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Recovery Potential Assessment for Southern Upland Atlantic Salmon: Habitat Requirements and Availability, Threats to Populations, and Feasibility of Habitat Restoration

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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.

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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 the Southern Upland 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 the Southern Upland having these properties,
3) the 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 the Southern Upland, and
5) the potential for mitigation of identified threats.

Each of these components was requested by the Terms of Reference (TOR) for the Recovery Potential Assessment for Southern Upland salmon. Information is presented for the freshwater and marine (and estuarine where appropriate) environments separately.

Habitat requirements of Atlantic salmon in fresh water 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 specific habitat types that are required to support essential life cycle processes. At the current low population sizes of Southern Upland Atlantic salmon, freshwater habitats are unlikely to be limiting recovery in rivers where a large proportion of accessible area remains. Unfortunately, impassable dams and highly acidic water have reduced freshwater habitat availability by approximately 40% for populations in the Designatable Unit.

Habitat requirements in marine and estuarine environments have not been delineated spatially. However, these are thought to be primarily related to food availability and oceanographic conditions, since individuals require resources and water conditions that support rapid growth. As such, the areas occupied by Atlantic salmon populations from the Southern Upland likely change over time depending on variation in oceanographic environments (currents, temperature, and food availability). Based on tagging data, Southern Upland Atlantic salmon are widely distributed in the marine environment along the Atlantic coast for the majority of the year. 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.

Multiple threats have been identified that are likely to have an effect on Atlantic salmon populations in the Southern Upland, 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 rivers in the Southern Upland. Where possible, the relative magnitude of a specific threat has been quantified among watersheds in the Southern Upland using GIS 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 des hautes terres du Sud : besoins en matière d'habitat et disponibilité, menaces pour les populations et faisabilité de la restauration de l'habitat

RESUME

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 les hautes terres du Sud 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 des hautes terres du Sud 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 les hautes terres du Sud,
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 des hautes terres du Sud. 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 besoin de types d'habitats particuliers pour soutenir les processus essentiels du cycle de vie. Les niveaux actuels des populations du saumon de l'Atlantique des hautes terres du Sud sont faibles, mais il est peu probable que les habitats d'eau douce limitent le rétablissement de l'espèce dans les rivières où il reste une grande proportion de zone accessible. Malheureusement, les barrages infranchissables et la forte acidité de l'eau ont réduit la disponibilité de l'habitat d'eau douce d'environ 40 % pour les populations de l'unité désignable.

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 des hautes terres du Sud changent avec le temps en fonction des modifications des milieux océanographiques (courants, température et disponibilité de la nourriture). D'après les données de marquage, les saumons de l'Atlantique des hautes terres du Sud sont répartis sur une grande partie du milieu marin le long de la côte Atlantique pendant la plus grande partie de l'année. 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 de nombreuses menaces susceptibles d'avoir des incidences sur les populations de saumons de l'Atlantique dans les hautes terres du Sud, 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 des rivières en particulier dans les hautes terres du Sud. Là où c'était possible, l'importance relative d'une menace particulière a été quantifiée dans des bassins versants des hautes terres du Sud en utilisant des analyses

du système d'information géographique (SIG). 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.

INTRODUCTION

The Southern Upland Designatable Unit (DU) of Atlantic salmon occupy rivers in a region of Nova Scotia extending from the northeastern mainland (approximately 45° 39’ N, 61° 25’ W) into the Bay of Fundy at Cape Split (approximately 45° 20’ N, 64° 30’ W) (COSEWIC 2010). This region includes all rivers south of the Canso Causeway on both the Eastern Shore and South Shore of Nova Scotia draining into the Atlantic Ocean (Figure 1), as well as rivers in the Bay of Fundy south of Cape Split. Historically, it has been divided into three Salmon Fishing Areas (SFAs) for management and assessment purposes: SFA 20 (Eastern Shore), SFA 21 (Southwest Nova Scotia), and part of SFA 22 (Bay of Fundy rivers inland of the Annapolis River). Although the natural ecology varies, rivers in this region of Nova Scotia are characterized by shallow soils or peat bogs underlain by granite and metamorphic rocks (Watt 1987). As a result, water tends to be organic acid stained and systems tend to be less productive than more mineral-rich rivers.

The Southern Upland Atlantic salmon DU was designated as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010). To aid in consultative processes following the designation, and to serve as a basis for recovery planning, Fisheries and Oceans, Canada (DFO) Science Branch undertook a Recovery Potential Assessment (RPA) for this Atlantic salmon DU. Information about Southern Upland Atlantic salmon populations has been compiled into four research documents. This document contains information about habitat requirements, habitat availability and status, threats to populations, and habitat allocation options. Two of the other documents contain information about:

1) abundance, trends and recovery targets for Southern Upland salmon populations (Bowlby et al. 2013); and
2) life history parameters and scenario analyses to identify and prioritize among recovery alternatives (Gibson and Bowlby 2012).

Information about genetic structuring among salmon populations in the Southern Upland is provided in the fourth research document (O’Reilly et al. 2012).

There were 22 terms of reference (TORs) for this RPA. The specific TORs addressed in this document are:

Habitat Considerations

4. Provide functional descriptions of the properties of the aquatic habitat that the Nova Scotia Southern Upland DU of Atlantic salmon needs for successful completion of all life-history stages.

5. Provide information on the spatial extent of the areas in the Nova Scotia Southern Upland DU of Atlantic salmon range that are likely to have these properties.

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

7. 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.

8. Provide advice on any tradeoffs (i.e. pros and cons) associated with habitat “allocation” options, if any options would be available at the time when specific areas may be designated as Critical Habitat.

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

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

Threats

13. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the COSEWIC Status Report (COSEWIC 2010), information from DFO sectors, and other sources including:
    - Poor marine survival,
    - Changes in climate,
    - Fishing (by-catch, subsistence, recreational, and illegal),
    - Dams and obstructions in freshwater,
    - Agriculture, forestry,
    - Urbanization,
    - Acidification,
    - Hatcheries,
    - Aquaculture, and
    - Invasive species.
14. Identify the activities most likely to result in threats to the functional properties of the habitat of the Nova Scotia Southern Upland DU of Atlantic salmon, and provide information on the extent and consequences of these activities within the species' range.
15. Assess to the extent possible how threats to habitats identified in the COSEWIC Status Report (COSEWIC 2010) have reduced habitat quantity and quality to date, if at all.

Mitigation and Alternatives

18. Provide advice on feasibility of restoring habitat to higher values, if supply may not meet demand by the time recovery targets would be reached.

1. FUNCTIONAL DESCRIPTION OF HABITAT PROPERTIES (TOR 4)

1.1 FRESHWATER ENVIRONMENT

Returning Adults and Spawning

Adult Atlantic salmon return to Southern Upland rivers as early as April and as late as November (O'Connell et al. 2006), but the largest proportion of the population enters the rivers in the spring (May/June) and summer (July/August) months (Gibson et al. 2009a). Adults can spend four to six months in fresh water prior to spawning, and there is some indication that multi-sea-winter (MSW) salmon enter rivers earlier than one-sea-winter (1SW) fish (Power 1981). Very generally, the upstream migration of salmon appears to 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). 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 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 (see Section 5.1 for details).

Juvenile Development

Upon emergence from the gravel, juvenile Atlantic salmon can remain in fresh water from one to more than four years in rivers in the Southern Upland, although the majority will undergo smoltification in their second year and migrate to sea (Gibson et al. 2009a). Juveniles in their first year (age 0) are termed fry, and older juveniles (age 1 and older) are called parr. 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 (see Section 5.1 for details).

Smolts

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^{o}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).

Kelts

Relatively little is known about freshwater habitat use by post-spawning adult salmon (kelts) in the Southern Upland, and considerable variability may exist among river systems. 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. 2008a), 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).

There is very limited information about the overwintering behaviour of kelts in the Southern Upland. In a recent acoustic tagging study in the St. Mary's River, no kelts were observed leaving the river immediately after spawning in 2010, and 24 tagged fish were observed leaving the river in the spring of 2011 (Gibson and Halfyard, unpublished data). The earliest observation of a salmon leaving the river was March 16th, but most salmon exited the river between April 22nd and May 11th. This suggests that the proportion of adults remaining in Southern Upland rivers after spawning to overwinter in fresh water is high (up to 100%), particularly in rivers with suitable overwintering habitat.

1.2 ESTUARINE ENVIRONMENT

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.

Returning Adults

Adult Atlantic salmon return to rivers in the Southern Upland throughout the spring, summer, and fall months (Gibson et al. 2009a). Similar to smolt use of estuaries, a variety of residency times have been observed, from moving through estuaries in a matter of days to spending 3.5 months holding in an estuary before moving into the river (Brawn 1982). 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). While holding in the estuary, adults seem to favour deep water of intermediate salinities ranging from 5 to 20 parts per thousand (Brawn 1982).

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. 2008a). 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. 2008a). 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. 2008a, Thorstad et al. 2011), suggesting that entry into the marine environment is not a critical component of at-sea mortality for post-spawning adults.

1.3 MARINE ENVIRONMENT

Postsmolts and Immature Adults

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.

Growth patterns of scale circuli (Hubley et al. 2008b) from two populations in the Southern Upland DU combined with tag returns from commercial fishing data (Ritter 1989) suggest that individual Southern Upland populations experience similar oceanographic conditions and use similar temporal and spatial routes during marine migration. 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) to rivers in the Southern Upland 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).

Adults

After spawning, the majority of adult salmon exit rivers in the spring of the following year (Bardonnet and Bagliniere 2000, Hubley et al. 2008a) 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. 2008a). 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).

2. SPATIAL EXTENT OF HABITAT FOR SOUTHERN UPLAND POPULATIONS (TOR 5)

2.1 FRESHWATER ENVIRONMENT

Wild Atlantic salmon populations exhibit nearly precise homing behaviour to natal rivers, to the extent that each river is thought to contain a distinct population. There is no information that suggests Atlantic salmon did not historically inhabit all available rivers within their freshwater range, and available assessment data demonstrates that there is no apparent minimum watershed size for occupancy. A recent review identified 63 river systems that were known to have historically contained Atlantic salmon populations (DFO and MRNF 2009). For the purposes of this document, rivers listed in past assessments, as well as regional survey information (e.g. Amiro et al. 2000, Gibson et al. 2009a), and scientific literature related to the Southern Upland (e.g. Watt 1987) were combined into a single list of rivers. Exclusions from this list were rivers sampled in the 2008/09 electrofishing survey which had not been mentioned previously in assessment documents and were not found to contain juvenile salmon (e.g. Purney Brook and Blacks Brook). Similarly, watersheds in which there was no information beyond a single reference from a single source were also not included. The combined list of rivers (Table 2.1.1, Figure 2.1.1) increases the number of watersheds thought to contain or to have contained salmon populations to 72. However, 513 additional watersheds (unnumbered in Figure 2.1.1) are identified in the Southern Upland on the secondary watershed layer for ESRI ArcGIS® from the Nova Scotia Department of the Environment (NSDoE), of which 256 are larger than Smith Brook (drainage area 19.8 km^2), the smallest watershed in the dataset known to have contained salmon (Appendix 1). These other watersheds contain 6,586 km^2 of drainage area (excluding coastal islands), or 23.9% of the total area occupied by populations in the DU, all of which has potentially supported or could support Atlantic salmon (Figure 2.1.1).

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 of the rivers in the Southern Upland, 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 48 of the 72 watersheds (Amiro 2000) (Table 2.1.1). The amount of productive area or rearing area for juvenile salmon in each watershed was estimated by summing the number of habitat units (100 m^2) with gradients between 0.12% and 25% (Table 2.1.1). For the majority of watersheds, productive habitat was most frequently more abundant than low gradient habitat, (i.e. >50% in all but three of the rivers) ranging from 34% to 100% (mean = 86%) of the total habitat area (Table 2.1.1).

For rivers in which gradient had not been classified (n = 24), it was necessary to develop an alternate method for calculating the productive area in these watersheds. Here 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 2.1.2). Multiplying the slope estimate (37.394) from the regression by the drainage area (in km^2) gives the predicted rearing area (in 100 m^2 habitat units) for the unclassified watershed. Total drainage area for all rivers in the Southern Upland was obtained from the secondary watershed layer for Nova Scotia, a GIS map product developed and maintained by the NSDoE. The linear regression of all data from Southern Upland watersheds had an R^2 value of 0.898 and was highly significant (p-value <<0.001; Figure 2.1.2).

Combining information from all watersheds known to have contained salmon, there is an estimated 20,981 km^2 of drainage area, which contains 783,142 habitat units (100 m^2) of rearing area for Atlantic salmon (Table 2.1.2). The 10 largest systems (river numbers 1, 5, 12, 15, 23, 24, 26, 44, 51, 61) contain slightly more than half of this productive area (436,572 habitat units), and only four watersheds (river numbers: 21, 33, 48, 60) have an estimated rearing area less than 1,000 habitat units (Figure 2.1.3). The median amount of rearing habitat contained in a single watershed is 5,332 habitat units.

2.2 ESTUARINE

Recent research using acoustic tagging suggests that Southern Upland Atlantic salmon populations do not make extended use of estuarine environments, either as smolts or kelts. The range of estuarine residence times observed for Southern Upland populations was 1 to 8 days per km of habitat for smolts in estuaries (Halfyard et al. 2012) and 3 to 32 days from release to open ocean for kelts (Hubley et al. 2008a). However, some smolts exhibited multiple changes in swimming direction, leading to longer residence times in the estuary (Halfyard et al. 2012) and approximately 40% of tagged kelts from the LaHave River lingered in the lower estuary (Hubley et al. 2008a). 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 behaviour 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. 2008a).

Relatively little is known about the use of particular habitat types within estuaries by smolts, adults and kelts by Southern Upland populations. Presumably it would be related to the behaviour exhibited by individual fish. For example, outward migrating smolts and kelts can use the estuary on a transitory basis as a migration corridor rather than as seasonally occupied habitat, which would suggest little association with habitat types within estuaries. Conversely, if longer residence times are associated with feeding behaviour or adaptation to physiological stresses, habitat use would likely be dependent on prey distributions or hydrological features within estuaries. The use of estuaries by returning adults is not well studied in the Southern Upland (see Section 1.1), but would presumably be concentrated in habitat types that minimize energy expenditure (e.g. minimal current) while adults wait for appropriate water levels to initiate upstream migration.

2.3 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 Southern Upland Atlantic salmon can be assessed from historical tagging programs for 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 fisheries off Labrador and West Greenland, few of the tag recaptures were assigned a latitude and longitude when they were 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.

In total, there were 5,158 recaptures of individual salmon tagged in the Southern Upland region (1,899 from SFA 20 and 3,259 from SFA 21). Recapture rates from groups of tagged fish were extremely low, generally less than 5% (mean = 3.9%, median = 0.8%, range: 0.02% - 73%). All of the higher recapture rates were associated with releases upstream of continuously monitored assessment facilities, like Morgans Falls fishway on the LaHave River. 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 (n=338) in the tagging database, there were only 13 recaptures (8 in the marine environment); for hatchery-origin adults, of 101 releases there were 4 recaptures (2 in the marine environment); and of 2,540 releases of wild-origin smolts, there were 35 recaptures (none in the marine environment). Therefore, the data that we present is based entirely on recaptures of hatchery-origin or mixed-origin (wild plus hatchery in the same release group) smolts (Ritter 1989). Due to the relative scarcity of recapture information, marine distribution patterns of Southern Upland Atlantic salmon as a group are presented, although 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. All smolts were released in the spring, from late April to early June.

Marine Distribution in the Year Following Release

The majority of tagged smolts were released in fresh water in April and May. By late May and throughout June, the pattern of tag recaptures suggests that smolts have begun leaving fresh water and are moving along the coast of Nova Scotia, both in a southern and northern direction (Figure 2.3.1). By July, tag returns indicate that individuals have spread out along the entire coast of Nova Scotia, from the inner Bay of Fundy to the tip of Cape Breton, while a smaller proportion have moved substantially farther northward, to eastern Newfoundland, northern Quebec and the tip of Labrador (Figure 2.3.1). A similar pattern exists during August. From September until the following March, there are very few tag recaptures (<10/month), but those observed indicate that a proportion of Southern Upland salmon remain along the coast of Nova Scotia during the winter months. Interestingly, there are no recaptures of immature Southern Upland Atlantic salmon off the coasts of Newfoundland, Quebec, and Labrador after September. This may suggest that immature Atlantic salmon from the Southern Upland do not overwinter this far north in their first winter at sea, or that they arrive after the closure of the various fishing seasons (i.e. after November). Additionally, immature salmon were not captured in the West Greenland fishery in the first year following release (based on a total of 430 recapture events), which may indicate that they do not travel this far north in their first year or are too small to be captured by the fishing gear.

Marine Distribution in the Second Year Following Release

In the second year following release, there are two components to the recaptures, potentially showing different distribution patterns:

1) individuals who return to natal rivers to spawn after 1SW, and
2) individuals that remain at sea for the second year (and will return as 2SW or older).

The earliest recaptures in the spring (April) are still off the coast of Nova Scotia (Figure 2.3.2), suggesting that a proportion of the individuals tagged remained relatively localized for their entire first year at sea. Beginning in May, the largest number of recaptures is along the northern coast of Newfoundland and spreads to more southerly locations in June, concentrated off the coast of Nova Scotia (Figure 2.3.2). Recaptures in the fishery off West Greenland take place from July to November, and the relative scarcity of recaptures in July, October and November may reflect reduced fishing effort rather than movement into or out of this area. The catch from the West Greenland fishery consists almost exclusively of individuals destined to return to natal rivers as 2SW spawners (ICES 2011), so these tag returns represent the 2SW component of populations. It is possible that the recaptures off the northern coast of Newfoundland and Labrador during the spring, summer and fall months (Figure 2.3.2) also consist of a proportion of 2SW individuals, as well as those returning to their natal rivers to spawn. The general range at sea over the course of a year for the 1SW component of Southern Upland populations is not clear from the tagging data. However, it is likely that most of the recaptures of salmon off the coast of Nova Scotia in the summer months represent 1SW individuals. It is similarly likely that the distribution of 1SW and 2SW fish partially overlap during the summer months.

Marine Distribution in the Third Year Following Release

In the third year following release, there are two main components to the recaptures:

1) individuals returning to the marine environment after spawning as 1SW salmon, and
2) individuals returning to natal rivers to spawn as 2SW adults.

Based on the results from kelt tagging in the LaHave River (Hubley et al. 2008a), it is likely that some portion of the salmon present off the coast of Nova Scotia in April and early May (Figure 2.3.3) come from individuals that overwintered in fresh water and are returning to the marine environment to recondition. Recaptures off the coast of Newfoundland are seen from May to November (Figure 2.3.3), and it is possible that they represent two groups of individuals: those moving from West Greenland and the Labrador Sea on their way to natal rivers (2SW spawners) and those moving northward to recondition (alternate year repeat spawners) after previously spawning.

General Patterns

Assuming that these data represent general distribution patterns in the marine environment, there appears to be very limited use of the Gulf of St. Lawrence (including the coastal areas around the Magdalen Islands, northern New Brunswick, or Quebec near Anticosti Island) by Southern Upland Atlantic salmon. However, they do move along both coasts of Newfoundland, and they have been recaptured at locations more southerly than where they were released. Contrary to predictions of progressive northward movement for immature individuals to overwintering areas in the Labrador Sea or West Greenland (e.g. Reddin and Short 1991), these tagging data suggest that Southern Upland Atlantic salmon are widely distributed in coastal marine habitats throughout their first year, particularly during the summer months.

Of the individuals moving northward, they appeared to require two to three months to reach the coastal areas of northern Newfoundland, they were not observed off the coast of Labrador in any month, and they were only captured off West Greenland the following June. If this pattern is representative of the physiological capabilities of immature Atlantic salmon from the Southern Upland, it suggests that reaching the Labrador Sea and West Greenland requires the better part of a year. This makes it unlikely that individuals destined to return to rivers after one winter at sea would have time to travel that distance, particularly when adults begin to ascend rivers in the Southern Upland in early summer (see Section 1.1).

Although it is not possible to explicitly describe the movement patterns of the various life stages of Southern Upland Atlantic salmon from these data, the inferences made above highlight a crucial point when designating critical habitat in the marine environment. Although different life stages may transiently occupy similar habitats, their overall direction of movement could be in opposite directions, potentially leading to a relatively ubiquitous distribution from Nova Scotia to the Labrador Sea and West Greenland throughout most 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 overwintering 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 Southern Upland Atlantic salmon along the near-shore environments of the Northwest Atlantic, meaning that marine distribution (and therefore habitat use) cannot be clearly delineated on a seasonal basis.

3. RESIDENCE REQUIREMENTS (TOR 9)

Under the *Species at Risk Act* (SARA), a residence is defined as a dwelling-place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating (SARA, Section 2.1). The Draft Operational Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk (DFO 2011a) uses the following four conditions to determine when the concept of a residence applies to an aquatic species:

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

Two dwelling places (used by three life stages) were evaluated for their potential consideration as a residence for Atlantic salmon. These were redds (used by eggs and alevins) and home stones (used by juvenile salmon in fresh water). Each of these is habitually occupied during part of the salmon's life cycle, individuals invest energy in its creation or defense, and it provides specific functions to enable the successful completion of the Atlantic salmon's life cycle. Of these, redds most closely match the definition of a residence because they are constructed, whereas home stones are not.

3.1 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). Once a redd is excavated, eggs are deposited and fertilized, and then the eggs are actively re-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). The 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 a 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 they are 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 a 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 a redd (Cunjak and Therrien 1998), sedimentation forming a layer across the surface entombing the eggs or the alevins, siltation of the redd interstices reducing percolation of water interfering with oxygen delivery and waste metabolite removal (Soulsby et al. 2001), or physical crushing by vehicles (e.g. ATVs) in streams running over redds.

Redds meet the following criteria for consideration as a residence:

> Condition 1: The dwelling-place (redd) is a nest,
>
> Condition 2: The female salmon has made a very large 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).

3.2 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 instream 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, Keeley and Grant 1995), suggesting acquisition and defense of this resource is important. Occupancy (prior residency) is a key determinant for successful defence (Cutts et al. 1999b).

Home stones are used through the summer and fall. Although salmon may change home stones intermittently, movement may be limited during 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 1 m 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. 1999b), 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 these stones are preferred and so their loss would affect the individual.

Home stones meet the following criteria for consideration as a residence:

> Condition 1: The dwelling place is physically and functionally similar to a den (offering cover and protection from environment, allowing energetic conservation).
>
> Condition 2: Although home stones are not created by individual salmon, the individuals make an investment in the protection of the dwelling-place (territorial behaviour),
>
> 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. SUPPLY OF SUITABLE HABITAT

In Section 2.1, the amount of rearing area in 72 rivers in the Southern Upland was calculated from previously collected gradient information (Amiro 2000) or estimated from linear regression (values listed in Table 2.1.2). These summed to a total of 783,142 units (100 m^2) of productive freshwater habitat for Southern Upland Atlantic salmon. Given that the amount of habitat estimated by linear regression does not take into account factors such as accessibility or habitat quality (other than gradient), the actual amount of salmon habitat available in a given watershed could be significantly less than that estimated using this method.

4.1 INFLUENCE OF BARRIERS OR WATER CHEMISTRY ON HABITAT ACCESSIBILITY (TOR 6)

Physical Barriers

Assessing the impact of physical barriers on the amount of habitat in a watershed is difficult given that structures can be partially or completely impassable under different flow conditions and their effects can also differ for various life stages. This section will focus on barriers thought to prevent access by Atlantic salmon (i.e. total barriers). The issue of barriers will be revisited under Section 5.3 because other structures with different characteristics (e.g. other dams, water diversion, and culverts) exist in Southern Upland watersheds. Currently, there is insufficient information to quantify the effect of each individual barrier.

Six rivers (Annapolis/Nictaux, Bear, Sissibo, Meteghan, Mersey and Indian; Table 2.1.2) were identified by Amiro (2000) as having impassable dams or falls near the head-of-tide that prevent access by Atlantic salmon to the majority of the watershed. In the case of the Annapolis/Nictaux system, the barrier to access is on the Nictaux tributary, which represents a substantial proportion of the total Annapolis watershed. Two of the river systems affected by total barriers are among the largest in the Southern Upland region (Annapolis/Nictaux and Mersey). Excluding the Annapolis/Nictaux, if the remaining five watersheds are completely inaccessible to Atlantic salmon, the total amount of rearing area lost is 120,087 habitat units (60% of this is the Mersey alone), leaving an estimated 660,362 habitat units available regionally. For the salmon populations that previously inhabited each of these five affected watersheds, the amount of rearing habitat available becomes zero (Table 4.1.1). This conclusion is supported by the results of the 2000 and 2008/09 electrofishing surveys where the estimated density of juveniles was zero in four of the five sampled watersheds (combining the results from the two surveys; the Meteghan River was not sampled). All six of the watersheds identified by Amiro (2000) were predicted to have a minimal amount of habitat that remained accessible based on barriers information associated with the National Hydro Network (NHN) data layer for ArcGIS® (see below).

An ArcGIS® layer detailing available information on barriers in Southern Upland 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, data is analyzed from barriers listed as having no fish passage, which it 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 watersheds of the Southern Upland, a more comprehensive analysis including partial barriers is not possible. While these data represent the most current regional survey of barriers in the Southern Upland, the information has been collected over several 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 to barriers that have taken place more recently would not have been captured in the database and thus would not be accounted for in these analyses.

By intersecting the NHN stream network with the barrier locations, it was possible to calculate the percentage of the flow network (stream length) affected in each of the Southern Upland watersheds (Table 4.1.1). There is an essentially linear relationship between the length of the flow network and the drainage area of watersheds in the Southern Upland (data not shown), so these percentages were multiplied by the amount of rearing area in a watershed to estimate the impact of barriers on habitat availability in the Southern Upland. The total amount of rearing area calculated to be inaccessible based on the intersection between the barriers layer from NSDoE and the DFO Habitat Division is 210,119 habitat units (100 m^2), leaving an estimated 573,024 habitat units available regionally. Based on this analysis, 24 systems indicate some loss of habitat, with 18 of these (including Amiro's six systems) showing >10% habitat loss.

It is important to keep in mind that the type of fish passage (e.g. upstream or downstream or both) is not listed in the barriers data, and that the barriers data is not an exhaustive survey (i.e. it is likely that more barriers exist than are listed). Both of these factors could lead to underestimates of the amount of area made inaccessable to Atlantic salmon in specific watersheds. For example, one of the dams on East River Sheet Harbour has only downstream passage, which would make the area upstream inaccessible to adults. For this river, it is likely that more than 9.2% of the watershed area is inaccessible to salmon. It is unknown how extensive these underestimates might be at a regional level, and corrections were not attempted in the analysis.

Acidification

Acidification is one of the primary factors limiting production of Atlantic salmon in many Southern Upland rivers (Watt 1987, Amiro 2000), and it can partially or completely eliminate suitable habitat within a watershed (Lacroix and Knox 2005a). Highly acidified water is not a barrier *per se* because adults can still enter the river and spawn; however, their progeny die so the habitat is considered unusable. Acidification levels in a given system vary seasonally and impact upon the various freshwater life stages of Atlantic salmon with different severity (see Section 5.1 for details). Therefore, the productivity associated with an estimated mean annual acidity level would be expected to vary, particularly for watersheds that are less severely impacted. Habitat loss in 13 watersheds (river numbers 13, 14, 15, 16, 17, 18, 19, 20, 22, 37, 38, 63, 67) that were expected to be unsuitable for spawning and juvenile rearing (based on their acidity classification) was quantified; a result corroborated by the mean density estimates from the 2000 and 2008/09 electrofishing surveys. These watersheds have a mean annual pH classification of <4.7 pH units (Watt 1987, Amiro 2000) and (when sampled) juvenile Atlantic salmon densities of zero as estimated by the electrofishing surveys (Table 2.1.2). The estimated amount of rearing area in these systems that is unsuitable for juvenile Atlantic salmon production ranges from 2,410 habitat units in Larrys River to 24,256 habitat units in Clyde River. Combined, these rivers contain a total of 100,198 habitat units (100 m^2), rendered unsuitable for Atlantic salmon production due to high levels of acidification (Table 4.1.1).

Remaining Habitat Unaffected by Total Barriers

There is no overlap between the five watersheds that are identified as impassable due to barriers at head-of-tide and those 13 that are unsuitable for Atlantic salmon due to having a mean annual pH less than 4.7 (Table 4.1.1). This leads to 18 of the identified salmon watersheds having very little or no rearing area available for Atlantic salmon. Of the remaining 54 rivers, 25 contain total barriers that impact a proportion of the watershed, ranging from 0.1% to 94.5% (Figure 4.1.1). There are 29 rivers that do not contain a known total barrier, and these tend to be either smaller systems or watersheds along the Eastern Shore of Nova Scotia. Of the 783,142 habitat units (100 m^2) within rivers of the Southern Upland region, 476,746 (61%) remain both accessible and useable to Atlantic salmon populations (Table 4.1.1; Figure 4.1.2).

4.2 ABILITY TO MEET HABITAT REQUIREMENTS AT PRESENT (TOR 7)

Current juvenile densities estimated for rivers in the Southern Upland are very low: 75.5% of rivers had densities less than 10 salmon/100 m^2 in 2000, and 98% of rivers had densities less than 10 salmon/100 m^2 in 2008/09 (Table 2.1.2). For comparison, historical estimates of juvenile salmon production from “normal” habitat are estimated to be 29 age 0 fish/100 m^2 and 38 age 1 and older fish/100 m^2. These values, termed Elson’s norm, are at times used as reference values and are based on populations in New Brunswick (Elson 1967, Elson 1975). Summing across age classes, Elson’s norm would equate to a total of 67 juveniles per habitat unit. Although 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), none of the density estimates from rivers in the Southern Upland in 2008/09 approach these values; the highest estimate being from the Musquodoboit River (17.72), which is slightly over 30% of Elson’s norm. Although it has been hypothesized that rivers in the Southern Upland have lower productive potential than those in other areas owing to their underlying geology (Amiro et al. 2006), it remains unlikely that the amount of rearing habitat for juveniles in a given watershed (i.e. habitat of suitable gradient) is currently limiting population size for unobstructed systems. At present, low juvenile abundance is more likely to result from the combined influence of low adult abundance (in part due to low at-sea survival) and the impacts of threats on freshwater habitat quality (see Section 4.3). Physical barriers and water quality have likely reduced the quantity of freshwater habitat available to spawning adults by almost one half (Section 4.1), which would be expected to reduce adult abundance by the same amount if other life history parameters remained unchanged. At the current low adult population sizes, it is likely that juvenile abundance is below what could be supported in the available freshwater habitat. However, any threats impacting the quality of freshwater habitats would compound this issue, and would further reduce the river’s capacity to support juvenile production.

4.3 ABILITY TO MEET FUTURE HABITAT REQUIREMENTS (TOR 7)

Juvenile Atlantic salmon production in a given watershed is determined by a combination of two factors:

1) adult abundance and subsequent egg deposition (which determines the maximum production possible in the absence of mortality), and
2) habitat quality and quantity (which determines the survival rates of juveniles among life stages).

Therefore, from a population-level perspective, “available” habitat becomes that which can support production. Variation in habitat quality (particularly in reference to threats in fresh water), was not included in the estimation of the amount of rearing area remaining in Southern Upland watersheds, and an assumption was made that all habitats with suitable gradient and pH can support juvenile production. Because threats influence functional processes in freshwater environments, and thus habitat quality, it is almost certain that the estimated rearing area does not actually represent habitat availability at present, but rather the potential amount of habitat available after mitigation of freshwater threats. If adult population sizes begin to increase, 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. 2009a). Therefore, the ability to reach recovery targets may be partially dependent on the mitigation of freshwater threats.

River-specific conservation requirements for Atlantic salmon populations in the Southern Upland DU are defined primarily from the amount of habitat thought to be available for juvenile salmon production (O'Connell et al. 1997). Therefore, reaching those conservation requirements presupposes that habitat quality or quantity is not limiting production in a given watershed.

The production of juvenile Atlantic salmon in freshwater habitats is governed by density dependent processes that impact growth, survival, and habitat use in a watershed (Armstrong 2005, Gibson 2006, Gibson et al. 2008a). At low abundance, juvenile populations are relatively unaffected by intra- or inter-cohort competition and can rapidly grow in size if abundant suitable habitat exists, provided survival in another part of the salmon life cycle is not limiting population growth (e.g. low adult survival). However, this potential for growth is inversely related to density and as populations become larger (with no change in the quality and quantity of available habitat) their potential rate of population growth declines. At high abundance, many fish populations exhibit relatively constant juvenile production over a very large range of egg deposition values (Rose et al. 2001). In the context of habitat limitation for Southern Upland Atlantic salmon at very high abundance, these statements lead to the implication that the productive capacity of freshwater habitats (i.e. habitat quality and quantity) can ultimately limit population size, as has also been shown using Population Viability Analyses (Gibson et al. 2008b, Gibson and Bowlby 2012).

Analysis of the population dynamics of salmon in the St. Mary's and LaHave rivers (Gibson and Bowlby 2012) indicate that populations have not reached their maximum potential for juvenile production in fresh water over the range of available monitoring data. The equilibrium model (Gibson and Bowlby 2012 - Section 2.5) indicates that the current carrying capacity of smolts in fresh water is 104,120 for the St. Mary's River and 119,690 for the LaHave River. However, these analyses require having data spanning a range of abundances (i.e. when populations are large and when they are small) and an assumption was made that the environment has not changed during the time period when the data were collected. Because all recent data has been collected while population abundance is very low on both rivers, current carrying capacity could be lower if freshwater habitat quality or quantity has been degraded. A preliminary examination of the total number of fish caught on the first pass of an electrofishing survey (excluding Atlantic salmon) standardized by the area sampled suggests that such degradation is possible, given the overall decline in abundance of other species collected during these surveys (Figure 4.3.1). Further analysis of existing data is necessary to quantify change in fish communities, as well as the extent of decline for various species in rivers of the Southern Upland.

Regardless of the present value for carrying capacity in a specific river, the marine survival rates experienced by populations would impact whether freshwater habitat is limiting population growth at a given level of abundance. The equilibrium analyses in Section 5 of Gibson and Bowlby (2012) show that the mean marine survival rates estimated for the St. Mary's River and LaHave River populations were sufficient to enable population growth to levels in excess of the conservation requirement during the 1980s. However, under current freshwater dynamics, these populations are predicted to not reach the conservation requirement even at the maximum observed marine survival rates (Figure 2.5.4 and 2.5.5 in Gibson and Bowlby 2012). Ultimately, whether freshwater habitat becomes limiting in the future depends on the dynamics of recovered populations. If survival in the marine environment were to meet or exceed levels of the 1980s, freshwater habitat would not be expected to become limiting until the population had reached abundance levels in excess of the conservation requirement (Figure 2.5.4 and 2.5.5 in Gibson and Bowlby 2012). Conversely, if marine survival remains at current levels or undergoes a modest increase, it is predicted that increases to freshwater productivity would be necessary to reduce extinction risk or promote population increase for Southern Upland Atlantic salmon populations (Gibson and Bowlby 2012 - Section 5). As such, whether available habitat will become limiting as populations increase depends both on the productive capacity of freshwater habitats, as well as the mortality rates experienced by Atlantic salmon in the marine environment.

4.4 TRADE-OFFS ASSOCIATED WITH HABITAT ALLOCATION OPTIONS (TOR 8)

The functional characteristics of freshwater and marine habitats required for the successful completion of the life cycle of Southern Upland Atlantic salmon are described in Section 1.1. All of these components need to be considered when identifying priority habitats for allocation to avoid discrepancies between that which is protected and what is necessary from a population-level perspective. Adult Atlantic salmon require appropriate river discharge conditions and unimpeded access upstream to reach spawning areas, as well as holding pools and coarse gravel/cobble substrate distributed throughout a river system on which to spawn. Eggs, alevins and juveniles require clean, uncontaminated water with a pH >5.0 for appropriate development, as well as steady, continuous water flow and areas with appropriate cover during winter and summer to deal with temperature extremes. Smolts need appropriate water temperature and river discharge as cues to migrate and require unimpeded access throughout the length of the river. Immature and mature Atlantic salmon in the marine environment require access to sufficient prey resources to support rapid growth, where prey distributions are likely correlated with temperature or other oceanographic variables. Further details can be found in Section 1.1.

Freshwater Habitats

Habitat allocation in fresh water should be focused on protecting the functional characteristics of habitats so as to minimize extinction risk for Southern Upland Atlantic salmon populations. Accomplishing this relies on protecting the remaining genetic and phenotypic diversity of Southern Upland Atlantic salmon and facilitating the re-establishment of wild self-sustaining populations in other rivers (Gibson et al. 2008b). As such, priorities for allocation in fresh water become watersheds that are currently known to contain Atlantic salmon and those that have a high probability of containing useable freshwater habitat.

