Barriers to Fish Passage in Nova Scotia

The Evolution of Water Control Barriers in Nova Scotia’s Watershed

By: Gillian Fielding

Supervisor: Shannon Sterling

Submitted for ENVS 4901- Environmental Science Honours
Abstract

Loss of connectivity throughout river systems is one of the most serious effects dams impose on migrating fish species. I examine the extent and dates of aquatic habitat loss due to dam construction in two key salmon regions in Nova Scotia: Inner Bay of Fundy (IBoF) and the Southern Uplands (SU). This work is possible due to the recent progress in the water control structure inventory for the province of Nova Scotia (NSWCD) by Nova Scotia Environment. Findings indicate that 586 dams have been documented in the NSWCD inventory for the entire province. The most common main purpose of dams built throughout Nova Scotia is for hydropower production (21%) and only 14% of dams in the database contain associated fish passage technology. Findings indicate that the SU is impacted by 279 dams, resulting in an upstream habitat loss of 3,008 km of stream length, equivalent to 9.28% of the total stream length within the SU. The most extensive amount of loss occurred from 1920-1930. The IBoF was found to have 131 dams resulting in an upstream habitat loss of 1,299 km of stream length, equivalent to 7.1% of total stream length. The most extensive amount of upstream habitat loss occurred from 1930-1940. I also examined if given what I have learned about the locations and dates of dam installations, are existent fish population data sufficient to assess the impacts of dams on the IBoF and SU Atlantic salmon populations in Nova Scotia? Results indicate that dams have caused a widespread upstream loss of freshwater habitat in Nova Scotia however fish population data do not exist to examine the direct impact of dam construction on the IBoF and SU Atlantic salmon populations in Nova Scotia. Because of the large extent of rivers behind dams, this research suggests that dam construction may have contributed to the decrease of Atlantic salmon populations or may be currently inhibiting recovery of salmon stocks in Nova Scotia.
# Table of Contents

1.0 Introduction ..................................................................................................................................................................................... 5  
1.1 Overview ....................................................................................................................................................................................... 5  
1.2 Research Problem ..................................................................................................................................................................... 7  
1.3 Scope .............................................................................................................................................................................................. 9  

2.0 Literature Review ................................................................................................................................................................ .......... 9  
2.1 Changes to the Hydrological Regime and Physical Habitat of Riverine Systems Imposed by Dams... 11  
  2.1.1 Flow Regulation ............................................................................................................................................................. 12  
  2.1.2 Conversion to Lentic Water Bodies and Temperature Changes ................................................................ 13  
  2.1.3 Altered Sediment Transport ..................................................................................................................................... 14  
2.2 Connectivity ................................................................................................................................................................ ............. 15  
2.3 Atlantic salmon in Nova Scotia ......................................................................................................................................... 18  
  2.3.1 Habitat Range ................................................................................................................................................................ .. 18  
  2.3.2 Status ................................................................................................................................................................ .................. 19  
  2.3.3 Threats ............................................................................................................................................................................... 19  
2.4 Identification of Literature Gaps ..................................................................................................................................... 21  

3.0 Methods ................................................................................................................................................................ ............................. 22  
3.1 Study Design................................................................................................................................................................ ............. 22  
3.2 Sources of Data ................................................................................................................................................................ ........ 23  
3.3 Focus Area ................................................................................................................................................................ ................. 25  
3.4 Instrumentation and Validity ............................................................................................................................................ 27  
3.5 Procedure ................................................................................................................................................................ .................. 27  
3.6 Analysis ................................................................................................................................................................ ...................... 31  
  3.6.1 Extent of Aquatic Habitat Loss .................................................................................................................................  31  
  3.6.2 Atlantic Salmon Population Data ............................................................................................................................ 31  
  3.6.3 Characteristics of Dams in Nova Scotia ................................................................................................................ 32  
3.7 Limitations and Delimitations .......................................................................................................................................... 32  

4.0 Results ................................................................................................................................................................ ............................. 33  
4.1 Characteristics of dams in Nova Scotia ......................................................................................................................... 33  
4.2 Associated Stream Loss ....................................................................................................................................................... 35  
4.3 Sufficiency of Fish Data ........................................................................................................................................................ 36  
4.4 Data Limitations ................................................................................................................................................................ ..... 40
5.0 Discussion .................................................................................................................................................................................. 41

