	2.34	0.33
22	False Bay Bk.	10.59	0.23	4.60	0.42
23	Black R.	7.67	0.98	3.25	1.53
24	River Inhabitants	14.97	2.81	1.84	1.45
25	Grand R.	11.09	0.99	1.08	0.91
26	St. Esprit (Taylors) Bk.	13.57	0.00	0.04	0.00
27	Marie Joseph Bk.	6.46	0.00	0.25	0.51
28	Framboise R.	9.03	0.22	0.40	0.43
29	Lorraine Bk.	10.20	0.02	0.34	1.03
30	Little Lorraine Bk.	7.63	0.00	0.65	1.81
31	Catalone R.	6.63	0.2	0.42	2.78
32	Mira R.	12.41	1.44	1.24	2.71
33	MacAskills Bk.	5.60	0.50	0.93	2.3
34	Northwest Bk.	4.92	1.77	5.92	8.14
35	Sydney R.	6.51	4.22	3.27	5.76
36	Grantmire Bk.	7.19	1.27	2.33	3.38
37	Frenchvale Bk.	7.97	3.40	2.85	3.64
38	Georges R.	15.75	1.77	3.08	3.81
39	Aconi Bk.	7.15	10.56	2.41	3.16
40	Benacadie Bk.	8.63	0.53	0.47	2.65
41	Indian Bk.(CB Co.)	4.14	0.00	0.06	0.73
42	MacIntosh Bk.	1.47	0.00	0.20	0.42
43	Gillies Bk.	7.52	0.54	0.17	1.16
44	Breac Bk.	15.92	0.81	0.21	0.84
45	River Tom	14.51	1.10	0.30	0.30
46	MacNabs Bk.	15.69	0.14	3.71	0.19

Table 15. Farmed Atlantic Salmon escapes observed in eastern Cape Breton rivers (adapted from Morris et al. 2008). Sampling effort is unknown, but most of the observations were opportunistic observations made during abundance surveys. Blank cells indicate data are not available.

Watershed Number	Watershed Name	Year	Total No. Farmed Adult Salmon	Total No. Wild Adult Salmon	Percent Farmed Salmon	Count / Estimation Method[1]	Identification Method[2]	Reference[3]
7	Indian Bk. (Vic. Co.)[4]	2000	1			Count		1
10	North R.	1995	295	388	8	SC		11
		1996	0	322	0		FE	4
		1997	0	335	0		EX	5
		1998	55	433	11	SC, M&R		6,1,7,2
11	Baddeck R.	1994	1	231	0.4	Count		5,8
		1995	23	338	6	M&R	EX	9,10,11,2
		1996	0	214	0		EX	3,4
		1997	1	233	0.7	Count	EX	12,3
		1998	5	190	3	M&R		6,1,2,7
12	Middle R.	1995	0	371	0		EX	11
		1996	1	358	0.3	Count	EX	10, 4,13
		1997	0	258	0		EX	5
		1998	9	213	4	M&R		6,1,2,7
15	Skye R.	1996	*Detected*					10
26	Grand R.	2003	0					14
n/a	Whycocomagh Bay	1994	2	116	2	Count		15
		1995	147	34	81	Count		9, 11
		1996	40	10	80	Count		4, 10

1. Estimate methods: SC, snorkel count; M&R, mark and recapture. “Count” indicates that this is the number of escaped fish directly observed and no extrapolation was done to estimate the total number in the population.
2. Methods used to identify farmed or wild origins of salmon: FE, fin erosion; EX, external characteristics.
3. References: 1, O’Neil et al. 2005; 2, O’Neil 1998; 3, L Marshall, DFO Science, personal communication in Morris et al. 2008; 4, Marshall et al. 1997; 5, Marshall et al. 1998; 6, Marshall et al. 1999; 7, Ritter 1999; 8, DFO 1995; 9, DFO 1996; 10, Marshall et al. 1997; 11, Marshall et al. 1996; 12, Marshall et al. 1998; 13, Ritter 1997; 14, S. Scott, Atlantic Salmon Federation, personal communication in Morris et al. 2008; 15, Amiro and Longard 1995.
4. A map in Morris et al. 2008 indicates that Indian Brook (Victoria Co.) is being referred to here, but it is possible that this observation was actually in Indian Brook (Cape Breton Co.).
5. This estimate is of fish considered to be of either hatchery or aquaculture origin.

13.0 FIGURES

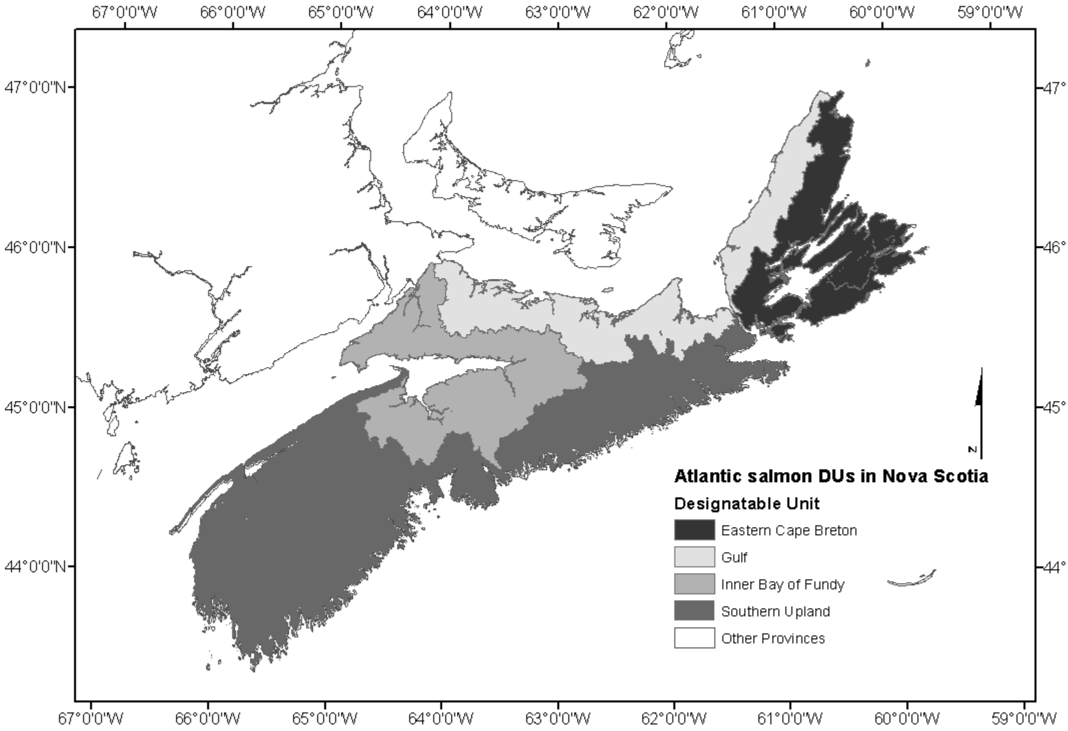

Figure 1. Map showing location of the ECB DU relative to the three other DUs for Atlantic Salmon in the Maritimes.

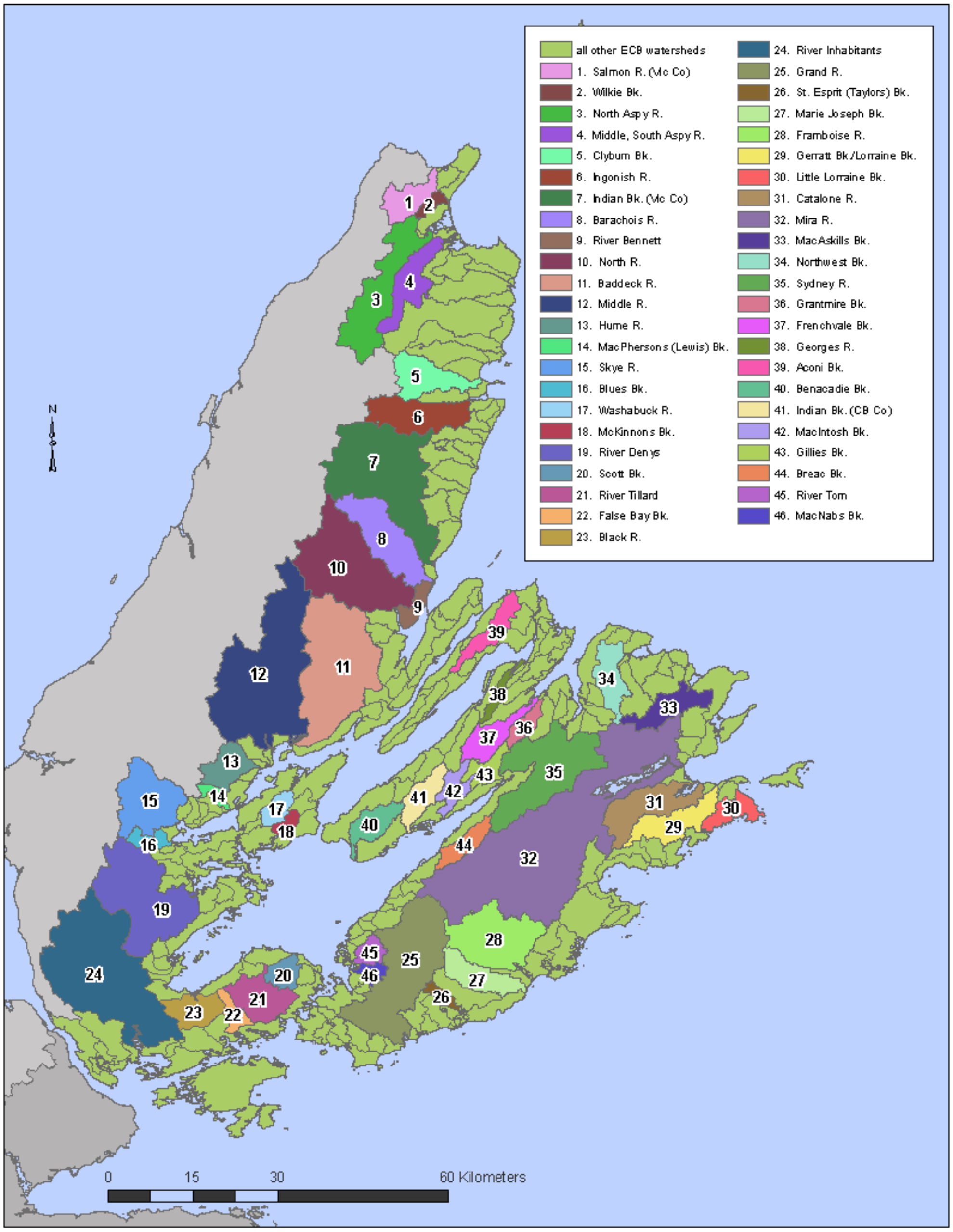

Figure 2. Map of the major watersheds associated with known Atlantic Salmon rivers in the eastern Cape Breton, labelled by number and colour. Boundaries are from the NSE Secondary Watersheds layer. All watersheds identified in the NASCO Rivers Database as salmon-containing watersheds are numbered, and Indian Brook in Cape Breton County (number 41) was added as it has been surveyed by DFO and is known to be a salmon river (Robichaud-LeBlanc and Amiro 2004). Other watersheds in eastern Cape Breton (not identified by NASCO or the authors as known salmon-containing watersheds) are coloured green.

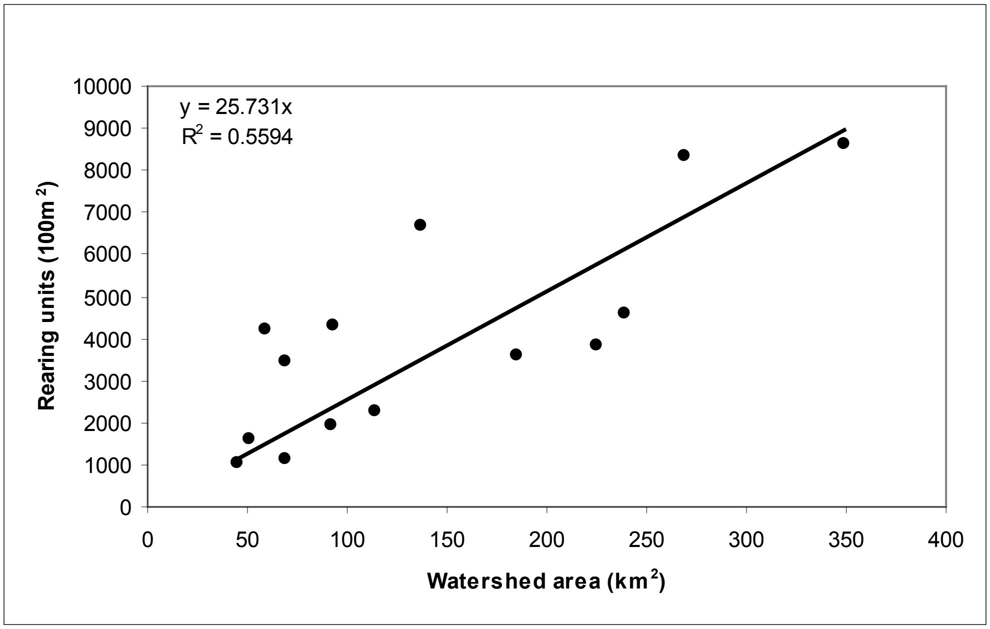

Figure 3. Relationship between drainage area (from the NSE Secondary Watersheds layer) and rearing area for juvenile salmon (river area with percent orthogradient >0.12 in Robichaud-LeBlanc and Amiro 2004) for 14 watersheds in eastern Cape Breton. Drainage area explains a large proportion of the variation in productive area (R^2= 0.5594) and the relationship is statistically significant (p-value <0.001). Data from the Mira River has been excluded.