At present (2008/09 survey), juvenile Atlantic salmon have been found in 21 of the 72 river systems considered in this document (Table 2.1.2). These 21 rivers should be considered the highest priority for habitat allocation, given that they are likely to contain small wild populations (Figure 4.4.1). Even if the juveniles resulted from straying behaviour (i.e. the river does not contain a distinct wild population), their presence demonstrates that the freshwater habitat is of sufficient quality to support spawning and potentially the establishment of a wild self-sustaining population. Within these rivers, rearing area has been defined as all area with gradients >0.12% and <25% (see Section 2.1), which typically encompasses a large percentage of each watershed (Table 2.1.1).

Barriers and pH are two factors that have had a large impact on freshwater habitat availability and quality, respectively (Section 4.1), and depending on the extent of each type of habitat loss, can be difficult or expensive to remediate. Therefore, rivers or parts of rivers that remain accessible to Atlantic salmon (due to the absence of total barriers) or rivers that remain mildly or un-impacted by acidification (mean annual pH that is greater than 5.0; category 3 and 4 rivers) should also be considered very important in terms of habitat allocation for Southern Upland Atlantic salmon (Figure 4.4.1). Even if the specific river does not contain Atlantic salmon at present, these areas likely contain useable freshwater habitat that could support populations in the future. Including some rivers with reduced levels of pH should also help to protect the remaining genetic diversity among populations in the Southern Upland, given that there are wild populations remaining with greater tolerance to low pH, which appears to have a genetic basis (e.g. in the Tusket River) (Fraser et al. 2008).

Future recovery efforts will likely focus on the elimination or remediation of threats to fresh water habitats, and may include measures such as barrier removal or lime dosing (to increase pH), which would increase the amount of habitat available to populations. However, the information presented in this section is meant to guide options for short-term as opposed to long-term goals. Using the two criteria outlined above (barriers and acidification) to prioritize among areas during habitat allocation would ensure that the included watersheds and areas (Figure 4.4.1) are distributed throughout the province, are of varying size, and encompass a range of environmental characteristics (i.e. are distributed among the watershed groupings identified in analyses pertaining to the distribution component of the recovery target (Bowlby et al. 2013). All of these factors are important in terms of the robustness and adaptive potential of populations in the Southern Upland, and thus should increase the probability of population persistence as well as the probability of recovery.

Estuarine Habitats

Estuaries are a habitat known to be used by Southern Upland Atlantic salmon on an annual basis, and in some cases the boundaries of the estuary can be clearly delineated (i.e. using coastlines). Although recent tagging research does not support the idea of extended residency periods for smolts or adults (e.g. Halfyard et al. 2012, Hubley et al. 2008a), estuaries should be considered important in terms of habitat allocation 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 the Southern Upland, and
3) salmon likely come into direct contact with human activities taking place within estuaries.

In terms of increasing the potential for connectivity among the marine and freshwater environments, the estuaries of the watersheds identified in Figure 4.4.1 would be high priorities for habitat allocation in the marine environment.

Marine Habitats

In comparison with estuarine areas, marine habitats used by Southern Upland Atlantic salmon are not as easily delineated. Based on the tagging data, marine habitats encompass coastal areas from the Bay of Fundy to Greenland, and are seasonally and annually variable depending on factors such as oceanographic conditions or prey distributions (see sections 1.3 and 2.3). Although the available tagging data give some indication of the seasonal location of Southern Upland salmon, these do not capture annual variability or the true extent of 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 tagged and spatial coverage of recapture effort) as well as the variability in marine conditions over time (see Section 6.2).

5. MAGNITUDE, EXTENT AND SOURCE OF THREATS TO SOUTHERN UPLAND ATLANTIC SALMON IN FRESHWATER ENVIRONMENTS (TOR 12+13)

In this section and the following (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 behavioural changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur*". As such, some threats may act on the population by degrading Atlantic salmon habitat (e.g. acidification), while others may affect population viability directly by increasing mortality (e.g. fishing), and others may affect the life history characteristics of populations (e.g. stocking).

Human activities that impact upon Atlantic salmon populations often represent an assemblage of threats to fish and fish habitat. For example, infrastructure (roads) as a threat category encompasses multiple changes to ecological, demographic or behavioural attributes of populations leading to reduced viability and consequently reduced abundance (Gucinski et al. 2001). This interaction between human activities and functional changes to salmon populations or habitats are summarized in Table 5.1 for fresh water and Table 5.2 for the marine environment. In most cases, it is not possible to consider a specific threat in isolation given the compounding and correlated nature of the majority of threats. Only those threats that cause functional changes are shown in Tables 5.1 and 5.2; additional threats are discussed in Sections 5 and 6 below.

Freshwater threats 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. Acidification, Invasive Species, etc.) are discussed. Relevant background information is provided for each threat followed by information specific to the Southern Upland, where available. When considering the impact of each threat, it is important to keep in mind that due to loss of life history variation, populations currently have very little capacity to increase in size following episodic mortality events, such as extreme temperature or flow events (Sections 2.5 and 4.2 in Gibson and Bowlby 2012). This implies that even after being removed (total remediation), threats may be expected to have longer-lasting effects on populations that are currently at low abundance and have low productivity than when populations were larger and productivity was higher.

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.

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 Southern Upland Atlantic salmon populations or habitats (where available).

As such, the text attempts to be inclusive on 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 Southern Upland 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 to populations in the Southern Upland DU.

The information presented in Sections 5 and 6 are summarized in Table 5.3 for fresh water and Table 5.4 for the marine environment. Both tables use the same definitions and are structured in the same way. In terms of organization, each threat category is organized according to the overall level of concern. Definitions for the column headings used in both tables are provided here, as well as immediately preceding Table 5.3 to aid in the interpretation of the threats tables as well as the information presented below.

Definition of table headings and column values – refer to Table 5.3:

Threat Category: The general activity or process (natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur. 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 Southern Upland DU, where stress is defined as changes to ecological, demographic, or behavioural 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 region 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 Southern Upland 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 affecting (C - current) or may be affecting (A - anticipatory) Atlantic salmon populations in the Southern Upland 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. Definitions of the levels for "Severity' are provided in Table 5.3.

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 Southern Upland DU specifically. Definitions of the levels for "Causal Certainty' are provided in Table 5.3.

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 the Southern Upland (threat and stress are defined above). This information puts the threat in context and helps to designate overall concern and severity.

5.1 WATER QUALITY AND QUANTITY

Acidification

Watersheds in the Southern Upland have been heavily impacted by acidification (Farmer et al. 1980, Watt 1987), which has predominantly originated from atmospheric deposition (i.e. acid rain) due to industrial sources in North America (Watt 1997). Such deposition is exacerbated by hardrock geology with little buffering capacity, poor soils, and an abundance of acidic heaths, peatlands and bogs throughout the region (Watt et al. 1983, Watt 1987, 1997, Korman et al. 1994). Significant effects of acidification on salmon populations in the Southern Upland are estimated to have begun in the 1950s, based on historical salmon angling catch statistics, where significant decline (estimated at 2.8% per year) began in 1954 in rivers at or below pH 5.0 (Watt et al. 1983). By the 1980s, population-level affects were apparent. In more recent years, industrial pollution and consequent atmospheric deposition has been reduced over time, largely through legislation and new technology for cleaner emissions. Clair et al. (1995) reported that systems in Southwest Nova Scotia are mostly stable with respect to pH and not acidifying further, although they also noted that very few systems are recovering. Similarly, Whitfield et al. (2006) concluded that improvements to alkalinity and pH have been largely absent in Nova Scotian lakes. In contrast, Lacroix and Knox (2005a) concluded that there is evidence that acidification had become more severe since 1990. Given the geologic characteristics of the Southern Upland, recovery from depressed pH (in the absence of mitigation) is projected to be extremely slow (Ritter and Rutherford 2000). Rivers in the Southwestern portion of the Southern Upland tend to be more highly acidified than those in the Northeastern portion (Figure 5.1.1).

Low pH can affect the survival of all freshwater stages of Atlantic salmon. 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 in Table 2.5.3 of Gibson and Bowlby (2012) and are based on the toxicity functions of Korman et al. (1994). This section focuses on fry (age 0) because multiple authors concur that this is 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). 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. Overwintering 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 5 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, even in rivers where residual populations were still present. Salmon populations were thought to be extirpated in rivers with mean annual pH values of <4.7 (Watt 1986).

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).

Frequently associated with reduced pH is the mobilization of aluminum. Aluminum concentrations in Southern Upland streams have approximately doubled between 1945-55 and 1980-81 (Watt et al. 1983). However, Lacroix (1989b) notes that despite high concentrations of total dissolved aluminum at low pH, the great majority (>90%) is in a non-exchangeable, organically bound form. The weight of evidence is that aluminum does not contribute to salmon mortality in low pH rivers (Lacroix and Townsend 1987, Lacroix 1989b, Peterson et al. 1989, Lacroix et al. 1990) but rather the mortality is due to acid toxicity.

Mean annual pH classifications have been completed for 60 rivers in the Southern Upland region (Watt 1987, Amiro 2000), where pH of <4.7 is category 1, 4.7-5.0 is category 2, 5.1-5.4 is category 3 and >5.4 is category 4 (Table 2.1.2; Figure 5.1.1). Based on a comparison of angling catch statistics with the pre-acidification period of 1936-53, Watt (1986) considered all salmon populations in extremely acidified systems (pH <4.7) to be extirpated, reduced by 90% in moderately impacted systems, reduced by about 10% in slightly impacted systems, and apparently unaffected when pH >5.4. These estimates suggest that 49.8% of the total production of adult salmon in the Southern Upland was lost to acidification by the early 1980s (Watt 1987). Recent estimates of juvenile densities from the 2008/09 electrofishing survey suggest that the impacts resulting from acidification could be more substantial, given that the overall mean juvenile density of rivers in category 2 is now only 5% that of rivers in category 4 (95% reduction). Similarly, the overall mean density in rivers of category 3 is 58% that of rivers in category 4 (42% reduction; Table 2.1.2). However, such results could be due to the compounding nature of multiple current threats to salmon populations in fresh water. Using the above range of estimates for declines in productivity to account for the impact of acidification on available rearing habitat (Section 4.1), an additional 316,726 to 334,322 habitat units (out of a total of 351,918) from pH category 2 rivers (based on a loss of 90% to 95% production), and 19,431 to 112,701 habitat units (out of a total of 194,312) from pH category 3 rivers (based on a loss of 10% to 58% production) would be unsuitable for juvenile production (refer back to Table 2.1.2).

Extreme Temperature Events

As 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.

Altered Hydrology

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).

River discharge in systems of the Southern Upland region is highly variable among years, as illustrated by the hydrological records for the St. Mary’s River (Figure 5.1.2). However, 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 Jonsson 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).

Long-term monitoring of water levels in the Southern Upland is conducted by Environment Canada at hydrometric stations on multiple rivers, including the St. Mary’s, Sackville, LaHave, Mersey and Roseway rivers. The St. Mary’s River was chosen as an example for illustration because its hydrology is not influenced by hydroelectric development or impassable dams. Figure 5.1.2 presents a sample of hydrological variables calculated from daily flow measurements from 1916 to 2010. These four examples demonstrate some of the patterns that can be evident in hydrological data and can indicate changes in the hydrological conditions experienced by Atlantic salmon over time. For example, the mean flow during June appears to have become more variable (relative to the series mean) and to have potentially increased after the 1960s (the lower measurements are closer to the mean than previously). Both the 1-day minimum flow and the 1-day maximum flow (which are measurements of extreme low and high water events, respectively) show the cyclical nature which characterizes long-term hydrology data (Fortin et al. 2004), with groups of years being lower or higher than average, but with multiple switches between them. It is interesting to note that both the 1-day minimum flow as well as the base flow measured for the St. Mary's River were characterized by years with relatively high water from the 1960s to the late 1980s, but then switched to exclusively low-water years in the 1990s and early 2000s, coincident with substantial declines in the Atlantic salmon population (Figure 5.1.2).

Chemical Contaminants

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.

Heavy metals and some nutrient concentrations are monitored at various locations by Environment Canada. In Kejimkujik National Park, increased acidification has been correlated with mercury uptake by biota (Beauchamp et al. 1997), leading to health advisories regarding high levels of mercury in sport fish as well as extremely high blood mercury levels in common loon (*Gavia immer*) populations (Nocera and Taylor 1998). It is possible that this is a more widespread issue given the extent of acidification in the Southern Upland. Insecticide spraying (Matacil 1.8D) by the forest industry to control spruce budworm, in which the solvent 4-nonylphenol was used, has been linked to reduced smolt survival and lower adult returns to the Restigouche River in New Brunswick (Fairchild et al. 1999). Similar chemicals have been applied in the Southern Upland, and 4-nonylphenol is also associated with industrial effluents and municipal sewage outfalls. Another potential source of chemical contaminants in the Southern Upland is historical mining operations. Over 4,000 abandoned mine openings (the surface component of abandoned mine workings resulting from past underground mining (NSDNR database)) are widely distributed throughout the Southern Upland. Drainage from abandoned mines (particularly those associated with metal extraction, which most of these are) can contain elevated levels of heavy metals and also tend to be acidic (see also Section 5.4).

Silt and Sediment

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 (see also Section 5.4).

5.2 CHANGES TO BIOLOGICAL COMMUNITIES

Invasive 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 goldfish is unlikely to have a significant interaction with Atlantic salmon, through either competition or predation. The impact of rainbow and brown trout stocking by the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) is considered in the section on stocking. The final two introduced species, chain pickerel and smallmouth bass, have substantially increased in abundance and distribution since first being introduced into the Southern Upland and they are both recognized as being significant piscivores.

Chain pickerel are a lacustrine species, favouring shallow, weedy warm lakes and ponds (Raney 1942, Foote and Blake 1945). 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 the Southern Upland, although they are documented to do so elsewhere (e.g. Newfoundland; DeGraaf and Bain 1986, Erkinaro and Gibson 1997). However, the potential for direct predation on salmon smolts during emigration in the spring is high. 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. Preliminary studies in Nova Scotia suggest that pickerel presence in a lake substantially reduces the abundance and species richness of the native fish community (Mitchell 2011). It is possible that smolts migrating through such depauperate lakes would be highly visible and accessible prey.

More research has been done on the impacts of introduced smallmouth bass to fish communities, where competition from, and predation by, invasive smallmouth bass have been linked to community shifts and extirpation of native fishes (Findlay et al. 2000). Smallmouth bass predation on emigrating Pacific salmon (*Oncorhynchus* spp.) smolts has been documented (e.g. Fayram and Sibley 2000); although the population-level effect on salmon abundance related to the presence of smallmouth bass has been variable among river systems (Valois et al. 2009). In terms of competition, Atlantic salmon juveniles have been found to shift habitat use in areas where smallmouth bass are also found (Wathen et al. 2011), although these results were dependent on water temperature and discharge conditions. Given that smallmouth bass are present in riverine areas of the Mersey, Carleton, Sackville and LaHave rivers (LeBlanc 2010), it is likely that they impact these Atlantic salmon populations through both predation and competition.

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 points occur in the correct watershed, and that 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 69 documented locations in the Southern Upland, while smallmouth bass are more widely distributed in 174 documented locations (Table 5.2.1). Although a very small number of smallmouth bass introductions were authorized by the Province during the 1950s and 1960s, the majority of introductions have been caused by people illegally transporting these species into new areas. Within the Southern Upland, both chain pickerel (Figure 5.2.1) and smallmouth bass (Figure 5.2.2) are presently limited to watersheds in Southwestern Nova Scotia (SFA 21).

Invasive Species (Other)

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 the Southern Upland.

Historical Stocking Practices

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). In the Southern Upland, such practices were standard for the majority of large river systems and used broodstock from a variety of sources. During the 1980s, there was increased reliance on stocking in the Southern Upland as an attempt to compensate for the impacts of acidification. However, the declines in abundance during the 1990s meant that no wild population was sufficiently large to ensure that the genetic risks of supplementation remained low, so federally funded stocking programs were discontinued (DFO and MNRF 2009). The last hatchery-raised smolts were released into the Tusket and LaHave rivers in 2005 (Amiro et al. 2006, DFO 2010) and the only juveniles released since that time have been small, isolated events associated with the Fish Friends (educational) program. The Province has conducted limited salmon stocking since 2005 (see *Current stocking practices*, below).

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 a formal analysis on the degree of interbreeding among fish of wild and hatchery origin for Southern Upland salmon populations has not been done, the literature suggests that such interbreeding (and the resulting fitness loss) would be expected to have contributed to the population decline from the 1990s to present. However, the rate at which population-level fitness declines during the supplementation program, and how long such declines persist after supplementation is ended, are both relatively unknown for wild Atlantic salmon populations (Bowlby and Gibson 2011).

A decadal summary of the historical stocking programs in rivers of the Southern Upland, including the total number of each life stage released and broodstock origin is provided in Table 5.2.2. Because the stocking database only includes information from 1976 to 2007, the values listed for the 1970s in Table 5.2.2 only span the years 1976 to 1979. Similarly, information for the 2000s only includes data from a maximum of eight years. This variation in data recording means that the total numbers of fish released in each decade are not directly comparable. However, the numbers do give a relative indication of the magnitude of stocking over recent years in the Southern Upland. All life stages released and broodstock origins are listed for a given decade, provided that each group was released in at least one year (but could also have been released in multiple years). 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 the Southern Upland, or from 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 5.2.2).

Of the 14,798,469 fish stocking records in Table 5.2.2. (which is the total of all fish stocked), 57.7% were stocked in only four rivers: the Tusket (1.8 million fish stocked over the period of record), Medway (2.1 million fish), LaHave (3.2 million fish), and Liscomb (1.4 million fish). Keeping the previous caveat regarding unequal number of years per decade included in the database, the 1970s experienced 725,000 salmon stocked in the Southern Upland, the 1980s 4.8 million, the 1990s 7.3 million, and the 2000s 1.9 million.

In terms of the impact of historical stocking on populations, it is expected to be less from stocking events that used native broodstock and that released younger age classes of juveniles (Fraser 2008). However, none of the stocked rivers in the Southern Upland region was consistently stocked with fry or parr from native broodstock (Table 5.2.2). In most cases, the particular life stages stocked, as well as the broodstock origins, varied both within and among decades. Typically, native broodstock were used in rivers with larger populations (e.g. Musquodoboit, Gold, LaHave, Medway, St. Mary's, and Tusket), and there was a distinct shift toward using exclusively native broodstock in more recent decades compared with the 1970s and 1980s. Similarly, the younger life stages were more commonly released in earlier years (particularly the 1980s) with a shift towards exclusively releasing late-stage parr and smolts in more recent years (Table 5.2.2).

Current Stocking Practices

In the past two years (2010 and 2011), there have been no federal stocking programs for Atlantic salmon in the Southern Upland. Beginning in 2005, the NSDFA released hatchery-reared smolts into one river in the Southern Upland (St. Francis Harbour River). The Provincial program was intended to establish an Atlantic salmon population in a river where the wild population had been extirpated, so this specific river was chosen for enhancement as it was thought that it no longer contained a self-sustaining wild population. Prior to 2010, there had been a very small supplementation program operated by the Federal government for multiple rivers in the Southern Upland. This Federal program was initiated to ensure that intervention programs (like supportive rearing or Live Gene Banking) remained as options in case of future population decline, by collecting fish while sufficient genetic diversity remained in the population. Approximately 200 juveniles were collected each year during 2003 and 2004 from six rivers in SFA 20 (Amiro et al. 2006). Collectively, these juveniles were released as adults into the Quoddy River in an effort to increase abundance in this single population. Similarly, in 2006 and 2007, DFO collected juvenile salmon from the St. Mary's River and released them as adults to spawn naturally once mature (DFO 2010). For both the Federal and Provincial programs, the genetic consequences to wild populations associated with such limited releases were considered to be minimal. Furthermore, the effectiveness of these types of captive rearing programs (in terms of increasing juvenile production in subsequent years) has been found to be highly variable in other rivers (O'Reilly et al. 2009).

Other Salmonid Stocking

The potential for competitive interactions among juvenile Atlantic salmon and introduced brown (*Salmo trutta*) or rainbow (*Oncorhynchus mykiss*) trout is high, given that all three species have similar habitat requirements and can co-exist in freshwater environments (Hearn 1987, Gibson 1988). There is evidence that brown trout are both more aggressive than 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 behaviour and feeding patterns in the presence of brown (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). Furthermore, the presence of non-native trout substantially disrupted dominance hierarchies and behavioural 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 interactions (i.e. how Atlantic salmon survival changes in the presence of non-native trout) have not been well-quantified.

Rainbow and brown trout are stocked in the spring and fall by NSDFA into a small number of lakes in the Southern Upland. In 2011 (combining data from spring and fall distributions), brown trout were distributed into five lakes, and rainbow trout into eight, three of which could be considered land-locked based on the NHN (Table 5.2.3, Figure 5.2.3; refer also to Appendix 1). Brown trout releases only take place in systems which currently have established populations of this species (from historical introductions), and the distribution of rainbow trout is focused on land-locked lakes. 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, so sterile adult fish (those of harvestable size) are released. There are isolated records of juvenile brown trout being captured in the LaHave, St. Mary's, Chezzetcook, Country Harbour, Gold, Indian Harbour Lakes, Liscomb and Medway rivers (most recently in the Gold and Medway). However, the scarcity of records strongly suggests that self-sustaining populations of brown trout have not become widely established in the Southern Upland. There are no records of juvenile rainbow trout being captured in the Southern Upland region. Therefore, it is likely that the impacts of stocked trout species on habitat use, resource acquisition or behaviour of Atlantic salmon are low. However, there remains the potential for disease transfer from the hatchery environment into the wild from these stocked fish, and predation on juvenile salmon from adult brown or rainbow trout has been observed in rivers in North America (Krueger and May 1991). These interactions are not quantified in the Southern Upland.

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 and multiple life stages are released. There were a total of 151 stocked locations (combining data from spring and fall distributions) in 2011 contained in the 72 known salmon rivers, and an additional 55 locations contained in the coastal watersheds in the Southern Upland region (Table 5.2.3, Figure 5.2.4; 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). As with the brown and rainbow trout, there remains the potential for disease transfer from the hatchery environment to the wild from these stocked fish.

Commercial Salmonid Aquaculture In Fresh Water

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).

Avian Predators

Multiple avian species have been found to prey on Atlantic salmon juveniles and smolts in eastern Canada, including double-crested cormorants (*Phalacrocorax auritus*), belted kingfishers (*Megaceryle alcyon*) and merganser species (see review by Moring et al. 1998). Although avian predators are a natural source of mortality on Atlantic salmon smolts (and thus would not be considered a threat), there is evidence of increasing population abundance of double-crested cormorants since the 1920s in Nova Scotia, and stomach contents analyses suggest that smolts constitute an increasing proportion of the birds' diet (Milton et al. 2002). Recent research using acoustic tracking to assess movement patterns and mortality rates of smolts in the Southern Upland has shown a typical pattern in tag disappearances (thought to be indicative of predation events), with tags no longer being detected once individuals reach the head-of-tide (i.e. during the transition from fresh water to salt water) (Halfyard et al. 2012). A similar pattern was found for emigrating smolts in Norway, where subsequent monitoring at sea bird colonies strongly suggested that such tag disappearances were linked to avian predation (Dieperink et al. 2002). It has been hypothesized that the physiological changes undergone by smolts to deal with osmotic stress induce behavioural changes that lead to increased susceptibility to predation (Jarvi 1989, 1990). As such, other threats in fresh water that interfere with osmoregulatory ability (e.g. acidification) (Saunders et al. 1983, Johnston et al. 1984) would be expected to exacerbate predation risk.

The population-level impact of predation in fresh water is partially dependent the timing of predation relative to density-dependent processes (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 predation on juveniles). 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.

Reduced Genetic Variation

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). However, three factors suggest that Atlantic salmon populations in the Southern Upland DU are experiencing inbreeding depression:

1) populations are currently at low abundance relative to historic sizes (Bowlby et al. 2013),
2) genetic variation estimated from microsatellite markers for Southern Upland salmon is lower than that measured for large reference populations, and
3) genetic variation within a population (as measured from a limited number of loci) has declined over the last three to four salmon generations (O'Reilly et al. 2012).

Allee Effects at Small Population Size

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 Southern Upland Atlantic salmon relative to historic population sizes (Bowlby et al. 2013) suggests that Allee effects may be reducing 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 the Southern Upland are limited to two river systems at present (St. Mary's and LaHave rivers) and consist of an electrofishing survey for juveniles and an adult count (either at a fishway or from seining). 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). The trap for adults on the LaHave River has been designed for relatively passive capture and holding free of entanglement. 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.

5.3 PHYSICAL OBSTRUCTIONS

Habitat Fragmentation Due to Dams, Culverts and Other Permanent Structures

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.

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 the Southern Upland were presented in Section 4.1 (refer also to Appendix 1). Here, all types of structures listed in the barriers layer from the NSDoE and the DFO Habitat Division are considered. These data indicate that of the 233 dams or barrier structures listed within the Southern Upland, 44 of them (18.9%) are considered to be passable to fish (Table 5.3.1, Figure 5.3.1). These are dispersed throughout the province and many of them occur on watersheds already fragmented by impassable barriers. It is important to note that the type of fish passage (e.g. upstream or downstream or both) is not provided in this data source.

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).

Culverts are ubiquitous throughout watersheds in the Southern Upland (see Section 5.4 for additional information). 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 in the majority of watersheds in the Southern Upland region.

The presence of culverts could not be assessed directly from the data available because river-specific surveys are required, such as those on the Annapolis and St. Mary's rivers (Hicks and Sullivan 2008, Mitchell 2010). Therefore, to assess the potential regional prevalence of culverts, road crossings were used as a proxy. In ArcGIS®, the NHR flow data were intersected with the National Road Network (Edition 8) for Nova Scotia, combining data from paved and unpaved roads (Appendix 1). Initially, crossings that would have intersected lakes, reservoirs or wetlands were excluded from the analysis, but this resulted in the exclusion of any crossing where the river was wide enough to be represented as a polygon rather than a line in the NHN data (the majority of crossings on the mainstem of rivers). The final analysis included such crossings, and the total number estimated for the Southern Upland region increased from 16,179 to 17,115 (i.e. by 5.7%).

The total number of road crossings in a given watershed were expressed as a density (# per 10km 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 densities (Figure 5.3.3) and thus the greatest potential for impact from culverts. However, the Annapolis/Nictaux, Medway, LaHave, Musquodoboit, and St. Mary's rivers all have more than 200 road/river crossings within the watershed and would be expected to contain the highest number of culverts (Table 5.3.3).

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 (e.g. Section 5.1).

The specific issues related to reservoirs have not been widely studied in the Southern Upland; however, effects consistent with the information presented above have been found. For example, Lake Rossignol in Kejimkujik National Park is a large reservoir which is noted for the bioaccumulation of methylmercury in sport fish, including salmonids (Beauchamp et al. 1997).

Two methods were used to identify reservoirs in the Southern Upland region for spatial analysis. The NHN data uses codes to identify water bodies as reservoirs and these were characterized (e.g. by area, counts in each watershed) in ArcGIS® (refer also to Appendix 1). Additional spatial analysis 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 the number of dammed water bodies (and therefore likely reservoirs) in the Southern Upland. 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) are widely distributed in the Southern Upland region and tend to be found in the larger river systems (Figure 5.3.2). The most heavily impacted system in terms of the number of reservoirs is the Annapolis/Nictaux watershed with a total of 102. However, the Mersey is by far the most impacted system in terms of the total area of reservoirs, with 19.3 km^2 of wetted area contained in six reservoirs (Table 5.3.2).

5.4 HABITAT ALTERATION

Infrastructure (Roads)

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).

For rivers in the Southern Upland, the total length of road contained in a specific watershed is not directly proportional to the size of the watershed (refer to Table 5.3.3 and Appendix 1). Although many of the larger watersheds contain the greatest length of road (e.g.

Annapolis/Nictaux, Medway, LaHave, and St. Mary's rivers; each with >1,000 km of road), some large watersheds have considerably less (e.g. Tusket, Musquodoboit, and Mersey rivers; each with <800 km of road). Therefore, road length is 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 the Southern Upland tend to have a greater amount (based on total length) of unpaved road versus paved road within a watershed (refer to Table 5.3.3). In some instances, the amount of unpaved road is an order of magnitude greater than that of paved (e.g. the Mersey, Medway, or Tusket rivers, among others). Unpaved roads contribute significantly greater quantities of sediment into rivers than paved surfaces and typically contain more culverts (Gucinski et al. 2001).

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 the land use data, industrial corridors (roads, railways, powerlines, and pipelines) were combined with other industrial sites such as gravel pits and landfills (Table A4 in Appendix 1). The percentage of watershed area affected by industrial sites/corridors for each river in the Southern Upland is given in Table 5.4.1. There are four rivers in which more than 3% of the drainage area is used for industrial sites/corridors: the Sackville, Nine Mile, East (St. Margarets) and Boudreau rivers. Although the overall percentages are very low, it is important to keep in mind that these corridors would be widely distributed throughout the watershed and that the majority of drainage area would be in close proximity to a corridor.

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 are two pulp mills in the Southern Upland area. The largest one is Bowater Mersey Paper Co. Ltd., which is located along the Mersey River estuary.

Hydropower Generation

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).

Nova Scotia Power Inc. provided the names and locations of the hydropower generating stations (18 facilities on 9 systems; Table 5.3.1) that they currently own and operate in Nova Scotia (refer to methods in Appendix 1). These data were restricted to the locations of turbines for power generation, and did not include the locations of the dams or diversion structures associated with each of the installations. Four of these facilities (two near St. Margarets Bay and two on Dickie Brook near Guysborough) are located in watersheds that are not included in the list of 72 rivers considered in this document. Six of these 18 installations have dams close to head-of-tide, thus impacting the majority of the river system in which they operate (Annapolis/Nictaux, Tusket, Bear, Sissibo, and Mersey rivers; Dickie Brook and St. Margarets Bay; refer to Table 5.3.1, Figure 5.4.1), with four of those six being identified by Amiro (2000) as being barriers to fish passage (refer back to Section 4.1). There is also one private company operating a hydro facility at Morgans Falls on the LaHave River, where approximately 51% of the habitat area available in the river is upstream of the falls and accessible via a fishway. In general, hydropower generation impacts rivers predominantly in southwestern Nova Scotia (SFA 21), with the greatest number of facilities (4) on the Mersey River.

Urbanization

Urbanization encompasses multiple types of land use related to human population growth, including: infrastructure (e.g. roads and buildings), residential, industrial, or commercial development. Strongly associated with urbanization is land clearing (deforestation), construction of roads, and increases in the amount of impervious surface (e.g. paved roads, or 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 Nova Scotia Department of Natural Resources (NSDNR) Forest Inventory (refer to Appendix 1), any area that is used primarily as residential or industrial (including sidewalks, golf courses, and parking lots), as well as some house lots in wooded areas are classified as urban. However, outside of cities and towns, the available data on land use is not of sufficient resolution to identify all rural settlements, so the amount of land classified as urban is underestimated.

The proportion of urban area within watersheds in the Southern Upland is provided in Table 5.4.1. Eight watersheds contain a proportion of urban area which is >5%. These watersheds vary in size from a drainage area of 36 km^2 (East, St. Margarets) to 166 km^2 (Porters Lake). Not surprisingly, six of the eight watersheds (river numbers 36, 37, 39, 40, 41, 42) are predominantly located within the Halifax Regional Municipality.

Agriculture and Forestry

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 Southern Upland (Table 5.4.1 and Appendix 1). 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 version 2 and 3), neither were of sufficient resolution to be comparable to the NHN used in these analyses. The land use data 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 the Southern Upland, the proportion affected by agriculture is very low, with only 12 watersheds having more than 1% of their total area classified as agricultural (Figure 5.4.2). Conversely, forestry activities encompass a much greater proportion of total watershed area for the majority of rivers in the region, with 17 rivers having up to 30% of their total area used for silviculture or timber harvest (Figure 5.4.3). Fourteen rivers have >15% of land use in the watershed classified as forestry, including the Musquodoboit (15.3%) and St. Mary's (30.2%) rivers. These two watersheds are large, with >700 km^2 in drainage area. The remaining 12 watersheds with >15% forestry are relatively small, ranging from 34 km^2 to 329 km^2. Other large watersheds (e.g. Tusket, Mersey, and Medway rivers) have <10% of area in forestry. Agricultural land use is the highest in the Annapolis and Musquodoboit valleys. Land use related to forestry is much more widespread than that related to agriculture, although it tends to be highest for rivers on the Eastern Shore (SFA 20).

Mining

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).

Gold mining was very common during the late 1800s and early 1900s in the Southern Upland. According to the NSDoE, 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 behavioural impacts.

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 NS Department of Natural Resources Abandoned Mines Database (refer to methods in Appendix 1). Of the 2,283 openings listed in Southern Upland watersheds, 2,131 (93%) were from historical gold mines. The most heavily impacted watershed was the Mersey River, containing 432 openings. An additional five watersheds (Gegogan, Tangier, Ship Harbour, Salmon (L. Major) and Gold) each have more than 100 openings (Table 5.4.2). Regionally, most of the abandoned mines are found in watersheds along the Eastern Shore of Nova Scotia (SFA 20) or in the middle of Southwest Nova Scotia (SFA 21) (Figure 5.4.4).

5.5 DIRECTED SALMON FISHING

Aboriginal Salmon Fisheries

In the Southern Upland (as elsewhere in Canada), Aboriginal food, social and ceremonial fisheries take place on specific rivers subject to negotiated agreements and licenses issued to individual groups. The Aboriginal communities in the Southern Upland include Indian Brook, Acadia, Millbrook, Annapolis Valley, Glooscap and Bear River. The licenses for fishing Atlantic salmon 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; termed grilse or 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). For example, in previous years, Aboriginal agreements permitted the harvest of Atlantic salmon only from rivers in the Southern Upland that were stocked with hatchery smolts (Amiro et al. 2000). Historically, estimates of salmon harvests under Aboriginal fishing agreements have been low; less than 10% of the estimated retention from the recreational fishery (Anon 1980).

Recreational Salmon Fisheries

Recreational fishery data have been collected for 55 of the watersheds in the Southern Upland (Figure 5.5.1). 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, mandatory catch-and-release angling was extended to include small salmon (<63 cm fork length) as well. Since 2000, several river systems have been closed to catch-and-release angling for Atlantic salmon due to conservation concerns. Between 1984 and 2008, the recreational angling data indicate declines of >95% in catch as well as effort for most rivers in the Southern Upland (Gibson et al. 2009a). Given such dramatic declines and the low abundance estimated for the index populations in 2010, all recreational salmon fishing in the Southern Upland was closed in 2011 (DFO 2011b), and other measures (pool closures) were implemented to reduce by-catch of salmon in other recreational fisheries.

Recreational angling can threaten Atlantic salmon populations through direct mortality of adults or sub-lethal effects such as reduced spawning success (DFO 2011b). 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 <10ºC consistently reported zero mortality, while mortality ranged from zero to 22% in water temperatures from 12ºC to 19ºC, and 30% to 80% in water temperatures from 20ºC to 23ºC (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 the Southern Upland in the years leading up to the closure of the recreational fishery.

Illegal Fishing and Poaching

In recent years, concerns have been raised over recreational anglers illegally targeting 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 2011b). 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 are high). Management measures put in place in 2011 to mitigate the impact to Atlantic salmon included a variation order that closed known salmon holding pools to trout fishing on multiple rivers with Atlantic salmon populations (e.g. LaHave and St. Mary's rivers).

There have also been anecdotal reports of harvests (i.e. poaching) of Atlantic salmon in the Southern Upland, either using recreational fishing gear or from other capture methods such as gillnets. The magnitude of this threat to specific populations is not possible to quantify, however, poaching would be expected to have the greatest impact when population sizes are small (as they are at present) because a larger proportion of the population would be affected. Additionally, the population dynamics modeling presented by Gibson and Bowlby (2012; Section 2.5) suggests that populations have very little capacity to recover from illegal removals (i.e. are not able to quickly increase in size).

5.6 BY-CATCH IN OTHER FISHERIES

By-catch in Aboriginal or Commercial Fisheries

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 have very little chance of catching an 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 juvenile salmon are unlikely to be targeted by anglers. Any population level effects from this source of by-catch are likely insignificant given the comparatively high abundance of this life stage relative to the suspected low levels of by-catch.

6. MAGNITUDE, EXTENT AND SOURCE OF THREATS TO SOUTHERN UPLAND ATLANTIC SALMON IN MARINE ENVIRONMENTS (TOR 12+13)

Reduced marine survival is contributing to population declines of Southern Upland Atlantic salmon. 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). Since the late 1980s/early 1990s, there has been a progressive decline in return rates of wild smolts in the LaHave (above Morgans Falls) and St. Mary's (West Branch) populations (refer to Section 2.2 in Gibson and Bowlby 2012 and Section 1.4 in Bowlby et al. 2013). A similar trend has been noted for hatchery-reared smolts (refer to Section 2.3 in Bowlby et al. 2013; Amiro et al. 2000, Marshall et al. 1999). The most recent return rate estimates (2010) were 3.5% for 1SW and 0.3% for 2SW adults on the LaHave River, and 1.0% for 1SW and 0.09% for 2SW on the St. Mary's River (refer to Section 1.4 in Bowlby et al. 2013). However, there have been recent years in which higher return rates have been observed (e.g. the 2005 smolt year). The maximum estimated return rates produced by population models from 2000 to 2009 are 4.13% and 0.52% for 1SW and 2SW, respectively, on the LaHave River, and 2.08% and 0.3% on the St. Mary's River (refer to Table 2.2.2 in Gibson and Bowlby 2012). While marine mortality rates are not as high as those impacting inner Bay of Fundy salmon, they are one of the factors limiting current population growth in the Southern Upland (Gibson et al. 2009a).