5.1 Spatial Occurrence of Dams in Nova Scotia ............................................................................................................................ 41

5.2 Implications for Endangered Salmon Populations ................................................................................................................. 42

5.3 Indicator Rivers ........................................................................................................................................................................... 43

5.4 Restoration Implications ............................................................................................................................................................ 44

5.5 Implication of Assumptions and Limitations .......................................................................................................................... 47

5.6 Conclusions and Future Work ............................................................................................................................................... 48

6.0 References .................................................................................................................................................................................. 50

7.0 Acknowledgments ..................................................................................................................................................................... 55

8.0 Appendices .................................................................................................................................................................................. 56

  Appendix A .................................................................................................................................................................................... 56

  Appendix B .................................................................................................................................................................................... 57

  Appendix C .................................................................................................................................................................................... 58

  Appendix D .................................................................................................................................................................................... 60

Figures

Figure 3.0. Map of Nova Scotia indicating the location of the Atlantic salmon Southern Uplands populations and the Atlantic salmon Inner Bay of Fundy population ............................................................................................................................... 26

Figure 3.1. Flow chart representing snap model ............................................................................................................................. 29

Figure 3.2 Example of method used to calculate upstream length from dam locations ............................................................................. 30

Figure 4.0. Spatial distribution of dams in Nova Scotia and habitat loss in the SU and IBoF watersheds from damming. ................................................................. 34

Figure 4.1. Length of cumulative habitat loss (km) from 1800-2000 and total catch per unit effort data for the SU Atlantic salmon populations from 1983-2007 ................................................................. 38

Figure 4.2. Length of cumulative habitat loss (km) from 1850-2010 and total catch per unit effort data for the IBoF Atlantic salmon population from 1954-2010 ................................................................. 40

Figure 5.0. Areas of acidified freshwater within Nova Scotia and subsequent consequences for Atlantic salmon populations ................................................................. 47

Tables

Table 2.0. List of high priority research and monitoring recommendations developed by the Department of Fisheries and Oceans regarding the recovery strategy of the IBoF Atlantic salmon population ............................................................................................................................... 22

Table 3.0. Description of newly created layers into a geo-database from the NSWCD, based on primary function class of structure ................................................................................................................................. 28

Table 4.0. Total length of accessible streams for potential salmonid habitat lost due to dam construction in the SU and IBoF from 1800-2010 ................................................................................................................................. 36
1.0 Introduction

1.1 Overview

Habitat fragmentation is an important causal agent in species decline (Allan et al. 1997). The development of water control barriers such as dams, have altered freshwater habitats and have had a profound effect on aquatic organisms around the world (Schilt 2006). For example, an estimated 80% of the total discharges of large rivers in North America are impacted by dams (Bednarek 2001). Dams are valuable as they provide inexpensive and efficient power generation, flood control, recreational activities, water supply, irrigation, and navigation (Bednarek 2001). However, with over 36,000 major dams and hundreds of thousands of smaller ones implemented on river systems around the world, they can also have significant negative impacts on hydrological resources and aquatic ecosystems (Wells 1999).

Impacts of dams on freshwater ecosystems have been intensely studied and are well documented. Dams impact freshwater ecosystems by altering the natural hydrology of river systems. Examples of these impacts include; alteration of flow regimes, changing of water temperatures upstream and downstream, disrupting sediment transport, modifying nutrient loads, and fragmenting the continuity of river systems (Bednarek 2001; Saunders et al. 2002). The complex interactions and flow regimes within freshwater ecosystems play a profound role in the distribution, abundance, and
diversity of the organisms which reside there (Bunn & Arthington 2002).

Alterations of natural freshwater hydrological systems, through the use of dams can create substantial impacts upon aquatic organisms. For example, dams placed in freshwater ecosystems create the potential of restricting or eliminating the movement of fish upstream and isolating upstream populations (Hoffman & Dunham 2007). Movement among fish species plays an essential role for acquiring the resources necessary in order to complete their life cycles (Hoffman & Dunham 2007).