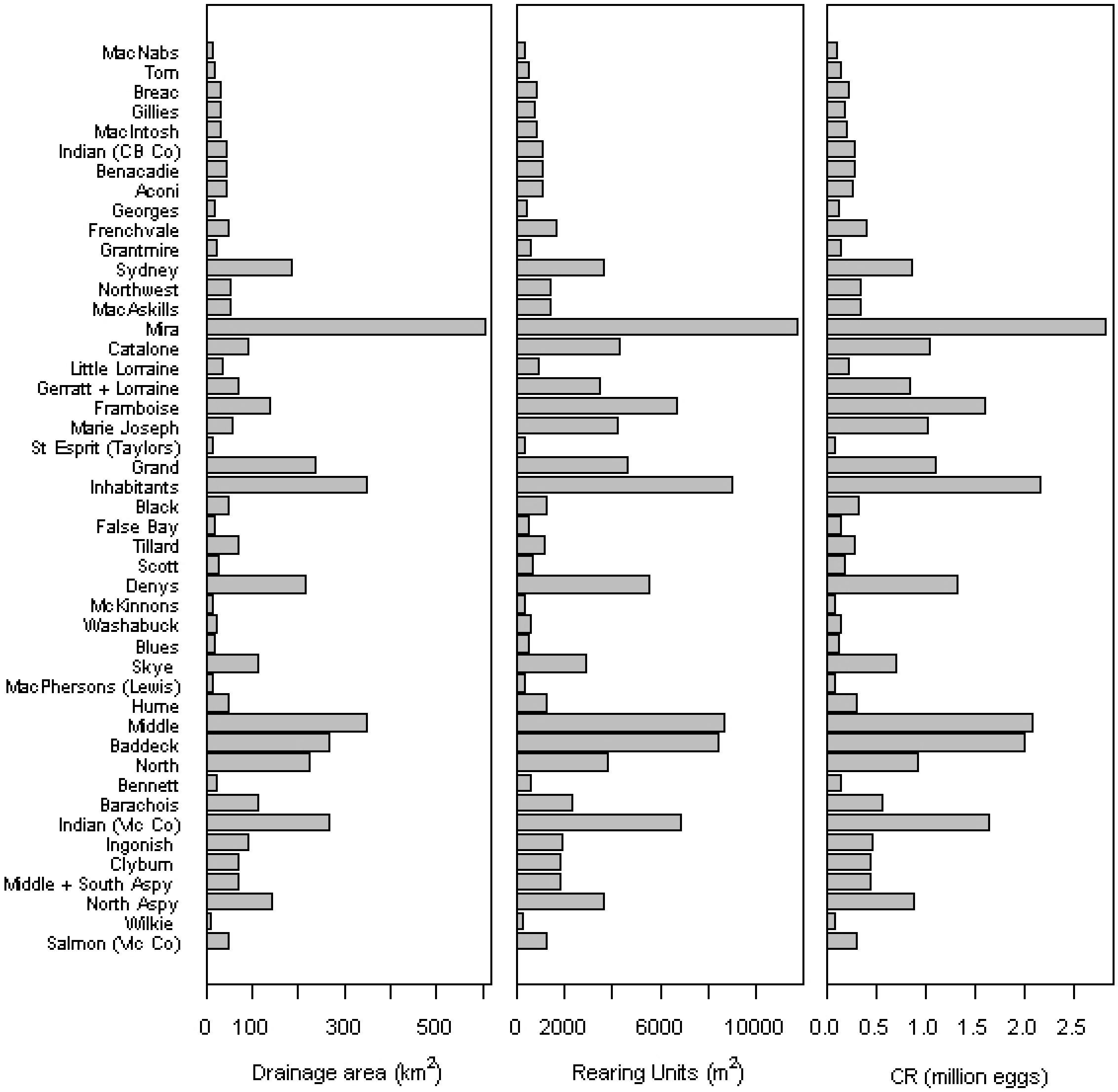

Figure 4. Barplots of the drainage area of all major watersheds in eastern Cape Breton (from the NSE Secondary Watersheds layer), their measured or calculated rearing area (in 100 m^2 habitat units, see Table 1), and the associated conservation requirement for egg deposition assuming a deposition rate of 240 eggs/habitat unit.

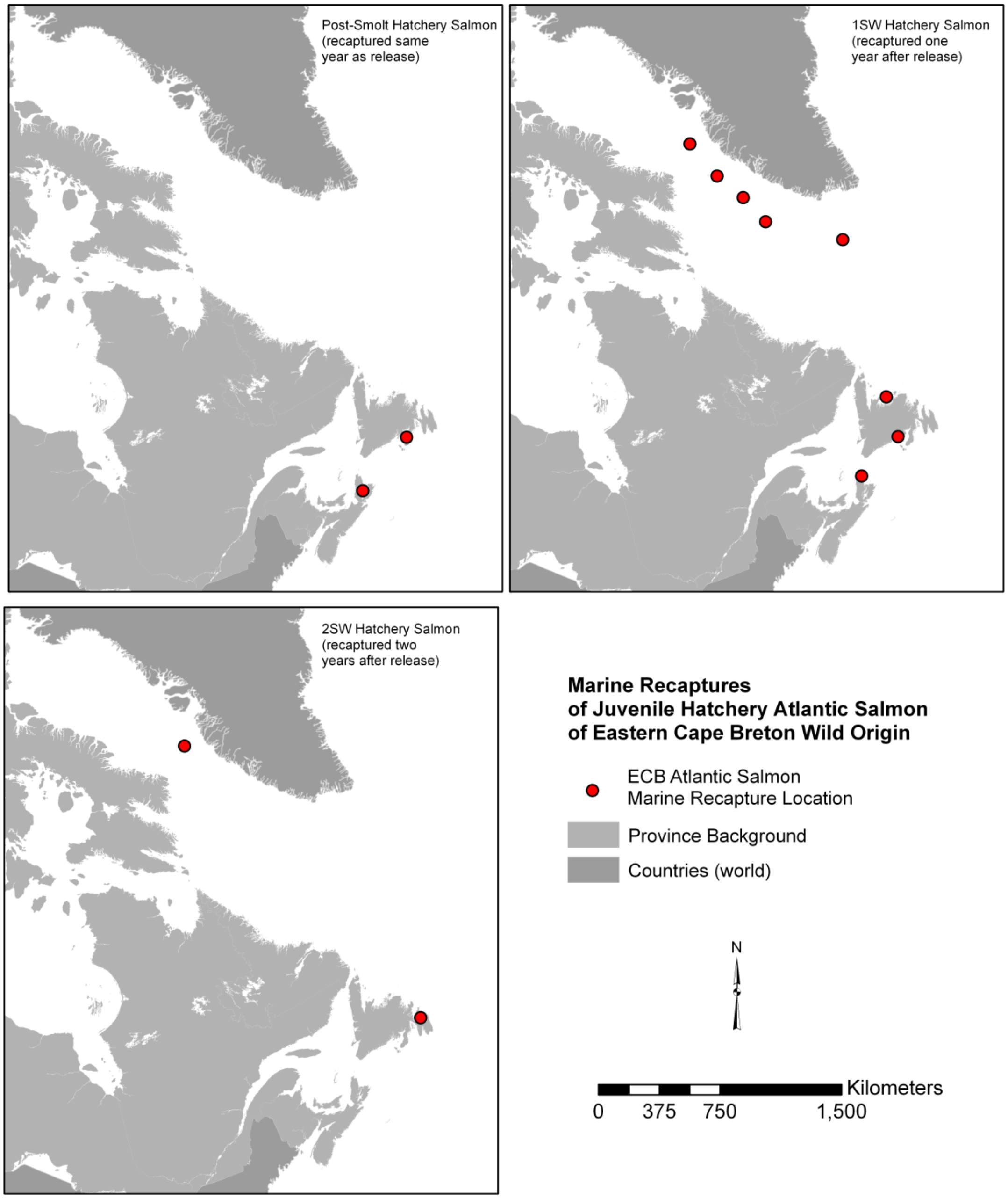

Figure 5. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts from wild eastern Cape Breton broodstock recaptured in the marine environment. Panels show recpatures in year of smolts release (as postsmolt), year proceeding smolt release (as one sea winter grilse) and the second year proceeding release (as 2SW salmon).

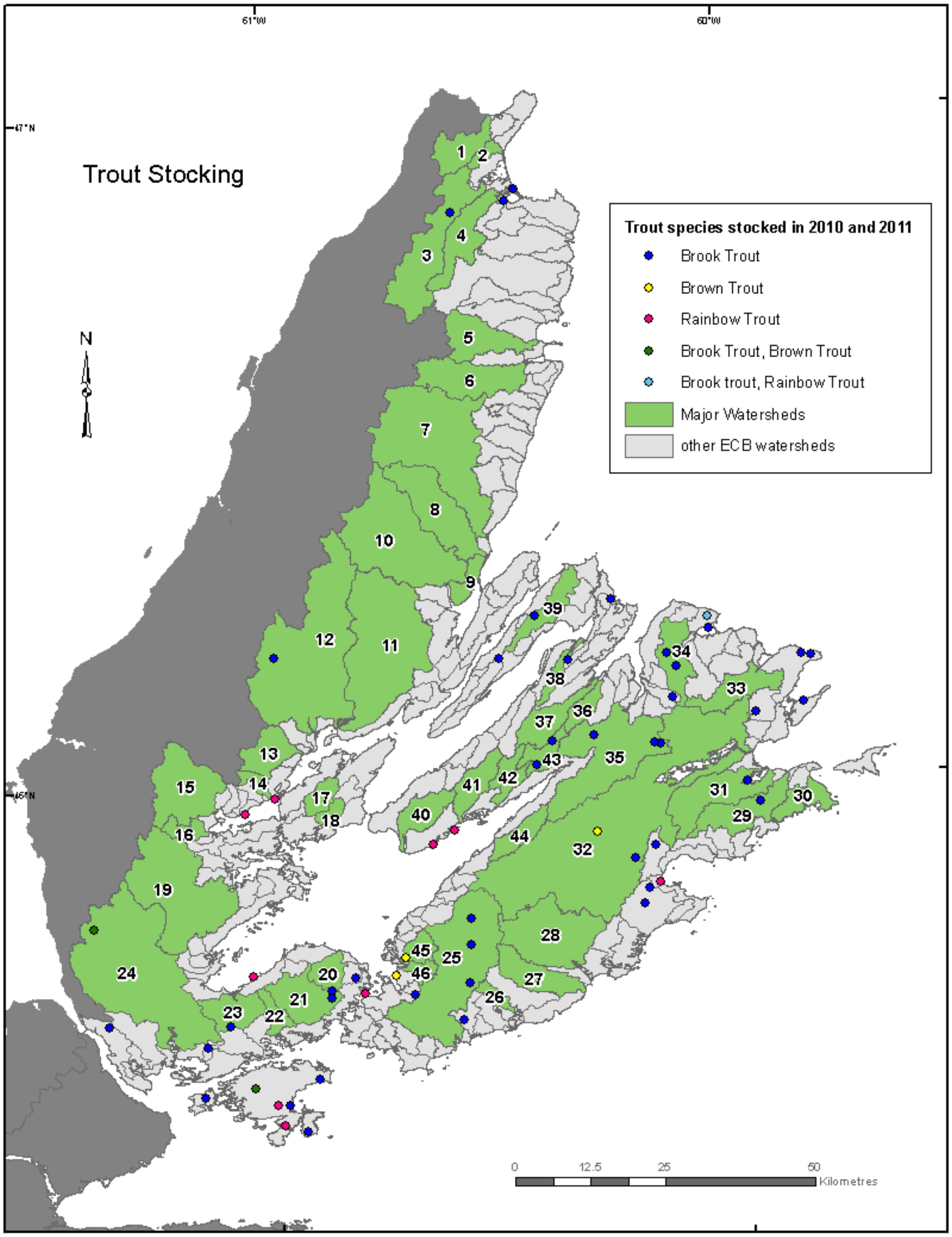

Figure 6. Locations of water bodies in eastern Cape Breton stocked in 2010 and/or 2011 with brook, rainbow, or brown trout by the NSDFA. Stocking locations are given by waterbody (river or lake), so points indicate the watershed and water body stocked, but do not necessarily show the stocking location within that water body.