Smolt-to-adult return rates are used as a proxy for at-sea survival, and are based on smolt abundance estimates and adult escapement estimates in the following years (after accounting for age distributions and variations in spawning history). As such, at-sea or marine mortality is a misnomer because it also includes sources of mortality for smolts or adults while in fresh water. For example, threats like chemical contaminants or low pH in fresh water that interfere with the successful transition to the marine environment (e.g. those that reduce osmoregulatory capabilities, influence homing ability, or lower individual growth or condition factor) would lead to higher mortality rates in the marine environment and thus would become a component of at-sea mortality. These specific threats may be exerting influence in fresh water, but their population-level impact on mortality rates occurs after smolts enter the marine environment. A second example would be adult removals in freshwater or estuarine environments that take place before fish are enumerated (e.g. mortality from by-catch or poaching). It is not known how large the freshwater components of at-sea mortality may be relative to threats taking place exclusively in the marine environment. As described in Gibson and Bowlby (2012), Hubley and Gibson (2011) found an increasing trend in mortality during the first year when evaluating survival between repeat spawning events for LaHave River salmon. Mortality in the first year includes that occurring after enumeration at Morgans Falls (during the summer or fall) through to the following summer. While their focus was on at-sea mortality, Hubley and Gibson (2011) pointed out that salmon were actually in fresh water more than two thirds of that first year.

6.1 CHANGES TO BIOLOGICAL COMMUNITIES

Invasive Species

There have been several introductions of non-native marine species to the Maritimes, including the green crab (*Carcinus maenus*), tunicates (*Ciona intestinalis*, *Botrylloides violaceus*, and *Botryllus schlosseri*), codium (*Codium fragile* spp.) and membranipora (*Membranipora membranacea*). All of these taxa have been found in the near-shore coastal environments of the Southern Upland and thus have the potential to affect the marine habitats used by Atlantic salmon.

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.

Salmonid Aquaculture

Commercial aquaculture of salmonids in the marine environment (predominantly rainbow trout and Atlantic salmon) 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, and several proposed sites are located in the Southern Upland. Currently, 39 of the 46 licensed aquaculture sites in the Southern Upland are permitted to culture salmon or both salmon and trout. Detrimental effects on wild Atlantic salmon populations from salmonid aquaculture occur by interaction in the immediate vicinity of the net-pens or by interactions between escaped aquaculture salmon and wild salmon (Leggatt et al. 2010). Aquaculture escapes, migration of wild salmon to or past aquaculture sites, and a combination of escapes and migration can potentially result in predator attraction, disease and pathogen exchanges, competition and genetic effects.

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).

More direct sources of mortality to wild Atlantic salmon from aquaculture sites (as opposed to reproductive consequences) have been hypothesized to arise from competition for resources, predator attraction to net-pens, and disease transfer from captive to wild fish. However, the available evidence suggests that growth and survival of immature Atlantic salmon in the marine environment are not limited by food (Lacroix and Knox 2005b, Friedland et al. 2009), and predator attraction to net-pens has not been directly linked to increased mortality in wild populations (Dempster et al. 2002, Leggatt et al. 2010, Sanchez-Jerez et al. 2008). Similarly, there are no proven cases in Canada where disease or sea-lice outbreaks in wild populations can be directly linked to aquaculture sites (Brooks and Jones 2008, Leggatt et al. 2010), although research in epidemiology demonstrates that exposure and the frequency of exposure are important contributing factors to the spread of disease.

In the Southern Upland, there has been relatively little monitoring effort to identify aquaculture escapes. Of 8,800 salmon examined from 11 Maritime rivers, 6,292 (71.5%) of which were from the LaHave River, aquaculture escapes constituted a mean proportion of 0.9% of a given wild population (range: 0-17%) (Morris et al. 2008). In other words, up to 17% of a given population estimate came from aquaculture escapes rather than from returning wild adults. In light of the recent growth of the aquaculture industry and the corresponding decline in wild population sizes, it is possible that the contribution from escapes is higher at present.

Licensed aquaculture locations for salmonids (rainbow trout and Atlantic salmon) in the Southern Upland region, as well as the amount of area licensed at each location are shown in Figure 6.1.1. All rivers in the Southern Upland region are within a 300 km radius of one or more aquaculture sites (Figure 6.1.2), which suggests that all wild populations have the potential to interact with escapes or to pass net-pens during migration. Leases in New Brunswick were not included in Figure 6.1.2, but would also be expected to contribute to the number of escapes found in Southern Upland rivers, particularly near the Bay of Fundy.

The influence of aquaculture escapes would be expected to decline with distance from a specific site and to be inversely related to the recipient population size. Rivers in close proximity to aquaculture leases include many of those likely to contain the larger remaining wild populations of Atlantic salmon in the Southern Upland, including the St. Mary's and LaHave rivers (Figure 6.1.1; refer also to Appendix 1). Individuals from populations such as the Annapolis/Nictaux would have the potential to interact with all salmonid aquaculture sites in the Southern Upland as fish move northward along the coast of Nova Scotia, while this would be less likely for more northern populations (e.g. those near Canso).

Aquaculture for Other Species

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, 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 impact the marine habitat of wild Atlantic salmon) in the Southern Upland have not been empirically demonstrated.

Shellfish and other fin-fish aquaculture sites are distributed throughout the near-shore coastal regions of the Southern Upland (Figure 6.1.3; refer also to Appendix 1), with a higher proportion of sites situated along the Eastern Shore (SFA 20) as compared to salmonid aquaculture. The area (number of hectares) licensed at a single site tends to be much higher than salmonid aquaculture licenses. As with salmon aquaculture, leases in New Brunswick were not included. These would be expected to have less impact on populations than sites in the Southern Upland, given the relatively limited use of the Bay of Fundy by Southern Upland salmon populations as indicated by the tagging data (refer to Section 2.3).

Diseases and Parasites

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*. Given that heavy infestation levels by the parasite have been found in surrounding regions (i.e. outer Bay of Fundy, Gulf) it is likely to be widespread (ICES 2011).

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).

6.2 PHYSICAL OR ABIOTIC CHANGE

Shifts in Oceanographic Conditions

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 (NAO) Current into the Nordic Seas. Although recent years have seen a return to low NAO values, climactic models favour a shift in the mean state of atmospheric circulation towards positive NAO conditions, likely due to anthropogenic impacts (Osborne 2011).

Winter NAO is strongly negatively correlated with sea-surface temperature and thus could influence Atlantic salmon overwintering behaviour and mortality rates at sea. Most research that has found a correlation between Atlantic salmon catches (Dickson and Turrell 2000), sea-age at maturity (Jonsson and Jonsson 2004), or adult survival and recruitment (Peyronnet et al. 2008) with winter NAO values has been from European populations, although there are weakly correlated examples from North America (e.g. Friedland et al. 2003). However, partitioning marine mortality into that experienced predominantly in freshwater and near-shore environments (first year) and that experienced in more distant marine environments (second year) demonstrated a strong correlation between NAO and survival in the second year for alternate-spawning Atlantic salmon from the LaHave River (Hubley and Gibson 2011).

Changed Predator or Prey Abundance

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

Shipping, Transport and Noise

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 (see Section 5.1 for more details).

Data on ship traffic density was obtained from the most current version of the Human Use Atlas for the Scotian Shelf, compiled and maintained by the Oceans and Coastal Management Division of DFO (Maritimes). Considering an 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 6.2.1). Relatively high traffic density also travels along the Atlantic coast of Nova Scotia, concentrated at the Canso Causeway, Halifax Harbour, and Yarmouth ferry, as well as into the Bay of Fundy (Figure 6.2.1). This traffic is concentrated close to the respective coasts and thus has a high potential to interact with immature or adult Atlantic salmon. Furthermore, migrating salmon that move northward along the coasts of Newfoundland towards Greenland (refer to Section 2.3) would have to cross the main shipping lane coming out of the Gulf of St. Lawrence.

Contaminants and Spills (Land or Water Based)

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. The study area encompassed marine habitat from Cape Sable Island in Nova Scotia to Cape North in Cape Breton, and thus included the majority of the Southern Upland. The assessment 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 of SFA 20 in the fall (Figure 6.2.2). This occurs in deeper basins with poor circulation and little exchange of dissolved oxygen with the atmosphere. These conditions occur most frequently in late summer or fall when water temperatures are high, net accumulation of organic debris from spring/summer plankton growth is high, and mixing is low (Yeats, unpublished data). Inputs of organic matter from sewage, fish plant wastes or other discharges can exacerbate an estuaries' natural tendency toward eutrophication (Yeats, unpublished data). 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 Southern Upland Atlantic salmon.

Tidal Power

There are several types of hydroelectric generating technologies that can be installed in marine environments, two of which are being used in the Bay of Fundy. The hydroelectric generating station in the Annapolis River estuary uses a STRAFLO turbine mounted in a pre-existing causeway and generates power when water is running seaward (Gibson and Myers 2002). In this type of installation, head is built up behind the causeway and a large-diameter, low-rpm turbine is used to generate power. The Annapolis generating station has two fishways for passage, but it is thought that the majority of fish moving seaward pass through the turbine (Gibson and Myers 2002). There are four main sources of mortality resulting from passage through the turbine: mechanical strikes, pressure changes, cavitation effects and shear forces. The specific impact of each varies with the size and physiology of the emigrating fish. For Atlantic salmon, it is expected that pressure, cavitation and shear are the main factors leading to smolt mortality, but that adults would have an increasing probability of mechanical strikes with fish size (Dadswell and Rulifson 1994). A recent study on mortality associated with passage through the Annapolis turbine (Gibson and Myers 2002) demonstrated a mortality range between zero and 23% for various fish species, with estimates between 7% and 23% for species of a similar size to Atlantic salmon smolts (American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*), Atlantic herring (*Clupea harengus*) and alewife (*A. pseudoharengus*)), although these rates may not be applicable to salmon because of physiological differences between salmon and these herring species.

Hydroelectric power generation using bottom-mounted turbines in marine environments is a relatively new technology that has only been installed at one test location in the Bay of Fundy, but has the potential to become much more widespread (Cada et al. 2007). Currently there is a second proposed site in the Minas Passage (near Black Rock) in the Bay of Fundy. These installations would have the potential for substantial disturbance to the surrounding substrate during installation and operation (e.g. increased turbidity, re-suspension of contaminants), as well as having the potential to cause direct mortality to fish or macroinvertebrates (e.g. from strikes or the hydraulic forces described above), to alter behaviour (e.g. migratory pathways), to reduce habitat use in proximity to the turbines, and to introduce contaminants (e.g. paint, electromagnetic radiation) into marine environments (Cada et al. 2007). This type of tidal power generation is predicted to have the greatest impact on benthic marine communities directly adjacent to the installation site, as well as on diadromous fish populations that regularly migrate through the area of installation (ICES 2011). However, this technology is very new and there is little empirical evidence for any of the aforementioned threats.

6.3 DIRECTED SALMON FISHERIES

Three groups in Canada had directed fisheries for Atlantic salmon in 2010: Aboriginal peoples, residents of Labrador fishing for food, and recreational fishermen. All commercial salmon fisheries in Canadian waters have been closed since 2000 (ICES 2011). The catch statistics from retention fisheries taking place in Atlantic Canada are aggregated estimates from both marine and freshwater fisheries, and we report on those estimates in this section, even though the impacts of fisheries in fresh water environments have been previously discussed (see Sections 5.5 and 5.6).

Aboriginal Fisheries

Three Aboriginal groups participated in the subsistence food fishery in Labrador in 2010. This fishery occurs in estuaries or coastal bays using multifilament gill nets (ICES 2011). 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 (mt). This represents a 16% increase from 2009, but is within the range of values reported for the last five years (ICES 2011). 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 Southern Upland Atlantic salmon populations.

Commercial and Near-shore Fisheries

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 the Southern Upland. However, the recent changes to regulations were established to minimize the capture of large salmon by this fishery. Furthermore, historical tag returns from the Labrador fishery indicate that captures of Southern Upland Atlantic salmon have not been numerous (refer to Figures 2.3.2 and 2.3.3). In 2010, the estimated catch for this fishery was 2.3 mt, representing approximately 1000 fish, 25% of which were large (ICES 2011).

Total Retained Catch

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 146 mt in 2010, with approximately half the catch taken in estuarine and coastal environments and the remainder in fresh water. The catch estimate represents approximately 54,000 small and 11,000 large salmon (ICES 2011). Atlantic salmon from the Southern Upland have essentially zero chance of being retained in (legal) recreational freshwater fisheries, and a very low probability of being retained in estuarine or coastal fisheries outside of Nova Scotia or

Newfoundland and Labrador, based on marine distribution patterns (refer to Section 2.3). This suggests that the contribution of salmon from the Southern Upland to the retained catch would be low, particularly when population sizes in the Southern Upland are small.

International Fisheries (St. Pierre et 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 57 recreational gillnet licenses were issued in 2010, an increase of one professional license and seven recreational licenses from 2009. Recreational licenses are restricted to one net of 180 m while professional licenses can have three nets, each up to 360 m (ICES 2011). A total harvest of 2.8 mt was reported in the professional and recreational fisheries in 2010, down from approximately 3.5 mt in 2008 and 2009 (ICES 2011). Genetic analysis of the composition of the catches indicates that 98% of the fish are of Canadian origin. As this fishery occurs in an area adjacent to the south coast of Newfoundland, it is likely to have some impact on Southern Upland populations, based on marine distribution patterns (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 mt in West Greenland and 2 mt in East Greenland (ICES 2011). This represents an increase of 53% over catches in 2009. Reporting by licensed fishermen has increased in recent years, as has the overall catch estimate (ICES 2011). Genetic analyses of the composition of the catches indicate that approximately 80% is of North American origin (ICES 2011). Atlantic salmon from the Southern Upland would contribute to catches in the Greenland fishery, but their overall contribution may be expected to be much lower than for regions with higher abundance or for populations with a higher component of adults maturing as 2SW.

6.4 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 Atlantic salmon (DFO and MNRF 2009). 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, regulations to reduce the number of salmon caught as by-catch include:

1) a moratorium on the groundfish fishery in Eastern Canada (which reduced the amount of gear that historically captured salmon), and
2) restrictions in fishing times, gear regulations or closures of bait and pelagic fisheries in Newfoundland. 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 Southern Upland 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).

6.5 COMMERCIAL FISHERIES ON PREY SPECIES OF SALMON

In the marine environment, Atlantic salmon 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 abundance and distribution of potential prey likely influences habitat use, as well as growth and survival in the marine environment (see also Section 1.3). Extensive fisheries on small demersal fishes (particularly herring, sand lance and gadoids) or crustaceans (e.g. krill) may have the potential to limit prey availability for immature Atlantic salmon (particularly upon first entering the marine environment), and could thus contribute to the marine mortality rates impacting populations from the Southern Upland. However, the shift in species composition toward smaller demersal fish species on the Scotian Shelf (refer to Section 6.1) does not lend substantial support for this hypothesis. For example, herring abundance was significantly greater in the most recent two decades than in the 1970s and 1980s when salmon abundance was high. Similarly, the abundance of sand lance was highest during the 2000s than in earlier time periods (Harvey and Hammill 2010), although it should be noted that the area sampled by the bottom trawl research vessel surveys does not include near-shore coastal habitats. Off the Grand Banks in Newfoundland, there is no question that gadoid abundance is significantly lower than it has been in previous decades after the collapse of cod populations (Hutchings 1996). Potential correlations between prey biomass, distribution patterns, and marine survival of Atlantic salmon should be investigated.

7. EXTENT TO WHICH THREATS HAVE REDUCED HABITAT QUALITY AND QUANTITY (TOR 14)

The degree to which acidification and barriers to fish passage have reduced habitat quantity for Atlantic salmon populations in the Southern Upland has been estimated in Section 4.1. These two threats are estimated to have reduced habitat availability throughout the region by approximately 60%. Thirteen individual watersheds are thought to contain essentially no useable habitat (based on acidification) and a range of 0.1% to 95% of habitat (based on stream length) is lost in other watersheds due to barriers (refer to Table 4.1.1). However, reductions in habitat quantity are likely underestimated, given that the barriers classified as passable are unlikely to be 100% efficient (particularly for all life stages), effectively reducing the number of fish that can access a given area (seasonally, intermittently or continuously). Furthermore, barrier structures that have fish passage in only one direction (either downstream or upstream) are functionally impassable to Atlantic salmon which need to move in both directions. Similarly, acidification levels that would not lead to population extirpation can be thought to cause partial reductions in habitat quantity because that habitat may be used less frequently for spawning, and juvenile survival is expected to be lower (refer to Section 2.5 and Table 2.5.3 in Gibson and Bowlby 2012). Other threats that have the potential to reduce habitat quantity in a watershed include:

1) increased frequency or duration of low water events (potentially caused by water extraction),
2) increased sedimentation (related to land use practices or roads),
3) altered hydrology (again, related to land use practices, water extraction, water diversion, or hydropower development),
4) reservoirs (that flood upstream rearing area), and
5) invasive species (that exclude Atlantic salmon from previously used habitats).

Each of these threats has the potential to affect a different portion of the river and thus could have substantial cumulative impact on freshwater habitat availability for Atlantic salmon in rivers in the Southern Upland.

The impact of threats to habitat quality is more difficult to determine for rivers in the Southern Upland. Habitat quality can be thought of in terms of productivity, with high quality habitat producing the greatest number of Atlantic salmon. Therefore, reduced productivity in a population would indicate a reduction in habitat quality relative to a given threat. Although multiple experimental studies demonstrate reduced survival, growth or some physiological change in the fish relative to threats (refer to Section 5), comparatively little research has been done that links these effects to changes in population-level productivity (i.e. demonstrates the degree to which total population size changes from a specific level of impact of a given threat). Such studies are required to develop quantitative measures of the reduction in habitat quality in freshwater or marine environments associated with threats. In other words, to be able to determine (for example) that freshwater habitat quality in a specific watershed has been reduced by 15% for a certain population due to an activity (e.g. forestry). However, the current dynamics of the LaHave River (above Morgans Falls) population indicates an overall reduction in freshwater productivity relative to the 1980s (refer to Table 2.2.1 in Gibson and Bowlby 2012). Similarly, the total catch per unit effort (of all species excluding Atlantic salmon) on the first pass of electrofishing surveys has declined from the 1970s to present on the St. Mary's and LaHave rivers (refer to Figure 4.3.1). Both of these results are likely indicative of a reduction in habitat quality (i.e. less production from the available habitat), albeit one that cannot be linked to a specific threat at present.

It was possible to determine the extent to which multiple activities occur in each watershed in the Southern Upland through an analysis of land use (e.g. forestry, agriculture, urbanization) and other threats (e.g. pH, road crossings, reservoirs). For each threat, this provides some indication of the relative degree of impact among watersheds (using the extent of the activity as a proxy for the extent of impact). 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. First, the majority of threats in fresh water influence Atlantic salmon populations at a variety of scales. For example, a reduction in pH may affect the entire watershed while the influence of agriculture activity may be localized to a tributary or stream reach and have progressively less influence with distance downstream. Second, each threat cannot be assumed to have the same magnitude of effect on salmon populations. For example, for a watershed containing both a high density of road crossings as well as invasive species, there is nothing to suggest that the population will decrease to an equal degree in response to both threats. Third, different threats are measured in different units preventing straightforward comparison. For example, the number of abandoned mine openings is a count, road crossings are expressed as a density, and forestry activity is given as a proportion. It is not possible to standardize to one unit of measurement for all types of threats unless impacts are considered categorically (e.g. low, medium, high). A categorical analysis would explicitly assume that a low impact of one threat is equivalent to a low impact of another, which is not realistic for the reasons mentioned previously. Lastly, threats are likely to be correlated, and their effects on salmon populations might compound. For example, it is likely that a population under severe stress from low pH would be more susceptible to reductions in habitat availability from dams than would a population at higher abundance. Although it was not possible to calculate a total amount of human impact in Southern Upland watersheds for this research document, understanding threats throughout the region is based on the premise that watersheds with very low juvenile densities are more highly impacted by threats than watersheds with very high juvenile densities (refer to Figure 1.1.3 in Bowlby et al. 2013).

All collected and compiled information on the extent of freshwater threats in watersheds of the Southern Upland is summarized in Table 5.2.1 to 5.4.2 (inclusive). It was not possible to consider all human activities affecting watersheds (i.e. all threats listed in Table 5.3) because of data limitations. For example, to include the relative impact of chemical contaminants, point-sources of pollution would have to have been identified spatially. For the threats that could be linked to specific locations, a count (e.g. the number of hydrodams), a density (e.g. the number of stream crossings per 10 km of road), or an estimate of the proportion of the watershed impacted by a specific threat was summarized (refer to Appendix 1 for methods). Overall, there is substantial variation in the relative magnitude and the type of threats affecting a specific watershed. In general, smaller watersheds (predominantly located close to the coast) tend to have a lower proportion of area affected by a specific threat relative to larger watersheds.

8. FEASIBILITY OF RESTORING HABITATS TO HIGHER VALUES (TOR 18)

For rivers of the Southern Upland that do not have large freshwater habitat limitations (e.g. due to acidification or barriers), survival from the smolt to adult life stages (refer to Figure 2.5.4 and 2.5.5 in Gibson and Bowlby 2012) is one of the main factors currently limiting population size. However, smolt-to-adult survival is not the sole limiting factor, and it is apparent that there are benefits to focusing on freshwater environments for remediation in terms of reducing extinction risk. Remediation actions that improve habitat quality or quantity in fresh water, and so increase productive capacity of a river, are predicted to prevent further extirpations (extinction risk drops to zero) and to promote wild self-sustaining populations, albeit at small population size (refer to Section 5 in Gibson and Bowlby 2012). This suggests that modest increases in freshwater productivity are sufficient to maintain viable populations of Southern Upland Atlantic salmon over the long-term, even at current rates of marine mortality (refer to Figure 5.1 to 5.6 in Gibson and Bowlby 2012). Additionally, it is likely more feasible to restore habitats to higher values (to increase productivity) in fresh water than at sea because functional processes (leading to changes in growth and survival) are much better understood in freshwater environments (see Section 1.1). Our inability to ascribe specific levels of impact from threats in the marine environment to specific populations significantly limits our ability to influence mortality rates. In addition, the spatial and temporal scope of many of the threats (e.g. changes in oceanographic conditions) is outside of our ability to change in the short term.

The recovery potential for Atlantic salmon populations in response to acidification has been the most studied of the threats in the Southern Upland. A small, potentially viable population was predicted for salmon in West River Sheet Harbour, if acidity was remediated for the entire river and marine mortality rates were similar to the mean estimated for the LaHave River from 1996 to 2004 (Gibson et al. 2008c). More substantial population increases were predicted for the LaHave River as a result of increasing pH to >5.6 in acidified reaches (Korman et al. 1994), but again, this result is contingent on higher marine survival than current estimates. Modeling results in Gibson and Bowlby (2012) suggest that increasing freshwater productivity by 20-50% would be sufficient to maintain a viable Atlantic salmon population in the LaHave River (above Morgans Falls). Korman et al. (1994) estimated that acidification effects in the LaHave River (a mildly impacted system) would cause a cumulative reduction in egg to smolt survival of up to

15%. Taken together, remediating the effects of acidification in the LaHave River would be projected to reduce the extinction risk to zero provided a slight increase in smolt-to-adult survival occurred concurrently. However, a review of the success of multiple liming projects in northern Europe and North America suggests that although water chemistry is commonly restored, liming durations of more than 60 years in regions like the Southern Upland may be required to naturally maintain less acidified conditions (Clair and Hindar 2005). Furthermore, aquatic fish communities (including Atlantic salmon and trout populations) do not necessarily return to their pre-acidified state and generally require additional restoration actions to promote population growth (Clair and Hindar 2005). There is also the possibility that the remaining populations of Southern Upland Atlantic salmon have locally adapted to acidified conditions since the 1980s (Fraser et al. 2008), a characteristic that has the potential to be lost if mildly acidified systems were remediated.

From the analyses of land use in the Southern Upland region, previous and on-going human activities are spatially extensive in the majority of drainage basins and have likely altered hydrological processes in Southern Upland watersheds. Landscape factors controlling hydrology operate at hierarchically nested spatial scales (regional, catchment, reach, instream habitat), which means they often override factors controlling salmon abundance at small spatial scales (Ugedal and Finstad 2011). For example, determinants of stream productivity like water chemistry, temperature or sediment supply are largely controlled by catchment scale processes (Folt et al. 1998). Therefore, remediation of landscape-level threats to watersheds (e.g. forestry, agriculture, urbanization, roads) requires working at a much larger scale than the stream reach, and typically includes actions that are distant from the stream channel (e.g. planting riparian vegetation, revisiting regulations on pesticide use, enforcement of land use regulations and policies, and community outreach on invasive species).

It is important to recognize that remediation actions to address land use issues will not produce immediate population increases of Atlantic salmon. For example, it could take decades before riparian vegetation would grow to a size that would significantly reduce sediment inputs, which would be expected to increase habitat quality and reduce juvenile mortality in the river (Broadmeadow and Nisbet 2004). Such large-scale changes are most likely to bring about substantial population increases of Atlantic salmon because:

1) they have a greater impact on total abundance in the watershed rather than on localized density, and
2) they address issues at the catchment scale.

However, a quantitative understanding of how localized negative impacts to Atlantic salmon populations from land-use practices scale up to effects on the entire river system is lacking for the majority of threats (Ugedal and Finstad 2011), so predicting how populations will respond to large-scale remediation actions is similarly uncertain. Furthermore, the effects of historical land use on the hydrological processes in a watershed can continue for decades after the actual disturbance (Harding et al. 1998, Swank et al. 2001). Given the limited ability of Southern Upland salmon populations to increase in size (refer to Section 2.5 in Gibson and Bowlby 2012) population-level response to recovery actions (i.e. increases in adult abundance) may not become measureable for several salmon generations.

In many cases, it is expected that recovery actions addressing multiple threats may be necessary to promote population recovery. For example, life history modeling of the Tobique River in New Brunswick suggests that addressing fish passage issues will only result in population increase if the issues of low freshwater productivity and high marine mortality are concurrently addressed (Gibson et al. 2009b). At a watershed scale, there has been relatively little success restoring wild self-sustaining salmon populations despite the enormity and diversity of technological and engineering solutions attempted in North America (Ruckelshaus et al. 2002). The magnitude of intervention necessary to effect recovery and the potential for residual populations to increase in size following recovery activities is largely unknown (Gibson et al. 2009b). Even though anthropogenic changes to the environment may have been the principal cause of population decline, recovery strategies focused entirely on alleviating specific human-mediated threats can fail owing to the way anthropogenic influences, environmental stochasticity and life history characteristics interact to determine population abundance over time (Jonsson et al. 1999, Hodgson and Townley 2004).

8.1. CONSIDERATIONS FOR FUTURE RECOVERY PLANNING

Restoration projects focus either on restoring habitats to a previous state or attempt to create new conditions that improve the survival of a given population. This is rarely done at a watershed scale and individual restoration activities tend to be localized (e.g. in a particular tributary or stream reach). Due to logistic considerations, it is often not possible to evaluate the effectiveness of such stream restoration projects in terms of increasing population size (i.e. the number of spawners in future generations) (Bash and Ryan 2002). Although there are many examples of increases in juvenile density (of various life stages) in the vicinity of remediation projects, these do not directly indicate increases in juvenile abundance (which would indicate population increase) in the watershed due to factors such as movement, density dependence, habitat partitioning, or fish community dynamics (Bash and Ryan 2002, Crisp 2000). It is important to recognize that many remediation techniques should still be considered experimental and will require validation of their effectiveness (through monitoring of successive life stages, up to smolt production and returning adult abundance). Implementing multiple types of remediation projects on several river systems simultaneously would be one way to achieve this goal. In other words, implement and monitor specific restoration actions to address specific threats on a given river and avoid a one-size-fits-all approach.

Selecting appropriate rivers for immediate recovery actions should take several factors into consideration (refer also to Section 3.4 in Bowlby et al. 2013). First, it is advisable to work on rivers that have a high proportion of rearing area relative to total area in the watershed (i.e. the majority of the watershed is suitable for the production of juvenile salmon) (refer to Table 2.1.1). Second, when a specific threat is chosen to be addressed, rivers that are less severely affected by the threat should be easier to remediate that those that are more severely affected. For example, if liming were to be used to reduce the acidity of a particular watershed, choosing a system that is in category 3 (i.e. pH of 5.1 to 5.4) would be more effective than choosing a system that is in category 1 (i.e. pH <4.7). However, the expected population-level change resulting from the remediation would be of a smaller magnitude and could be more difficult to detect. Third, the potential for a population to increase in size can be limited at extremely low abundance (refer to the current estimates of lifetime reproductive rates in Table 2.5.2 of Gibson and Bowlby 2012) and the risk of extinction from environmental variation increases (Gibson et al. 2009b, Norris 2004), so it is beneficial to focus on rivers with larger remaining populations. It is also expected that larger populations would be better sources for emigration (straying) and eventual colonization of surrounding rivers than smaller populations. Fourth, local habitat variation and genetic structuring among the Atlantic salmon populations in the Southern Upland (refer to Section 3.2 and 3.3 in Bowlby et al. 2013, O'Reilly et al. 2012) suggest that rivers with a variety of characteristics should be considered priorities for recovery.

9. RESEARCH RECOMMENDATIONS

9.1 RECOMMENDATIONS TO COMPLETE HABITAT-USE TORS (TOR 10)

There were no major research gaps identified that prevented addressing the habitat-use Terms of Reference for Southern Upland Atlantic salmon, even though there is information related to population dynamics, recovery potential and the impacts of threats that is not known at present.

The functional descriptions of habitat properties required by Atlantic salmon to complete their life history are comprehensively studied and reported in the literature, particularly for freshwater environments. There is variation among populations both within and outside of the Southern Upland (Chaput et al. 2006), but this variation does not alter the overall conclusions presented in Section 1.

Large-scale surveys have been completed to assess the spatial extent of productive rearing area in fresh water for 48 rivers in the Southern Upland (Amiro 2000). A highly significant regression between rearing area and total watershed drainage area could be used to estimate rearing area for the other 24 rivers. Data from the tagging database demonstrates the marine distribution within a year and among years for hatchery smolts tagged in the Southern Upland. The scale of tagging and diversity of sampling effort is not possible to replicate under the current conditions of low population size and restricted or eliminated marine fisheries. Therefore, further research on marine distribution using traditional tag-recapture studies is not feasible. Attempts have been made to use acoustic technology to better understand habitat use by smolts and adults in more restricted areas (i.e. estuaries) over the duration of months for a small number of individuals from a small number of rivers (e.g. Halfyard et al. 2013, Hubley et al. 2008a). However using fixed stations for recaptures does not provide information on small-scale habitat use in the estuary. Satellite technology has the potential to become useful for questions on the distribution of Atlantic salmon at sea, but is currently limited by the extreme cost, size of the transmitters, necessity of external attachment, and imprecise geopositioning on small spatial scales. Furthermore, the distribution of Atlantic salmon at sea depends on the spawning strategy of individual fish (e.g. Hubley et al. 2008b) as well as prey distributions and oceanic conditions which vary over space and time (Rikardsen and Dempson 2011).

The most current information on barriers to habitat access (compiled prior to 2011) and acidification (compiled prior to 2000) were used in the assessment of spatial constraints for Atlantic salmon in the Southern Upland. It is likely that the information on barriers will change over time as new construction, remediation projects or surveys are completed, but this would necessitate an update of the current analysis rather than a new research project. In terms of acidification, it is expected that acidity levels in lakes and rivers have either remained relatively constant or have undergone slight declines (i.e. increases in mean pH associated with sulphur emission reductions) since peak levels in 1970s (Clair et al. 2004, Clair et al. 2007). For highly impacted systems, even large decreases in sulphur emissions are not expected to cause substantial improvement to water chemistry within the next 25 years (Clair et al. 2007). Unless there is compelling evidence of further increases to acidification in particular watersheds, future surveys are unlikely to alter the conclusions presented in this research document in terms of freshwater habitat loss.

As detailed in Section 4, whether the supply of available habitat meets the demands of a species at present and at higher abundance depends on the life history parameters (vital rates) that govern the entire life cycle. For Atlantic salmon, this means that current or potential habitat limitations in fresh water will partially depend on survival rates experienced by salmon at sea (and vice versa). Thus, the question of habitat limitations must be analysed relative to population dynamics. The current life history dynamics of two Southern Upland Atlantic salmon populations demonstrate that freshwater habitat quantity is not currently limiting population size in either the St. Mary's (West Branch) or LaHave (above Morgans Falls) rivers. Current data are sufficient to demonstrate that monitored populations are well below predicted carrying capacities for production in fresh water. Whether freshwater habitat will become limiting as populations increase in size depends on the dynamics of recovered populations; information that cannot be known at present. In the marine environment, there is no evidence that survival is resource-limited for Atlantic salmon (including populations in the Southern Upland) (Gibson 2006, Einum and Nislow 2011), which means that habitat in the marine environment is not and will not become limiting.

9.2 RESEARCH RECOMMENDATIONS FOR USE DURING RECOVERY PLANNING

The Atlantic salmon populations of the Southern Upland provide a unique opportunity to develop research concurrently with that taking place in surrounding regions in order to address a wider diversity of questions related to population viability and recovery. For example, much of the research on inner Bay of Fundy salmon focuses on marine distribution and mortality, or on the efficacy of the Live Gene Bank for maintaining genetic variation in populations. The outer Bay of Fundy region already has research programs related to the population-level consequences of stocking programs, as well as research into the degree of mixing (e.g. straying) among populations. Although it is expected that some variation in results would be seen for populations in the Southern Upland (which would prevent results from being directly transferable), it is likely that the general patterns found for other areas would also apply to populations of the Southern Upland. By focusing recovery planning and future research on a different suite of questions in the Southern Upland, there is the potential to substantially increase the breadth of scientific knowledge with the expectation that results from the Southern Upland would benefit other areas as well. Focusing on questions that relate to fish community dynamics as indicators of habitat quality, increasing freshwater production, or a population's response to land use would be useful in this context. Additionally, evaluating the efficacy of remediation programs (for threats such as barriers, acidification, siltation, etc.) would be beneficial to determine if particular methods should be applied more generally.

CONCLUSIONS

The overall amount of rearing area for Atlantic salmon populations in the Southern Upland region is estimated to be 783,142 habitat units (100 m^2), of which impassable dams and extremely low pH (<4.7) have eliminated slightly less than half (including the majority of habitat in 18 of the 72 river systems considered in this document). Within the area remaining, habitat requirements for the various life stages include (but are not limited to) upstream and downstream accessibility, adequate water quality (including moderate temperatures), available cobble substrates, appropriate cover, and sufficient discharge. Within watersheds, both eggs/alevins and juvenile Atlantic salmon have specific habitat requirements that support essential life cycle processes and that individuals modify or defend. Given the low population sizes of Atlantic salmon in the Southern Upland at present, freshwater habitat quantity is unlikely to be limiting population recovery in rivers with a large proportion of accessible area. However, freshwater habitat quality has the potential to be, or to become, limiting in watersheds that are highly impacted by threats, relative to un-impacted systems.

Habitats in estuarine and marine environments are variable in space and time for Atlantic salmon populations of the Southern Upland, although estuaries are one option for habitat allocation. There is little evidence of extended residency times in estuaries for either smolts or kelts, although adults may reside for longer periods before entering rivers to spawn. Unimpeded access from the marine environment to fresh water is critical, and it has been hypothesized that residency in estuaries may be related to physiological acclimation to salt water or to feeding behaviours. Marine distributions are widespread along the Atlantic coast (from Nova Scotia to Newfoundland and Labrador) for the majority of the year. Immature and mature Atlantic salmon in the marine environment require access to sufficient prey resources to support rapid growth, and prey distributions are likely correlated with temperature or other oceanographic conditions that vary spatially and temporally.

There are many types of threats affecting Atlantic salmon populations in both freshwater and marine environments. In general, there is a large amount of information regarding how threats affect Atlantic salmon in terms of changes to growth, survival or behaviour of a given life stage (predominantly juveniles). However, there is comparatively little research linking threats in Southern Upland watersheds with changes to adult abundance of specific Atlantic salmon populations. Mortality from the smolt to adult life stage (which includes the impacts of some threats in fresh water as well as those in the marine environment) is thought to be the main factor limiting population size. There have been ecosystem-level shifts in species composition and oceanographic conditions on the Eastern Scotian Shelf and a landscape analysis of threats in fresh water demonstrates substantial variation in the relative magnitude and types of threats impacting each of the assessed watersheds. It is likely that some threats are correlated and that their effects on salmon productivity compound to limit overall population sizes for Southern Upland salmon.