Some fish species are known to have complex life cycles in which they need to migrate for; spawning, overwintering, feeding, and seeking refuge (Meixler et al. 2009). Consequences of barriers include reducing the ability of fish to migrate upstream to critical habitats, extirpation of species from upstream populations, fragmenting or isolating upstream populations, increasing vulnerability to negative impacts of habitat disturbances, increasing the loss of genetic diversity at the population level and creating new habitats preferred by non-native species (Hoffman & Dunham 2007). Decreasing stream network connectivity is a significant threat which has caused freshwater species, especially diadromous fish in North America, to be listed as either endangered, vulnerable, or extinct (Saunders 2002).

The Atlantic salmon (Salmo salar) Inner Bay of Fundy population (IBoF) and the Atlantic
salmon Southern Upland population (SU) in Nova Scotia are endangered species potentially threatened by dams (DFO 2010; Gibson 2010). In order to aid in the recovery of these species, connectivity should be maintained in river systems, allowing critical habitat to be accessible. Installing a barrier without providing adequate fish passage will result in the permanent loss of access to upstream habitat.

Until 2011, limited knowledge existed regarding general information on dams along river systems within Nova Scotia such as; where the dams are located, what parts of Nova Scotia are most affected by dams, how many dams are there in Nova Scotia, when were they constructed, how many dams contain fish passage technology, and how much critical upstream habitat has been lost. This knowledge is critical as recovery efforts in a greater number of rivers are becoming increasingly important for long term fish population self-sustainability.

1.2 Research Problem

My research questions are:

1) “To what extent has aquatic habitat been lost due to artificial water control barriers,

2) when did this aquatic habitat loss occur, and

3) if given what I have learned about the locations and dates of dam installations, are existent fish population data sufficient to assess the impacts of dams on the IBoF and
SU Atlantic salmon populations in Nova Scotia?

There are three related hypotheses:

1) the construction of dams has led to a reduction of 1/3 of the habitat for fish species in Nova Scotia,

2) the largest aquatic habitat loss occurred between 1920 to 1930, and

3) existent data regarding fish populations will not be sufficient to assess the impacts of dams on the IBoF and SU Atlantic salmon populations in Nova Scotia.

To achieve the goal of exploring the impacts of dams on fish habitat and to address these research questions, there are three related objectives. The primary objective of this research is to determine the spatial distribution of dams throughout Nova Scotia. The second objective is to calculate the extent of aquatic habitat loss upstream due to dam construction in the SU and IBoF regions from 1800-2010. The third objective is to examine patterns between any observed SU and IBoF Atlantic salmon population declines and dam construction.

It is my goal that this research will be able to help fill in essential information gaps pertaining to dams in freshwater ecosystems and contribute to the body of knowledge that exists regarding endangered aquatic species and their freshwater habitats in Nova Scotia.
1.3 Scope

Examining the extent of aquatic habitat loss upstream due to dams and when it occurred will be limited to the SU region and the IBoF region of Nova Scotia, mainly due to time constraints and because these two regions contain endangered Atlantic salmon populations that depend on freshwater habitats which may be threatened by dam construction (DFO 2010; Gibson 2010). Artificial water control barriers will also be limited to solely examining dams, due to available database. Upstream river or stream length from each dam that is considered inaccessible to fish (no fish passage technology) is deemed as upstream habitat loss for the purpose of this study. Examining habitat suitability upstream from each dam site is beyond the scope of this research, therefore, results are preliminary and conservative.

2.0 Literature Review

Freshwater ecosystems have received less attention and support in conservation efforts compared to adjacent terrestrial or marine ecosystems, despite the fact that freshwater ecosystems contain a large extent of the world’s global biodiversity and are exposed to higher pressures and threats from human impacts (Hermoso et al. 2011).
Habitat fragmentation is one of the most serious ecological concerns imposed on riverine environments (Raeymaekers et al. 2009). The cumulative construction of dams worldwide continues to increase and has led to extensive fragmentation of river systems (Lucas et al. 2009). Decreased connectivity can prevent or disrupt natural patterns of migration and dispersal between critical habitats especially for diadromous fish species that depend on access between different habitats in order to complete their life cycle (Lucas et al. 2009). Loss of connectivity can result in reduced fitness of organisms and in worst case scenarios can result in population extinction (Blanchet et al. 2010; Lucas et al. 2009).