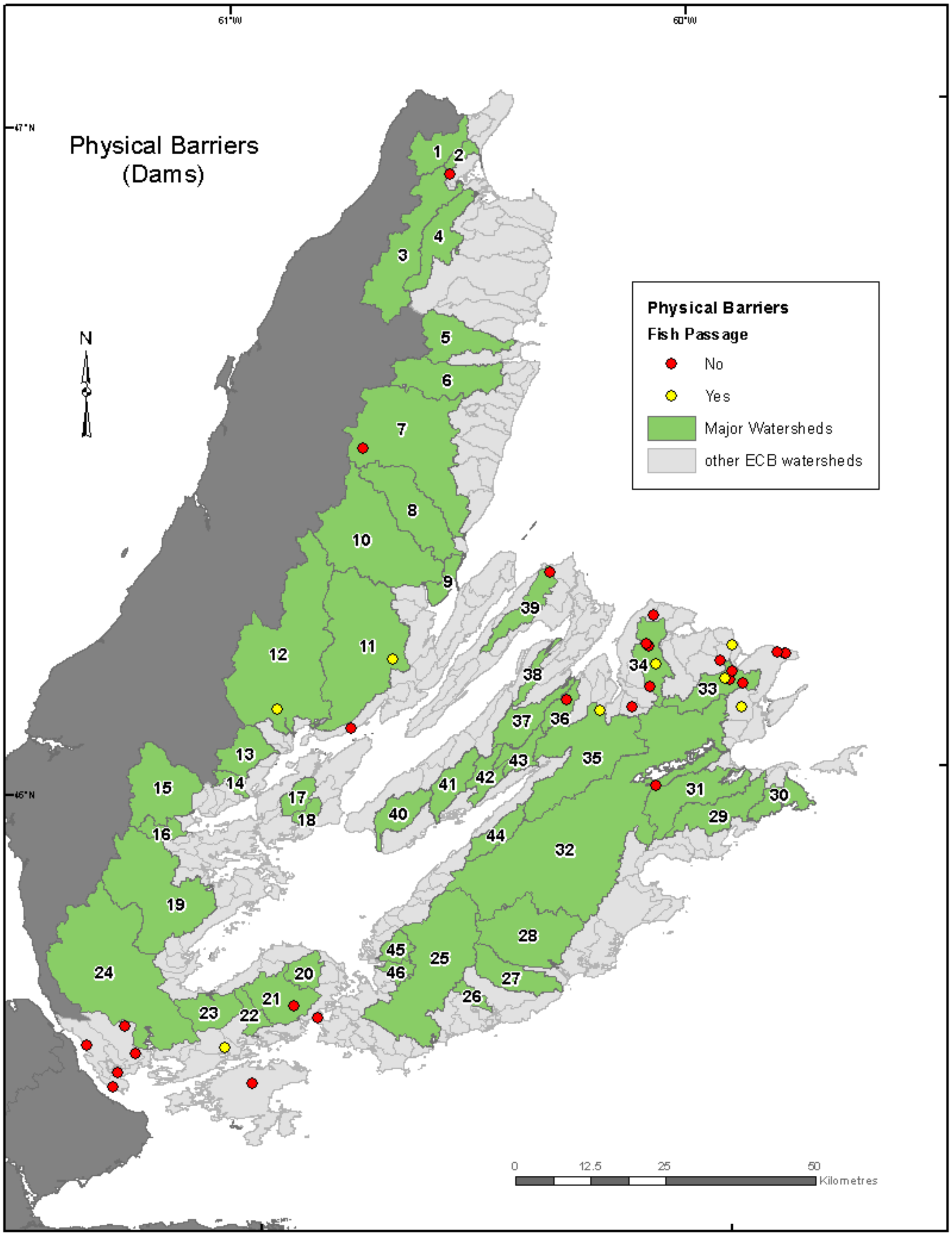

Figure 7. Barrier structures in eastern Cape Breton listed on the NSE barriers layer. Fish passage information comes from the same database and the efficacy of fish passage provided has not been independently evaluated. Dam locations that are part of the Wreck Cove Hydroelectric Project (watersheds 6 and 7) are not shown. Major watershed numbers correspond to the legend in Figure 2.

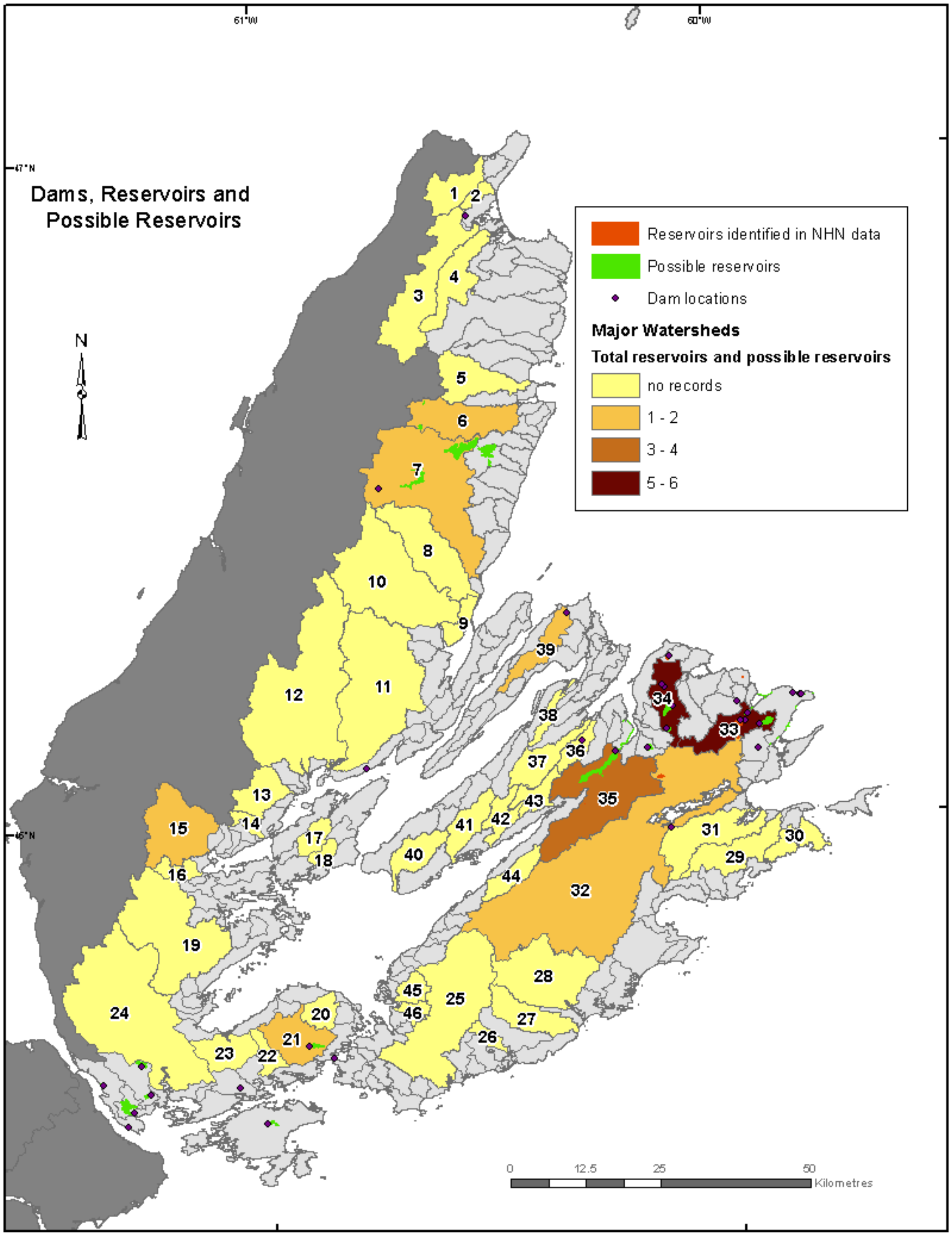

Figure 8. Watersheds containing reservoirs identified from the NHN water body data (in red) or possible reservoirs (in green) identified based on intersection of water bodies with dams. Dam locations are based on the NSE barriers layer. Possible reservoirs related to the Wreck Cove Hydroelectric Project (based on signage provided at the site by NS Power) are also identified. Major watershed numbers correspond to the legend in Figure 2.

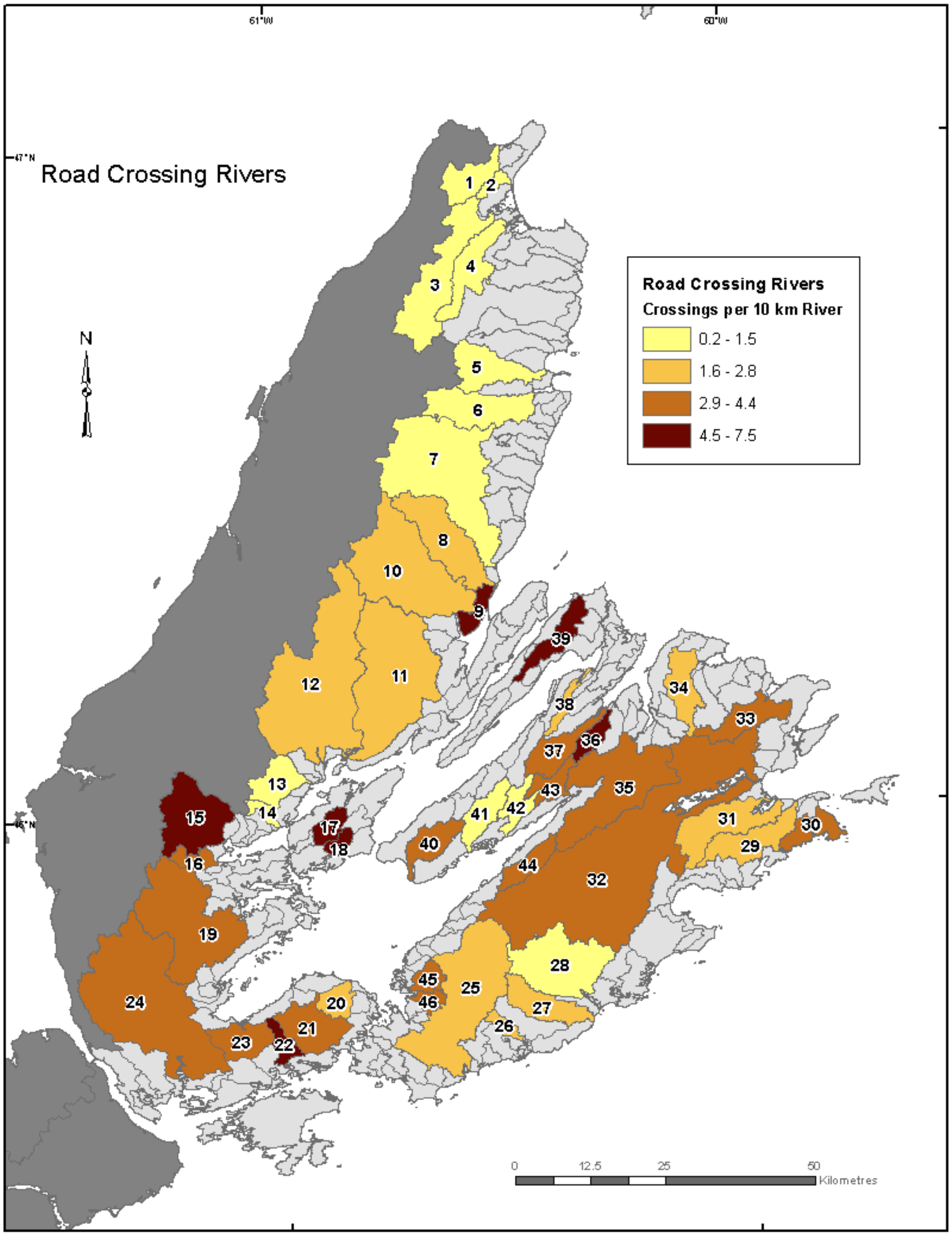

Figure 9. Density of road crossings within major watersheds in eastern Cape Breton. Analysis is based on road segments from the National Road Network and water courses in the NHN hydrologic network. Both datasets have approximately 1:50,000 scale resolution. Major watershed numbers correspond to the legend in Figure 2.