Restoring marine or freshwater habitats to higher values requires the ability to quantify the impact of a given threat on a specific population, something that is much more feasible in fresh water than in the marine environment. Threats in fresh water are also more localized and can be addressed with remediation actions in the . It is likely that increasing habitat quality and quantity in fresh water will prevent further extirpations and promote self-sustaining populations at low size. Some threats (like acidification) have well-known remediation actions (liming) that can lead to population growth. In other cases, recovery actions addressing multiple threats simultaneously may be required to increase abundance. It has been suggested that watershed restoration for salmon species should focus first on reconnecting isolated fish habitats (i.e. remediating barriers) before moving on to restoring hydrologic, geologic and riparian processes at a watershed scale, and lastly to focusing on in-stream habitat enhancement (Roni et al. 2002). When selecting rivers for restoration, an attempt should be made to capture the range of variation among systems in the Southern Upland and to prioritize the larger remaining populations for recovery.

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TABLES

Table 2.1.1. The number of habitat units (100 m^2) in each gradient category, the estimated amount of rearing habitat (sum of habitat amounts in gradient categories >0.12%) for each watershed, and the ratio of rearing area to the total number of habitat units, for 48 rivers used by Southern Upland salmon (adapted from Amiro 2000).

		Number of 100 m^2 habitat units by area weighted percent stream gradient interval													
Number	River	0.00-0.12	0.121-0.249	0.25-0.49	0.50-0.99	1.00-1.49	1.50-1.99	2.00-2.49	2.50-2.99	3.00-3.49	3.50-5.00	5.00-25.0	Total	Rearing Area (Total >0.12)	Ratio *
1	Annapolis	Not available													
2	Round Hill	106	2,521	478	977	419	91	218	25	89	29	42	4,995	4,889	0.98
3	Le Quille	0	737	676	742	63	110	82	72	30	5	16	2,533	2,533	1.00
4	Bear	1,140	1,958	2,146	1,359	1,088	428	347	244	177	188	105	9,178	8,038	0.88
5	Sissiboo	Not available													
6	Beliveau	Not available													
7	Boudreau	Not available													
8	Meteghan	Not available													
9	Salmon (Digby)	2,070	5,170	2,228	196	66	40	20	1	3	3	0	9,797	7,727	0.79
10	Chegoggin	Not available													
11	Annis	Not available													
12	Tusket	51,566	33,030	20,989	7,851	2,378	732	402	138	77	100	68	117,330	65,764	0.56
13	Argyle	Not available													
14	Barrington	3,878	2,150	1,658	942	217	27	5	0	0	0	0	8,877	4,999	0.56
15	Clyde	31,016	14,882	7,166	1,702	266	176	32	13	5	11	3	55,272	24,256	0.44
16	Roseway	17,960	5,516	6,554	3,510	1,279	318	210	130	38	94	42	35,652	17,692	0.50
17	Jordan	13,496	8,405	5,269	1,274	408	213	126	24	10	37	13	29,273	15,777	0.54
18	East (Lockeport)	533	1,002	1,189	261	60	0	4	0	0	2	0	3,052	2,519	0.83
19	Sable	Not available													
20	Tidney	Not available													
21	Granite Village	Not available													
22	Broad	1,067	2,469	1,294	1,384	482	57	111	0	4	3	0	6,869	5,802	0.84
23	Mersey	Not available													
24	Medway	23,793	32,275	23,427	8,771	1,875	542	196	212	120	179	56	91,446	67,653	0.74
25	Petite	730	2,404	2,347	1,285	268	38	80	8	1	9	4	7,174	6,444	0.90
26	LaHave	13,902	20,905	16,202	9,668	2,133	917	353	212	121	235	101	64,750	50,848	0.79
27	Mushamush	440	161	1,093	725	226	45	12	11	16	13	1	2,743	2,303	0.84
28	Martins	0	1,778	1,904	1,245	121	155	38	97	23	40	40	5,441	5,441	1.00
29	Gold	1,447	8,676	3,787	4,026	628	280	80	36	50	116	62	19,188	17,741	0.92
30	Middle	0	1,713	3,692	2,440	586	128	290	125	82	83	130	9,270	9,270	1.00
31	East (Chester)	198	126	1,321	1,626	337	192	164	50	48	72	33	4,167	3,969	0.95
32	Little East	Not available													
33	Hubbards	13	0	117	471	86	84	24	40	54	34	11	936	923	0.99
34	Ingram	253	273	1,181	1,144	715	207	25	11	33	73	39	3,955	3,702	0.94
35	Indian	Not available													
36	East (St. Margarets)	Not available													
37	Nine Mile	284	201	1,369	902	363	118	145	91	45	54	45	3,618	3,334	0.92
38	Pennant	Not available													
39	Sackville	287	2,376	2,137	1,133	429	194	51	83	60	11	11	6,772	6,485	0.96
40	Salmon (L. Major)	Not available													

Number	River	Number of 100 m^2 habitat units by area weighted percent stream gradient interval 0.00-0.12	0.121-0.249	0.25-0.49	0.50-0.99	1.00-1.49	1.50-1.99	2.00-2.49	2.50-2.99	3.00-3.49	3.50-5.00	5.00-25.0	Total	Rearing Area (Total >0.12)	Ratio *
41	Salmon (L. Echo.)	89	1,711	1,378	2,317	489	236	107	70	38	61	39	6,535	6,446	0.99
42	Porter's Lake (West Bk. + East Bk.)	0	310	1,804	709	283	164	118	59	43	11	19	3,517	3,517	1.00
43	Chezzetcook	0	0	133	845	432	131	161	22	40	66	22	1,852	1,852	1.00
44	Musquodoboit	15,206	3,948	2,289	833	268	280	90	92	30	83	7	23,125	7,919	0.34
45	Salmon (Halifax)	23	228	436	1,571	225	77	77	78	51	30	38	2,834	2,811	0.99
46	Ship Harbour	Not available													
47	Tangier	3,556	4,381	4,479	2,982	915	386	145	119	37	119	19	17,139	13,583	0.79
48	West Taylor Bay	0	0	117	225	180	0	19	7	15	5	11	580	580	1.00
49	Little West	350	290	339	390	193	75	0	35	47	1	26	1,745	1,395	0.80
50	West River (Sheet Harbour)	380	4,726	5,357	4,102	1,377	274	293	290	142	66	47	17,052	16,672	0.98
51	East Sheet Harbour	1,479	7,272	11,563	7,849	1,814	525	475	83	55	51	63	31,227	29,748	0.95
52	Kirby (Halfway Bk.)	Not available											1,604	1,604	1.00
53	Salmon (Port Dufferin)	1,357	1,352	1,603	1,816	429	103	32	19	11	24	0	6,746	5,389	0.80
54	Quoddy	0	1,348	4,298	851	119	119	18	58	26	12	0	6,849	6,849	1.00
55	Moser	62	4,866	7,688	1,483	475	506	160	7	0	20	2	15,270	15,208	1.00
56	Smith Brook	0	402	255	284	85	28	0	0	0	0	0	1,055	1,055	1.00
57	Ecum Secum	2,231	1,833	3,340	1,968	180	150	99	49	0	45	0	9,894	7,663	0.77
58	Liscomb	12,362	9,275	5,133	4,500	1,696	341	153	178	29	44	43	33,753	21,391	0.63
59	Gaspereau Brook	3	1,301	821	456	114	104	21	0	0	2	4	2,826	2,823	1.00
60	Gegogan	Not available													
61	St. Mary's	18,863	24,664	8,554	4,543	1,109	487	302	102	44	49	0	58,717	39,854	0.68
62	Indian Harbour Lakes	Not available													
63	Indian	Not available													
64	Country Harbour	187	1,108	829	1,050	176	32	30	16	24	1	4	3,457	3,270	0.95
65	Issacs Harbour	16	0	408	1,007	451	91	4	24	2	33	22	2,059	2,043	0.99
66	New Harbour	Not available													
67	Larrys	222	28	417	379	729	240	164	167	57	117	112	2,632	2,410	0.92
68	Cole Harbour (Jamieson Bk.)	1,244	602	124	602	115	27	0	0	2	3	11	2,730	1,486	0.54
69	Salmon (Guys. Co.)	1,051	2,731	6,507	1,483	265	411	160	114	31	71	17	12,840	11,789	0.92
70	Guysborough	105	569	1,017	1,083	632	394	260	67	48	92	55	4,322	4,217	0.98
71	Clam Harbour	273	410	361	1,630	170	99	11	0	27	4	25	3,009	2,736	0.91
72	St. Francis Harbour	Not available													

* Rearing area/Total area. The ratio describes the amount of productive habitat relative to the total number of habitat units in the watershed.

Table 2.1.2. General characteristics of 72 salmon rivers known to be used, either in the present or in the past, by Southern Upland Atlantic salmon. Measured rearing area, pH classification, as well as the recognised barrier information comes from Amiro (2000). Estimated salmon densities come from two large-scale surveys conducted in 2000 (Amiro et al. 2000) and 2008/09 (Gibson et al. 2011).

Number	Name	Drainage Area (m^2)*	Rearing Area (m^2)** measured	estimated	Conservation Requirement (eggs)	pH Category***	Recognised Barrier****	Salmon survey mean density (#/100m^2) 2000	2008/09
1	Annapolis/Nictaux	1,448,173,835	-	54,153	12,996,723	2	impassible dam/falls	-	0.31
2	Round Hill	135,805,556	4,889	-	1,173,360	3	-	2.45	0.00
3	Le Quille	146,896,500	2,533	-	607,920	-	-	-	-
4	Bear	329,345,827	8,038	-	1,929,120	2	impassible dam/falls	-	0.00
5	Sissibo	641,091,570	-	23,973	5,753,515	2	impassible dam/falls	0.00	-
6	Beliveau	44,525,616	-	1,665	399,598	4	-	0.00	0.00
7	Boudreau	47,989,312	-	1,795	430,683	4	-	-	-
8	Meteghan	233,800,765	-	8,743	2,098,259	4	impassible dam/falls	-	-
9	Salmon (Digby)	234,073,037	7,727	-	1,854,480	3	-	10.12	0.66
10	Chegoggin	37,030,524	-	1,385	332,333	-	-	-	0.00
11	Annis	158,245,453	-	5,917	1,420,183	3	-	0.00	0.00
12	Tusket	1,456,220,963	65,764	-	15,783,360	2	-	2.61	0.04
13	Argyle	72,506,728	-	2,711	650,716	1	-	0.00	-
14	Barrington	184,413,431	-	6,896	1,655,029	1	-	-	-
15	Clyde	777,280,540	24,256	-	5,821,440	1	-	0.00	0.00
16	Roseway	549,909,272	17,692	-	4,246,080	1	-	-	0.00
17	Jordan	414,076,847	15,777	-	3,786,480	1	-	0.00	0.00
18	East (Lockeport)	60,510,639	2,519	-	604,560	1	-	0.00	0.00
19	Sable	178,169,717	-	6,662	1,598,995	1	-	0.00	0.00
20	Tidney	141,061,525	-	5,275	1,265,965	1	-	0.00	0.00
21	Granite Village	22,763,038	-	851	204,288	-	-	-	0.00
22	Broad	195,544,715	5,802	-	1,392,480	1	-	-	-
23	Mersey	1,936,238,697	-	72,404	17,376,890	2	impassible dam/falls	0.00	0.00
24	Medway	1,519,139,618	67,653	-	16,236,720	3	-	7.38	4.11
25	Petite	229,780,814	6,444	-	1,546,560	4	-	10.78	0.44
26	Lahave	1,524,155,608	50,848	-	12,203,520	3	-	14.20	5.63
27	Mushamush	154,776,571	2,303	-	552,720	4	-	40.56	0.60
28	Martins	96,298,268	5,441	-	1,305,840	2	-	0.00	0.00
29	Gold	386,186,970	17,741	-	4,257,840	3	-	11.68	3.41
30	Middle	182,130,294	9,270	-	2,224,800	2	-	3.73	2.14
31	East (Chester)	136,596,127	3,969	-	952,560	2	-	6.44	0.26
32	Little East	29,314,620	-	1,096	263,086	2	-	-	0.00
33	Hubbards	75,113,107	923	-	221,520	-	-	-	-
34	Ingram	74,395,055	3,702	-	888,480	2	-	0.00	0.00
35	Indian	185,304,042	-	6,929	1,663,022	2	impassible dam/falls	0.00	-
36	East River (St. Margarets)	36,809,689	-	1,376	330,351	-	-	-	0.00
37	Nine Mile	135,376,626	3,334	-	800,160	1	-	0.00	0.00
38	Pennant	85,067,140	-	3,181	763,440	1	-	-	-
39	Sackville	150,556,924	6,485	-	1,556,400	3	-	-	-
40	Salmon (L Major)	80,200,676	-	2,999	719,766	2	-	0.00	0.00
41	Salmon (L. Echo)	161,259,649	6,446	-	1,547,040	2	-	0.04	0.00
42	Porters Lake (West Bk. + East Bk.)	166,427,507	3,517	-	844,080	-	-	-	0.00
43	Chezzetcook	95,147,617	1,852	-	444,480	3	-	0.00	-
44	Musquodoboit	719,084,011	7,919	-	1,900,560	4	-	65.36	17.72

Number	Name	Drainage Area (m^2)*	Rearing Area (m^2)** measured	Rearing Area (m^2)** estimated	Conservation Requirement (eggs)	pH Category***	Recognised Barrier****	Salmon survey mean density (#/100m^2) 2000	Salmon survey mean density (#/100m^2) 2008/09
45	Salmon (Hfx)	103,228,551	2,811	-	674,640	2	-	0.00	0.00
46	Ship Harbour (Fish River -L. Charlotte)	352,790,266	-	13,192	3,166,137	4	-	4.54	4.17
47	Tangier	283,314,640	13,583	-	3,259,920	2	-	0.00	0.00
48	W Taylor Bay	59,678,662	580	-	139,200	3	-	0.00	0.00
49	Little West (Grand Lake)	58,487,201	1,395	-	334,800	-	-	0.00	0.00
50	West (Sh Hbr)	288,917,212	16,672	-	4,001,280	2	-	6.37	0.09
51	East (Sh Hbr)	576,661,750	29,748	-	7,139,520	2	-	-	-
52	Kirby (Halfway Bk)	34,836,151	1,604	-	384,960	3	-	35.97	5.03
53	Salmon (P.D.)	138,216,779	5,389	-	1,293,360	3	-	1.01	1.40
54	Quoddy	51,292,117	6,849	-	1,643,760	4	-	1.39	0.46
55	Moser	177,300,411	15,208	-	3,649,920	3	-	12.26	1.96
56	Smith	19,764,096	1,055	-	253,200	-	-	12.52	5.24
57	Ecum Secum	94,837,352	7,663	-	1,839,120	4	-	10.16	2.40
58	Liscomb	400,736,050	21,391	-	5,133,840	2	-	8.34	-
59	Gaspereau Bk	75,163,798	2,823	-	677,520	3	-	2.85	0.00
60	Gegogan	23,218,204	-	868	208,373	4	-	0.00	0.00
61	St Marys	1,336,821,877	39,854	-	9,564,960	4	-	17.57	7.00
62	Indian Harbour Lakes	30,839,311	-	1,153	276,769	4	-	0.46	0.00
63	Indian	98,471,975	-	3,682	883,743	1	-	0.00	0.00
64	Country Harbour	183,469,792	3,270	-	784,800	4	-	26.29	8.35
65	Issacs Harbour	78,242,645	2,043	-	490,320	2	-	0.62	0.00
66	New Harbour	149,632,884		5,595	1,342,889	3	-	0.13	-
67	Larrys	72,044,873	2,410	-	578,400	1	-	-	-
68	Cole Harbour (Jamieson Bk.)	52,675,844	1,486	-	356,640	2	-	-	-
69	Salmon (Guys.)	298,709,932	11,789	-	2,829,360	-	-	-	18.66
70	Guysborough	116,841,158	4,217	-	1,012,080	-	-	-	-
71	Clam Harbour	70,107,428	2,736	-	656,640	-	-	-	-
72	St. Francis Harbour	86,088,355	-	3,219	772,605	-	-	-	-

* Drainage areas were calculated from the Secondary Watersheds layer for ArcGIS® developed by the NSDoE.

** Measured rearing areas came from gradient classification data for each watershed as per the methods detailed in Amiro (1993). Calculated rearing areas are based off of the linear regression described in Section 2.1 of this document.

***pH classification categories as per Watt (1987): 1 = <4.7; 2 = 4.7-5; 3 = 5.1-5.4; 4 = >5.4 pH units.

**** In these rivers most of the salmon habitat is unavailable due to impassable dams or falls.

Table 4.1.1. Summary of the effects of total barriers on the amount of rearing area available for Southern Upland Atlantic salmon. Three sources of information were used: (1) the National Hydro Network (NHN) database intersected by the barriers layer from the NSDoE and DFO Habitat Division, (2) previous assessment information from Amiro (2000) on impassable dams and falls, and (3) previous assessment information from Amiro (2000) on highly acidified rivers.

				Physical		Chemical	
River Number	Name	Drainage Area (m^2)	Rearing Area (100 m^2)	Amiro (2000) % affected	NHN database % affected	Amiro (2000) % affected	Remaining Rearing Area (100 m^2)
1	Annapolis/Nictaux	1,448,173,835	54,153	-	30.7	-	37,533
2	Round Hill	135,805,556	4,889	-	94.2	-	282
3	Le Quille	146,896,500	2,533	-	77.6	-	567
4	Bear	329,345,827	8,038	100	55.7	-	3,559
5	Sissibo	641,091,570	23,973	100	90.2	-	2,341
6	Beliveau	44,525,616	1,665	-	0	-	1,665
7	Boudreau	47,989,312	1,795	-	0	-	1,795
8	Meteghan	233,800,765	8,743	100	74.6	-	2,221
9	Salmon (Digby)	234,073,037	7,727	-	11.0	-	6,880
10	Chegoggin	37,030,524	1,385	-	0	-	1,385
11	Annis	158,245,453	5,917	-	46.6	-	3,162
12	Tusket	1,456,220,963	65,764	-	10.1	-	59,112
13	Argyle	72,506,728	2,711	-	85.1	100	**0**
14	Barrington	184,413,431	6,896	-	0	100	**0**
15	Clyde	777,280,540	24,256	-	1.1	100	**0**
16	Roseway	549,909,272	17,692	-	0	100	**0**
17	Jordan	414,076,847	15,777	-	8.3	100	**0**
18	East (Lockeport)	60,510,639	2,519	-	0	100	**0**
19	Sable	178,169,717	6,662	-	0	100	**0**
20	Tidney	141,061,525	5,275	-	0	100	**0**
21	Granite Village	22,763,038	851	-	0	-	851
22	Broad	195,544,715	5,802	-	0	100	**0**
23	Mersey	1,936,238,697	72,404	100	75.6	-	17,667
24	Medway	1,519,139,618	67,653	-	17.7	-	55,702
25	Petite	229,780,814	6,444	-	43.4	-	3,646
26	Lahave	1,524,155,608	50,848	-	0	-	50,848
27	Mushamush	154,776,571	2,303	-	85.5	-	334
28	Martins	96,298,268	5,441	-	0	-	5,441
29	Gold	386,186,970	17,741	-	0	-	17,741
30	Middle	182,130,294	9,270	-	0	-	9,270
31	East (Chester)	136,596,127	3,969	-	0	-	3,969
32	Little East	29,314,620	1,096	-	0	-	1,096
33	Hubbards	75,113,107	923	-	0	-	923
34	Ingram	74,395,055	3,702	-	0	-	3,702
35	Indian	185,304,042	6,929	100	93.7	-	439
36	East River (St. Margarets)	36,809,689	1,376	-	0	-	1,376
37	Nine Mile	135,376,626	3,334	-	1.1	100	**0**
38	Pennant	85,067,140	3,181	-	0	100	**0**

River Number	Name	Drainage Area (m^2)	Rearing Area ($100\ m^2$)	Physical: Amiro (2000) % affected	Physical: NHN database % affected	Chemical: Amiro (2000) % affected	Remaining Rearing Area ($100\ m^2$)
39	Sackville	150,556,924	6,485	-	2.2	-	6,341
40	Salmon (L Major)	80,200,676	2,999	-	32.8	-	2,017
41	Salmon (L. Echo)	161,259,649	6,446	-	0	-	6,446
42	Porters Lake (West Bk. + East Bk.)	166,427,507	3,517	-	0	-	3,517
43	Chezzetcook	95,147,617	1,852	-	0	-	1,852
44	Musquodoboit	719,084,011	7,919	-	16.2	-	6,635
45	Salmon (Hfx)	103,228,551	2,811	-	0	-	2,811
46	Ship Harbour (Fish River - L. Charlotte)	352,790,266	13,192	-	0	-	13,192
47	Tangier	283,314,640	13,583	-	0	-	13,583
48	W Taylor Bay	59,678,662	580	-	0	-	580
49	Little West (Grand Lake)	58,487,201	1,395	-	0	-	1,395
50	West (Sh Hbr)	288,917,212	16,672	-	0	-	16,665
51	East (Sh Hbr)	576,661,750	29,748	-	9.2	-	27,003
52	Kirby (Halfway Bk)	34,836,151	1,604	-	0	-	1,604
53	Salmon (P.D.)	138,216,779	5,389	-	0	-	5,389
54	Quoddy	51,292,117	6,849	-	0	-	6,849
55	Moser	177,300,411	15,208	-	0	-	15,208
56	Smith	19,764,096	1,055	-	0	-	1,055
57	Ecum Secum	94,837,352	7,663	-	0	-	7,663
58	Liscomb	400,736,050	21,391	-	0	-	21,391
59	Gaspereau Bk	75,163,798	2,823	-	0	-	2,823
60	Gegogan	23,218,204	868	-	0	-	868
61	St Marys	1,336,821,877	39,854	-	0	-	39,836
62	Indian Harbour Lakes	30,839,311	1,153	-	12.0	-	1,015
63	Indian	98,471,975	3,682	-	0	100	**0**
64	Country Harbour	183,469,792	3,270	-	0	-	3,270
65	Issacs Harbour	78,242,645	2,043	-	0	-	2,043
66	New Harbour	149,632,884	5,595	-	0	-	5,595
67	Larrys	72,044,873	2,410	-	0	100	**0**
68	Cole Harbour (Jamieson Bk.)	52,675,844	1,486	-	0	-	1,486
69	Salmon (Guys.)	298,709,932	11,789	-	0.1	-	11,777
70	Guysborough	116,841,158	4,217	-	0	-	4,217
71	Clam Harbour	70,107,428	2,736	-	0	-	2,736
72	St. Francis Harbour	86,088,355	3,219	-	0	-	3,219
		Totals (rearing area)	**783,142**	**120,087**	**210,119**	**100,198**	**476,746**

Table 5.1. The relationship between human activities affecting watersheds used by Southern Upland Atlantic salmon (rows) and the functional changes to freshwater habitats (column headings) associated with those activities. All interactions are marked with an 'X'.

Human Activities	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
Pulp and paper mills		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			

Table 5.2. The relationship between human activities in the oceans (rows) and the functional changes to marine habitats (column headings)for Southern Upland Atlantic salmon associated with those activities. All interactions are marked with an 'X'.

Human Activities	Invasive species	Changed predator or prey abundance	Diseases/parasites	Contaminants
Aquaculture	X	X	X	X
Shipping/Transport	X	X		X
Tidal power		X		X
Fisheries on prey species		X		

Table 5.3 and Table 5.4. Threats tables for the freshwater and marine environments, respectively, summarizing human activities or sources of environmental change that either negatively impact Southern Upland Atlantic salmon populations (i.e. cause reduced abundance) or cause reduced quality and/or quantity of their habitat.

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 behavioural changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur. 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 Southern Upland DU, where stress is defined as changes to ecological, demographic, or behavioural 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 Southern Upland 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 Southern Upland 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. Habitat-level impacts are adapted from the DFO risk assessment framework for science advice and the expected changes in population productivity are adapted from the Conservation Status Report Part II: Anthropogenic impacts (DFO and MNRF 2008). 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 Southern Upland DU specifically (this does not apply to threats that are anticipatory). See table below for definitions.

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

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 the Southern Upland (threat and stress are defined above). This information puts the threat in context and helps to designate overall concern and severity.

Table 5.3. Threats to Southern Upland (SU) Atlantic salmon populations in freshwater environments.

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 SU salmon populations	**Rationale**
Freshwater environment								
Water quality and quantity	Acidification	**High**	Very High (78% of assessed populations affected)	H, C and A Continuous and recurrent	Extreme	Very High	Very High	Sulfate deposition from acid rain. SU rivers have little buffering capacity and cannot recover in the short term from lowered pH. Low pH has physiological effects on juveniles, as well as reduces juvenile survival. The large scale extent, long-term nature of this threat, together with it affecting multiple life stages, and very high SU-specific causal certainty lead to a ranking of a High Level of Concern.
	Extreme temperature events	**Medium**	High to Very High (anecdotal information suggests the majority of rivers are affected)	H, C and A Seasonal	High	High	Medium	Brought on by factors such as removing cover, changing water flow patterns, and climate change. Affects behaviour, growth and survival of freshwater life stages, reduces freshwater habitat, and exacerbates impacts of other threats. Fish kills have been observed. The high severity, affecting multiple life stages, and medium SU-specific causal certainty lead to a ranking of 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	Due to development along rivers (e.g. agriculture, municipal, or industrial use, climate change, hydroelectric development). Significantly reduced or increased flow decreases survival of juveniles, affects adult returns to rivers, as well as altering sedimentation rates and habitat availability. The uncertain location and extent, low evidence of SU-specific impacts, and ranges of severity result in a Low Level of Concern.
	Altered hydrology	**High**	High to Very High	H, C and A Seasonal	High	High	Medium	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. Medium evidence of SU-specific impacts, but extreme flow events are observed, resulting in a High 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 SU salmon populations	Rationale
Freshwater environment								
	Chemical contaminants	**Low**	Unknown (anecdotal information suggests the majority of populations affected)	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 freshwater 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 SU-specific impacts, and ranges of severity result in a Low Level of Concern.
	Silt and sediment	**Medium**	Very High (100%)	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 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 communitie s	Invasive species (fish)	**High**	Medium (22% of assessed populations)	H, C and A Continuous	High	High	Medium	Chain pickerel and smallmouth bass are most significant invasives. Efficient predators leading to direct mortality of salmon. Some potential for competition to salmon from introduced salmonids. The high severity, medium SU-specific causality, medium location or extent, and increasing widespread distribution of pickerel and bass result in a Medium Level of Concern.
	Invasive species (other)	**Low**	Low	A Continuous	Low to High	Medium	Very Low	*Didymo* forms dense mats that alter the composition of aquatic insect communities. Has the potential to cause habitat alteration and changes in prey communities for juvenile salmon. The very low SU-specific causality, and that the major impacts are in New Zealand, with limited observed impacts within its spreading range in Canada 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** evidence linking the threat to stresses in general	**Causal Certainty** evidence for changes to viability of SU salmon populations	Rationale
Freshwater environment								
	Stocking (historical) Stocking for fisheries enhancement using traditional methods	**Medium**	Very High	H and C Continuous	Medium 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	Declines in fitness associated with traditional stocking practices are well established. There is a trade-off between short-term gain for population increase vs. long-term impact on population productivity. The very high location or extent, very large number of historically stocked fish, high severity, and possible long-term detrimental fitness effects of stocking result in a Medium Level of Concern.
	Stocking (current)	**Low**	Low (several Fish Friends projects; educational programs)	C and A Continuous	Low to High (dependent upon number of juveniles stocked and size of recipient population)	High	Low	Limited broodstock collection and release of juveniles; extremely low potential to contribute to population increase but similarly low impact on population productivity due to very low extent. The very small scale of this activity results in a Low Level of Concern.
	Other salmonid stocking (rainbow, brown, & brook trout)	**Low**	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 Extent combined with the limited evidence of population level effects from interactions result in a Low Level of Concern.
	Salmonid aquaculture (commercial)	**Low**	Low	H, C and A Continuous	Medium	High	Low	Potential impacts from juvenile escapes from commercial rearing sites, introduction of chemical contaminants, increased competition, potential for disease transfer, and reduced habitat quality. The Low ranking for Location/Extent and Medium ranking of Severity result in a Low Level of Concern.
	Avian predators	**Medium**	High	C and A Seasonal	High	Medium	Medium	Several species of birds are known to prey on migrating smolts. Existing literature is equivocal as to the impact on salmon populations by bird predators, which is likely population specific. The medium causality, high location or extent, and high severity, together with cormorant populations increasing over time, 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 SU salmon populations	
Freshwater environment								
	Reductions in Genetic Variation (due to 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	None (Not evaluated)	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	**Medium (abundance specific)**	Very High (abundance is low in all rivers)	H, C and A Continuous	Low to High (dependent on population-specific abundance)	Medium	Low	Allee effects occur when survival or productivity decrease as abundance decreases. Examples include inability to find mates reducing spawning success and too few fish to form effective schools. The low abundance in most rivers coupled with the Medium causal certainty result in a Medium Level of Concern.
	Scientific Activities	**Low**	Low (Two Index 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 behaviour, disruption of smolt migration. The very small spatial extent of this activity, low known impacts, sampling of only a small aprt of the populations in most cases, and the fact that activities are designed to minimize risk to sampled organisms result in a Low Level of Concern.
Physical obstructions	Habitat fragmentation due to dams, culverts and other permanent structures	**High**	Medium to Very High	H, C and A Continuous	Medium to Extreme (Dependent upon design of structure and location within the watershed)	Very High	Very High	These obstructions 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. 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 large number of structures on some large-river systems, potentially very high severity, and very high SU-specific certainty result in a High 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 SU salmon populations	Rationale
Freshwater environment								
	Reservoirs	**Medium**	Medium	H, C and A Continuous	Low to High (Dependent upon size of individual reservoirs and number in series on a system)	High	Medium	Impacts of reservoirs include bioaccumulation of methylmercury, changes to hydrological patterns and altered freshwater habitat from impounding water. These may also delay smolt migration downstream and expose smolt to predation by bass and pickerel. The Medium location/extent, potentially high severity, medium SU-specific certainty, and impacts to both habitat and the salmon themselves result in a Medium Level of Concern
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 SU-specific certainty result in a Medium Level of Concern.
	Pulp and paper mills	**Low**	Low (only two known pulp mills in DU)	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. The very low location/extent, regulated effluent quality, and low SU-specific certainty result in a Low Level of Concern.
	Hydro power generation	**Medium**	Medium	H, C and A Continuous	Medium to Extreme (dependent upon facility design and operating schedule)	High	Medium	Impacts include channelization, habitat loss from impoundment, introduction of chemical contaminants, temperature changes, turbine mortality, fish passage issues and modified flow patterns. Each station may have different impacts dependent upon design and operating schedule. The medium location/extent, potentially high-extreme sevcerity, and multiple impacts (habitat, direct mortality, altered flows affecting behaviour) result in a Medium Level of Concern.
	Urbanization	**Medium**	Medium	H, C and A Continuous	Low to High (dependent upon density of urbanization and infrastructure development)	High	Medium	This is associated with multiple threats impacting populations, such as roads, contaminant, 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 locations of urban centers in the DU which 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** evidence linking the threat to stresses in general	**Causal Certainty** evidence for changes to viability of SU salmon populations	**Rationale**
Freshwater environment								
	Agriculture	**Medium**	High	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 and that some watershed are under intensive agriculture, while most are subject to lesser agiculture result in a Medium 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 variation in the extent of the activity among watersheds result in a Medium Level of Concern.
	Mining	**Medium**	Unknown	H, C and A Continuous	Low to High (dependent upon type of mine, processes used, and susceptibility to acid rock drainage)	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 (ARD). The low to medium certainty coupled with the widespread exploration and exploitation result in a Medium Level of Concern.
Directed salmon fishing (current)	Aboriginal FSC fishery	**Low**	Low	H, C and A Seasonal	Negligible	Very High	High	Harvest of salmon for permitted food, social or ceremonial purposesharvest is low in SU 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	Very High	High	There is no permitted fishery 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.
	Illegal fishing and poaching	**High**	Unknown (but potentially high)	H, C and A Seasonal	Low to High (dependent on number of salmon removed and size of impacted population)	High	High	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 for some populations, and high risk a s a few individual poachers could remove a large proportion of a small population result in a High 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 SU salmon populations	Rationale
Freshwater environment								
By-catch in other fisheries	Aboriginal or commercial fisheries	**Low**	Low	H, C and A Seasonal	Low	High	High	Immature and adult mortality is low from permitted gear types and seasons. The low location/extent and low severity result in a Low Level of Concern relative to other threats.
	Recreational fisheries	**Low**	High	H, C and A Seasonal	Low	High	High	Recreational fisheries for other salmonids, American shad, 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 relative to other threats, True by-catch is low, in contrast to illegally targeting salmon while fishing for other species (see below)
	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	High	This threat can lead 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 5.4. Threats to Southern Upland Atlantic salmon populations in marine and estuarine environments.

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 SU salmon populations	**Rationale**
Marine and Estuarine environments								
Changes to biological communities	Invasive species	**Low**	Very High (all populations)	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	H, C and A Continuous	Medium to High (dependent upon location of aquaculture sites and operating practices)	High	Low	Impacts include near-shore habitat loss, possible disease transfer, predator attraction, and interbreeding. May contribute to immature and adult mortality rates and lower reproductive success. Individual sites have the potential to impact multiple populations. The high location/extent, medium-high severity, 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, location and operating practices)	Low	Low	Impacts include near-shore habitat loss and changes in ecological communities. The low severity and low causal certainty result in a Low Level of Concern.
	Diseases and parasites	**Medium**	Very High (all populations)	H, C and A Continuous	Low to High (dependent upon irruptive behavior of disease/parasites resulting in outbreaks)	Low	Low	Examples. *Anasakis*, sea lice. Introduces physiological stress on individuals and lowers overall condition, leading to increased mortality rates. The high location/extent, potentially high severity, and low causal certainty result 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** evidence linking the threat to stresses in general	**Causal Certainty** evidence for changes to viability of SU salmon populations	Rationale
Marine and Estuarine environments								
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)	Medium	Low	Includes climate change affecting sea temperatures, currents and ice cover; ecosystem shifts; and human-induced changes topredator/prey populations. Effects mortality rates at sea for immature and adult salmon. The very high location/extent, potentially high severity, and low causal certainty result in a High 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 of salmon 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.
	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.

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 SU salmon populations	Rationale
Marine and Estuarine environments								
	Tidal power	**Low**	Low	C and A Seasonal	Medium to High (dependent upon facility design and operating schedule)	High	Medium	There is a single tidal power generating station in the Annapolis River estuary. The majority of the flow goes through the turbine. Direct mortality of smolts and adults from passage through the facility is expected. Given that there is only one facility in the DU, despite the medium-high severity this threat results in a Low Level of Concern for the DU as a whole.
Directed salmon fisheries	Subsistence fisheries (Aboriginal and Labrador residents)	**Low**	Low	H and A Seasonal	Negligible	High	High	All commercial salmon fisheries of the Southern Upland are closed. Retentions from the subsistence fishery were low in 2010 and are thought to come predominantly from local (non-SU) populations. 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.
	International fisheries (Greenland; St. Pierre-Miquelon)	**Medium**	Very High (MSW component of all populations)	H, C and A Seasonal	Negligible to High	High	Medium	Greenland fisheries have been reduced to a subsistence harvest from historical commercial fisheries. Level of concern would be higher if TAC's were increased. Exploitation rates high enough to result in a Medium Level of Concern if SU salmon are captured in proportion to other stocks.
By-catch in other fisheries	Commercial fisheries	**Low**	Very High (all populations)	H, C and A Seasonal	Low	High	High	Immature and adult mortality is thought to be low from permitted gear types and seasons leading to a low scoring for Severity. The low severity results in a Low Level of Concern.
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	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.

Table 5.2.1. Summary of the distribution of chain pickerel and smallmouth bass in Southern Upland rivers as of 2010. Individual watersheds and the number of locations within each watershed are shown. River numbers correspond to those in Table 2.1.1. Data are from NSDFA. The category “All coastal Southern Upland drainages” includes watersheds that are not included in the list of 72 rivers used by Southern Upland Atlantic salmon.

Chain pickerel		
River Number	Watershed Name	# of Occurrences
7	Boudreau	5
8	Meteghan	25
9	Salmon (Digby)	1
11	Annis	8
12	Tusket	4
26	Lahave	4
39	Sackville	1
All coastal Southern Upland drainages		21

Smallmouth bass		
River Number	Watershed Name	# of Occurrences
1	Annapolis/Nictaux	5
3	Le Quille	2
7	Boudreau	2
8	Meteghan	7
9	Salmon (Digby)	13
10	Chegoggin	1
11	Annis	3
12	Tusket	20
16	Roseway	3
23	Mersey	2
24	Medway	11
25	Petite	9
26	Lahave	17
27	Mushamush	9
29	Gold	7
35	Indian	3
37	Nine Mile	1
38	Pennant	2
39	Sackville	5
All coastal Southern Upland drainages		52

Table 5.2.2. Decadal summary of the stocking programs in Southern Upland rivers 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 Southern Upland and hybrid is a crossbreed of two different populations (either native x local or local x local). River numbers correspond to those in Table 2.1.1. Data are from the hatchery distributions database maintained by DFO Science.