The principal objective of this literature review is to provide the reader with context of where current literature stands with regards to the research proposed. This section will examine the extent of changes to the hydrological regime which dams impose on riverine systems and the connection of these physical attributes to aquatic habitats and associated biological communities. This review will also examine the connection between dam construction and upstream habitat loss for diadromous species such as, the endangered Inner Bay of Fundy Atlantic salmon population and the Southern Uplands Atlantic salmon population in Nova Scotia, as well as the necessity of this study in addressing information gaps regarding freshwater habitat loss in Nova Scotia due to dam installations.
Literature was located using apriori and aposteriori methods, by searching academic journal
databases using various combinations of the phrases “effects of dams on hydrology” and “effects of
dams on fish populations and habitats”. Cited works in relevant articles were also examined for other
relevant articles. Literature was limited to using relevant articles from 1980-2011.

Grey literature regarding endangered Atlantic salmon populations were found on provincial and
federal websites using a snowball method. Only the most recent documents concerning status, habitats,
population abundance and distribution, and threats for Atlantic salmon were incorporated.

2.1 Changes to the Hydrological Regime and Physical Habitat of Riverine
Systems Imposed by Dams

The alteration of a rivers hydrological regime, due to dam installations, threatens the ecological
integrity and sustainability of riverine systems. The physical characteristics, operating rules, and
general climatic setting of a dam determines the extent of changes imposed to the hydrological regime
(Graf 2006; Burke et al. 2008). A considerable amount of research exists in regards to the hydro-
ecological impacts of dams, both upstream and downstream however, an exhaustive review of the
literature is beyond the scope of this project.

This section of the literature review will focus on common themes which have appeared
through various case studies and model-based research pertaining to the hydro-ecological effects of
dams. Common themes include changes to flow, temperature, sediment transport, and connectivity in the unregulated upstream and regulated downstream portions of dams.

2.1.1 Flow Regulation

Flow regimes are fundamental in determining the physical characteristics of a river's habitat. Spatial and temporal variations in frequency, magnitude, and duration of flows, regulates the shape and size of channels, distribution of riffle and pool habitats, the stability of substrate, and the temperature of riverine systems (Bunn & Arthington 2002; Bednarek 2001). Biological communities are dependent on specific habitat requirements, therefore, alteration of the natural flow regime indirectly affects the distribution and abundance of biodiversity within the river system. Dams physically block the river, store excess water, and release water according to human needs, resulting in altering the natural flow regime of the river, both upstream and downstream (Bednarek 2001).

Studies of altered flow regime downstream due to dams have concluded that; 1) dams reduce flood peaks, 2) dams alter low flow patterns, and 3) dams alter the timing of peak flows (Graf 2006). For example, a study conducted across the Connecticut River watershed in the United States concluded that peak flows declined by 32%, in rivers impacted by dams (Graf 2006). Magilligan and Nislow (2005) also assessed hydrological changes at twenty-one different dam sites across the United States
and found that on average the 2-year flow decreased by 60% after dam installation. The greater the deviation in magnitude and frequency of the flow regime from pre disturbance conditions, the greater the expected shift in species composition (Magilligan & Nislow 2005).

2.1.2 Conversion to Lentic Water Bodies and Temperature Changes

The creation of a reservoir through damming turns upstream free flowing rivers (lotic) into slow moving lake like water bodies (lentic). A study on the Colorado River found that dam installations converted one quarter of the river to lentic habitat, which resulted in the loss of fish who are naturally adapted to turbid riverine habitats (Bunn & Arthington 2002). The newly created lentic habitat also accompanied the success of invasive species which have contributed to the extirpation of native fish species in the Colorado River (Bunn & Arthington 2002).

The creation of lake like habitats upstream from dams also alters the natural temperature of the river (Bednarek 2001). For migrating cold water fish such as salmon, warm water temperatures act as thermal barriers to movement (Bednarek 2001). Fish species therefore may be forced to find alternate routes which can lead to decreasing their chance of reaching appropriate spawning grounds (Lucas et al. 2009)

Warmer temperatures upstream of dams can favour invasive fish species populations. For
example, the damming of the Peticodiac River in New Brunswick resulted in an increased abundance of non-native species, such as; small mouth bass, due to warm water temperatures facilitating high successful reproduction rates of the species (Locke et al. 2003)

Temperature changes can also occur downstream of dams, if large amounts of water from the stratified reservoir upstream is released. The release can cause cold water with low levels of dissolved oxygen to move downstream (Bednarek 2001; Bunn & Arthington 2002). Oxygen-poor cold water downstream can influence spawning behaviour of some fish species (Bunn & Arthington 2002). For example, cold water releases downstream of dams have been found to delay spawning of some fish species by up to thirty days (Bunn & Arthington 2002).