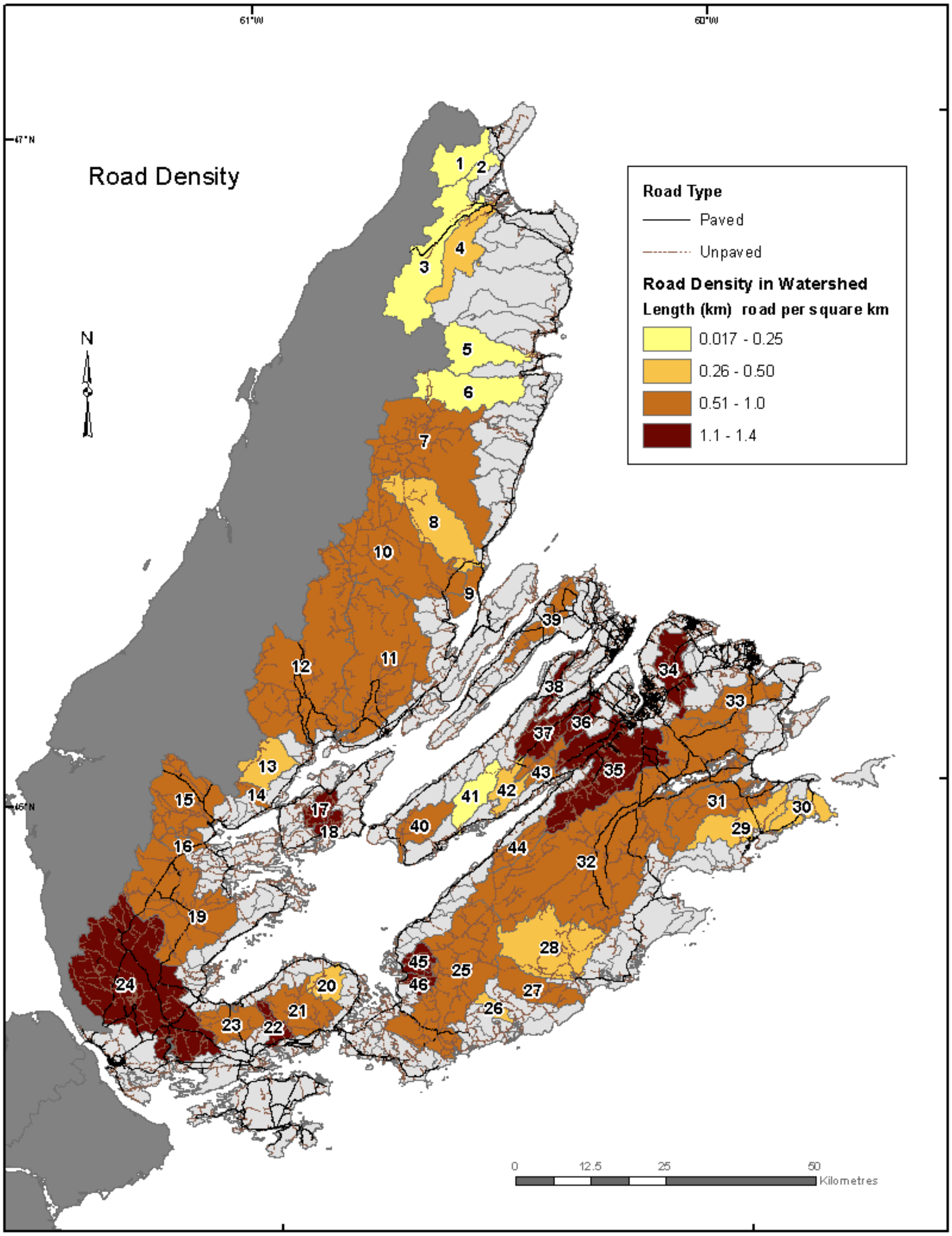

Figure 10. Density of roads in major watersheds (km road per km^2 of watershed) in eastern Cape Breton. Analysis is based on road segments from the National Road Network. Major watershed numbers correspond to the legend in Figure 2.

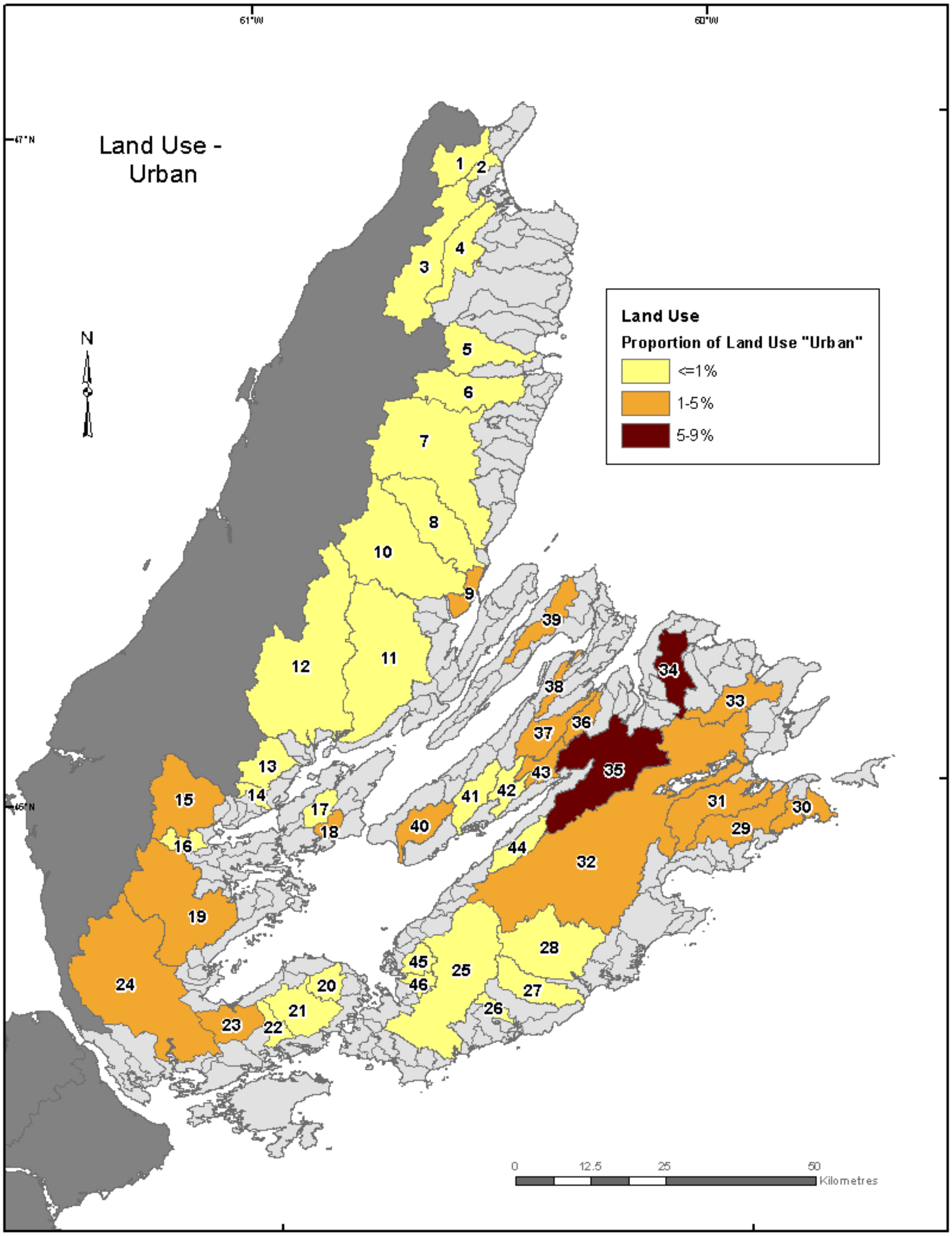

Figure 11. The proportion of major watershed areas classified as "urban" for rivers in eastern Cape Breton based on aerial surveys from 1995 to present (NSDNR Forest Inventory Data). Major watershed numbers correspond to the legend in Figure 2.

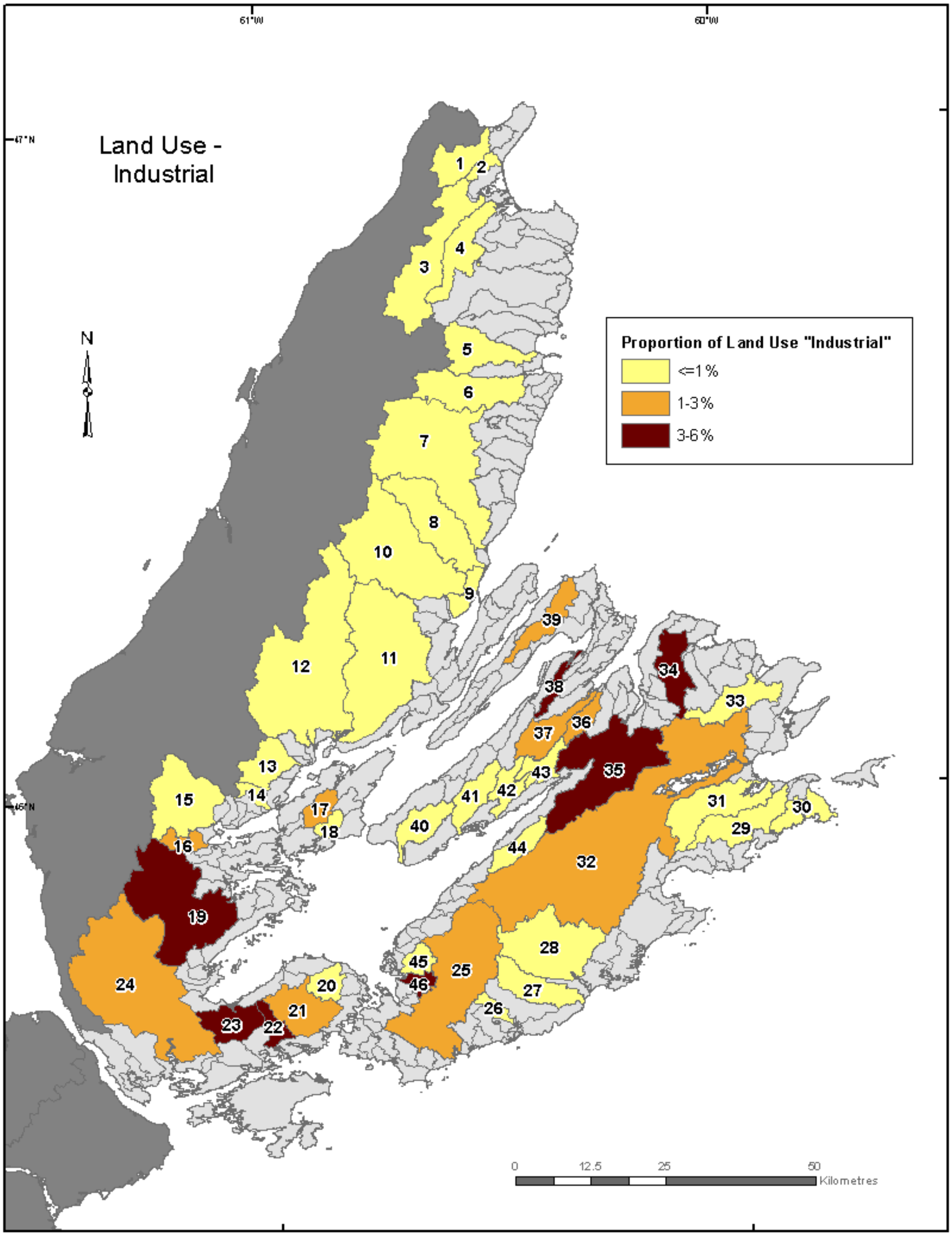

Figure 12. The proportion of major watershed areas classified as "industrial" for rivers in eastern Cape Breton based on aerial surveys from 1995 to present (NSDNR Forest Inventory Data). Major watershed numbers correspond to the legend in Figure 2.