River Number	River Name	Decade	Number of Fish	Life Stage	Stock Origin
4	Bear	1990	89,489	smolt	native/local
4	Bear	2000	28,828	smolt	native
6	Beliveau	1990	2,000	parr	local
8	Meteghan	1980	9,325	fry	local
8	Meteghan	1990	113,830	parr	local
8	Meteghan	2000	56,271	parr	local
9	Salmon (Digby)	1980	222,466	smolt/parr/fry	native/local
9	Salmon (Digby)	1990	297,179	smolt/parr/fry	native
9	Salmon (Digby)	2000	206,795	smolt/parr/fry	native
12	Tusket	1970	66,390	smolt	local
12	Tusket	1980	525,269	smolt/parr/fry	native/local/hybrid
12	Tusket	1990	920,285	smolt/parr/fry	native
12	Tusket	2000	293,394	smolt/parr	native
15	Clyde	1980	110,949	smolt	local
15	Clyde	1990	137,612	smolt	local
15	Clyde	2000	9,132	smolt	local
17	Jordan	1980	15,000	smolt	local
17	Jordan	1990	69,092	smolt/parr	local
23	Mersey	1980	104,366	smolt	local
23	Mersey	1990	153,989	smolt/parr	local
23	Mersey	2000	47,094	smolt/parr	native/local
24	Medway	1970	90,181	smolt/parr	local
24	Medway	1980	877,958	smolt/parr/fry	native/local/hybrid
24	Medway	1990	907,634	smolt/parr	native/local
24	Medway	2000	247,109	smolt/parr	native
25	Petite	1980	181,168	smolt/parr/fry	local
25	Petite	1990	280,119	smolt/parr/fry	local
25	Petite	2000	18,571	smolt/parr	local
26	LaHave	1970	331,174	smolt/parr	native/local
26	LaHave	1980	935,669	smolt/parr/fry	native/local
26	LaHave	1990	1,426,691	smolt/parr	native/local
26	LaHave	2000	514,350	smolt/parr	native
27	Mushamush	1980	213,695	smolt/parr/fry	local
27	Mushamush	1990	276,591	smolt/parr	local
27	Mushamush	2000	29,583	smolt/parr	local
28	Martins	1990	6,999	parr	local
29	Gold	1980	77,997	smolt/parr	native
29	Gold	1990	300,675	smolt/parr	native
29	Gold	2000	40,552	smolt/parr	native
34	Ingram	1980	14,813	smolt	local
35	Indian	1980	8,000	fry	local
39	Sackville	1970	6,910	parr	local
39	Sackville	1980	58,172	smolt/parr	local

River Number	River Name	Decade	Number of Fish	Life Stage	Stock Origin
39	Sackville	1990	377,827	smolt/parr	native/local
39	Sackville	2000	256,504	smolt/parr/fry	native
44	Musquodoboit	1980	265,126	smolt/parr	native
44	Musquodoboit	1990	406,343	smolt/parr	native
44	Musquodoboit	2000	92,544	smolt/parr	native
50	West River (Sheet Harbour)	1980	94,424	smolt/parr/fry	local/hybrid
50	West River (Sheet Harbour)	1990	56,247	smolt/parr	local
51	East Sheet Harbour	1970	115,998	smolt	native/local
51	East Sheet Harbour	1980	159,385	smolt/parr/fry	native/hybrid
51	East Sheet Harbour	1990	415,199	smolt/parr/fry	native/local/hybrid
51	East Sheet Harbour	2000	95,538	smolt/parr	native/local
54	Quoddy	2000	417	smolt	local
55	Moser	1980	28,444	smolt/parr	native
55	Moser	1990	75,666	smolt/parrr	native/local
58	Liscomb	1970	114,506	smolt	local/hybrid
58	Liscomb	1980	596,661	smolt/parr/fry	native/local/hybrid
58	Liscomb	1990	653,300	smolt/parr	native
58	Liscomb	2000	36,907	smolt/parr	native
59	Gaspereau Brook	2000	55	smolt	local
61	St. Mary's	1980	339,159	smolt/parr/fry	native/local
61	St. Mary's	1990	294,853	smolt/parr	native

Table 5.2.3. Number of locations stocked with trout (brook, brown, and rainbow trout) in watersheds of the Southern Upland by the NSDFA during their spring and fall stocking distributions (data from 2011). "All coastal Southern Upland drainages" includes watersheds that are not considered in the list of 72 rivers used by Southern Upland Atlantic salmon.

River Number	Watershed Name	Brook Trout	Rainbow Trout	Brown Trout
1	Annapolis/Nictaux	4	-	2
2	Round Hill	3	-	-
4	Bear	2	-	-
5	Sissibo	4	1	-
6	Beliveau	3	-	-
9	Salmon (Digby)	9	-	-
10	Chegoggin	1	-	-
12	Tusket	10	-	-
13	Argyle	1	-	-
14	Barrington	2	-	-
15	Clyde	1	-	-
17	Jordan	2	-	-
18	East (Lockeport)	1	-	-
19	Sable	2	-	-
22	Broad	1	-	-
23	Mersey	1	-	-
24	Medway	14	1	-
25	Petite	3	-	-
26	Lahave	16	-	-
27	Mushamush	4	1	-
29	Gold	8	-	-
30	Middle	2	-	-
33	Hubbards	3	-	-
36	East (St. Margarets)	2	2	-
37	Nine Mile	2	-	-
39	Sackville	6	-	-
42	Porters Lake (West Bk. + East Bk.)	1	-	-
43	Chezzetcook	3	-	-
44	Musquodoboit	5	-	-
46	Ship Harbour (Fish River - L. Charlotte)	4	-	-
50	West (Sh Hbr)	1	-	-
55	Moser	5	-	-
61	St Marys	13	-	-
64	Country Harbour	1	-	-
66	New Harbour	3	-	-
68	Cole Harbour (Jamieson Brook)	3	-	-
69	Salmon (Guys.)	3	-	1
70	Guysborough	1	-	-
71	Clam Harbour	1	-	-
72	St Francis Harbour	1	1	1
All Coastal Southern Upland Drainages		55	5	-

Table 5.3.1. The number of dams or barrier structures in watersheds used by Southern Upland Atlantic salmon. Data are from three data sources: (1) the National Hydro Network (NHN), (2) the NSDoE and DFO Habitat Division barriers layer, and (3) Nova Scotia Power Inc. (NSPI; these data only includes dams with hydroelectric turbines).

River Number	Watershed Name	NHN Barrier Count	NSDoE & DFO Barrier Count	NSPI Hydro Turbine
1	Annapolis/Nictaux	41	43	3
2	Round Hill	0	1	0
3	Le Quille	2	4	1
4	Bear	10	9	2
5	Sissibo	12	10	3
7	Boudreau	1	0	0
8	Meteghan	7	4	0
9	Salmon (Digby)	3	1	0
10	Chegoggin	1	0	0
11	Annis	5	1	0
12	Tusket	13	7	1
13	Argyle	2	1	0
14	Barrington	1	1	0
15	Clyde	0	1	0
16	Roseway	2	1	1
17	Jordan	3	1	0
18	East (Lockeport)	1	0	0
22	Broad	1	0	0
23	Mersey	15	15	4
24	Medway	10	7	1
25	Petite	5	7	0
26	Lahave	2	5	0
27	Mushamush	5	1	0
29	Gold	1	0	0
30	Middle	1	0	0
31	East (Chester)	1	0	0
35	Indian	6	4	0
37	Nine Mile	1	2	0
38	Pennant	1	1	0
39	Sackville	0	3	0
40	Salmon (L Major)	1	2	0
43	Chezzetcook	1	1	0
44	Musquodoboit	5	17	0
47	Tangier	2	1	0
50	West (Sh Hbr)	1	0	0
51	East (Sh Hbr)	10	7	2
55	Moser	1	0	0
58	Liscomb	3	1	0
61	St Marys	1	0	0
62	Indian Harbour Lakes	0	1	0
65	Issacs Harbour	0	1	0
67	Larrys	1	0	0
72	St Francis Harbour	1	1	0

Table 5.3.2. The number and total area of water bodies in rivers used by Southern Upland Atlantic salmon identified as reservoirs from the National Hydro Network (NHN) or as likely reservoirs from the barriers layer from NSDoE and the DFO Habitat Division.

River #	Watershed Name	NHN identified		Likely reservoirs		Total Number	Total Area (m^2)
		Number	Area (m^2)	Number	Area (m^2)		
1	Annapolis/Nictaux	66	125,071	36	28,027,120	102	28,152,191
2	Round Hill	-	-	1	183,352	1	183,352
3	Le Quille	-	-	3	3,595,492	3	3,595,492
4	Bear	1	1,822	7	17,466,540	8	17,468,362
5	Sissibo	1	1,932	4	22,794,470	5	22,796,402
7	Boudreau	3	5,028	-	-	3	5,028
8	Meteghan	3	5,605	4	741,751	7	747,356
9	Salmon (Digby)	-	-	3	11,810,906	3	11,810,906
10	Chegoggin	-	-	1	9,180	1	9,180
11	Annis	-	-	4	520,412	4	520,412
12	Tusket	1	1,975	5	23,306,936	6	23,308,911
13	Argyle	-	-	2	6,604	2	6,604
14	Barrington	-	-	1	154,183	1	154,183
16	Roseway	-	-	2	540,772	2	540,772
17	Jordan	-	-	1	872,697	1	872,697
22	Broad	-	-	1	137,819	1	137,819
23	Mersey	-	-	6	193,333,192	6	193,333,192
24	Medway	-	-	8	53,226,674	8	53,226,674
25	Petite	-	-	6	11,926,925	6	11,926,925
26	Lahave	-	-	2	5,650,675	2	5,650,675
27	Mushamush	-	-	4	4,999,681	4	4,999,681
29	Gold	-	-	1	182,005	1	182,005
30	Middle	-	-	1	1,176,843	1	1,176,843
31	East (Chester)	-	-	1	4,571	1	4,571
35	Indian	-	-	3	13,363,417	3	13,363,417
36	East (St. Margarets)	2	6,467	-	-	2	6,467
38	Pennant	-	-	1	997,447	1	997,447
40	Salmon (L Major)	-	-	2	4,817,180	2	4,817,180
43	Chezzetcook	-	-	1	1,388,085	1	1,388,085
44	Musquodoboit	-	-	4	1,238,804	4	1,238,804
47	Tangier	-	-	2	1,058,696	2	1,058,696
50	West (Sh Hbr)	-	-	1	618,985	1	618,985
51	East (Sh Hbr)	-	-	7	11,975,320	7	11,975,320
54	Quoddy	1	2,841	-	-	1	2,841
55	Moser	-	-	1	212,534	1	212,534
58	Liscomb	-	-	2	6,460,582	2	6,460,582
61	St Marys	2	3,887	-	-	2	3,887
72	St Francis Harbour	-	-	1	3,613,435	1	3,613,435

Table 5.3.3. Summary of the analysis of the number of road crossings in Southern Upland watersheds.

River number	River name	Unpaved crossings: Count	Unpaved crossings: Length of unpaved road (km)	Paved crossings: Count	Paved crossings: Length of paved road (km)	Total number of crossings	Total length of road (km)	Length of flow network (km)	Crossing density (#/10km)
1	Annapolis/Nictaux	262	724.2	382	691.9	**644**	1,416.1	1,524.11	**4.23**
2	Round Hill	16	82.0	5	15.9	**21**	97.9	85.60	**2.45**
3	Le Quille	19	86.3	16	49.4	**35**	135.7	113.56	**3.08**
4	Bear	65	204.2	22	29.6	**87**	233.8	326.97	**2.66**
5	Sissibo	66	284.4	17	44.5	**83**	328.9	508.95	**1.63**
6	Beliveau	16	48.8	2	13.1	**18**	61.9	33.06	**5.44**
7	Boudreau	13	35.7	26	44.4	**39**	80.0	43.05	**9.06**
8	Meteghan	39	140.1	28	90.4	**67**	230.5	179.92	**3.72**
9	Salmon (Digby)	39	148.0	19	40.5	**58**	188.5	201.82	**2.87**
10	Chegoggin	8	18.6	11	27.2	**19**	45.8	41.08	**4.63**
11	Annis	25	102.9	17	48.6	**42**	151.5	133.77	**3.14**
12	Tusket	80	671.6	38	122.3	**118**	793.9	1,189.67	**0.99**
13	Argyle	13	38.8	2	3.5	**15**	42.3	61.98	**2.42**
14	Barrington	3	21.8	3	17.0	**6**	38.8	177.62	**0.34**
15	Clyde	42	193.5	8	25.2	**50**	218.7	620.10	**0.81**
16	Roseway	23	141.8	19	56.5	**42**	198.3	486.64	**0.86**
17	Jordan	34	135.9	3	9.0	**37**	145.0	327.76	**1.13**
18	East (Lockeport)	4	18.7	4	6.1	**8**	24.8	47.25	**1.69**
19	Sable	4	32.6	1	3.9	**5**	36.5	117.16	**0.43**
20	Tidney	0	0.0	1	2.1	**1**	2.1	101.31	**0.10**
21	Granite Village	0	0.0	2	1.2	**2**	1.2	15.45	**1.29**
22	Broad	6	44.4	1	1.1	**7**	45.5	111.17	**0.63**
23	Mersey	71	451.3	31	134.5	**102**	585.8	1,880.88	**0.54**
24	Medway	156	889.3	57	229.6	**213**	1,118.8	1,258.56	**1.69**
25	Petite	32	133.1	28	112.2	**60**	245.4	198.02	**3.03**
26	Lahave	230	938.2	130	386.8	**360**	1,325.0	1,163.78	**3.09**
27	Mushamush	22	106.6	14	40.0	**36**	146.6	141.34	**2.55**
28	Martins	6	31.1	4	4.0	**10**	35.0	73.54	**1.36**
29	Gold	35	184.3	33	74.8	**68**	259.1	263.42	**2.58**
30	Middle	24	92.9	8	39.6	**32**	132.5	136.67	**2.34**
31	East (Chester)	18	74.8	4	8.6	**22**	83.4	119.01	**1.85**

		Unpaved crossings		Paved crossings					
River number	River name	Count	Length of unpaved road (km)	Count	Length of paved road (km)	Total number of crossings	Total length of road (km)	Length of flow network (km)	Crossing density (#/10km)
32	Little East	1	9.2	3	7.7	**4**	17.0	21.67	**1.85**
33	Hubbards	12	53.2	4	5.6	**16**	58.8	71.08	**2.25**
34	Ingram	26	65.3	4	3.4	**30**	68.7	137.01	**2.19**
35	Indian	86	142.9	18	27.4	**104**	170.3	298.80	**3.48**
36	East (St. Margarets)	2	30.2	21	52.2	**23**	82.4	32.33	**7.11**
37	Nine Mile	16	38.7	14	106.3	**30**	145.0	132.65	**2.26**
38	Pennant	3	20.1	5	24.4	**8**	44.5	99.98	**0.80**
39	Sackville	53	90.2	85	295.5	**138**	385.7	200.13	**6.90**
40	Salmon (L Major)	1	16.4	10	29.8	**11**	46.1	102.41	**1.07**
41	Salmon (L. Echo)	27	53.9	22	56.3	**49**	110.2	264.10	**1.86**
42	Porters Lake (West Bk.+East Bk.)	49	116.1	26	67.4	**75**	183.5	215.74	**3.48**
43	Chezzetcook	19	56.2	16	27.8	**35**	84.0	149.27	**2.34**
44	Musquodoboit	216	507.0	113	146.1	**329**	653.1	947.64	**3.47**
45	Salmon (Hfx)	16	34.8	1	0.2	**17**	35.0	179.09	**0.95**
46	Ship Harbour (Fish River-L. Charlotte)	59	181.5	9	26.0	**68**	207.5	429.37	**1.58**
47	Tangier	24	118.9	6	16.4	**30**	135.3	354.89	**0.85**
48	W Taylor Bay	9	9.8	4	5.4	**13**	15.2	40.16	**3.24**
49	Little West (Grand Lake)	7	27.4	5	5.7	**12**	33.1	68.10	**1.76**
50	West (Sh Hbr)	34	179.7	7	32.8	**41**	212.5	303.64	**1.35**
51	East (Sh Hbr)	80	342.5	17	56.8	**97**	399.2	569.11	**1.70**
52	Kirby (Halfway Bk)	7	18.8	2	3.5	**9**	22.3	31.31	**2.87**
53	Salmon (P.D.)	14	65.4	1	0.4	**15**	65.8	120.52	**1.24**
54	Quoddy	10	34.4	1	0.2	**11**	34.6	46.16	**2.38**
55	Moser	18	79.0	3	3.4	**21**	82.4	171.70	**1.22**
56	Smith	0	0.0	3	3.5	**3**	3.5	20.40	**1.47**
57	Ecum Secum	29	74.5	1	4.1	**30**	78.7	90.44	**3.32**
58	Liscomb	44	174.2	1	0.8	**45**	175.0	388.33	**1.16**
59	Gaspereau Bk	6	29.0	2	3.0	**8**	31.9	73.23	**1.09**
60	Gegogan	4	15.8	2	6.2	**6**	22.0	20.50	**2.93**
61	St Marys	335	975.4	100	165.7	**435**	1,141.1	1,323.31	**3.29**
62	Indian Harbour Lakes	7	29.3	2	14.2	**9**	43.5	20.58	**4.37**
63	Indian	9	29.4	4	4.1	**13**	33.4	114.97	**1.13**
64	Country Harbour	55	172.2	15	29.3	**70**	201.5	186.80	**3.75**

River number	River name	Unpaved crossings: Count	Unpaved crossings: Length of unpaved road (km)	Paved crossings: Count	Paved crossings: Length of paved road (km)	Total number of crossings	Total length of road (km)	Length of flow network (km)	Crossing density (#/10km)
65	Issacs Harbour	3	24.7	1	0.2	**4**	24.8	71.50	**0.56**
66	New Harbour	17	61.3	2	7.6	**19**	68.9	136.94	**1.39**
67	Larrys	1	4.9	3	11.6	**4**	16.5	88.71	**0.45**
68	Cole Harbour (Jamieson Brook)	7	13.0	6	9.4	**13**	22.5	67.3	**1.93**
69	Salmon (Guys.)	52	142.7	19	32.8	**71**	175.5	275.16	**2.58**
70	Guysborough	31	70.6	1	3.1	**32**	73.7	118.59	**2.70**
71	Clam Harbour	18	64.3	4	7.2	**22**	71.5	76.61	**2.87**
72	St Francis Harbour	21	33.6	1	0.8	**22**	34.4	107.38	**2.05**

Table 5.4.1. Proportion of each watershed in the Southern Upland DU that is used for agriculture, forestry activity, industrial sites (municipal landfills and gravel pits) and corridors (e.g. cut lines for power poles), and urban settlement. Data are from the NSDNR Forest Inventory (collected between 1995 and 2012).

River number	River name	% Agriculture	% Forestry activity	% Industrial sites & corridors	% Urban
1	Annapolis/Nictaux	14.19	9.58	1.65	3.66
2	Round Hill	0.00	18.49	0.69	0.71
3	Le Quille	0.00	12.93	1.56	1.46
4	Bear	1.33	16.43	0.46	0.97
5	Sissibo	0.62	10.78	0.41	0.55
6	Beliveau	0.00	9.72	2.43	1.23
7	Boudreau	0.00	7.97	3.48	7.37
8	Meteghan	1.59	8.87	1.60	2.28
9	Salmon (Digby)	1.54	10.40	0.96	1.41
10	Chegoggin	0.00	6.07	1.81	5.71
11	Annis	1.79	15.02	1.39	3.24
12	Tusket	0.66	8.45	0.37	0.62
13	Argyle	0.00	12.17	0.68	0.84
14	Barrington	0.00	0.00	0.34	0.64
15	Clyde	0.00	2.07	0.54	0.29
16	Roseway	0.00	2.43	0.49	0.38
17	Jordan	0.00	7.07	0.27	0.18
18	East (Lockeport)	0.00	1.59	0.00	0.18
19	Sable	0.13	2.51	0.43	0.19
20	Tidney	0.00	1.41	0.35	0.07
21	Granite Village	0.00	5.43	0.00	0.07
22	Broad	0.00	4.56	0.00	0.01
23	Mersey	0.15	5.13	0.36	0.41
24	Medway	0.90	9.36	0.71	1.23
25	Petite	4.93	8.01	2.63	3.85
26	Lahave	2.64	9.09	0.80	2.03
27	Mushamush	0.00	6.97	1.35	3.02
28	Martins	0.00	2.33	0.86	0.38
29	Gold	1.12	9.73	0.60	1.45
30	Middle	0.00	7.06	1.26	2.58
31	East (Chester)	0.00	5.35	1.24	0.34
32	Little East	0.00	9.76	2.60	2.35
33	Hubbards	0.00	21.94	1.17	0.85
34	Ingram	0.00	23.01	1.19	0.04
35	Indian	0.00	20.93	1.33	0.61
36	East (St. Margarets)	0.00	0.00	4.55	19.29
37	Nine Mile	0.00	1.80	3.34	8.21
38	Pennant	0.00	0.23	0.91	4.36
39	Sackville	0.00	8.10	7.70	18.99
40	Salmon (L Major)	0.00	1.85	1.50	5.17
41	Salmon (L. Echo)	0.00	6.20	1.17	5.16
42	Porters Lake (West Bk. + East Bk.)	0.00	8.54	1.41	5.87
43	Chezzetcook	0.00	6.49	1.43	3.68

River number	River name	% Agriculture	% Forestry activity	% Industrial sites & corridors	% Urban
44	Musquodoboit	7.43	15.35	0.63	1.35
45	Salmon (Hfx)	0.00	1.79	0.04	0.06
46	Ship Harbour (Fish River - L. Charlotte)	0.00	7.42	0.24	0.46
47	Tangier	0.00	5.29	0.13	0.26
48	W Taylor Bay	0.00	4.22	0.33	0.21
49	Little West (Grand Lake)	0.00	10.28	0.46	0.10
50	West (Sh Hbr)	0.00	10.84	0.34	0.25
51	East (Sh Hbr)	0.00	14.28	0.46	0.17
52	Kirby (Halfway Bk)	0.00	15.11	1.33	0.53
53	Salmon (P.D.)	0.00	6.46	0.14	0.16
54	Quoddy	0.00	5.82	0.00	0.22
55	Moser	0.00	8.27	0.06	0.51
56	Smith	0.00	0.00	0.63	1.13
57	Ecum Secum	0.00	15.08	0.09	0.83
58	Liscomb	0.00	12.18	0.04	0.01
59	Gaspereau Bk	0.00	14.69	0.00	0.11
60	Gegogan	0.00	14.72	1.04	0.72
61	St Marys	1.74	30.25	0.57	0.41
62	Indian Harbour Lakes	0.00	14.18	1.44	3.49
63	Indian	0.00	2.80	0.29	0.07
64	Country Harbour	2.42	23.95	0.82	1.34
65	Issacs Harbour	0.00	6.18	0.00	0.00
66	New Harbour	0.00	8.35	0.28	0.82
67	Larrys	0.00	1.03	0.38	0.74
68	Cole Harbour (Jamieson Brook)	0.00	2.50	0.61	0.13
69	Salmon (Guys.)	0.67	15.52	0.79	0.33
70	Guysborough	1.42	14.62	0.10	0.34
71	Clam Harbour	0.00	18.75	0.35	0.69
72	St Francis Harbour	0.00	15.25	0.24	0.03

Table 5.4.2. The number and type of historical mines in 70 watersheds used by Southern Upland Atlantic salmon. Data are from the NSDNR Abandoned Mines Opening Database.

River number	River name	Arsenic	Clay	Copper	Gold	Graphite	Iron	Lead	Manganese	Mica	Molybdenum	Tin	Tungsten	Total
1	Annapolis/Nictaux	-	3	-	1	-	56	-	2	-	-	-	-	62
4	Bear	-	-	-		-	1	-	-	-	-	-	-	1
11	Annis	-	-	-		-	-	-	-	1	-	-	-	1
12	Tusket	-	-	-	50	-	-	1	-		-	1	-	52
22	Broad	-	-	-	3	-	-	-	-	-	-	-	-	3
23	Mersey	-	-	-	42	-	-	-	-	-	-	-	-	42
24	Medway	-	-	-	432	-	-	-	-	-	-	-	-	432
25	Petite	-	-	-	92	-	-	-	-	-	-	-	-	92
26	Lahave	-	-	1	8	-	-	-	-	-	-	-	-	9
27	Mushamush	-	-	-	4	-	-	-	-	-	-	-	-	4
29	Gold	-	-	-	112	-	-	-	13		1	5	-	131
36	East (St. Margarets)	-	-	-		-	-	1	-	-	-	-	-	1
39	Sackville	-	-	-	52	-	-	-	-	-	-	-	2	54
40	Salmon (L Major)	-	-	-	152	-	-	-	-	-	-	-	-	152
41	Salmon (L. Echo)	-	-	-	60	-	-	-	-	-	-	-	1	61
42	Porters Lake (West Bk. + East Bk.)	-	-	-	2	-	-	-	-	-	-	-	-	2
44	Musquodoboit	1	-	-	29	-	-	8	-	-	-	-	1	39
46	Ship Harbour (Fish River - L. Charlotte)	1	-	-	264	-	-	-	-	-	-	-	27	292
47	Tangier	-	-	-	101	-	-	-	-	-	-	-	-	101
49	Little West (Grand Lake)	-	-	-	1	-	-	-	-	-	-	-	-	1
50	West (Sh Hbr)	-	-	-	31	-	-	-	-	-	-	-	-	31
51	East (Sh Hbr)	-	-	-	94	-	-	-	-	-	-	-	-	94
53	Salmon (P.D.)	-	-	-	63	-	-	-	-	-	-	-	-	63
54	Quoddy	-	-	-	1	-	-	-	-	-	-	-	-	1
56	Smith	-	-	-	5	-	-	-	-	-	-	-	-	5
57	Ecum Secum	-	-	-	32	-	-	-	-	-	-	-	-	32
58	Liscomb	-	-	-	17	-	-	-	-	-	-	-	-	17
59	Gaspereau Bk	-	-	-	2	-	-	-	-	-	-	-	-	2
60	Gegogan	-	-	-	313	-	-	-	-	-	-	-	-	313
61	St Marys	-	-	5	28	-	1	3	-	-	-	-	-	37
64	Country Harbour	-	-	-	42	-	-	-	-	-	-	-	-	42
65	Issacs Harbour	-	-	-	93	-	-	-	-	-	-	-	-	93
66	New Harbour	-	-	-	5	-	-	-	-	-	-	-	-	5
69	Salmon (Guys.)	-	-	2	-	3	4	-	-	-	-	-	-	9
70	Guysborough	-	-	-	-	-	7	-	-	-	-	-	-	7
	TOTALS	2	3	8	2131	3	69	13	15	1	1	6	31	2283

FIGURES

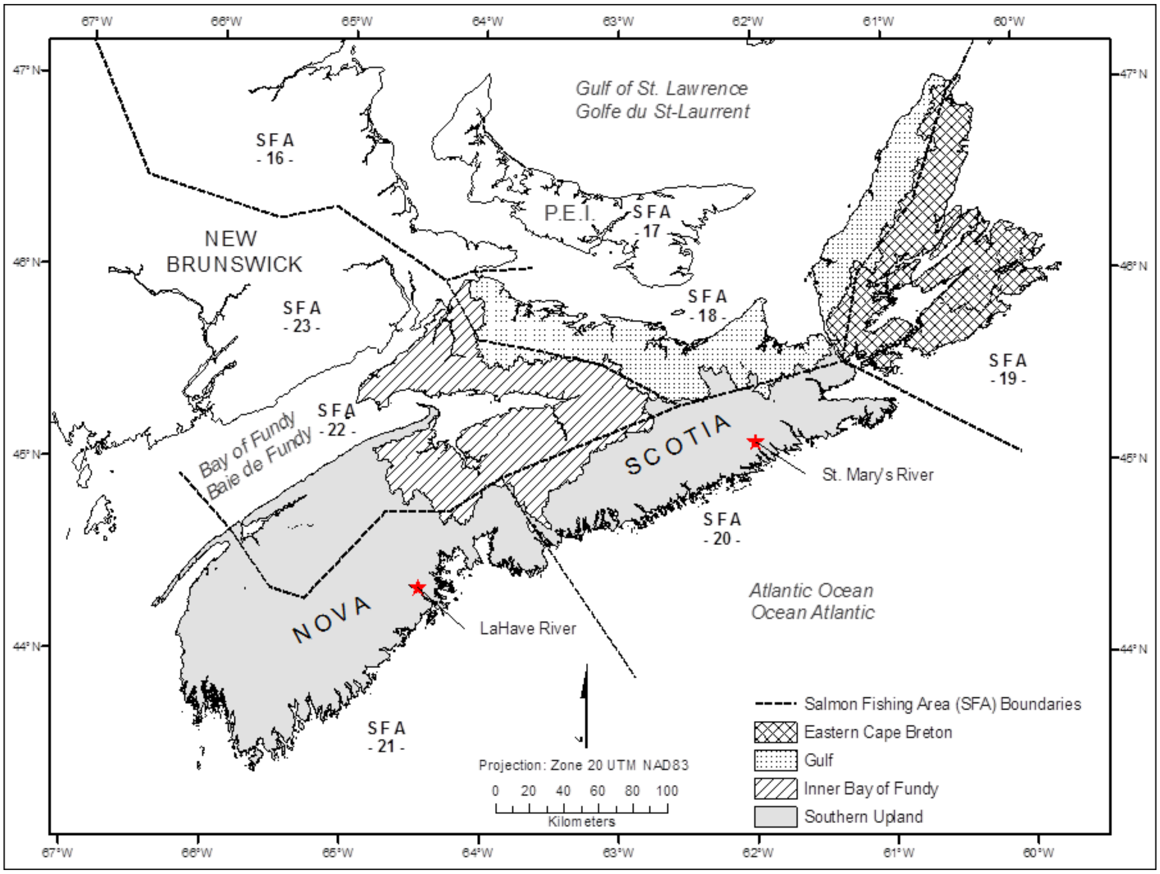

Figure 1. Map showing the freshwater range of Southern Upland Atlantic salmon relative to the three other Atlantic salmon DUs in Nova Scotia. The location of the St. Mary's and LaHave rivers (red stars) and the boundaries of the Salmon Fishing Areas (SFAs) in Nova Scotia, New Brunswick, and PEI, are also shown.

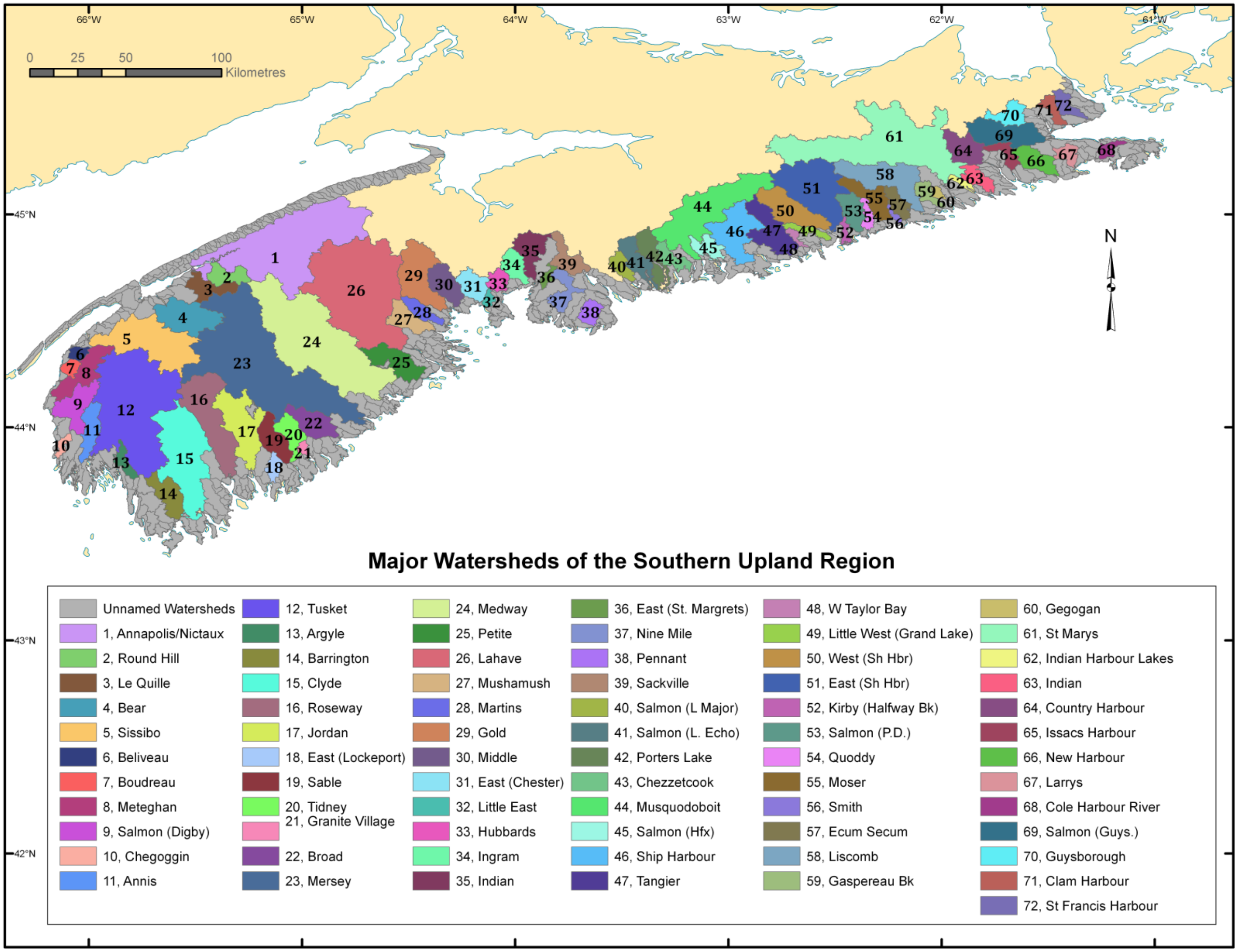

Figure 2.1.1. Map of the 72 watersheds known to be used by Southern Upland Atlantic salmon either at present or in the past. Boundaries are from the Secondary Watersheds layer for ArcGIS® developed by the NSDoE. Watersheds contained within the Southern Upland that are not known to have been used by Atlantic salmon are not labelled by number and are shown in grey.

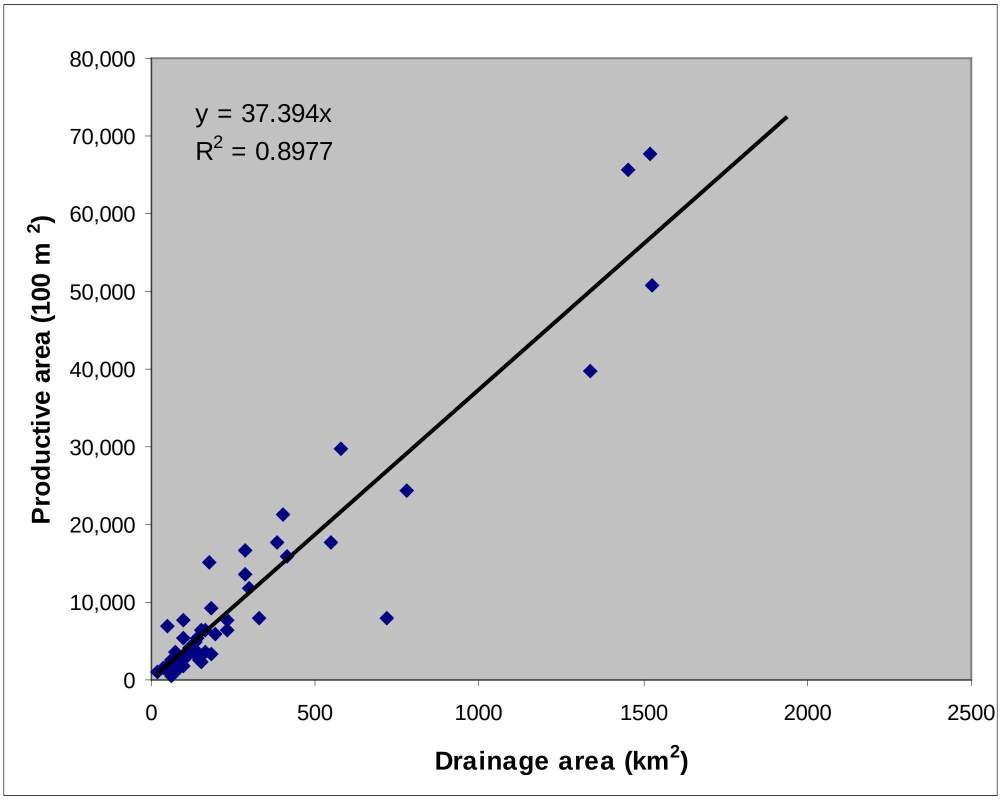

Figure 2.1.2. Relationship between drainage area (as measured from the NSDoE Secondary Watersheds layer for ArcGIS®) and productive rearing area for juvenile salmon for 48 watersheds used by Southern Upland Atlantic salmon. Drainage area explains a large proportion of the variation in productive area (R^2 = 0.8977) and the relationship is statistically significant (p-value <<0.001).