2.1.3 Altered Sediment Transport

Changes to the natural flow regime can also alter the transportation of sediment which changes the natural physical structure of aquatic habitats. Sediment transport is a key factor in developing a rivers natural structural habitat. Altering sediment transport through dam construction generally causes stream bed deposition upstream of the dam site (Magilligan & Nislow 2005). Reducing suspended sediment and bed load transport also results in increased erosion downstream (Magilligan & Nislow 2005).
Increased erosion downstream of dams can result in a loss of critical habitat used by some fish species for spawning, refuge, and migration. For example, downstream sediment-related effects include the loss of riffle pool sequences, collapse of banks, and loss of riparian habitat, which are considered to be critical habitat for the successful completion of some fish species' life cycles (Lucas et al. 2009).

It is evident through these examples that dams can make profound changes to freshwater habitat and may therefore, indirectly lead to the decline of aquatic species. The following section of the literature review will examine the effects of dam installations experienced by fish species only, with focus on the Inner Bay of Fundy and Southern Uplands Atlantic salmon populations. The focus of dam-related impacts on fish species will be limited to examining the impact of lost connectivity throughout river systems.

2.2 Connectivity

Connectivity is an important component of all aspects in a functioning river. Connectivity is defined as the spatial continuity of a habitat type (Cote et al. 2008). In freshwater ecosystems, connectivity can be used to measure and describe longitudinal river network connectivity (Cote et al. 2008). Longitudinal connectivity refers to connections between upstream and downstream sections of a river network (Cote et al. 2008).
Loss of connectivity throughout the river system is one of the most serious effects that dams impose on migrating fish species (Schick & Lindley 2007; Lucas et al. 2009; Blanchet et al. 2010). It is widely referred to as the “barrier effect” (Morita & Yamamoto 2002). The barrier effect is defined as the prevention of migration throughout the freshwater ecosystem (Morita & Yamamoto 2002). The terms migration and movement are used interchangeably within this review. For the purpose of this review, migration and movement will be used as defined by the Department of Ocean and Fisheries as, the spatial and temporal movement between spawning, feeding, and refuge habitats in response to genetic or environmental stimuli.

Aquatic fish species are impacted by dams as upstream habitats become inaccessible and populations can become isolated or extirpated due to impassibility of dam structure (Blanchet et al. 2010; Lucas et al. 2009). Lack of accessibility or poor connectivity between habitats can potentially lead to population decline as populations that are physically and genetically isolated upstream suffer from decreasing population sizes and inbreeding, this further increases the risk of extinction (Blanchet et al. 2010; Lucas et al. 2009; Raeymaekers et al. 2009).

Riverine ecosystems are considered to be dynamic landscapes, therefore, movement, habitat patchiness, and life stage dependent shifts in critical habitat interact with one another and influence
fish populations across the broader ecosystem (Poplar-Jeffers et al. 2009). Movement therefore is an important determinant of how fish species are distributed across the ecosystem and is related to their persistence within the system.

Examples of consequences of dam installations on fish species include, but are not limited to (Hoffman & Dunham 2007): 1) reduction or elimination of the ability for fish to reach upstream habitats; 2) extirpation of populations from upstream habitats; 3) fragmentation and isolation of upstream populations; 4) increased vulnerability to environmental change; 5) prevention of recolonization of disturbed upstream habitats; and 6) population-level genetic impacts. Impediments to migration caused by dams is exceptionally problematic for diadromous fish species as they must make migrations between marine and freshwater habitats in order to complete their life cycle (Cote et al. 2009).

Studies have shown that some declines of diadromous fish species have been attributed to the loss of connectivity from dam construction. For example, addition of large water storage dams to rivers in California’s Central Valley resulted in a dramatic decline in the distribution and abundance of spring-run Chinook salmon due to blocked access to spawning habitat (Schick & Lindley 2007). It has also been found that in the Peticodiac River in New Brunswick, poor upstream passage for migrating
fish species was the dominant reason for the decline and eventual extirpation in diadromous stocks (Locke et al. 2003). Another example is the extensive network of dams constructed in the Colombia River Basin, which blocked access to critical spawning habitats for Chinook salmon (Bunn & Arthington 2002). More than 75% of the spawning and rearing habitats that existed prior to dam installations are now eliminated within the Basin (Bunn & Arthington 2002). Decreasing connectivity amongst river systems is potentially a significant threat which may be inhibiting the recovery of endangered fish species in Nova Scotia.