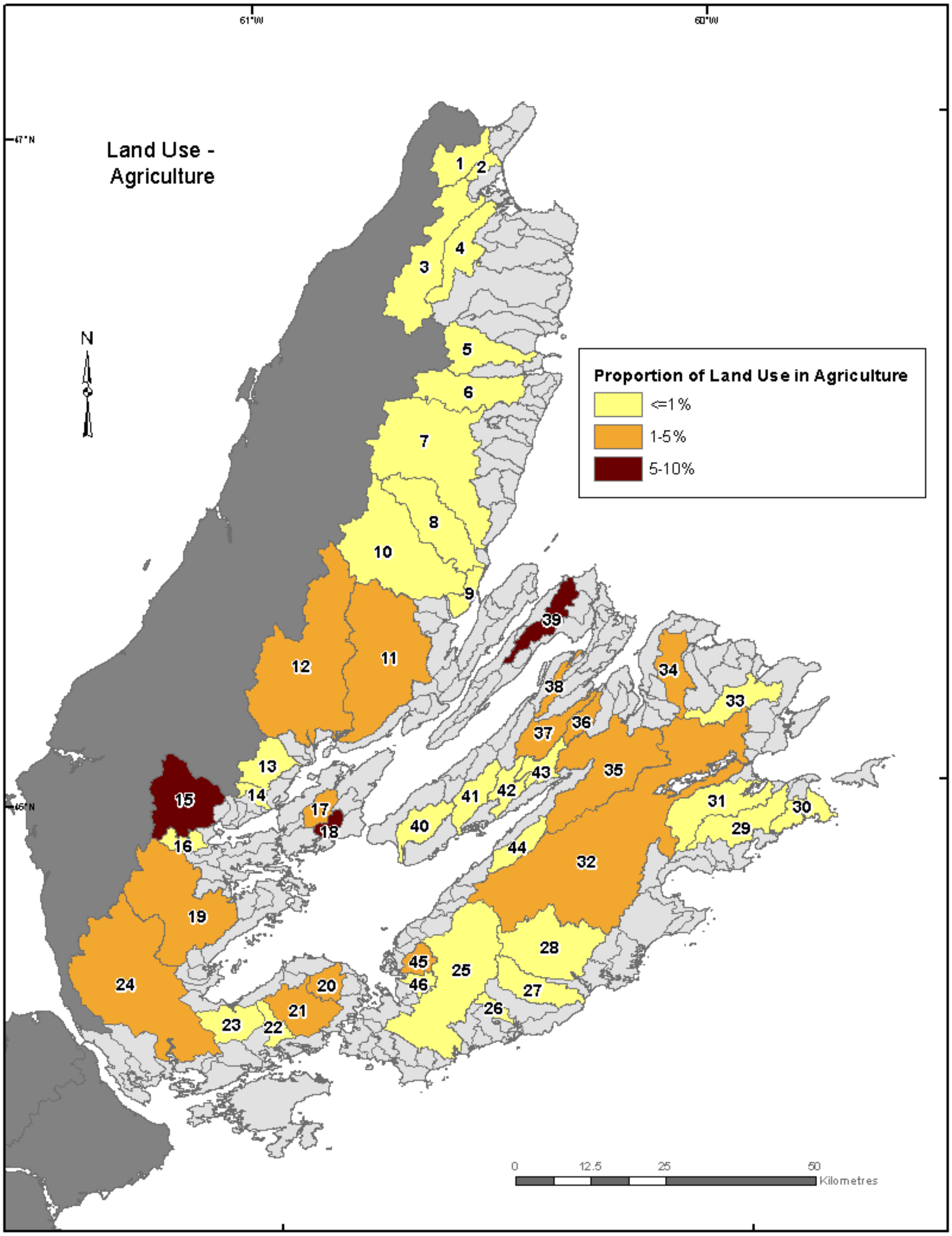

Figure 13. The proportion of major watershed areas classified as agricultural (including blueberry production) in eastern Cape Breton, based on aerial surveys from 1995 to present (NSDNR Forest Inventory Data). Major watershed numbers correspond to the legend in Figure 2.

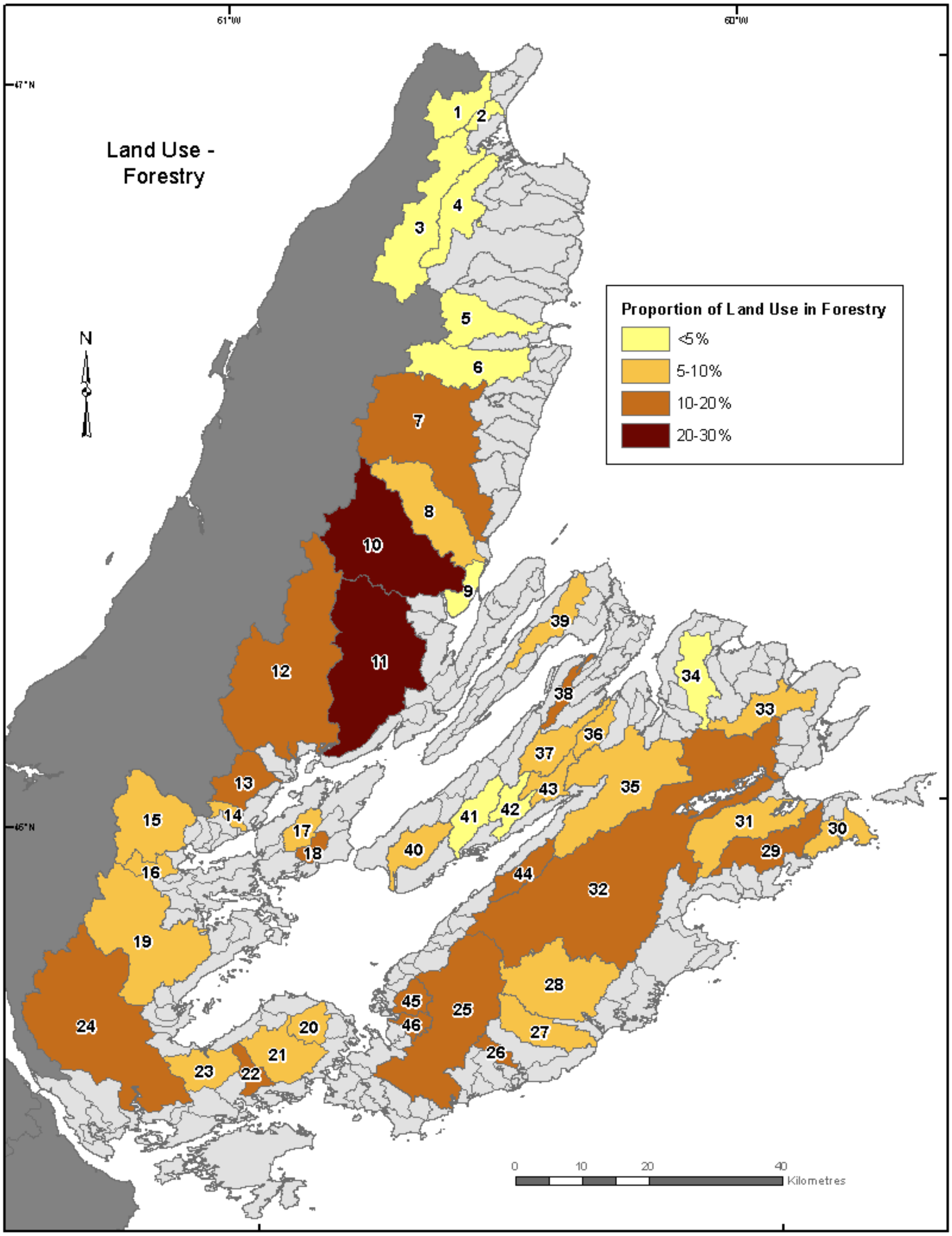

Figure 14. The proportion of major watershed areas classified as forestry lands (silviculture, timber harvest, Christmas tree farms and experimental stands) for rivers in eastern Cape Breton based on aerial surveys from 1995 to present (NSDNR Forest Inventory Data). Major watershed numbers correspond to the legend in Figure 2.

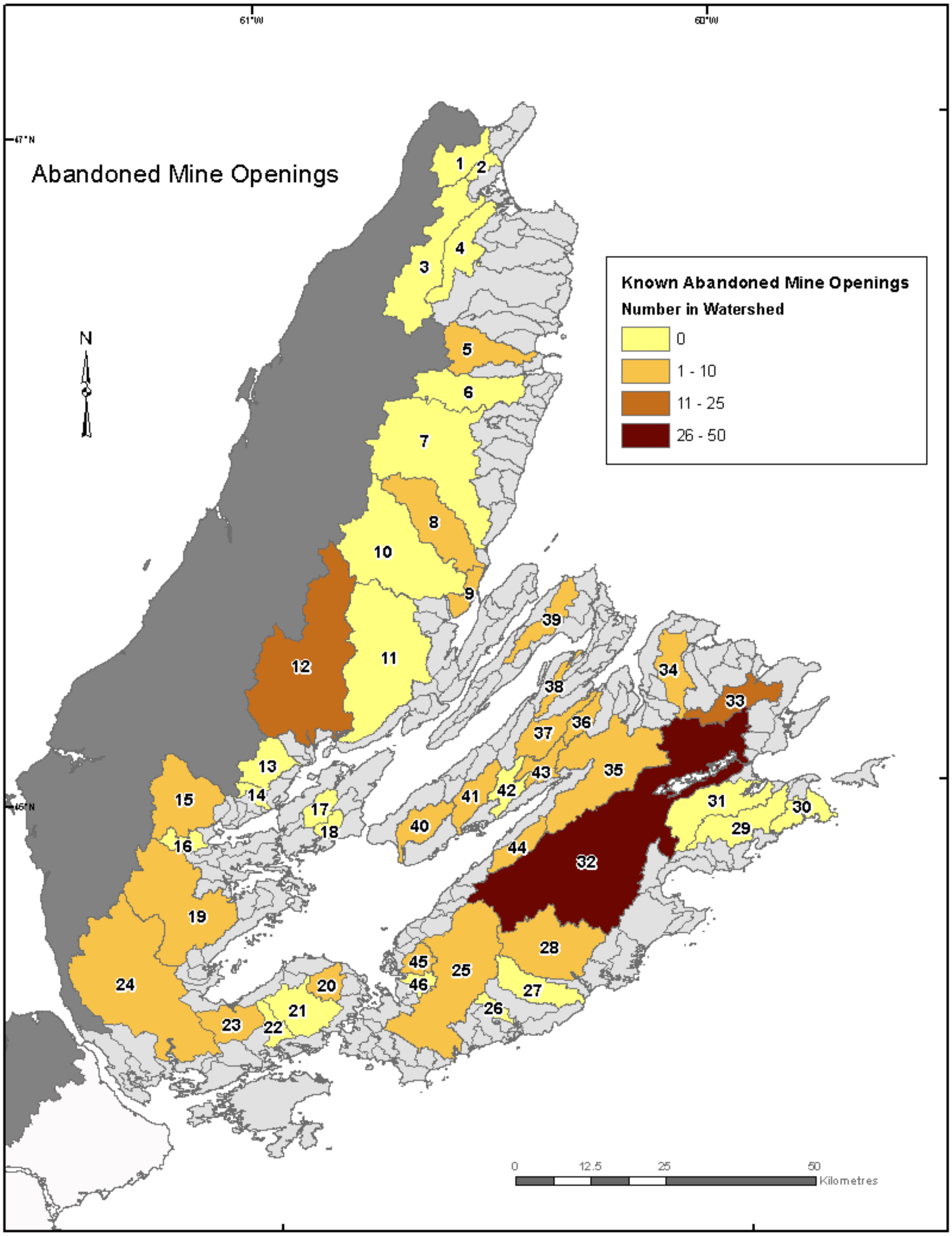

Figure 15. Distribution of abandoned mines identified in the Abandoned Mine Openings Database from NSDNR within the major watersheds of eastern Cape Breton. Major watershed numbers correspond to the legend in Figure 2.