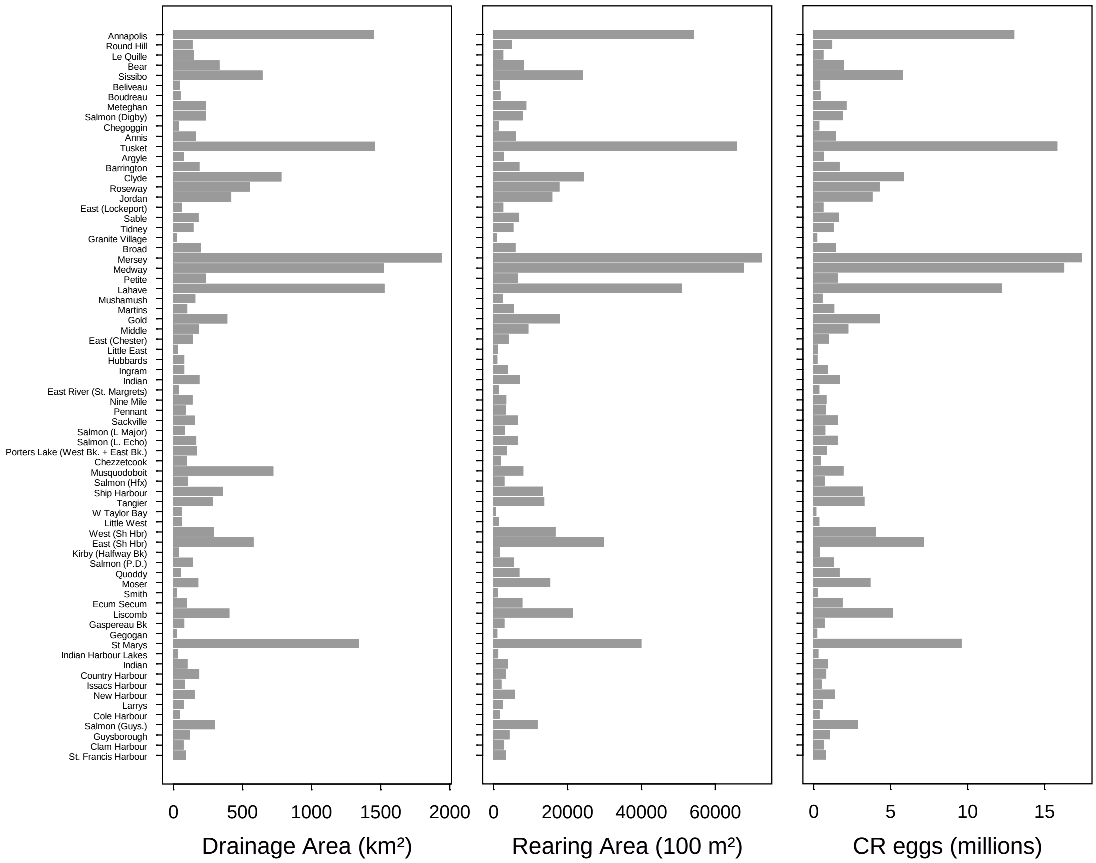

Figure 2.1.3. Barplot of the drainage area of all watersheds in the Southern Upland, their measured or calculated rearing area (in 100 m^2 habitat units), and the associated Conservation Requirement for egg deposition assuming a deposition rate of 240 eggs/habitat unit of rearing area.

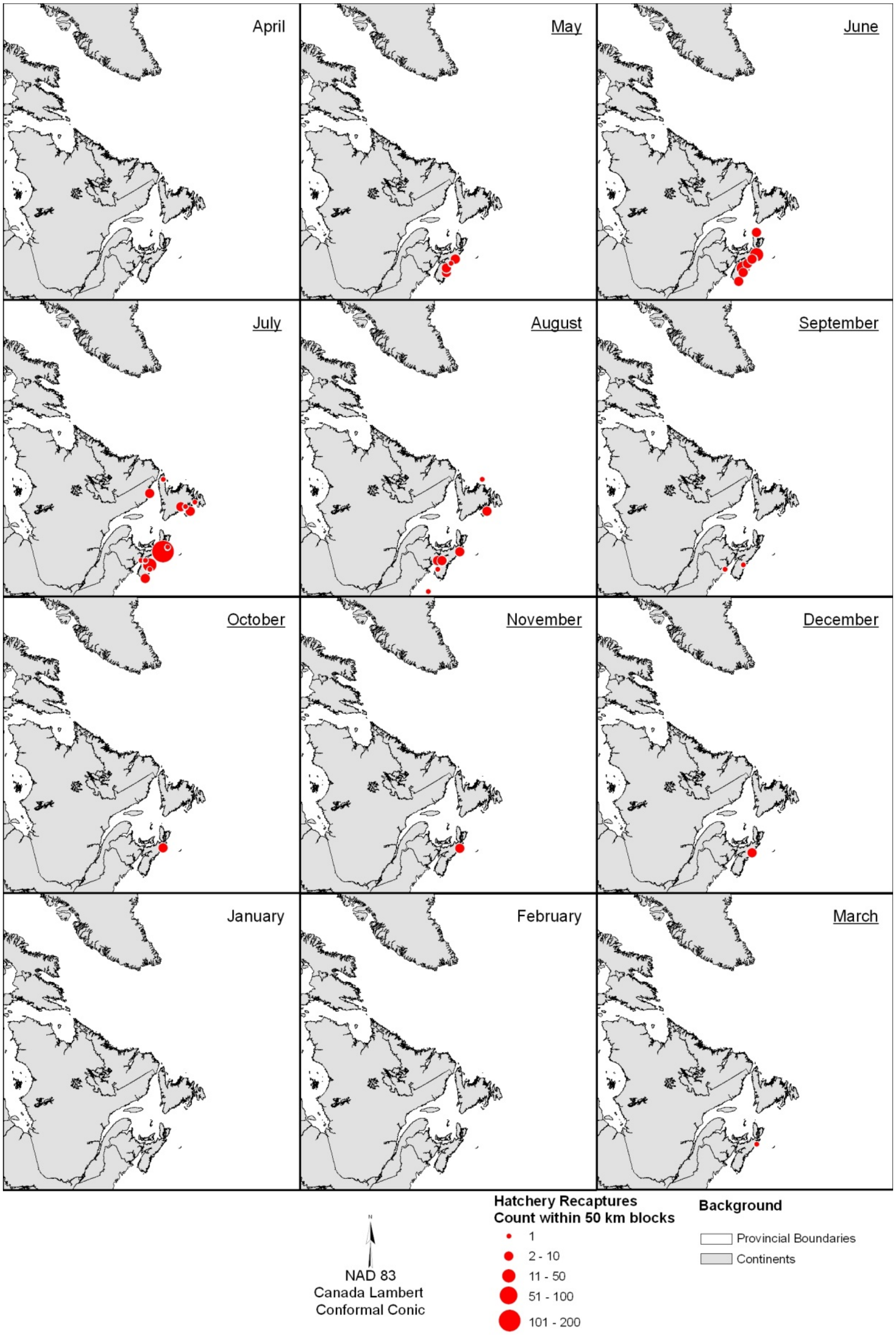

Figure 2.3.1. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the first year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km^2 grid.

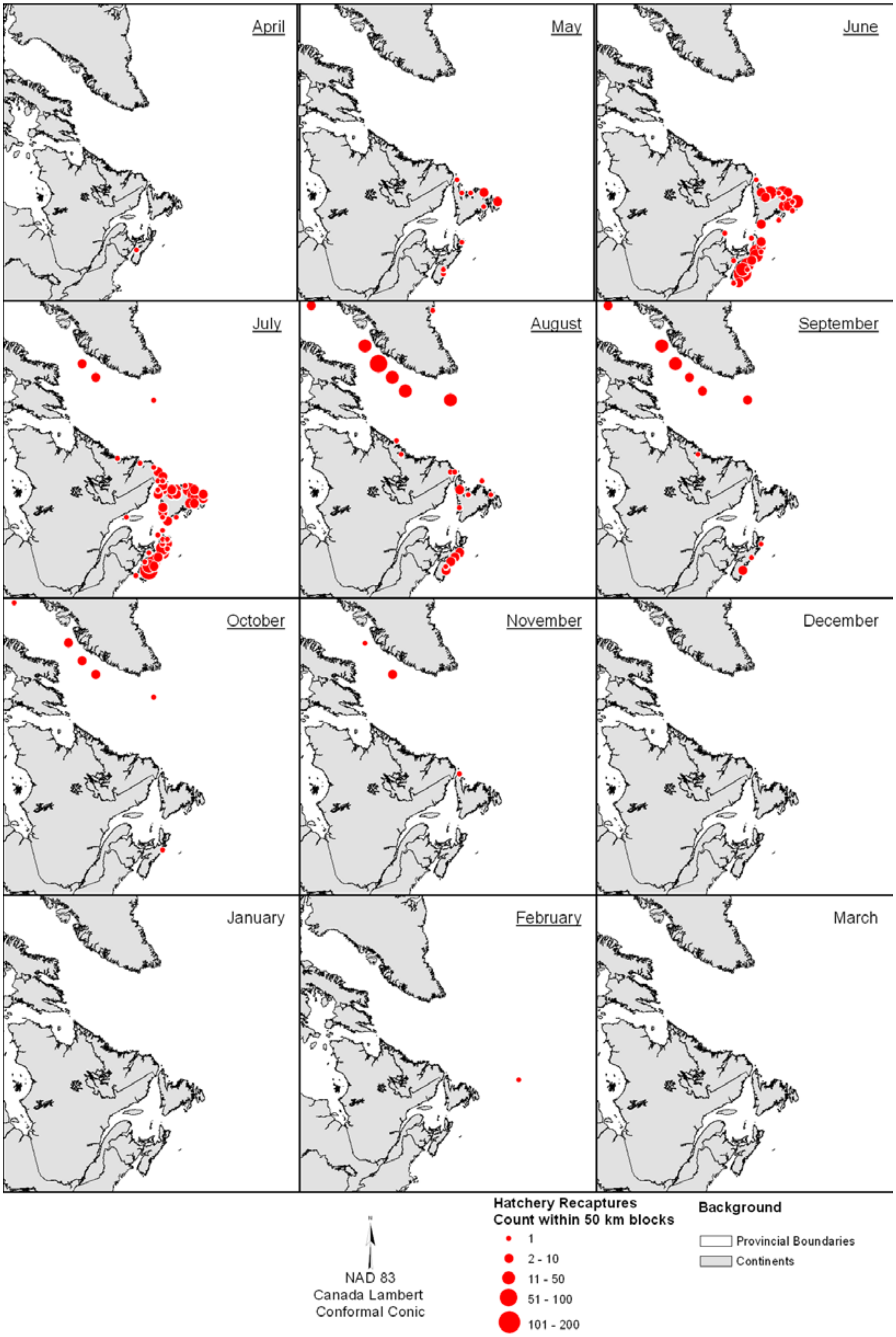

Figure 2.3.2. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the second year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km^2 grid.

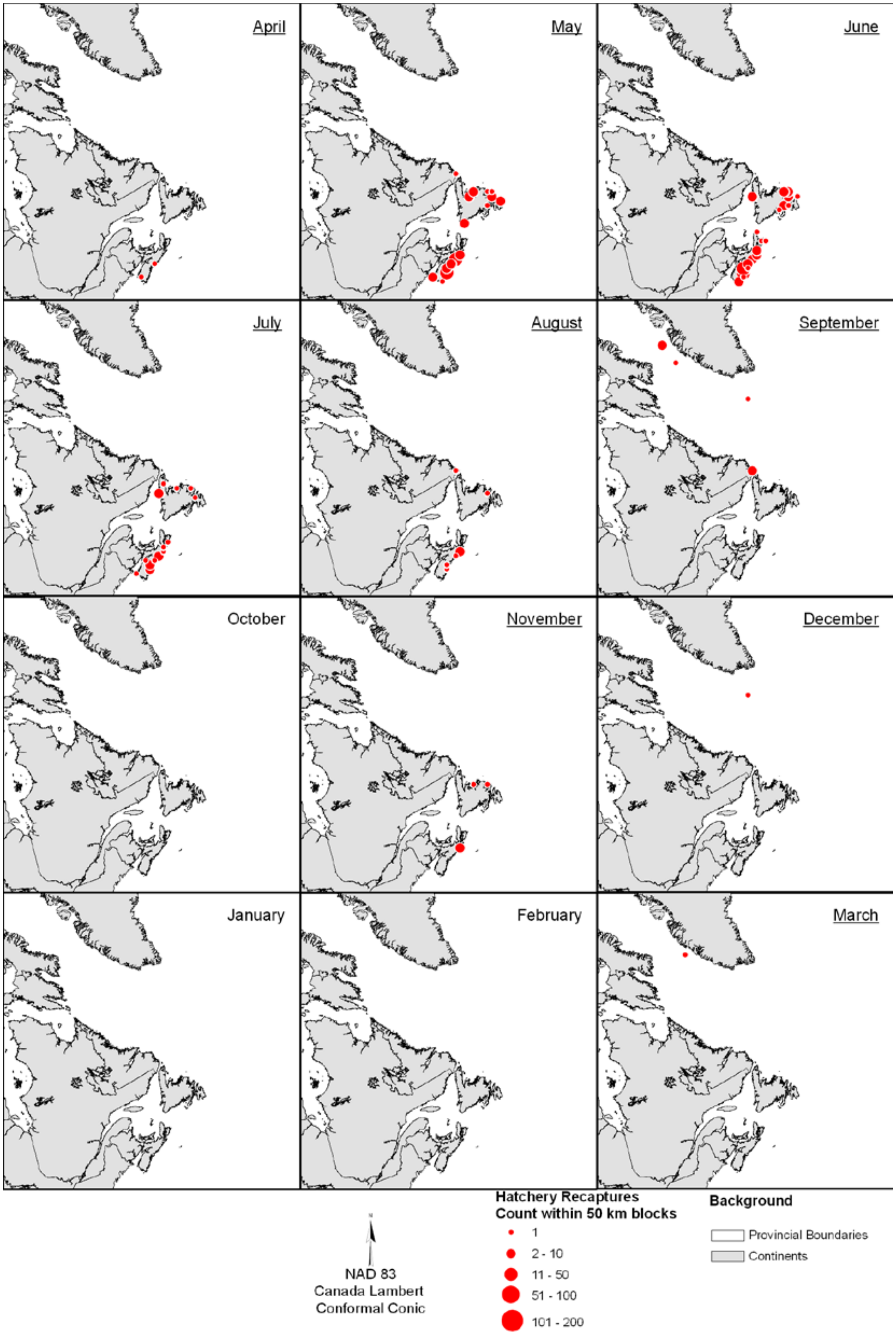

Figure 2.3.3. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the third year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km² grid.

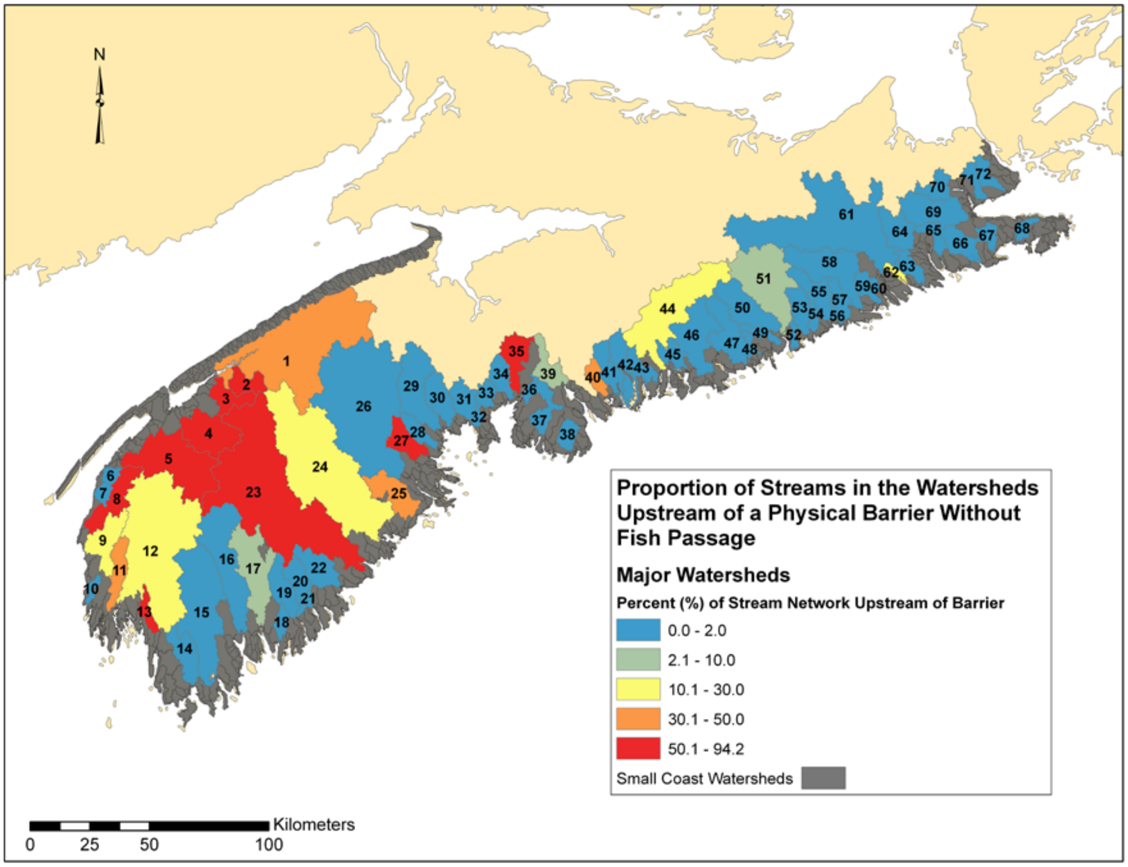

Figure 4.1.1. Proportion of each watershed (percentage of stream length affected multipled by rearing area) impacted by dams without fish passage in Southern Upland rivers. Stream lengths were derived from the NHN flow data and the information on barriers without fish passage came from the NSDoE and DFO Habitat Division barriers data. Watershed numbers correspond to the legend in Figure 2.1.1.

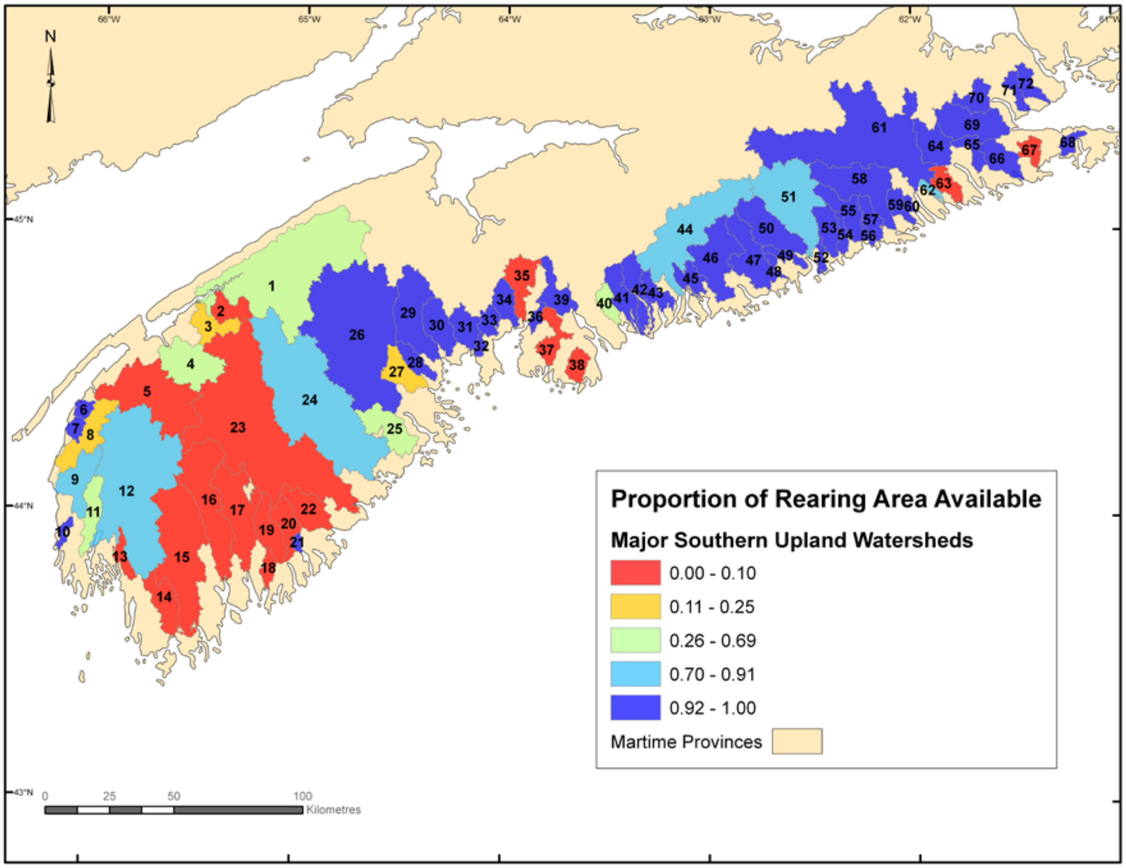

Figure 4.1.2. Proportion of rearing area available to Atlantic salmon for watersheds in the Southern Upland based on accessible habitat area (i.e. area below impassable dams), as well as pH category (where mean annual pH <4.7 is considered unusable). Watershed numbers correspond to the legend in Figure 2.1.1.

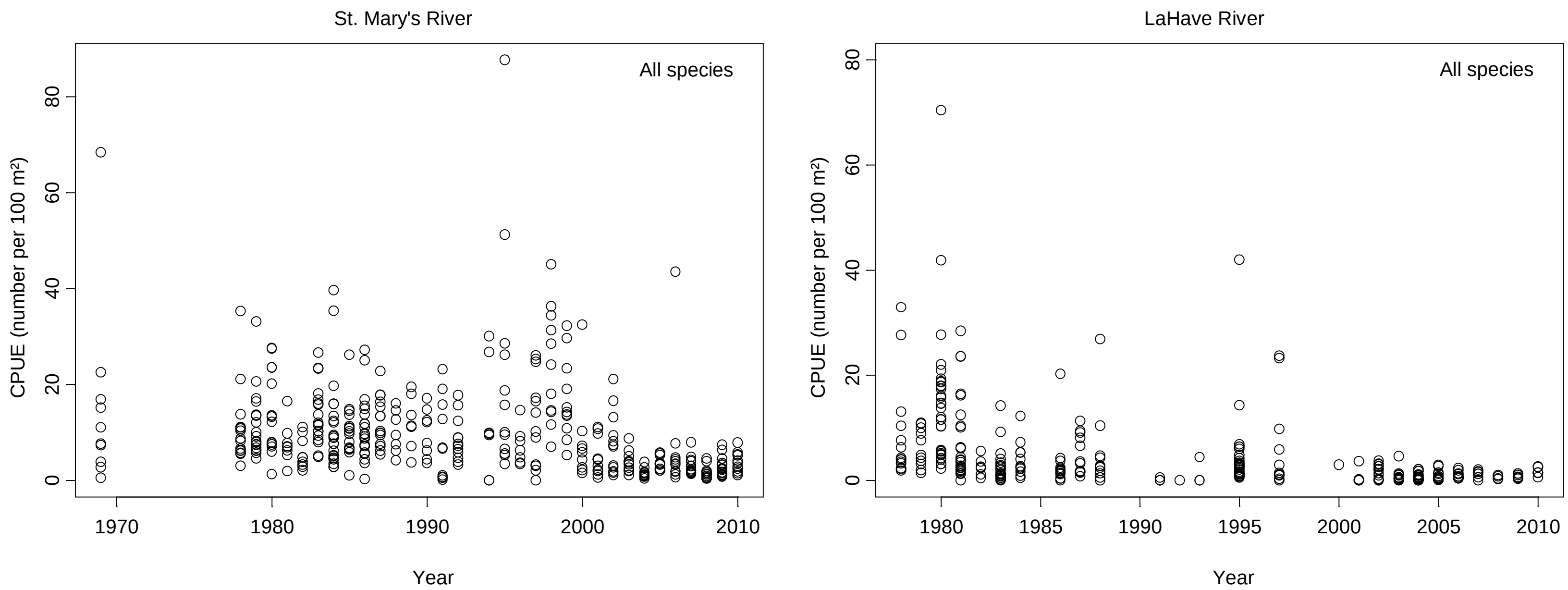

Figure 4.3.1. Catch per unit effort for all fish species combined (excluding Atlantic salmon) from the first pass of each electrofishing survey completed on the St. Mary's and LaHave rivers. Notice that the scale differs between rivers on both axes.

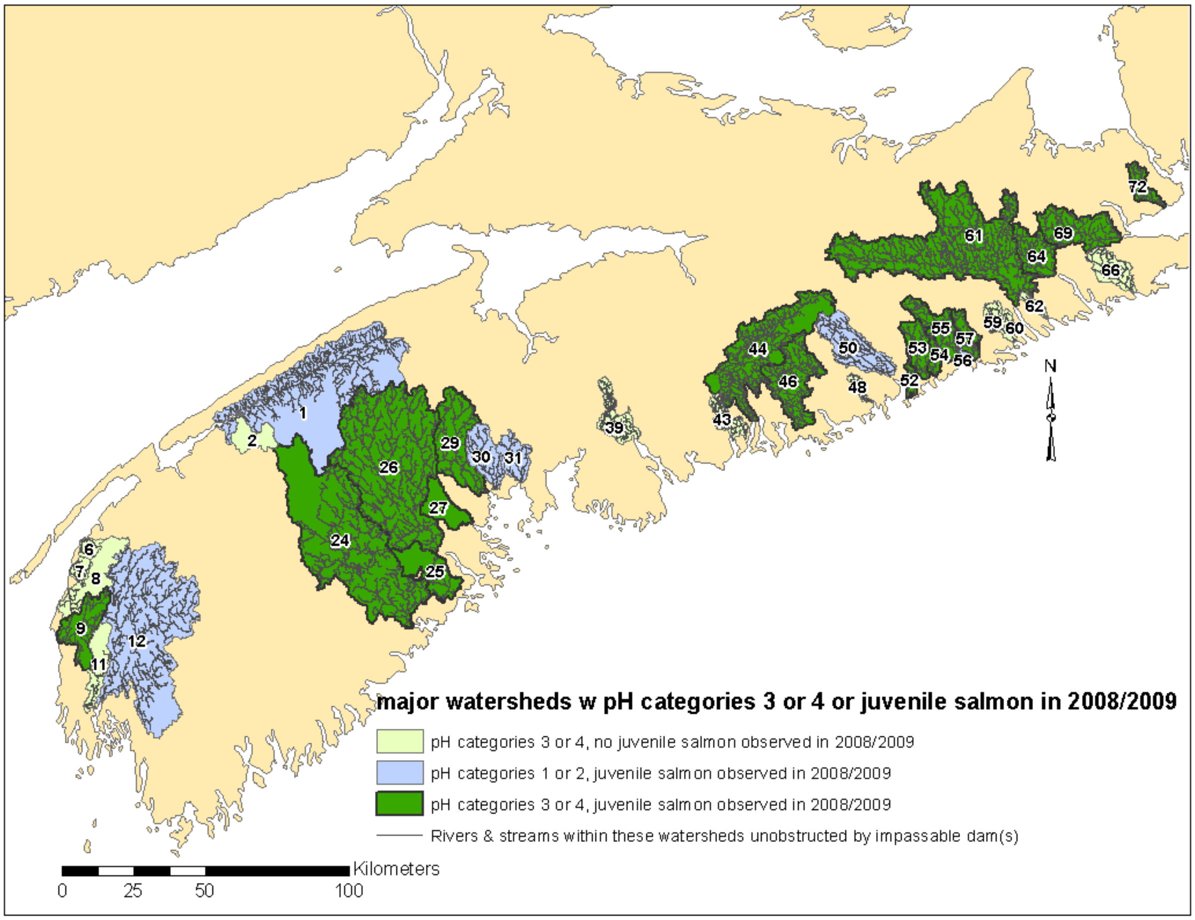

Figure 4.4.1. Location of freshwater habitats that exhibit one (or more) of three characteristics: have a pH greater than 5.0 (category 3 and 4 rivers), have a high proportion of the watershed not impacted by barriers to fish passage, and/or contained Atlantic salmon in the most recent (2008/09) electrofishing survey. Although the St. Francis Harbour River (#72) was not sampled in 2008/09, it is known to contain salmon based on current restoration work by the NSDFA. Watershed numbers correspond to the legend in Figure 2.1.1.

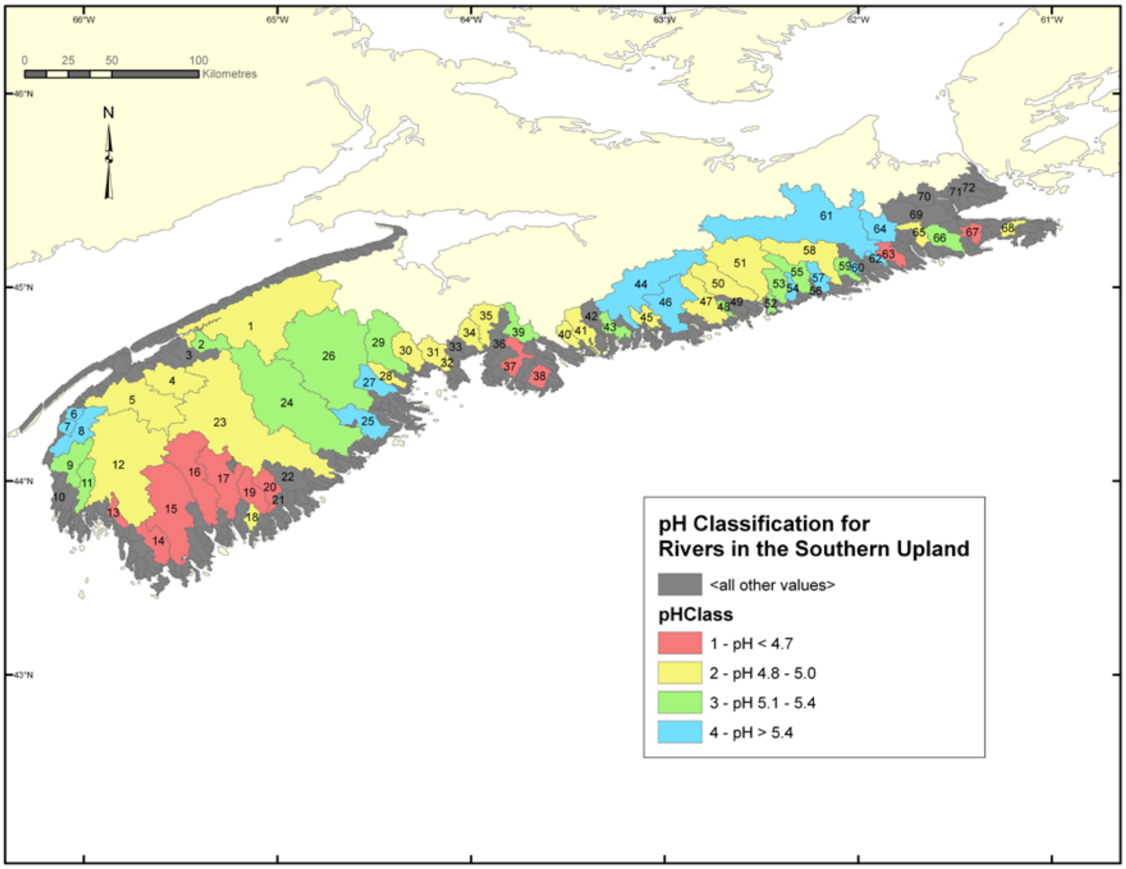

Figure 5.1.1. Classification of mean annual pH for rivers in the Southern Upland DU; data are from Amiro (2000). Watershed numbers correspond to the legend in Figure 2.1.1.

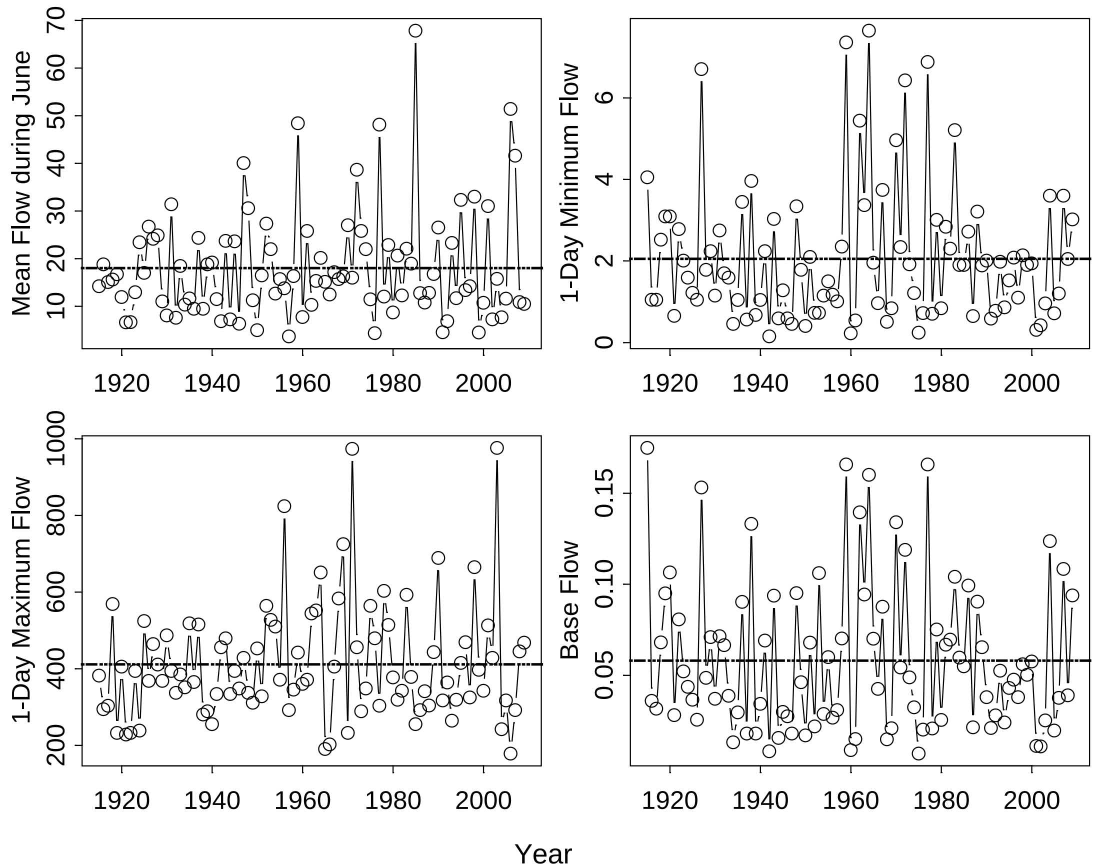

Figure 5.1.2. A sample of the hydrological records for the St. Mary's River from the monitoring station maintained by Environment Canada (1916 to 2010) illustrating high degree of variation over time. The dashed horizontal line in each plot shows the series mean.