2.3 Atlantic salmon in Nova Scotia

Two endangered Atlantic salmon (*Salmo salar*) populations found in Nova Scotia will be examined within this literature review: 1) Atlantic salmon Inner Bay of Fundy population (IBoF) and 2) Atlantic salmon Southern Uplands populations (SU).

2.3.1 Habitat Range

The IBoF population is an anadromous fish species endemic to the northern temperate hemisphere (DFO 2010). The entire population exists within Eastern Canada, in rivers draining into the Inner Bay of Fundy beginning at Mispec River in New Brunswick to the Pereaux River in Nova Scotia (DFO 2010). The IBoF Atlantic salmon are known to possess distinct genetic traits which are
associated with unique and complex life history characteristics (DFO 2010).

The SU population resides throughout the Southern Upland region of Nova Scotia, including all rivers along the Eastern Shore and south-western portion of the province that drain into the Atlantic Ocean (Gibson et al. 2010).

2.3.2 Status

Presently, both the IBoF and the SU populations of Atlantic salmon are at critically low levels and are listed as endangered (COSEWIC 2006; SARA 2011). The SU Atlantic salmon population has been designated as endangered by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) in 2010 (SARA 2011). The IBoF population has been listed as endangered under both COSEWIC and the Species at Risk Act (SARA) since 2001 (COSEWIC 2006).

2.3.3 Threats

The SU and IBoF Atlantic salmon populations suffer from various anthropogenic and natural threats within the marine and freshwater environment. Examples of threats identified in the 2010 recovery strategy report for the IBoF and the review of information for the SU population by the Department of Fisheries and Oceans in 2010 include; marine survival, acidification of freshwater, over fishing, and barriers to fish passage (DFO 2010; Gibson et al 2010). The scope of this review is limited
to examining barriers to fish passage.

It has been recognized that habitat in spawning rivers of both the SU and IBoF Atlantic salmon populations are threatened by human activities such as; agriculture, urbanization, road building, dam construction, and poor forestry practices (DFO 2010). Decreased smolt production due to habitat degradation has been observed, however, overall impacts on the IBoF and the SU from freshwater habitat degradation has not been quantified (DFO 2010).

Hydroelectric power is known to impact more than 30% of the salmon populations in the Southern Uplands and barriers are known to exist on at least 25 major rivers around the Bay of Fundy (DFO 2010; Gibson et al. 2010). However, overall impact of barriers and consequences of lost connectivity throughout the river system within the SU and IBoF remains largely unknown and is therefore of concern especially within the Southern Uplands as freshwater production is depressed due to acidified freshwater within the region (Gibson et al. 2010). It is acknowledged that barriers alter habitat and change the hydrology of rivers which has no known positive effects on salmon populations, therefore, spawner loss could be substantial and persistence of salmon populations within these regions could be threatened (DFO 2010; Gibson et al. 2010).

The quality and quantity of freshwater habitat will become increasingly important, as it
must be able to support increased returns of adult salmon and provide adequate accessible habitat for spawning if recovery progresses (DFO 2010; Gibson et al. 2010). It is evident that barriers to fish passage in fresh water habitats must be identified and prioritized for mitigation in order to ensure that freshwater habitats will not pose a limiting factor for potential recovery of these populations.

2.4 Identification of Literature Gaps

A review of the relevant literature indicates that there is scientific consensus regarding the disruption of ecological integrity caused by dam installations. However, literature pertaining to the recovery of both Atlantic salmon populations reveals extensive gaps in baseline information pertaining to characteristics of barriers to fish passage in Nova Scotia such as; locations of dams across Nova Scotia, what parts of Nova Scotia are most affected by dams, how many dams are there in Nova Scotia, when were they constructed, how many dams contain fish passage technology, and how much critical upstream habitat has been lost.