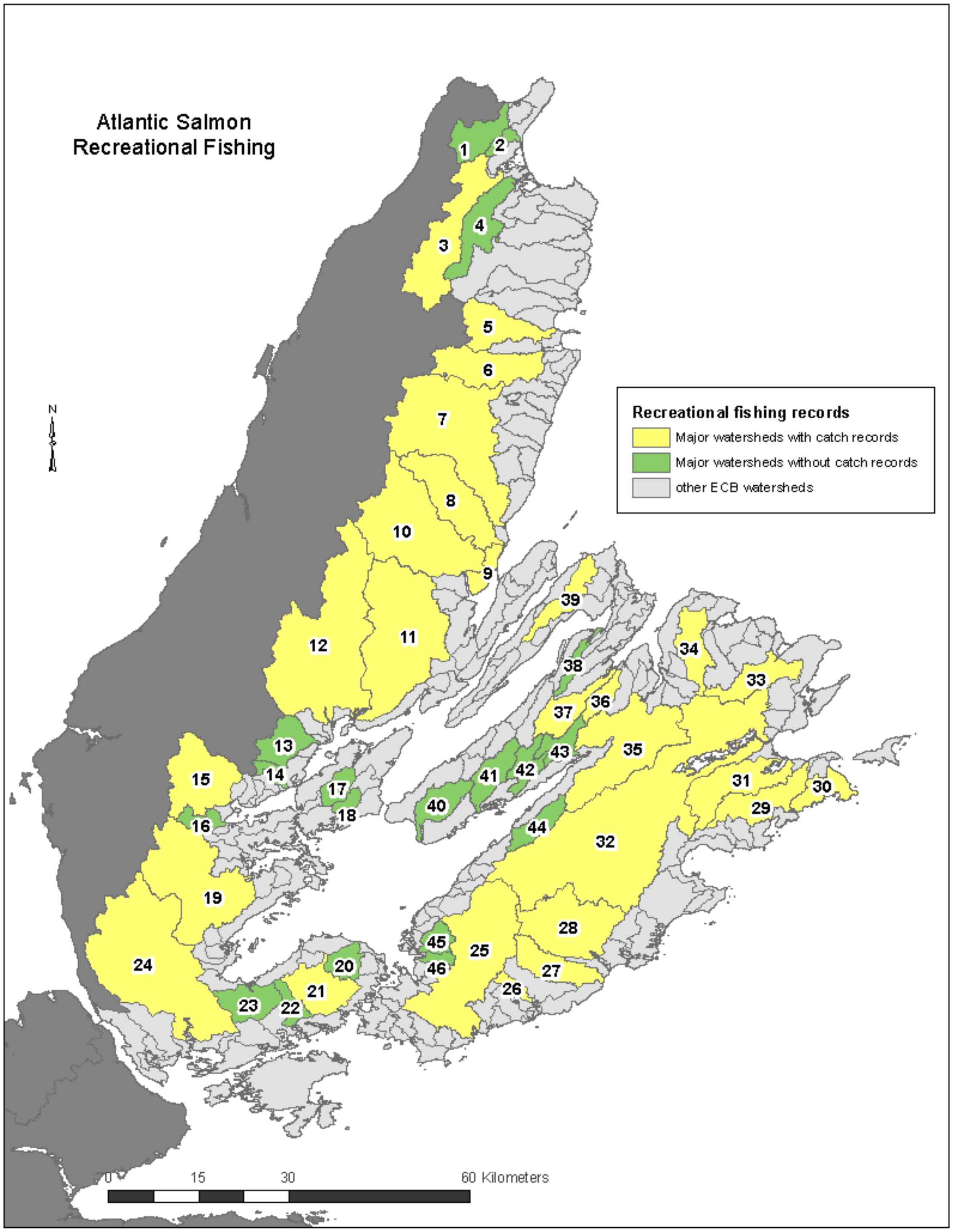

Figure 16. Watersheds in eastern Cape Breton with reported recreational catch of salmon (total reported catch >0) between 1983 and 2007. No watersheds outside the named "major watersheds" had reported recreational catch. Major watershed numbers correspond to the legend in Figure 2.

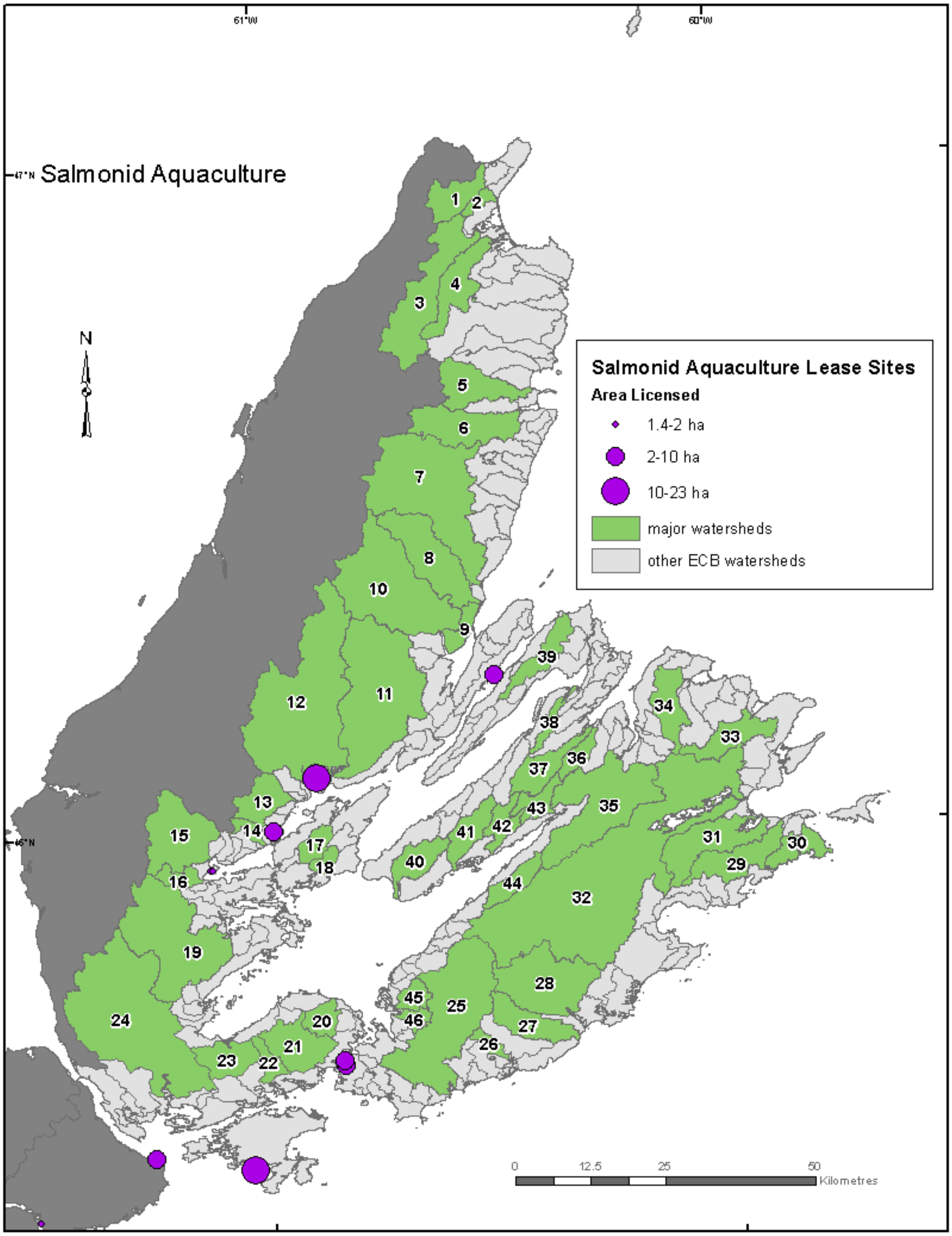

Figure 17. Locations and relative size of salmonid aquaculture lease sites in eastern Cape Breton. Of the nine salmonid aquaculture leases in eastern Cape Breton, eight are licensed for Atlantic Salmon and all are licensed for rainbow trout. Lease data from the NSDFA. Watershed numbers correspond to the legend in Figure 2.

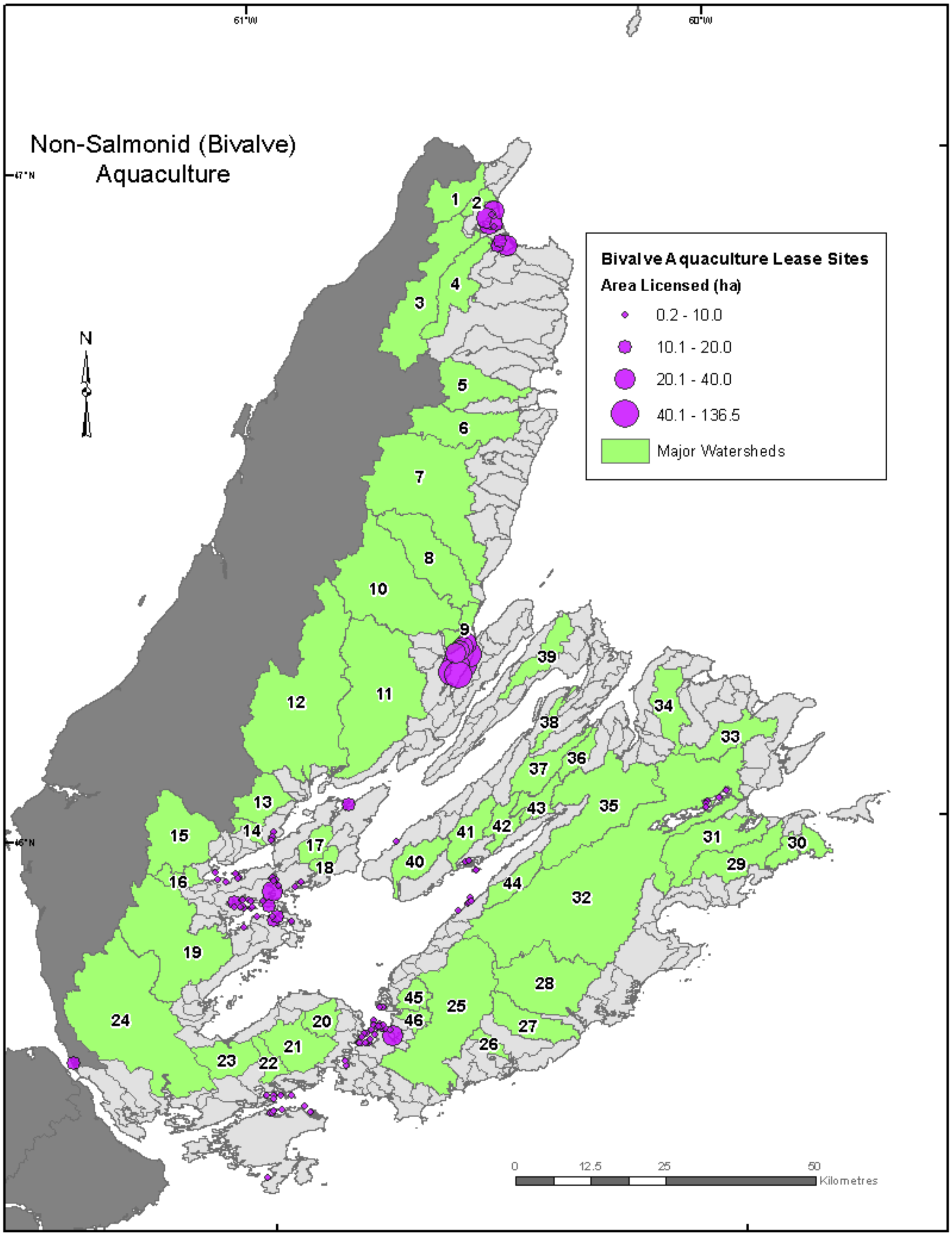

Figure 18. Locations and relative size of non-salmonid aquaculture sites in eastern Cape Breton. All sites are licensed for bivalves: American Oyster, Blue Mussel, sea scallop and/or bay scallop. Data are from the NSDFA. Watershed numbers correspond to the legend in Figure 2.