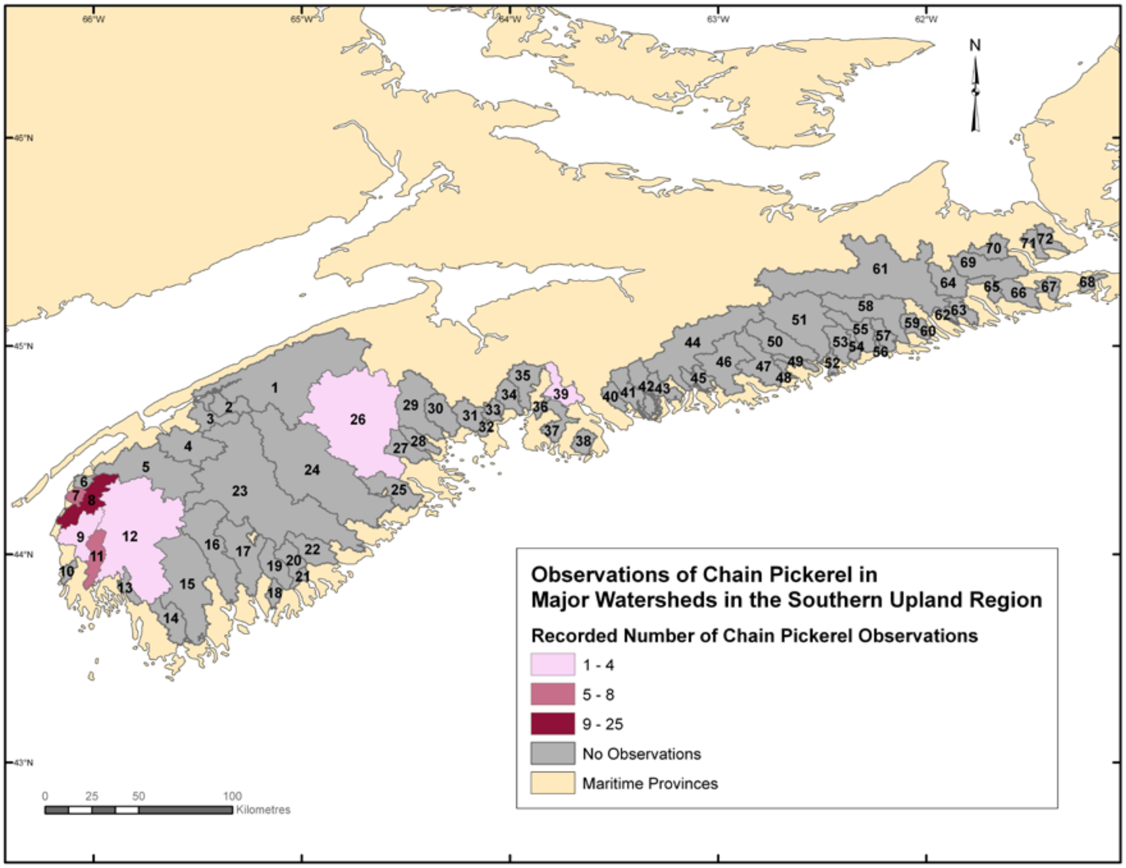

Figure 5.2.1. Documented occurrences of chain pickerel in watersheds of the Southern Upland as of 2010. Data are from the NS Department of Fisheries and Aquaculture. Watershed numbers correspond to the legend in Figure 2.1.1.

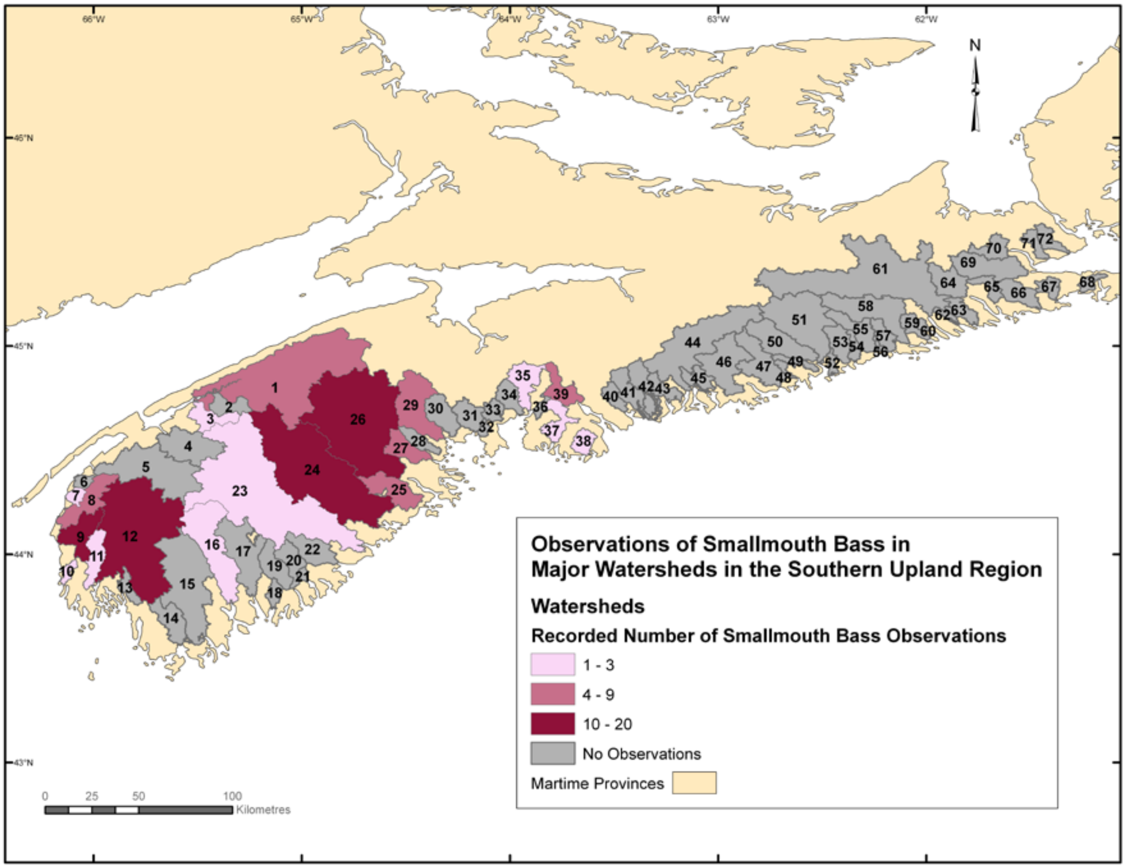

Figure 5.2.2. Documented occurrences of smallmouth bass in watersheds of the Southern Upland as of 2010. Data are from the NS Department of Fisheries and Aquaculture. Watershed numbers correspond to the legend in Figure 2.1.1.

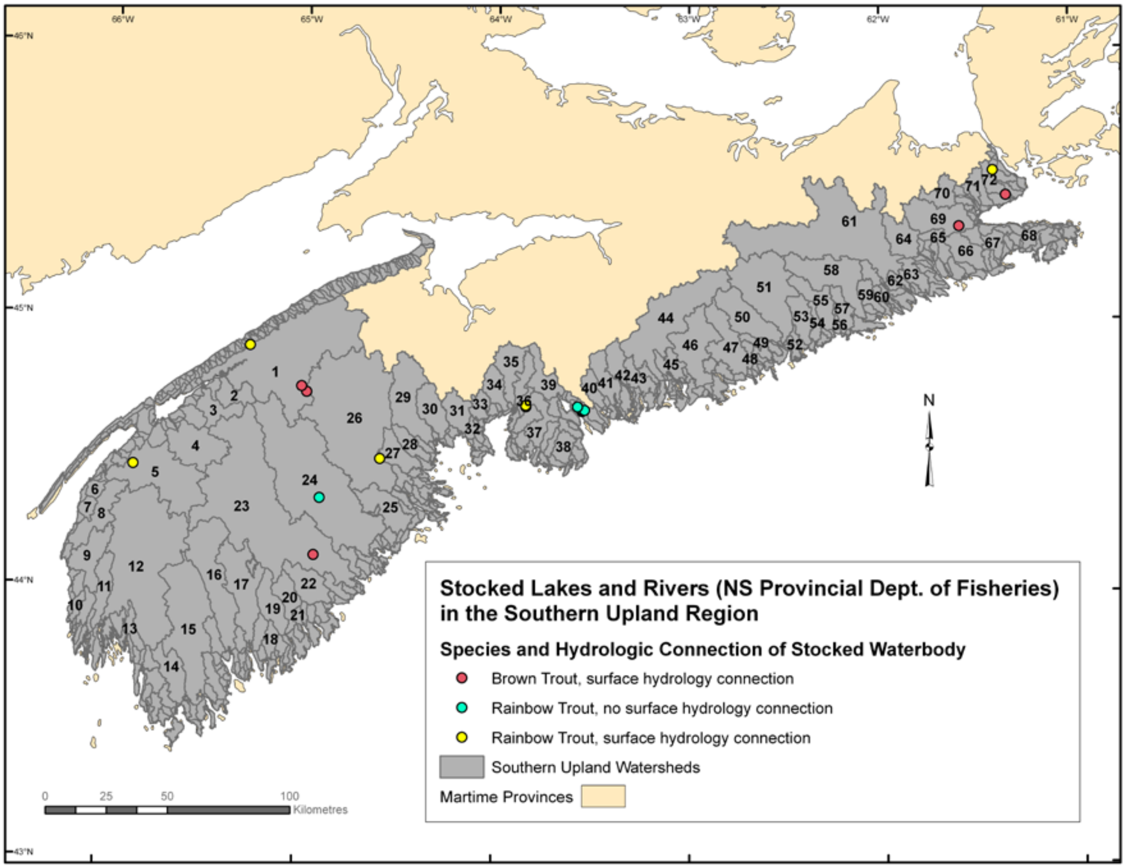

Figure 5.2.3. Locations of lakes in the Southern Upland stocked in 2011 with either rainbow or brown trout by the NSDFA. Watershed numbers correspond to the legend in Figure 2.1.1.

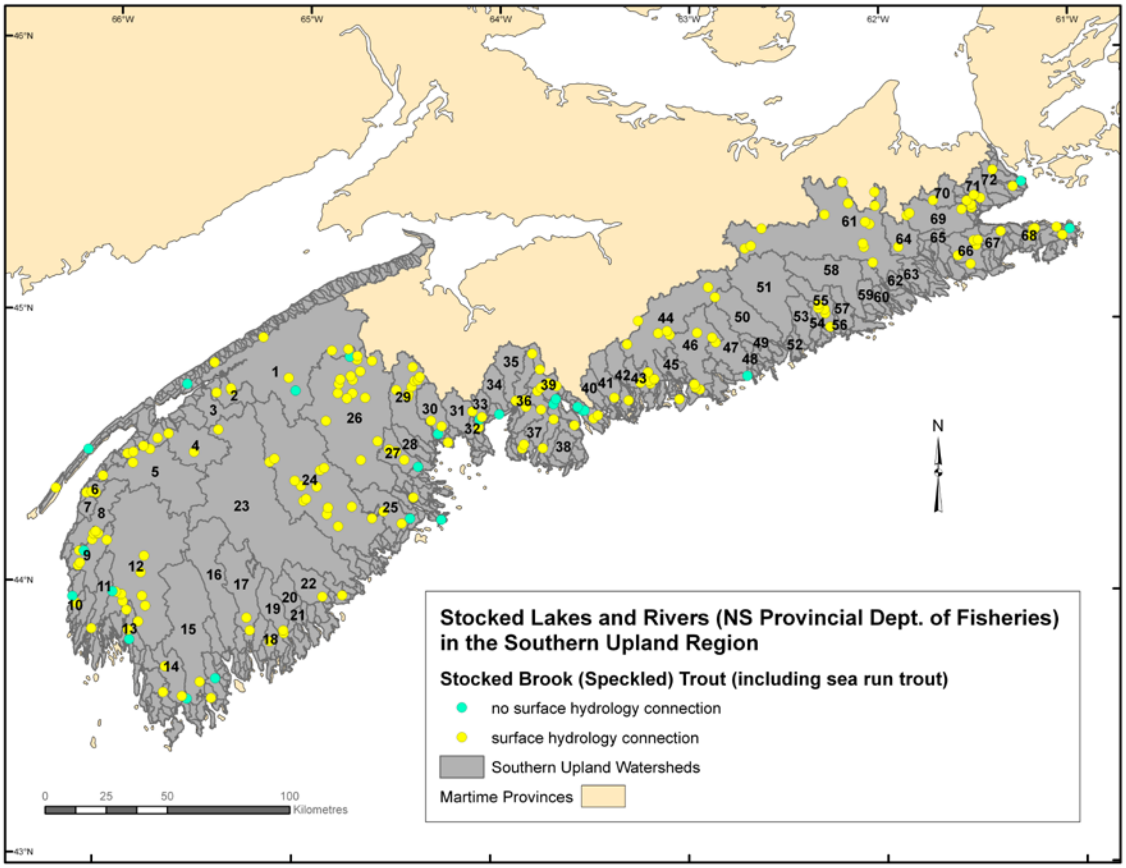

Figure 5.2.4. Distribution locations for the spring and fall stocking program of brook trout operated by the NSDFA in 2011. Watershed numbers correspond to the legend in Figure 2.1.1.

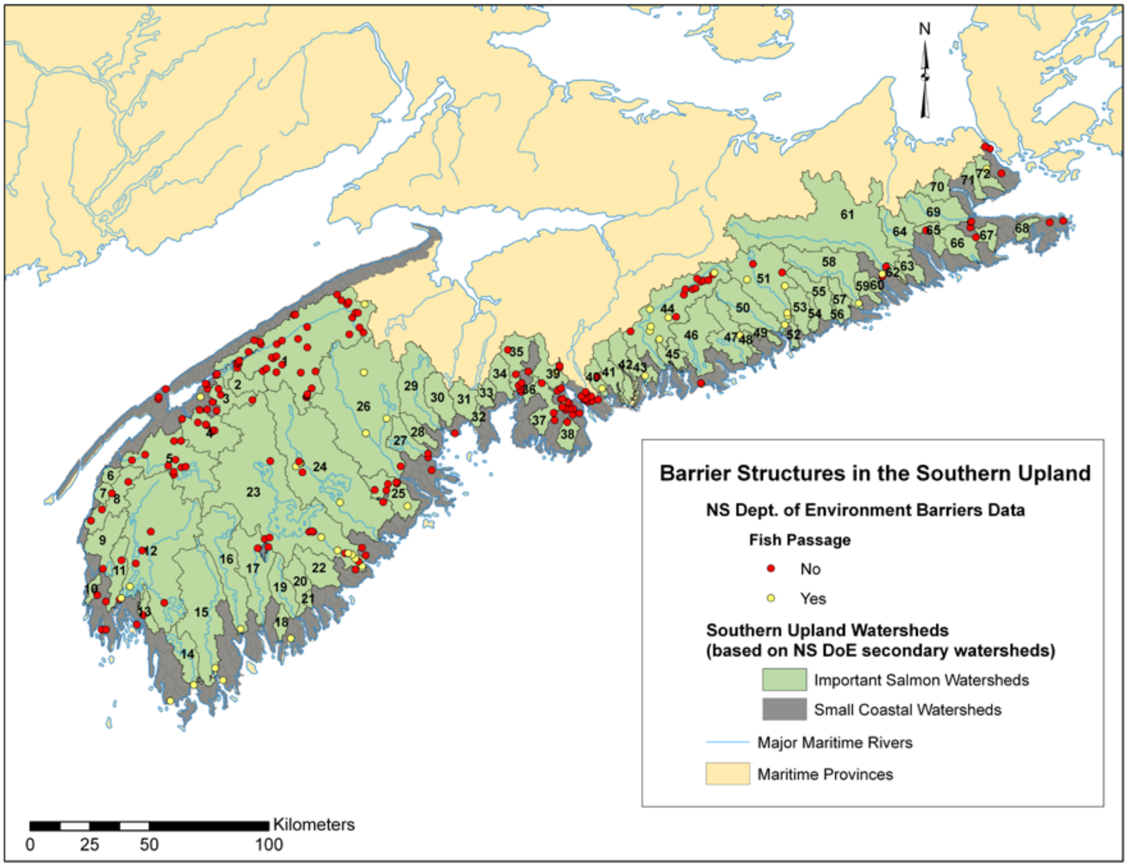

Figure 5.3.1. Barrier structures in the Southern Upland listed on the barriers layer from the NSDoE and the Habitat Protection (Maritimes) of DFO. Those without fish passage are shown in red, while those with at least partial passage are in yellow. Watershed numbers correspond to the legend in Figure 2.1.1.

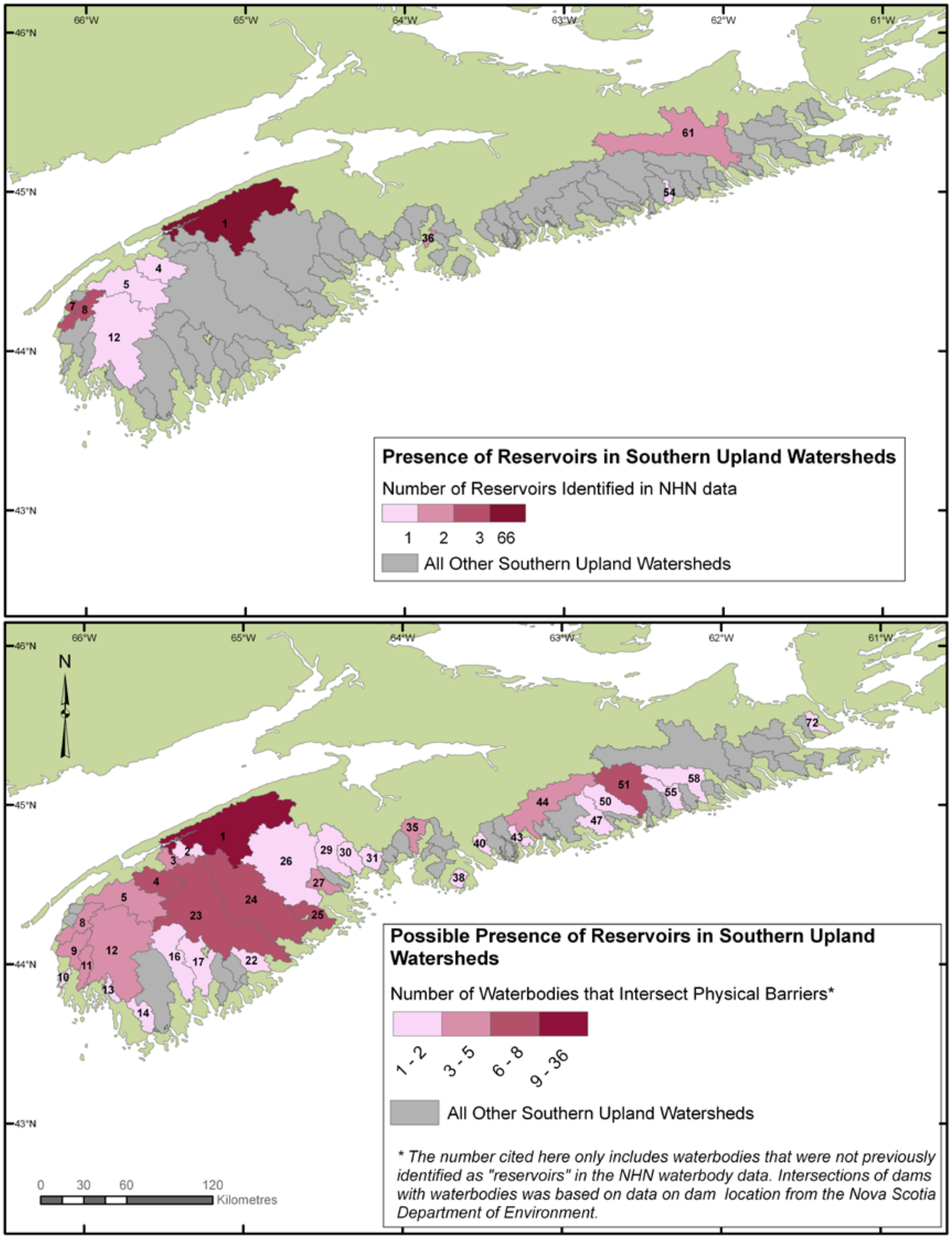

Figure 5.3.2. Watersheds containing reservoirs as identified from the NHN data (top panel) or intersection with the barriers layer from the NSDoE and DFO Habitat Division (bottom panel). Watershed numbers correspond to the legend in Figure 2.1.1.

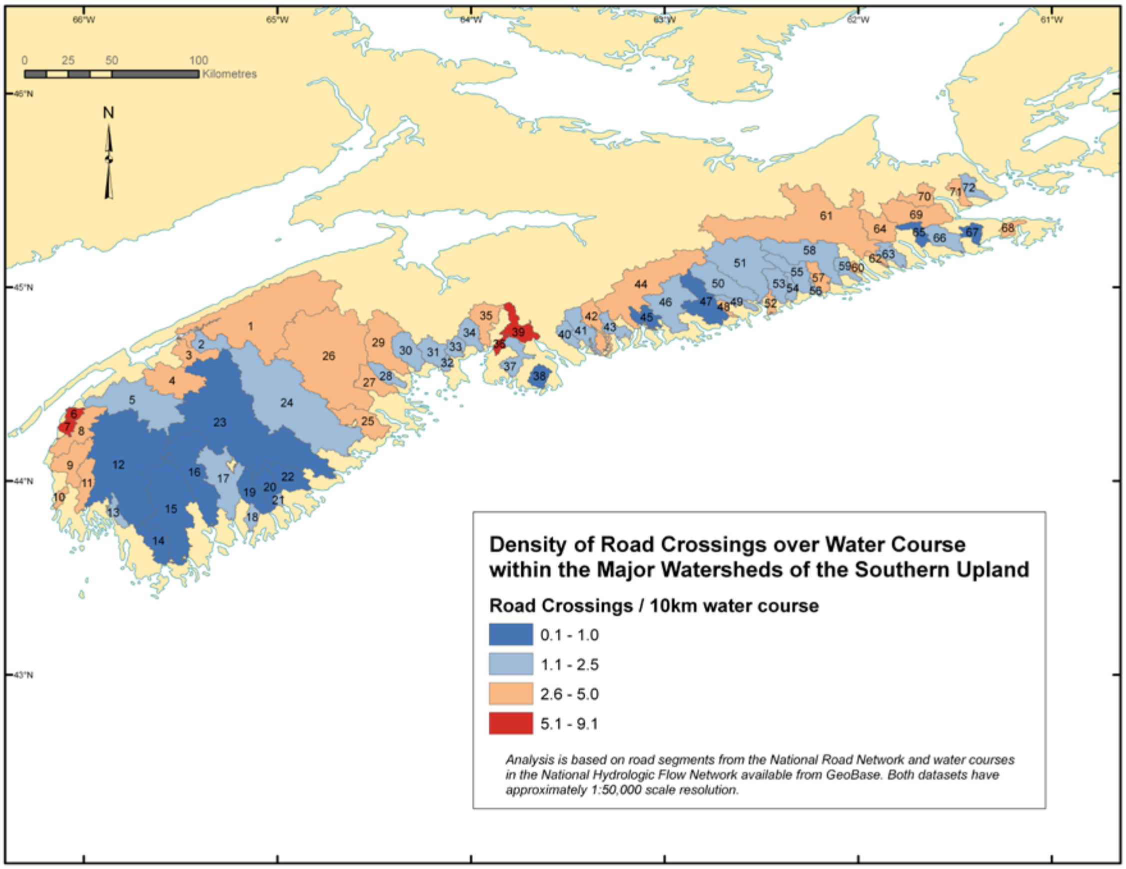

Figure 5.3.3. Density of road crossings within watersheds of the Southern Upland. Watershed numbers correspond to the legend in Figure 2.1.1.

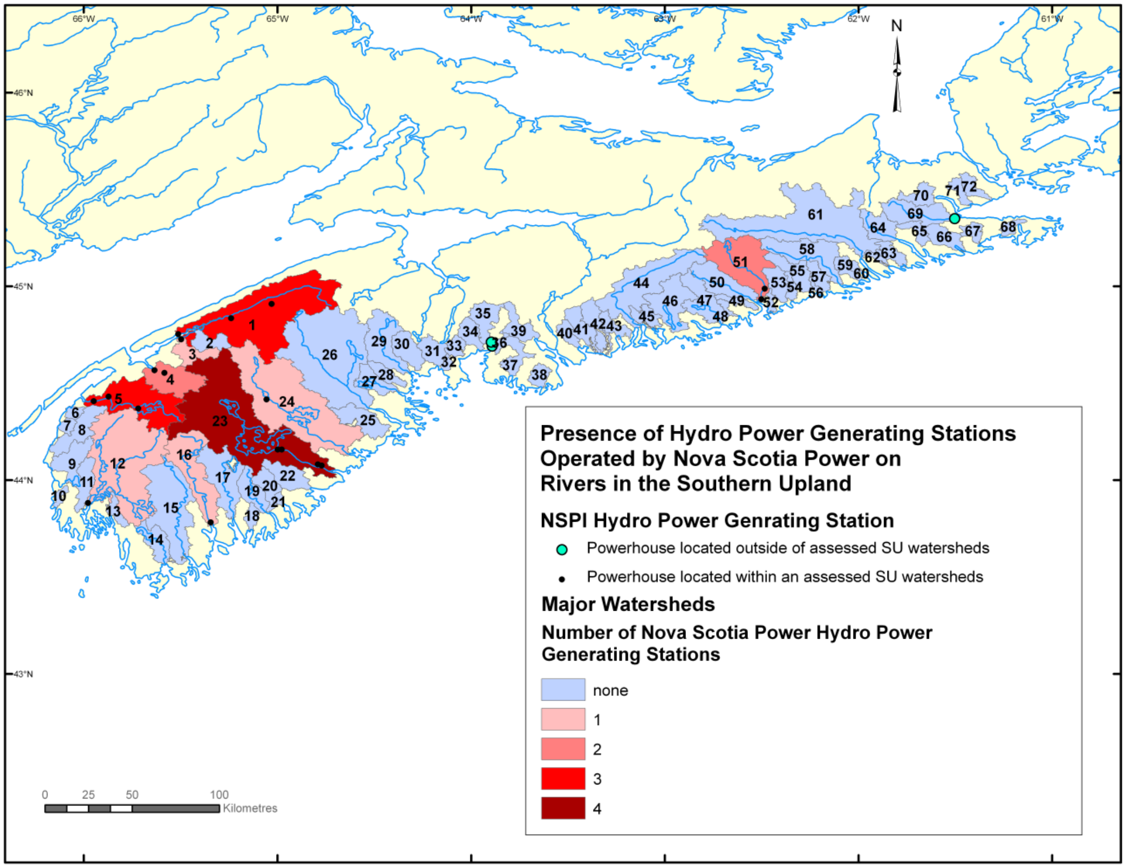

Figure 5.4.1. Locations of the hydropower generation facilities currently owned and operated by Nova Scotia Power Inc. in the Southern Upland. Watershed numbers correspond to the legend in Figure 2.1.1.

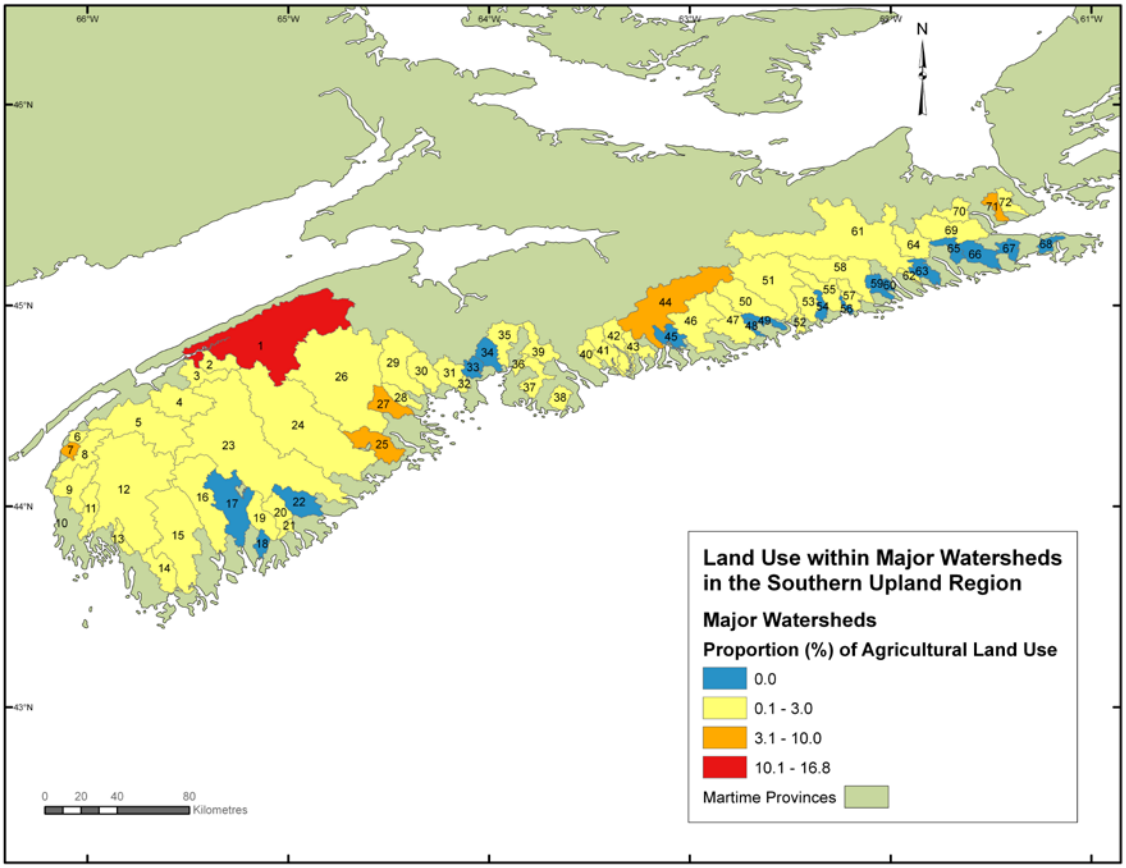

Figure 5.4.2. The proportion of watershed area classified as agricultural (including blueberry production) for rivers in the Southern Upland, based on aerial surveys from 1995 to present. Watershed numbers correspond to the legend in Figure 2.1.1.

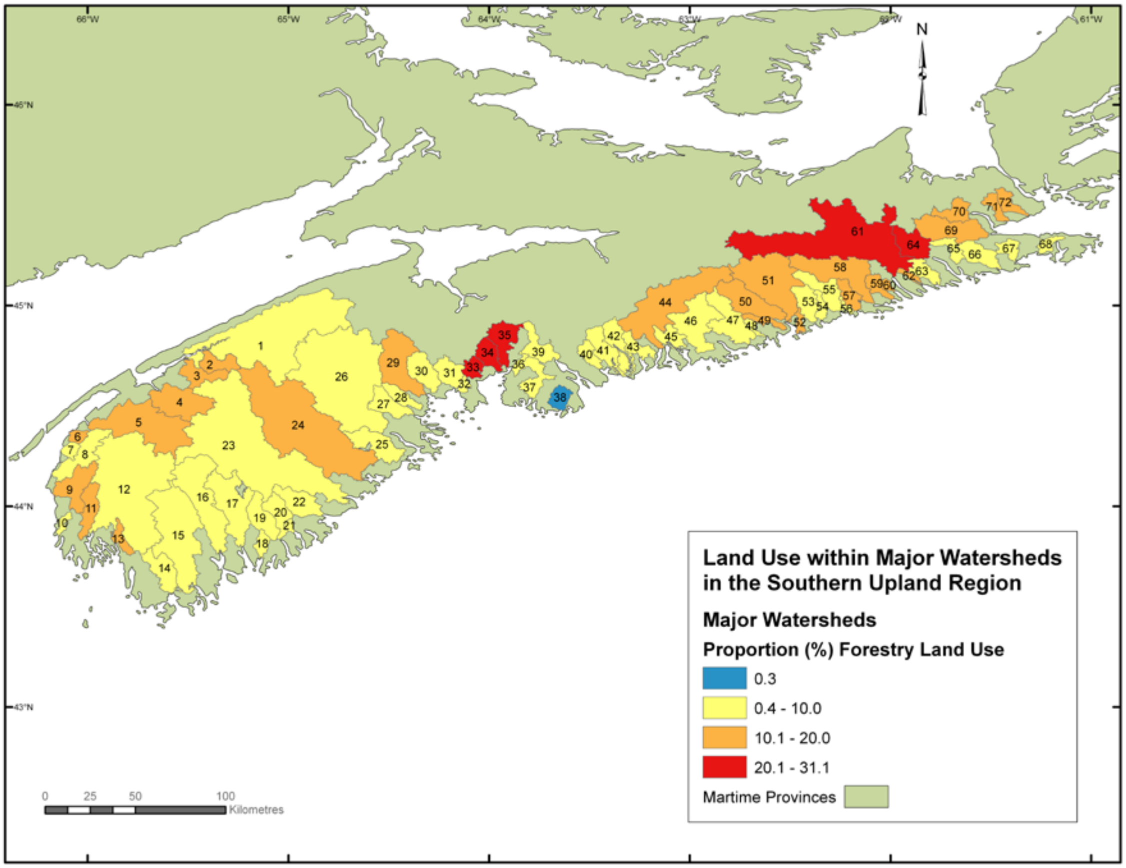

Figure 5.4.3. The proportion of watershed area classified as forestry lands (silviculture, timber harvest, Christmas tree farms and experimental stands) for rivers in the Southern Upland based on aerial surveys from 1995 to present. Watershed numbers correspond to the legend in Figure 2.1.1.

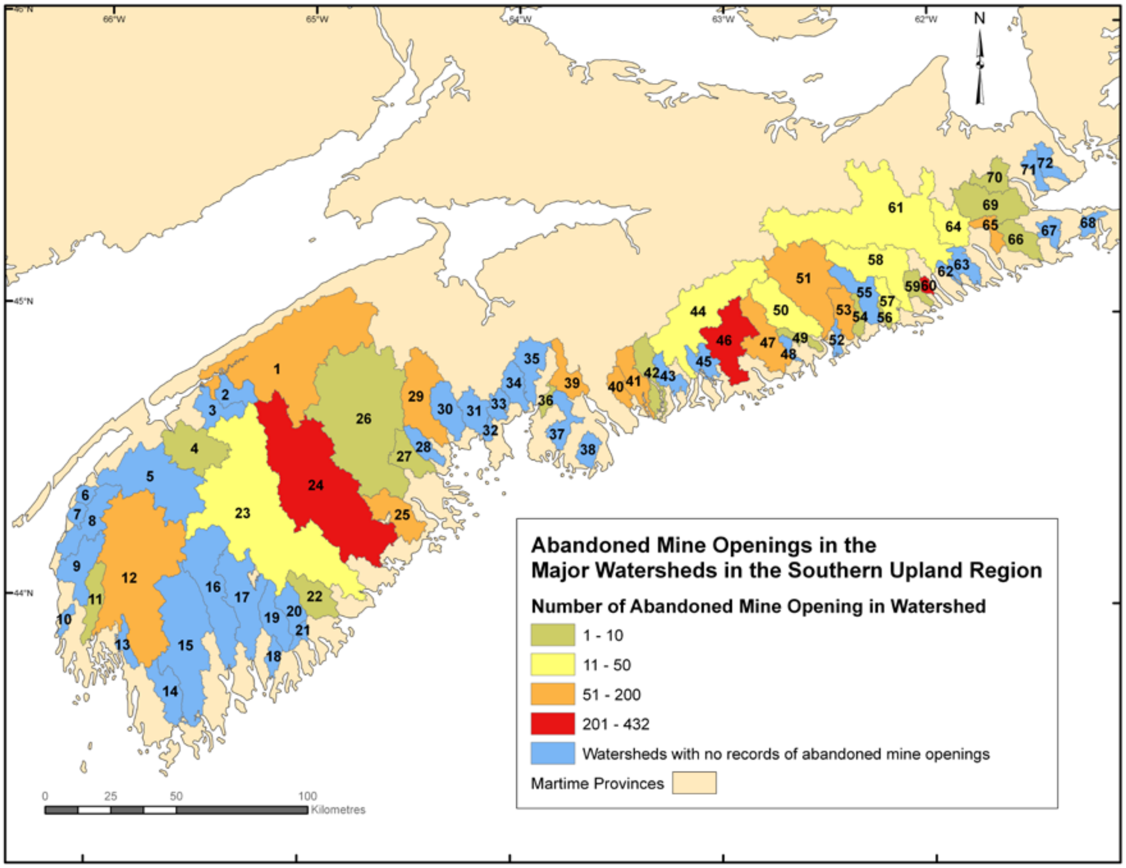

Figure 5.4.4. Distribution within the Southern Upland of the abandoned mines identified in the Abandoned Mines Opening Database from the NS Department of Natural Resources. Watershed numbers correspond to the legend in Figure 2.1.1.