The IBoF recovery strategy implies that freshwater habitat is currently not limiting the reproductive success and persistence of the IBoF Atlantic salmon population (DFO 2010). However, this remains inconclusive due to lack of research aimed at identifying and evaluating habitat loss due to dam construction and the necessary mitigation measures for addressing it. I have not found any
literature pertaining to examining connectivity within freshwater habitats in the SU or the IBoF regions in Nova Scotia, nor to the extent of upstream habitat which is deemed inaccessible to Atlantic salmon populations due to dams. The recovery strategy for IBoF Atlantic salmon acknowledged various knowledge gaps regarding barriers in freshwater habitats (Table 2.0) (DFO 2010).

Table 2.0. List of high priority research and monitoring recommendations developed by the Department of Fisheries and Oceans regarding the recovery strategy of the IBoF Atlantic salmon population. Modified from DFO 2010.

<table>
<thead>
<tr>
<th>Knowledge Gaps Regarding Barriers in Freshwater Habitats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barriers</td>
</tr>
<tr>
<td>Barriers</td>
</tr>
<tr>
<td>Barriers</td>
</tr>
<tr>
<td>Barriers</td>
</tr>
</tbody>
</table>

3.0 Methods

3.1 Study Design

Geographic Information System (GIS) (ESRI 2010) was used to integrate existing databases to investigate the; 1) extent of aquatic habitat loss due to dams and 2) occurrence of aquatic habitat loss due to dams.
3.2 Sources of Data

The objectives of this research are achievable through recent progress of databases which have been made available. The Nova Scotia Water Control Structure Database (NSWCD) was sourced from Nova Scotia Environment, along with associated metadata (NSE 2010) (Appendix A). The NSWCD is considered an ongoing project within Nova Scotia Environment (NSE 2010). The NSWCD was initialized for legal and engineering purposes in regards to maintenance and status of dams across Nova Scotia (NSE 2010).

The NSWCD contains 586 total dam locations. 473 dam locations have assigned coordinates. Only dams with coordinates were used throughout this study. 229 of 473 dam locations do not possess dates of construction. Only dam locations with known dates of construction were used to temporally analyze length of stream loss overtime within the SU and IBoF regions.

There are several sources of error in the NSWCD. The majority of errors arise primarily from the data collection process. The NSWCD database has been collected over a number of years and has been the responsibility of a variety of people within Nova Scotia Department of Environment. As a result, a variety of data collection techniques was employed. For example some dam locations were verified using Global Positioning Systems (GPS), while others were located using hard copies of maps.
Various errors can occur when using GPS units such as, interference of satellite signals. Employing different data collection techniques compromise the consistency and accuracy of the data.

Stream network for the SU region was derived from The Nova Scotia Hydrographic Network (NSHN). Stream network for the IBoF was derived from the Digital Elevation Model (DEM). Both databases for stream networks are from the Nova Scotia Topographic Database created by Service Nova Scotia Municipal Relations in 2009. Total stream length for the SU region derived from the NSHN is 32,414 kilometers and from the DEM in the IBoF region is 18,242 kilometers. Calculations for the total stream length used for these two regions excludes lake dimensions. The DEM was used instead of the NSHN to derive the stream network within the IBoF as it resulted in a better resolution, therefore, direction of flow was more accurate. The Nova Scotia Watershed Assessment Project (HSRG2011) provided data for primary watershed and lake boundaries.

Population data for Atlantic salmon in Nova Scotia is limited. Recreational fisheries data does exist however for both Atlantic salmon populations. Recreational fisheries data is subjected to numerous uncertainties and biases such as unknown or unreported effort or falsified catches.

Recreational fisheries data pertaining to several rivers within the SU and IBoF regions were chosen for the purpose of this research as they provide the longest historic indicator of population.
trends (Gibson et al. 2010; Gibson et al. 2003). Recreational fisheries data for IBoF and SU Atlantic salmon populations were obtained from the Department of Fisheries and Oceans Canada (Gibson et al. 2010; Gibson et al. 2003). Recreational catch and effort data for the SU population exists from 1983-2007 and from 1954-2002 for the IBoF population. In 2007, a majority of rivers in the SU region were closed and in 2001 IBoF fisheries were closed.

Catch and effort data from the annual recreational salmon fishery for the SU and IBoF regions were collected using a license-stub return program since 1983 (DFO 2010). After the close of the fishing season, stubs are collected from anglers during autumn and winter (DFO 2010). Preliminary estimates of the season’s catch and effort are provided the following spring, and estimates are finalized during the next year (DFO 2010). Effort is denoted as rod days which indicates the number of days during which an angler fished for part or all of that day (DFO 2010). Catch is considered to be the number of fish caught (DFO 2010).