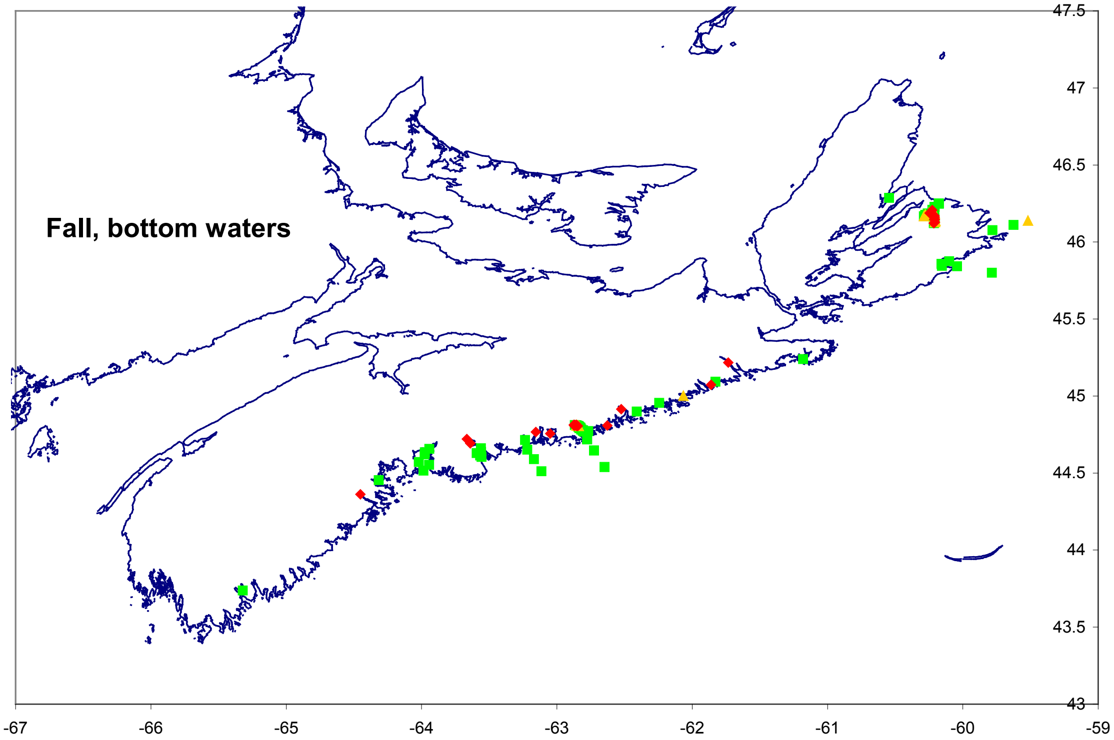

Figure 19. Potential for eutrophication in bottom waters during the fall for near-shore marine habitats on the Scotian Shelf and in coastal areas of eastern Cape Breton. Green indicates concentrations that are within the expected normal range, yellow are intermediate, and red indicates those sites above the water quality guidelines for eutrophication. Figure obtained from Yeats (unpublished).

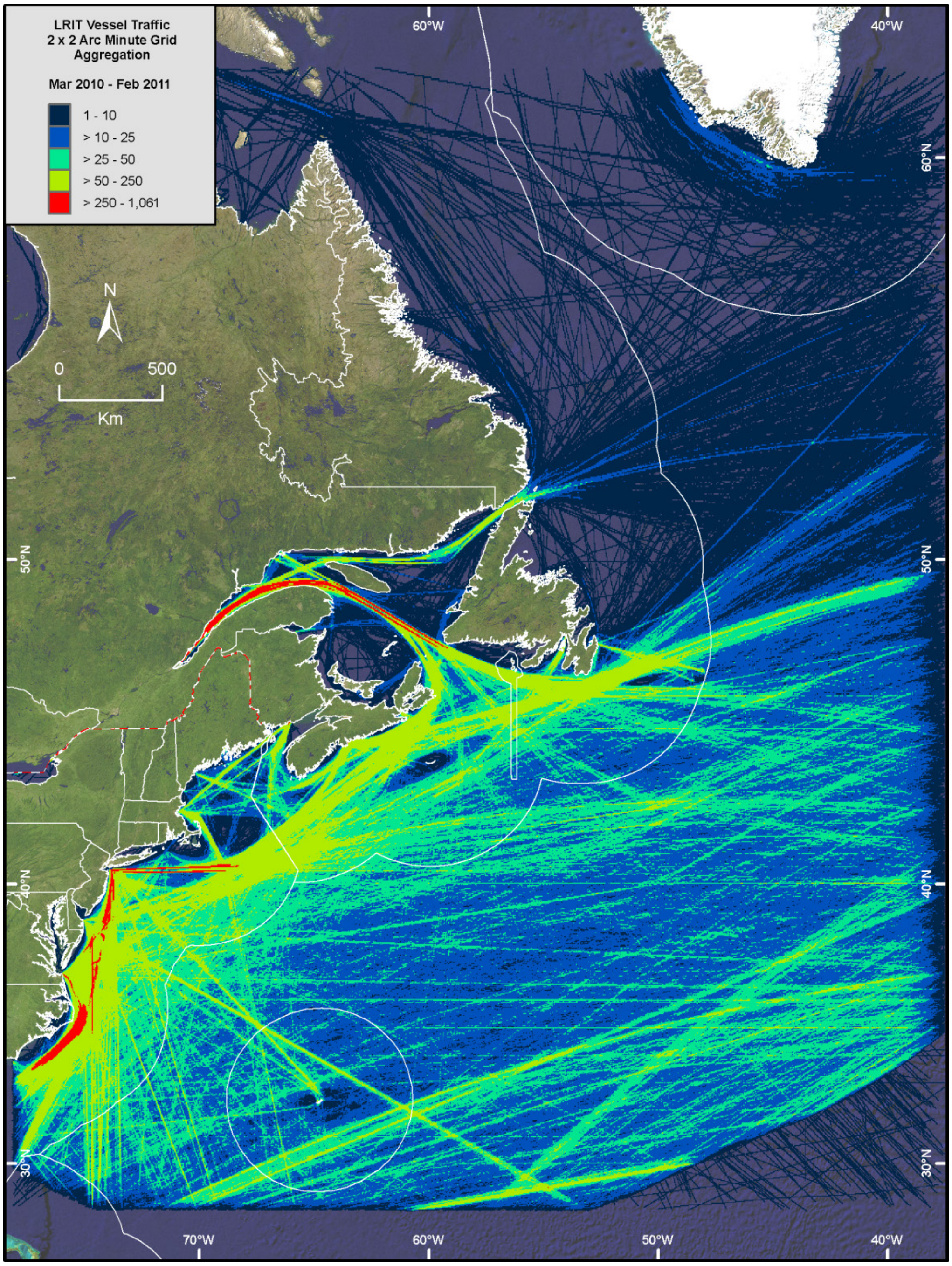

Figure 20. Twelve month (March 2010 – February 2011) composite map of vessel traffic (number of transits of vessels >300 gross tonnage per 2 x 2 arc minute grid) in waters off Atlantic Canada. Data for this map were provided by the Canadian Coast Guard's Long Range Identification and Tracking System National Data Centre (modified from Koropatnick et al. 2012).

APPENDIX 1

A.1 GEOGRAPHIC INFORMATION SYSTEMS ANALYSES

Geographic Information Systems (GIS) analyses were conducted to assess the physical, geological and human use components of the 46 identified watersheds used by Atlantic Salmon in the ECB DU. Both general information about the watersheds, such as area and perimeter, and more complex spatial queries and analyses combining a variety of spatial data sets were performed using ESRI® ArcGIS 10.0 software (service pack 3). All geographic measurements made of spatial data used Universal Transverse Mercator projection, NAD83 datum for Zone 20 North. Tabular queries to aggregate information and generate basic statistical information (sum, mean, etc.) were performed primarily using Microsoft® Access 2002 software (service pack 3). Sources of geographic data used in the analyses are provided in Table A1 and the characteristics of the standardized coordinate system used in these analyses are given in Table A2.

A.2 DELINEATION OF WATERSHED BOUNDARIES AND FLOW NETWORK

Although multiple data layers of watershed boundaries exist, the most comprehensive was the Secondary Watershed Layer developed by the NSDoE. Basing the analyses on this data layer ensured that a consistent source was used to derive boundaries and areas for all of the watersheds in the ECB DU.

Hydrologic data used to characterize streams, rivers and other water bodies (e.g. lakes, stillwaters) within a watershed boundary were based on the watershed attribute data (e.g. water bodies, polygons of wide rivers, arcs of streams) from the National Hydro Network (NHN), which is publicly available from GeoBase (1:50,000 scale). It was decided to use the NHN data rather than hydrologic features in the 1:10,000 topographic series data because the resolution of the data provides a better representation of potential salmon habitat and the data contained attributes (e.g. lake or river names) that did not exist in the 1:10,000 series. From the NHN data, a topologically connected hydrologic network (i.e. one that represented the direction of water flow) was created and used in analyses requiring upstream or downstream accumulation (e.g. evaluating the extent of watercourse affected by physical obstructions without fish passage).

The watershed boundaries and associated flow network formed the basis for all subsequent analyses of the physical and geological characteristics of watersheds, as well as the extent of human impact in freshwater environments.

Of note with respect to the Secondary Watershed Layer for eastern Cape Breton: Gerratt Brook and Lorraine Brook appear to have shared hydrology, with both coastal rivers connecting to Stewarts Lake and as such this area has been identified in the NSE as a single watershed, though in most other applications they are considered separately.

In some locations, including Little Lorraine Brook, several small coastal rivers have been amalgamated into a single coastal watershed. Where reporting stream length and other linear data, only the Little Lorraine Brook will be evaluated, but where watershed analyses are performed the entire coastal watershed is considered.

Similarly, River Bennett is a composite of several small coastal watersheds rather than a single watershed.

A.3 GEOPHYSICAL CHARACTERISATION OF WATERSHEDS

Hydrology

Basic characteristics of watersheds, such as size and shape, were determined by area and perimeter calculations of the secondary watersheds. The length of the river plus all mapped tributaries within each watershed was estimated as the total length of arcs (i.e. lines) in the NHN hydrologic network. Given that lakes, stillwaters and wide sections of the river are not typically represented by lines but by polygons, these arcs included “inferred” flow through larger water bodies. The total length of inferred and explicit watercourse arcs was calculated for each watershed and used to represent total stream length. Excluding inferred stream length would have excluded large section of major rivers (represented by polygons) and would have resulted in significant underestimates of total watercourse length in a watershed. In many instances the field containing data for “flow type” was either absent or appeared inaccurate. For the purposes of the analyses described we determined through spatial analysis “inferred flow” as the centerline arcs through water bodies and coded them as “inferred flow” (per the NHN data dictionary) in the attribute.

NHN data was also used in the assessment of water bodies (e.g. calculating the proportion of inland lakes in a watershed). As noted above, water bodies included features such as wide rivers, stillwaters, lakes, ponds, marshes, and reservoirs. Attribute coding in the NHN data was inadequate to accurately identify these features, so inferences from alternate data sources were used (e.g. in the identification of reservoirs).

A number of corrections were made to the NHN hydrologic network data for eastern Cape Breton:

1. The Middle River watershed and Baddeck River watershed are indicated as having a hydrologic connection between Gillis and MacRae Brook. This arc was split and linked arcs were flipped to make corrections in flow direction where required.
2. The river at the head of the Washabuck watershed (17) does not flow from Walker Brook, as was indicated. These arcs were flipped to flow in opposite direction at the head of the watersheds.
3. The Black River watershed (23) is improperly delineated in the NSE data. It has the watershed flowing both into the Bras d’Or and to the Atlantic to the south. The correct southern drainage is the Moulin River, MacPherson Brook. Using ArcInfo and the hydrologically corrected 20 m DEM (digital elevation models) from NSDNR, the Black River watershed was cut into 2 polygons. The Moulin River (MacPherson Brook) watershed was renamed under the ECB_RPA_name field and given and ECB_RPA_Num of 0 (zero).
4. There were rivers to the southeast of the Inhabitant River watershed (24) that needed to be disconnected from the network. It was determined that the watershed boundary should be edited rather than the stream network, which is how the issue was resolved.
5. The flow network needed repair in the Gerratt/Lorraine Brook watershed (29). Arcs were flipped near Stewarts Lake.
6. Some disconnections in the stream network required repair in the northern portion of the Mira (32). A suspicious looking arc (straight line from one watershed to another) was deleted.

7. There was a missing stream connection in the Aconi Brook watershed (39). A suspicious looking arc (straight line from one watershed to another) was deleted and arcs were flipped as required to fix the flow direction.

Elevation and slope

Digital elevation models (DEM), available from GeoBase as 20 meter horizontal resolution and 1 meter vertical resolution raster data (Table A1), were used to evaluate the topographical characteristics of watersheds. Zonal statistical analysis (where each of the eastern Cape Breton secondary watersheds represented a zone) was used to evaluate the mean, minimum, maximum and standard deviation of elevation within each watershed. Using the Spatial Analyst extension in ArcGIS, mean slope was calculated from the DEM and zonal statistics for slope were also derived for each of the watersheds. Using a 5 x 5 cell moving window analysis, the standard deviation of slope within each window was calculated to assess the topographic roughness of the watershed.

A.4 SPATIAL ANALYSES IN THE MARINE ENVIRONMENT

Analysis of marine tagging data

Spatial analysis of marine distribution patterns relied on data in the Tag Return Database maintained by the Population Ecology Division of the DFO (Maritimes). These data include information on all releases of individually tagged Atlantic Salmon in the ECB DU (in addition to other DUs), as well as individual recapture information (e.g. date, gear type, etc.) and, in most instances, biological information on the recaptured fish. Tag releases spanned the years 1966 to 1998 and tags were returned for a monetary reward (Ritter 1989) by fishermen or those associated with the fishing industry (e.g. fish plant workers). Group tagging events (where all fish would have been given identical tags), as well as release event with zero recaptures were not included in the analysis.