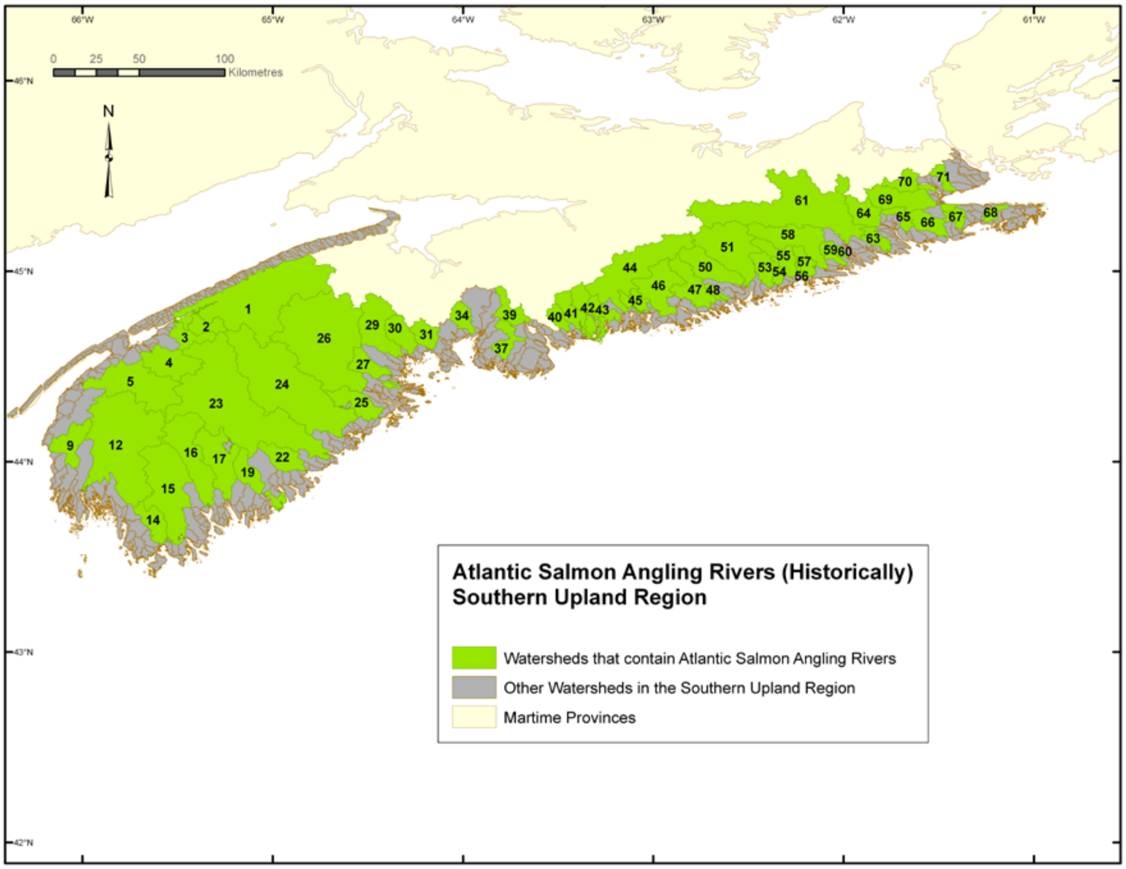

Figure 5.5.1. Watersheds in the Southern Upland that have reported recreational salmon catches and are included in the license stub returns database maintained by the Science Branch of the Department of Fisheries and Oceans. Watershed numbers correspond to the legend in Figure 2.1.1.

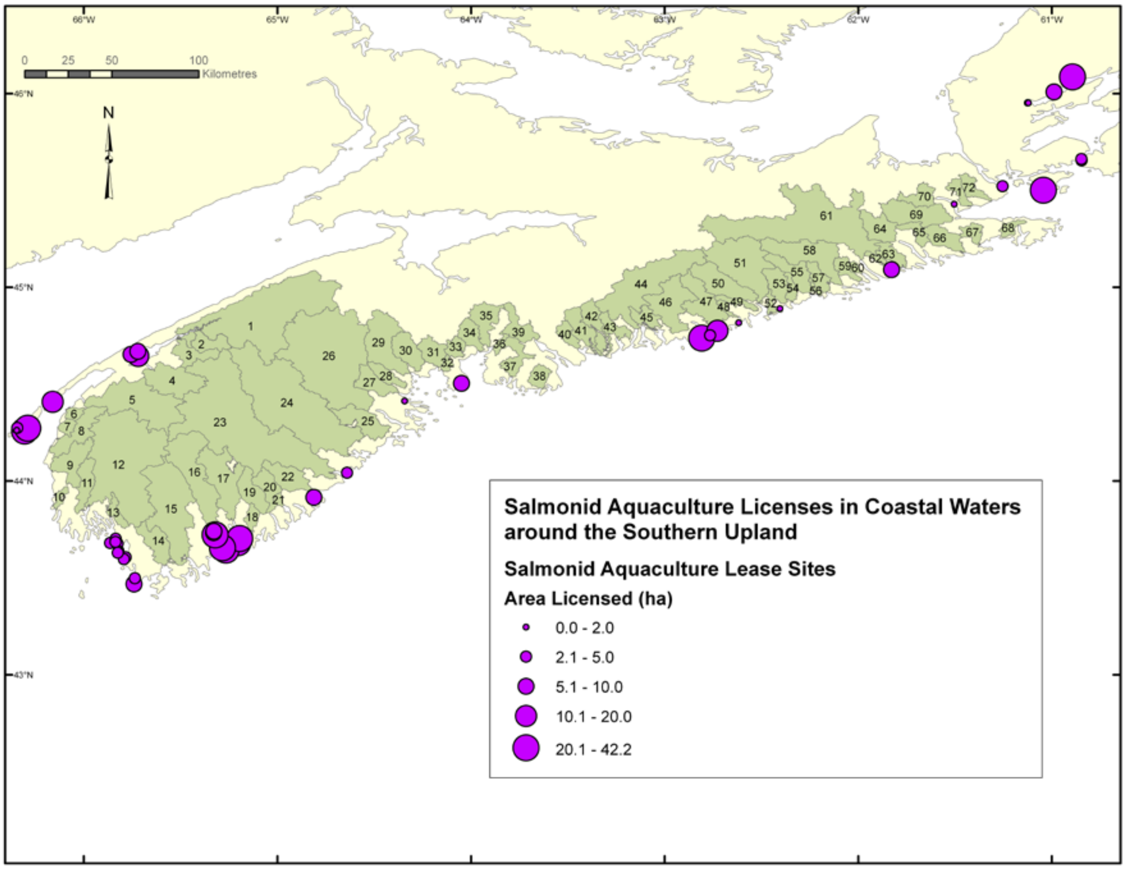

Figure 6.1.1. Locations and relative size of salmonid aquaculture lease sites in the coastal waters around the Southern Upland. Data from the NS Department of Fisheries and Aquaculture and only includes sites from Nova Scotia. Watershed numbers correspond to the legend in Figure 2.1.1.

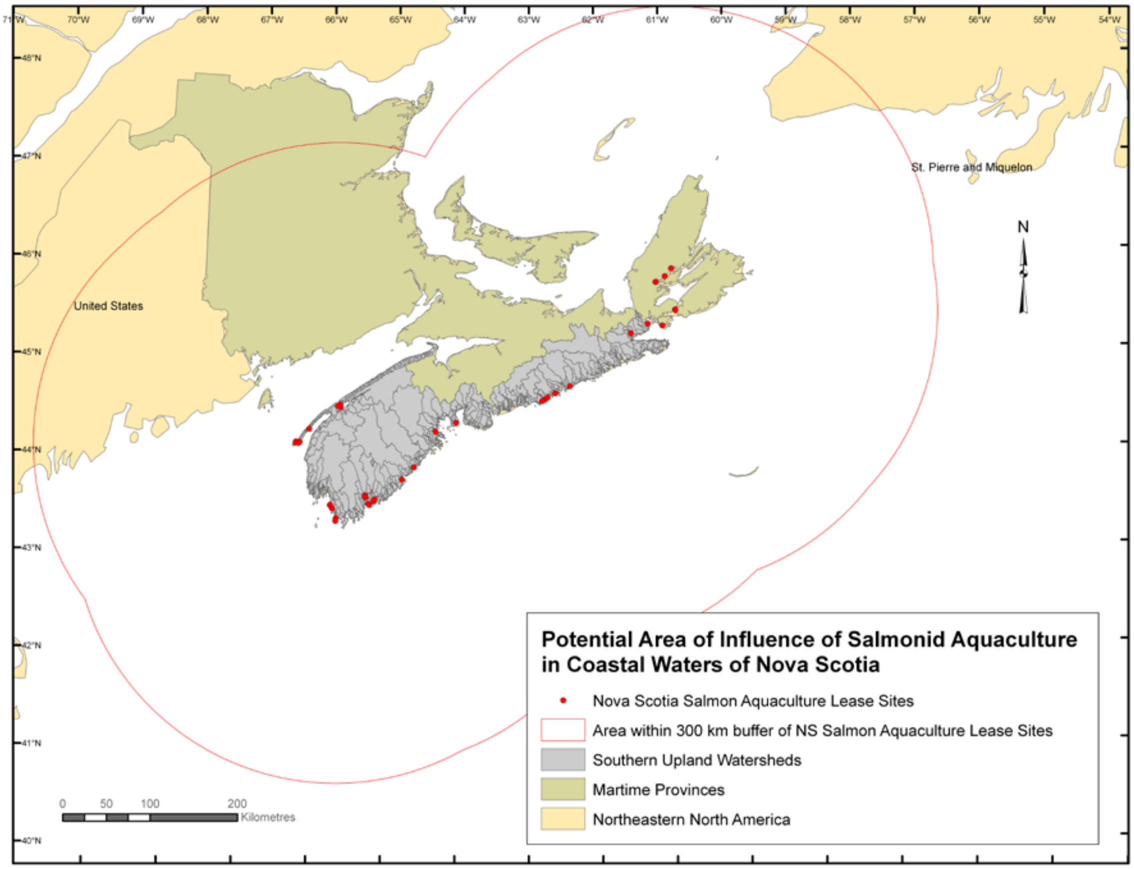

Figure 6.1.2. Aquaculture sites with a permit to culture Atlantic salmon or rainbow trout with a 300 km reference line (red line) which represents the maximum distance considered by Morris et al. (2008) when investigating the occurance of escaped aquaculture fish in wild Atlantic salmon populations in the Southern Upland.

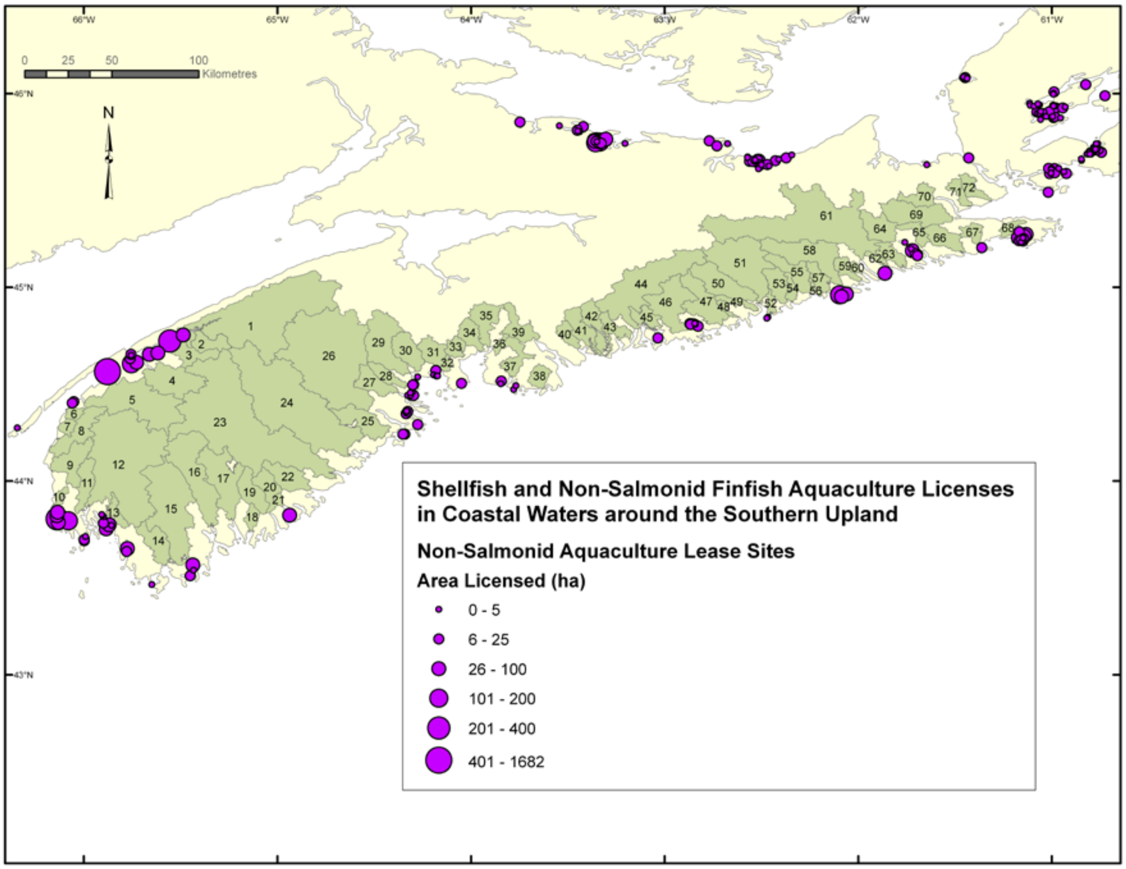

Figure 6.1.3. Locations and relative size of shellfish and fin-fish (excluding salmonids) aquaculture licenses in the coastal region surrounding the Southern Upland. Data are from the NS Department of Fisheries and Aquaculture and only includes sites from Nova Scotia. Watershed numbers correspond to the legend in Figure 2.1.1.

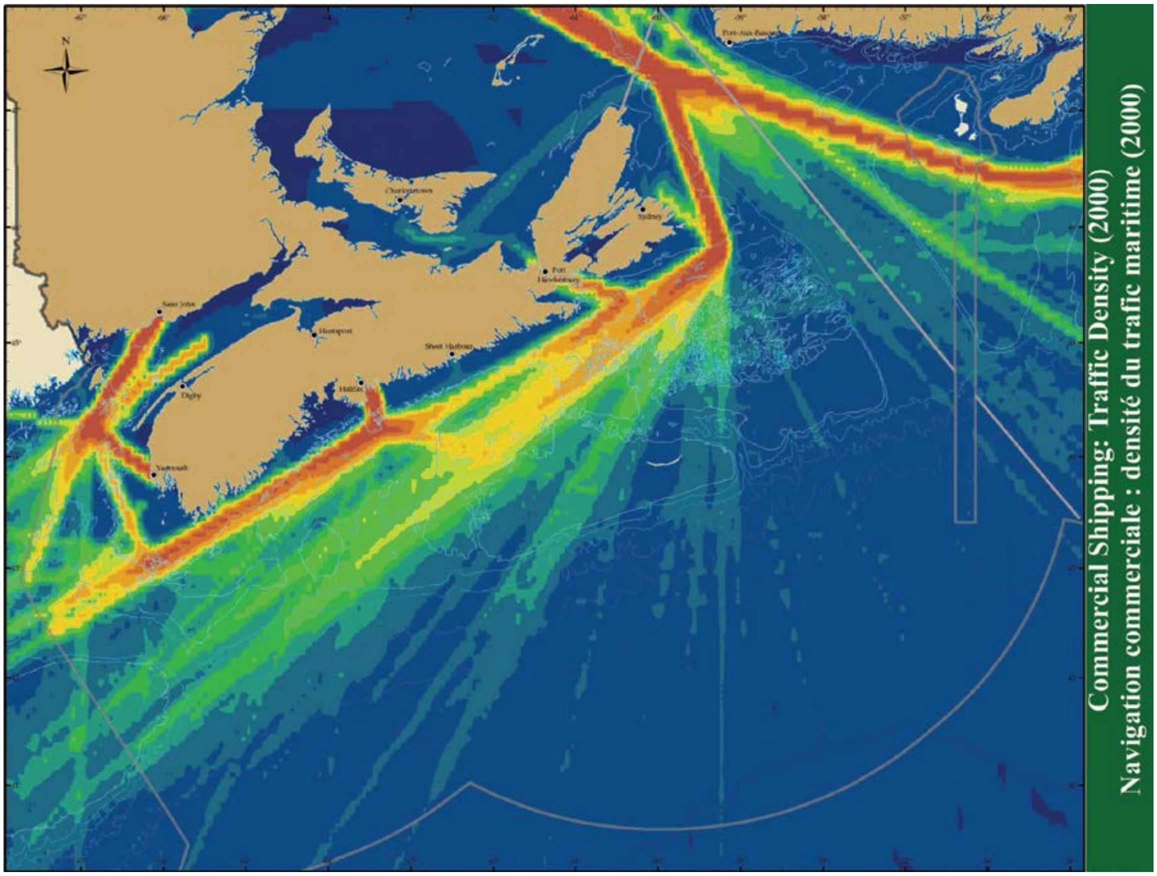

Figure 6.2.1. Density of inbound commercial shipping traffic (from the year 2000) along the Scotian Shelf, where red indicates the highest and blue the lowest densities from a vessel count and weighting analysis. Figure was reprinted from The Scotian Shelf: An Atlas of Human Activities published by the Oceans and Coastal Management Division of DFO (2005).

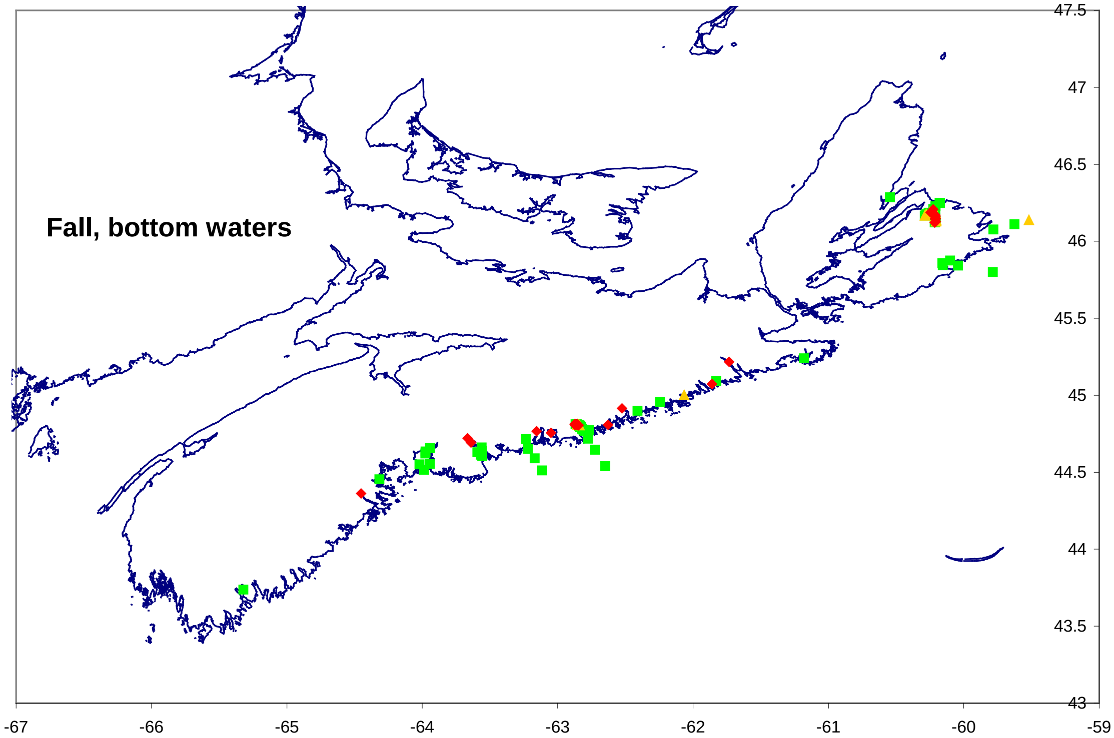

Figure 6.2.2. Potential for eutrophication in bottom waters during the fall for near-shore marine habitats on the Scotian Shelf. Green indicates concentrations that are within the expected normal range, yellow are intermediate, and red indicates those that are above the water quality guidelines for eutrophication. Figure obtained from Yeats (unpublished).

APPENDIX 1

GEOGRAPHIC INFORMATION SYSTEMS ANALYSES

Geographic Information Systems (GIS) analyses were conducted to assess the physical, geological and human use components for the 72 identified watersheds used by Atlantic salmon in the Southern Upland Designatable Unit (DU). Both general queries for information about the watersheds, such as area and perimeter, and more complex spatial queries and analyses combining a variety of spatial data sets, were carried out 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 carried out 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 provided in Table A2.

DELINEATION OF WATERSHED BOUNDARIES AND FLOW NETWORK

Although many data layers of watershed boundaries exist, the most comprehensive was the Secondary Watershed Layer developed by the Nova Scotia Department of the Environment (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 Southern Upland, with the exception of Round Hill River. In the Secondary Watershed Layer, Round Hill River was considered part of the Annapolis watershed. Given that recreational fishing data, annual mean pH (Amiro 2000), habitat area by gradient category (Amiro 1993), as well as electrofishing survey information from 2000 and 2008/09 (Gibson et al. 2011), had all been collected independently for the Round Hill River, the decision was made to delineate the watershed as distinct from the Annapolis system. Using 1:10,000 hydrological maps, all waters that flowed into Round Hill were identified and the likely boundary between the Round Hill River and the Annapolis River was drawn. Watershed boundaries are shown in Figure 2.1.1.

Hydrological data used to characterize streams, rivers and other waterbodies (e.g. lakes, stillwaters) within a watershed boundary were based on the watershed attribute data (e.g. waterbodies, polygons of wide rivers, arcs of streams) from the National Hydro Network (NHN), which is publicly available from GeoBase (1:50,000 scale). The decision to use the NHN data rather than the hydrological features in the 1:10,000 topographic series data was made because it provides a better representation of potential salmon habitat and the NHN 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 hydrological 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.

GEOPHYSICAL CHARACTERIZATION 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 including all mapped tributaries within each watershed was estimated as the total length of arcs (i.e. lines) in the NHN hydrological 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 the total watercourse length in a watershed. In most instances, the inferred flow was manually entered because the coding associated with the NHN data which described inferred flow had poor accuracy.

NHN data was also used in the assessment of waterbodies (e.g. calculating the proportion of inland lakes in a watershed). As noted above, waterbodies 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, described below).

Elevation

Digital elevation models (DEM), available from GeoBase as 20 m horizontal resolution and 1 m vertical resolution raster data, were used to evaluate the topographical characteristics of watersheds. Zonal statistic analysis, where each of the Southern Upland 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 by 5 cell moving window analysis, the standard deviation of slope within each window was calculated to assess the topographic roughness of the watershed.

Bedrock and Surficial Geology

Geological data available from the Nova Scotia Department of Natural Resources (NSDNR) was used to evaluate bedrock and surficial geology types within Southern Upland watersheds. There were nine bedrock geology types that characterized the majority of watersheds used by Southern Upland salmon, as well as 49 relatively minor or unique types that encompassed a small amount of the total area. Therefore, the bedrock geology types were aggregated into the following groups for analyses:

1) granites,
2) sandstones and slate-sandstones,
3) undivided, and
4) other (Table A3).

Using this type of an aggregation meant that greater weight was given to the main types of bedrock formations in the analyses of watershed characteristics (see below) and proportionately less given to individual minor formations. Other groupings are possible, but would require input from a geologist to accurately identify equivalent bedrock formations. A similar aggregation was not done for surficial geology classes because it is likely that even relatively rare formations could have a large impact on watershed characteristics (by providing isolated locations of less acidified water, for example). Therefore, surficial geology classes were evaluated for each watershed as identified in the source data.

Ecological Land Classification

Natural processes which structure forest ecosystems within watersheds have an impact on hydrological processes in rivers. Furthermore, the biodiversity of the province has evolved and adapted to reflect natural disturbance processes in the forest. Therefore, the Natural Disturbance Regime (NDR) data (part of the Ecological Land Classification from the NSDNR) was used to characterize forest structure and composition in watersheds in the Southern Upland. The NDR classification is based on a wide variety of environmental data such as soils, surficial geology, topography, forestry, climate, and natural history (NSDNR 2008). The following natural disturbance regimes are described and delineated in the ecological land classification data:

1) Open Seral: ecosystems where site conditions restrict or limit tree growth. Some of these site limitations are a result of repeated disturbances such as fire. Other limitations are a result of natural processes such as extreme exposure to wind and seasonal flooding. Also in this class are wetlands where excessive moisture, thick peat layers and heavy shrub or low-lying vegetation restrict tree growth;
2) Frequent Disturbance: ecosystems which result in the rapid mortality of an existing stand and the establishment of a new stand of relatively even age. The interval between stand-initiating events is normally shorter than the average longevity of the dominant tree species;
3) Gap: ecosystems where areas are seldom exposed to disturbances. They are characterized by gap and small patch mortality (i.e. isolated tree death), followed by under-story recruitment, resulting in forest stands with multiple age classes; and
4) Infrequent: ecosystems where stand-initiating events are characteristic in the development of these forests, but the interval between these events is normally long enough to enable distinct under-story development.

The proportion of each NDR class was calculated for each of the watersheds in the Southern Upland.

LAND USE AND THREATS INFORMATION FOR SOUTHERN UPLAND WATERSHEDS

pH

Data on the mean annual pH categories for rivers in the Southern Upland was based on work by Amiro (2000) and does not exist for all of the 72 watersheds considered in these analyses. Here, pH categories were joined to the corresponding watershed in the GIS feature class and mapped results were displayed (Figure 5.1.1).

Introduced Fish

Data on the number of confirmed locations where smallmouth bass and chain pickerel had been captured were obtained from the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) in spreadsheet format. Location information was provided in latitude and longitude with 1 arc minute resolution (i.e. low resolution) along with the grid reference from the Nova Scotia Road Atlas mapbook (page and primary grid reference). To accurately map this data at the higher resolution considered in these analyses, geographical corrections were made manually using the references to lake names and corresponding positional data, to ensure that points were mapped in both the correct watershed and correct water body. A separate feature class was created for each species (smallmouth bass, chain pickerel) and an overlay analysis with the secondary watersheds for the Southern Upland was conducted to generate statistics about the presence and number of observations of introduced species within each watershed (Figures 5.2.1 and 5.2.2, Table 5.2.1).

Fish Stocking

Data about 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 iand waterbody for locations in the Southern Upland DU. Spatial analysis was performed to determine the number of waterbodies within each watershed in the Southern Upland that were stocked with each species, combining information from the spring and fall distribution lists. The NHN flow data was used to assess the hydrological connection of the stocked water body with the surrounding watershed (i.e. to determine land-locked lakes versus lakes that are connected by surface water to other streams and rivers within the watershed). These results are presented in Figures 5.2.3 and 6.2.4, as well as Table 5.2.2.

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 (hereafter called the DFO Habitat Division). This layer contains the characteristics of known 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 5.3.1, where the locations of the barriers were intersected with the NHN hydrologic network. The location and number of dams within watersheds was assessed (Table 5.3.1), and ArcGIS® Network Analyst was used to perform “Trace Upstream” analyses on each of the dams identified as having no fish passage (i.e. impassable) in order to calculate the length of the stream network (km) that was inaccessible to fish. This was converted into a percentage of inaccessible area for Atlantic salmon populations in each of the watersheds in the Southern Upland (Figure 4.1.1). With the available data, it was not possible to estimate the amount of wetted area isolated by total barriers to fish passage because a higher vertical resolution DEM would have been required. However, there was an essentially linear relationship between the length of the flow network and the drainage area in watersheds in the Southern Upland (data not shown), making the percentage of the stream network affected a good proxy for the percentage of the watershed impacted. Therefore, the percentage of stream length isolated was multiplied by the amount of rearing area in a watershed to give an approximation of the impact of barriers on habitat availability in the Southern Upland (Figure 4.1.2).

Reservoirs

Two methods of identifying reservoirs from the NHN waterbody data were used. In the first method, look-up tables for NHN codes used to describe each waterbody were linked to the appropriate field to identify and select the waterbodies classified as reservoirs. Spatial analysis of these waterbodies was performed to identify and generate statistics (count of reservoirs, total area, etc.) for the watersheds in the Southern Upland (Figure 5.3.2, top panel). However, the number of features in the NHN waterbody 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, NSPI data on hydropower turbine locations). Therefore, spatial analysis was performed to identify waterbody 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) in the Southern Upland. However, attempting to reduce this error by increasing the search radius for the intersection analysis would have likely included waterbodies that were not reservoirs (i.e. increased the misclassification rate of waterbodies as reservoirs). Therefore, only waterbody 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. Again, spatial analysis of these waterbodies was performed to generate statistics on the number and area of likely reservoirs as determined through spatial analysis (Figure 5.3.2; bottom panel). 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) (Table 5.3.2).

Road Crossings

Locations at which roads intersected the flow network within watersheds used by Southern Upland salmon 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 data following methodology described by Haskins and Mayhood (1997). Initially, crossings that would have intersected lakes, reservoirs or wetlands (i.e. features represented by polygons rather than lines in GIS) were excluded from the analysis, but this resulted in the exclusion of any crossing where the river was wide (i.e. the majority of crossings on the mainstem of rivers). Although it is recognized that including these crossings may result in a slight overestimation of the impact of roads in watersheds (because crossings spanned by bridges would be considered equivalent to those spanned by culverts), the difference between the two analyses were slight. In the entire Southern Upland, the number of crossings increased from 16,179 to 17,115 (i.e. by 5.7%) between the two approaches. Statistics for the number of road crossings and crossing density (# per 10 km of stream length) were generated for all paved and unpaved roads in each watershed (Figure 5.3.3 and Table 5.3.3).

Hydro Power

Locations of hydroelectric generating stations in Nova Scotia were provided by Nova Scotia Power Incorporated. This information was restricted to dam locations that housed turbines, not the many diversions or dam structures commonly associated with such installations. Dam locations were spatially overlaid on the secondary watersheds of the Southern Upland and statistics generated to assess the number of powerhouses within each of the watersheds (Table 5.3.1). Results are displayed in Figure 5.4.1.

Historical Data on Salmon Angling

Of the 72 rivers discussed in this document, 53 have recreational catches reported via license stub returns. The license stub return program used to monitor catch and effort from these rivers, initiated in 1983, does not include precise geographical information. Location information for these rivers was available from a hand-drawn hardcopy map (O'Neil et al. 1996). Additionally, the river names listed in the license stub database did not always match the official names of rivers published in the Nova Scotia Road Atlas (6^{th} edition) or GeoBase (e.g. Guysborough River). For each angling river, the hand-drawn positions were compared with online topographic maps and watershed boundaries from the Secondary Watershed Layer from NSDoE to match each of the angling rivers with one of the 72 watersheds in the Southern Upland region. Matches were coded as having been angling rivers in the attribute table for the NHN flow data. Watersheds where angling for salmon is believed to occur are displayed (Figure 5.5.1).

Land Use

The Forest Inventory Data from the NSDNR was used to evaluate land use in the 72 watersheds (Table A1). The forest inventory data used in this analysis was the most current version (Forest Inventory cycle 2 & 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 version 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 extent of a general type of human activity in the watersheds (e.g. forestry). For this analysis the Fornon codes were reclassified to represent larger groupings of human activity to characterize the extent of forestry, agriculture, and industrial sites/industrial corridors in the Southern Upland (Table A4). The amount of area impacted by each major type of human activity (Table 5.4.1) was calculated for each of the 72 watersheds included in the analysis.

Mining Operations

Data from the NSDNR Abandoned Mines Database was used a surrogate for historical mining activity in the Southern Upland. 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 Southern Upland watersheds, and the number of mines of each type within each watershed (Table 5.4.2) calculated and mapped (Figure 5.4.4)

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 Department of Fisheries and Oceans (Maritimes). These data include information on all releases of individually tagged Atlantic salmon in the Southern Upland (in addition to other DUs), as well as individual recapture information (e.g. date, gear type, etc.) and, in some 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 occured 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 (Figures 2.3.1 to 2.3.3).

Aquaculture

Data on the location, lease size and licensed species for all permitted aquaculture sites in the marine environment off 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 Southern Upland.

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 6.1.1 and 6.1.3). One study in the Southern Upland suggested that the maximum extent of straying by escaped fish from a given aquaculture site for Atlantic salmon would be 300 km (Morris et al. 2008). Therefore, a 300 km buffer with dissolved boundaries was created around the salmonid aquaculture lease sites as an illustration of the potential maximum area of influence for wild salmon from salmon aquaculture activity (Figure 6.1.2).

Table A1. Description and data sources of information used in the geographic analyses of watersheds of the Southern Upland.

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 Nova Scotia Department of Environment
Digital Elevation Data (DEM)	GeoBase's Canadian Digital Elevation Data (CDED)
Bedrock Geology, DP ME 43, Version 2, 2006	Nova Scotia Department of Natural Resources – Mineral Resources Branch
Surficial Geology DP ME 36, Version 2, 2006	Nova Scotia Department of Natural Resources – Mineral Resources Branch
Forest Inventory Cycle 2 & 3	Nova Scotia Department of Natural Resources – Forestry Branch
Ecological Land Classification	Nova Scotia Department of Natural Resources – 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 (pers. comm., DFO–HPSD March 2011)
Hydro Power Generating Stations	Nova Scotia Power Inc. ((pers. comm. NSPI, February 6, 2012)
Aquaculture – licensed marine sites in Nova Scotia	Nova Scotia Department of Fisheries and Aquaculture
Nova Scotia Abandoned Mine Openings (AMO) Database	Nova Scotia Department of Natural Resources – Mineral Resources Branch
Fall and spring trout stocking distribution lists for 2010, 2011	Nova Scotia Department of Fisheries and Aquaculture

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

Table A2. Standardized coordinate system used in geographic analyses of watershed of the Southern Upland.

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. Aggregation applied to the bedrock geology types within the Southern Upland (SU), area by unit, and percent representation of each type and group. The groupings were used as inputs for the landscape analysis to describe the bedrock geology of watersheds.

Group	Legend	Area (km^2)	Percent of SU Watersheds	Percent of Total Area in SU
GRANITES	Middle - Late Devonian biotite monzogranite	2753.61	10.0	26.1
	Middle - Late Devonian granodiorite	981.84	3.6	
	Middle - Late Devonian leucomonzogranite	1631.99	5.9	
	Middle - Late Devonian muscovite biotite monzogranite	1836.19	6.7	
SANDSTONES AND SLATE SANDSTONES	Wolfville Formation: southern mainland	341.90	1.2	54.0
	Goldenville Formation	9817.69	35.6	
	Halifax Formation	4742.27	17.2	
UNDIVIDED	Horton Group: northern mainland	395.28	1.4	4.7
	Horton Group: southern mainland	890.76	3.2	
OTHER	Bears Brook Formation	20.60	0.1	15.3
	Beechhill Cove, Ross Brook, French River, McAdam, Moydart and Stonehouse Formations	41.55	0.2	
	Blomidon Formation: southern mainland	187.73	0.7	
	Clam Harbour River Formation	246.44	0.9	
	Devonian - Carboniferous gabbro: northern mainland	2.00	0.0	
	Devonian - Carboniferous granite: Cape Breton Island	17.44	0.1	
	Early Cretaceous units	9.95	0.0	
	Fundy Group	0.30	0.0	
	George River Metamorphic Suite: undivided	0.81	0.0	
	Georgeville Group	4.02	0.0	
	Glenkeen Formation	50.24	0.2	
	Green Bay Formation	178.06	0.6	
	Hastings Formation	1.75	0.0	
	James River Formation	2.12	0.0	
	Kentville Formation	16.19	0.1	
	Keppock Formation	111.37	0.4	
	Knoydart and Stonehouse Formations	40.55	0.1	
	Late Carboniferous monzogranite	24.55	0.1	
	Lime-Kiln Brook, Churchville and Hood Island Formations	2.28	0.0	
	Liscomb Complex: Orthogneiss	11.87	0.0	

Group	Legend	Area (km^2)	Percent of SU Watersheds	Percent of Total Area in SU
	Liscomb Complex: Paragneiss	42.78	0.2	
	Lower and Middle Windsor Groups undivided: northern mainland	0.04	0.0	
	Mabou Group	20.45	0.1	
	Maple Ridge Formation	3.02	0.0	
	Middle - Late Devonian diorite	0.49	0.0	
	Middle - Late Devonian diorite - grabbro	9.28	0.0	
	Middle - Late Devonian fine grained leucomonzogranite	477.04	1.7	
	Middle - Late Devonian granitoid	184.73	0.7	
	Middle - Late Devonian monzogranite	454.17	1.6	
	Middle - Late Devonian muscovite leucomonzogranite	20.34	0.1	
	Middle - Late Devonian tonalite	408.39	1.5	
	Middle Ordovician granite	22.76	0.1	
	Murphy Road, Pesaquid and Green Oaks Formations	27.63	0.1	
	Neoproterozoic diorite - gabbro	16.44	0.1	
	Neoproterozoic granitoid	12.77	0.0	
	North Mountain Formation: southern mainland	919.61	3.3	
	Pomquet Formation	2.66	0.0	
	Proterozoic - Devonian amphibolite	12.43	0.0	
	Proterozoic - Devonian granite	1.74	0.0	
	Pugwash Mine, Forbes Lake, Addington, Wallace Brook and Lakevale Formations	0.08	0.0	
	Scots Bay Formation	1.12	0.0	
	Sunnyville Formation	46.26	0.2	
	Torbrook Formation	72.60	0.3	
	Wentworth Station, Miller Creek, MacDonald Road and Elderbank Formations	31.85	0.1	
	White Quarry, Stewiacke, Carrolls Corner, Macumber and Gays River Formations	135.37	0.5	
	White Rock Formation, lavas and volcaniclastic rocks	144.07	0.5	
	White Rock Formation, primarily near-shore marine	137.95	0.5	
	Windsor Group: northern mainland	0.72	0.0	
	Windsor Group: southern mainland	32.58	0.1	

Table A4. Reclassification of the Nova Scotia Forest Inventory classification (Fornon) for land use analysis of watersheds of the Southern Upland.

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 m polygons around active and abandoned rail lines (STAND_values 9001 & 9005)	99
Industrial Site/Corridor	Pipeline corridor	A 25 m 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