There were relatively few release events of exclusively wild-origin fish (either adult or smolt) or of adults (either hatchery or wild), which limited our ability to analyze their marine distribution over time. For example, of the individuals identified as wild-origin adults in the tagging database, there were only 13 recaptures (8 in the marine environment) out of a total of 338 releases; for hatchery-origin adults, there were 4 recaptures (2 in the marine environment) from 101 releases; and for wild-origin smolts, there were 35 recaptures (none in the marine environment) from a total of 2,540 releases. Therefore, the analysis of marine distribution patterns is based entirely on recaptures of hatchery-origin or mixed-origin (wild plus hatchery in the same release group) smolts (Ritter 1989). Given the low recapture rates associated with each tagging event, it was not possible to analyze specific populations in the Southern Upland independently. Here, all tag recaptures are grouped even though it is likely that there are differences among populations in habitat use in the marine environment.

Quality control queries of the marine tagging data indicated several recapture events that occurred after an improbable amount of time from the initial tagging event (i.e. >15 years), so those were removed from the data. Similarly, recapture events that could not be attributed to a specific location (e.g. lat/long or fishing district) were not considered. A small proportion of smolt release events that took place in October were also removed from the analyses (<150 records) to ensure that the data represented fish that were released in the spring (late April to early June).

Queries were used to separate data by life stage and year of recapture following release. Maps were produced for hatchery-origin individuals in the 12 month period following release (e.g. April to March in year *t*), distribution in the next year following release (April to March of year *t*+1), as well as distribution in the second year following release (April to March of year *t*+2). This means that for individuals released in May or June, the data in each map does not span exactly 12 months. Individual recapture locations were initially plotted and then grouped using a 50 km^2 grid, where the size of the point on the map is proportional to the number of recaptures within that grid (Figure 5).

Aquaculture

Data on the location, lease size and licensed species for all permitted aquaculture sites in the marine environment of Nova Scotia were obtained from the NSDFA. It is important to note that these data do not indicate whether a specific site is active, rather just if a permit is in place. The majority of sites hold licenses for multiple species (e.g. salmonids, other fin-fish, bivalves, algae etc.). Therefore, the data are a better representation of the current potential for impacts, rather than the current realized impact, of aquaculture on Atlantic Salmon in the ECB DU.

Permits that had licenses for salmonid species (Atlantic Salmon and Rainbow Trout) were analyzed separately from those with licenses for other species, and lease sites are represented as points and displayed as graduated symbols based on the area licensed. Separate maps are presented for salmonid and non-salmonid leases (Figures 17 and 18).

A.5 LAND USE AND THREATS INFORMATION FOR EASTERN CAPE BRETON WATERSHEDS

Historic Atlantic Salmon stocking

A hatchery distributions database for Atlantic Salmon and other salmonids is maintained by DFO Science for the years 1976-2007.

Non-native fish

Confirmed locations where Smallmouth Bass, Chain Pickerel, and Rainbow Trout have been captured were obtained from the NSDFA in spreadsheet format. Information on juvenile Rainbow Trout observations were taken from the literature as described in Table 11.

Trout stocking

Data on the locations of lakes and rivers stocked with Brook Trout, Rainbow Trout or Brown Trout by the NSDFA in the years 2010 and 2011 were obtained from the provincial government website (Table A1). Similar to the invasive fish species data, only the location (waterbody) name plus the grid reference from the Nova Scotia Road Atlas mapbook (page and primary grid reference) were provided. These locations were converted to latitude and longitude coordinates with manual corrections made based on the lake name references and the corresponding mapbook data, to ensure that points occurred in the correct watershed and waterbody for locations in the ECB DU.

Dams and other barrier structures

A data layer detailing available information on barrier structures in Nova Scotia watersheds was compiled jointly by the NSDoE and the former Habitat Protection and Sustainable Development Division (Maritimes) of DFO. This is referred to herein as the “NSDoE barriers layer”. Natural barriers such as waterfalls are not included in this layer. The layer contains the characteristics of known anthropogenic barriers (e.g. type of structure, height, purpose, etc.), including fish passage capabilities (classified as passable or impassable). This attribute information was used to produce Figure 7, where the locations of the barriers were intersected with the NHN hydrologic network. The location and number of dams within watersheds was assessed (Table 3). An approximation of the impact of dams on habitat availability in major watersheds of eastern Cape Breton was done visually, considering the rough proportion of the hydrologic network that would be upstream of the barrier in a given watershed (Table 3).

Reservoirs

Two methods of identifying reservoirs from the NHN water body data were used. In the first method, look-up tables for NHN codes used to describe each water body were linked to the appropriate field to identify and select the water bodies classified as reservoirs. Spatial analysis of these water bodies was performed to identify and generate statistics (count of reservoirs, total area, etc.) for the watersheds in eastern Cape Breton (Table 14, Figure 8). However, the number of features in the NHN water body data classified as reservoirs was clearly under-reported, based on local knowledge and supporting documentation (e.g. the NSDoE and DFO Habitat Division barriers layer, Nova Scotia Power Inc. (NSPI) data on hydropower turbine locations). Therefore, spatial analysis was performed to identify water body features that intersected physical barriers. Due to slight spatial inaccuracies, likely resulting from differences in spatial resolution of the data (i.e. not all barriers plot directly on the NHN flow network), this intersection method is believed to have underestimated dammed water bodies (and therefore likely reservoirs). However, attempting to reduce this error by increasing the search radius for the intersection analysis would have likely included water bodies that were not reservoirs (i.e. increased the misclassification rate of water bodies as reservoirs). Therefore, only water body features that intersected dams were classified as “Likely Dam/Reservoir” and only in cases where the NHN had not already identified the water body as a reservoir. In addition, known reservoirs related to the Wreck Cove Hydroelectric Project were identified. Spatial analysis of these water bodies was performed to generate statistics on the number and area of likely reservoirs as determined through spatial analysis (Table 14, Figure 8). The total impact of reservoirs in a given watershed is expected to be the sum of the two types of classifications (reservoirs and likely reservoirs).

Road crossings

Locations at which roads intersected the flow network within watersheds of the ECB DU were evaluated using the National Road Network (NRN) Edition 8.0 (revision and distribution circa 2010) and arcs representing the flow network in the NHN hydrologic network data following methodology described by Haskins and Mayhood (1997). Statistics for the number of road crossings and crossing density (number per 10 km of stream length) were generated for all paved and unpaved roads in each watershed (Table 18, Figures 9 and 10).

Historical data on salmon angling

In eastern Cape Breton, records of recreational catch of Atlantic Salmon from the license stub return program exist for 27 rivers, all of which are included in our “major watersheds” set (Table 2). Previous assessments include these data and consider them in more detail (e.g. Gibson and Bowlby 2009).

Land use

The Forest Inventory Data of the NSDNR was used to evaluate agricultural, forestry, industrial, and urban land use in watersheds of eastern Cape Breton (Table A1). The forest inventory data used in this analysis was the most current version (Forest Inventory, cycles 2 and 3, based on aerial photography from 1995 to present and with additional updates from satellite data, downloaded November, 2011). Although alternate spatial datasets exist on land use in Nova Scotia (e.g. Land Cover circa 2000 from GeoBase, and the US Geological Survey Global Land Cover Characteristics Database, versions 2 and 3), neither were of sufficient resolution to be comparable to the NHN used in these analyses.

The Forest Inventory Data includes numerical codes and an associated description for each type of land use (Fornon codes). These were broken into categories and many could be grouped together to consider the impacts of a general type of human activity in watersheds (e.g. forestry). Therefore, for this analysis the Fornon codes were reclassified to represent larger groupings of human activity to describe the impacts of forestry, agriculture, and industrial sites/industrial corridors (Table A3). The amount of area impacted by each major type of human activity (Table 16, Figures 12-14) was calculated for each of the 46 watersheds in the ECB DU.

Mining operations

Data from the NSDNR Abandoned Mines Database was used a surrogate for historical mining activity in eastern Cape Breton. These data are known to be incomplete, but provide some indication of the amount, target mineral and location of historical mining activity in the DU. For this analysis, the data was spatially overlaid on major watersheds, and the number of mines of each type within each watershed (Table 10) calculated and mapped (Figure 15).

Table A1. Description and data sources of information used in the geographic analyses of watersheds for the ECB Atlantic Salmon DU.

Description	Data Source / Data Credit
Hydrology – rivers and water bodies	GeoBase's National Hydro Network (NHN), Level 1, Edition 1 / Natural Resources Canada
Secondary Watersheds	Custom Data Product derived from NSTDB[2] obtained from NSDoE
Digital Elevation Data (DEM)	GeoBase's Canadian Digital Elevation Data (CDED)
Bedrock Geology, DP ME 43, Version 2, 2006.	NSDNR – Mineral Resources Branch
Surficial Geology DP ME 36, Version 2, 2006	NSDNR – Mineral Resources Branch
Forest Inventory, cycles 2 & 3	NSDNR – Forestry Branch
Ecological Land Classification	NSDNR – Forestry Branch
Roads	GeoBase's National Road Network, Edition 8.0 / Natural Resources Canada
Dams – NHN	GeoBase's National Hydro Network (NHN), Level 1, Edition 1 / Natural Resources Canada
Dams – NSE	Nova Scotia Department of Environment and Fisheries and Oceans Canada, Maritimes Region, Habitat Protection and Sustainable Development Division (DFO–HPSD, pers. comm., March 2011)
Aquaculture – licensed marine sites in Nova Scotia	NSDFA
Nova Scotia Abandoned Mine Openings (AMO) Database	NSDNR – Mineral Resources Branch
Fall and spring trout stocking distribution lists for 2010, 2011	NSDFA

[1] All on-line data accessed between October 15, 2011, and August 23, 2012, unless otherwise noted.
[2] NSTDB = Nova Scotia Topographic Database.

Table A2. Standardized coordinate system used in geographic analyses of watersheds in eastern Cape Breton.

Projected Coordinate System	NAD 1983 UTM Zone 20N
Projection	Transverse Mercator
False Easting	500000.00000000
False Northing	0.00000000
Central Meridian	-63.00000000
Scale Factor	0.99960000
Latitude of Origin	0.00000000
Linear Unit	Meter

Table A3. Reclassification of the Nova Scotia Forest Inventory classification (Fornon) for land use analysis of the watersheds in eastern Cape Breton.

Land Use Reclassification	Fornon Type	Description	Fornon Code
Agriculture	Agriculture	Any hay field, pasture, tilled crop, or orchard which contains no merchantable species.	86
Agriculture	Blueberries	Areas that appear to have been or are being used for blueberry production.	91
Forestry	Clear cut	Any stand that has been completely cut and any residuals make up less than 25% crown closure and with little or no indication of regeneration.	60
Forestry	Partial depletion verified	Any stand that has been cut and Hardwood residuals make up 25% or more of the crown closure on the site, identified by photo Interpreters or field data.	61
Forestry	Partial depletion not verified	A temporary code given to a stand identified from satellite imagery as a partial cut. Further verification from photo interpretation or field data required for residuals. Non-Forested	62
Forestry	Treated	Treatment not classified, not Christmas trees. An area where silviculture activity has been identified from photos, but field data is not yet available.	1
Forestry	Christmas trees	Any stand being used for Christmas tree cultivation.	3
Forestry	Research stand	Stands treated in some manner primarily to provide data on growth, etc. which contain sample plots for evaluation of response rather than intended as operational treatment.	10
Forestry	Seed orchard & seed production area	Any stands designated by the Department as an area reserved for seed production.	11
Forestry	Treated stand	Treatment classified-an area where silviculture activity has occurred and the actual treatment has been identified primarily by field data, not including plantations, harvests, Christmas trees or sugarbush.	12
Forestry	Plantation	A group of trees artificially established by direct seeding or setting out seedlings, transplants or cuttings.	20
Industrial Site/Corridor	Sanitary land fill	Areas used by municipalities for disposal of garbage by means of burying the material.	93
Industrial Site/Corridor	Gravel pit	Any area either active or non-active used for the purpose of extracting gravel.	95
Industrial Site/Corridor	Rail corridor	Generated 20 meter polygons around active and abandoned rail lines (STAND_values 9001 & 9005)	99
Industrial Site/Corridor	Pipeline corridor	A 25 meter buffer around a defined linear feature of a gas or oil pipeline route defining limited or restricted use lands.	96
Industrial Site/Corridor	Powerline corridor	Corridor of land with limited use due to powerlines, as defined from photography (STAND_ value9002)	97
Industrial Site/Corridor	Road corridor	Generated polygons of varying widths for paved roads, based on road classes. (STAND_ value 9000)	98