### 3.3 Focus Area

The IBoF and SU regions in Nova Scotia were chosen as the study site for four reasons (Figure 3.0). First, Nova Scotia is the scale used in available databases and it is the scale for which important new information exists for the NSWCD. Second, both the IBoF and SU Atlantic salmon populations
are endangered within Nova Scotia and freshwater habitat may be inhibiting their recovery. Third, there is limited knowledge regarding the prevalence of dams and the potential for salmonid habitat loss within these two regions in Nova Scotia. Fourth, 410 of the 473 dams that contain coordinates are located within the SU or IBoF regions.

Figure 3.0. Map of Nova Scotia indicating the location of the Atlantic salmon Southern Uplands populations and the Atlantic salmon Inner Bay of Fundy population. Gibson 2010.

The SU region includes all rivers along the eastern shore and the south-western portion of the province that drains into the Atlantic Ocean. The IBoF region includes all rivers draining into
the Inner Bay of Fundy beginning at Mispec River in New Brunswick to the Pereaux River in Nova Scotia (DFO 2010).

3.4 Instrumentation and Validity

GIS was used to analyze extent and occurrence of habitat loss. GIS is a valuable tool for examining interactions, patterns, and trends in watersheds, this has been used in a broad array of recent studies. For example, Fukushima et al. 2007 used GIS to quantify fragmented aquatic habitats, which lead to identifying affected fish species and providing spatially explicit predictions of the areas of greatest impact. GIS analysis has also been previously used to calculate the extent of habitat loss due to impoundments, this led to identifying restoration priorities (Poplar-Jeffers et al. 2009).

3.5 Procedure

The NSWCD was imported into a geographic information system according to primary function class of the structure, resulting in the creation of a new geo-database. Primary function class defines the primary reason for the structures existence. The categories of the newly created layers can be found in Table 3.0. The newly created layers were then overlaid onto the NSHN layer for the SU region and over the DEM for the IBoF region. A layer displaying primary watershed boundaries of Nova Scotia and a layer illustrating boundaries of lakes in Nova Scotia were then overlaid onto the existing layers.
Table 3.0. Description of newly created layers into a geo-database from the NSWCD, based on primary function class of structure.

<table>
<thead>
<tr>
<th>Layer number in geo-database</th>
<th>Primary Function Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Aboiteaux/ Flood reduction structure</td>
</tr>
<tr>
<td>Layer 2</td>
<td>Decommissioned</td>
</tr>
<tr>
<td>Layer 3</td>
<td>Fish ladder</td>
</tr>
<tr>
<td>Layer 4</td>
<td>Mine tailings management</td>
</tr>
<tr>
<td>Layer 5</td>
<td>Navigation aid</td>
</tr>
<tr>
<td>Layer 6</td>
<td>Water impoundment/Storage</td>
</tr>
</tbody>
</table>

A snap model was created in order to improve accuracy and create consistency amongst the NSWCD and the NSHN and DEM layers. The snap model was able to move the location of dams to the nearest point on the associated river or stream (Horne 2011). The densify command in ArcGIS toolbox was first used in the model. The densify tool allows vertices to be created within the river/stream line file. This allowed the water control structure point files to join to the line file. The multiple ring buffer tool was then used in the model. This tool creates a new feature class of buffer features using a set of buffer distances. In this model the buffer distance was chosen to be fifty meters around the original location of the dam. Each ring represents increments of five meters. Creating the multiple buffer ring, allows for determining the accuracy of the dam location to the water line. If the
dam's location was greater than fifty meters from the stream/river location, it was deemed inaccurate
therefore it was not snapped to the stream/river file and was omitted from the study. The snap tool was
then used which allows movement of a point file to the nearest line file. The snap tool moved the
location of each dam to the closest vertex on the NSHN and DEM files (Figure 3.1).

Figure 3.1. Flow chart representing snap model

Network analyst was used in order to calculate upstream river or stream length from each dam
site. Network analyst is an extension of ArcGIS that allows conduction of network-based spatial
analysis. Network analyst was first used to determine direction of water flow within the NSHN and the
DEM. Once flow direction was set, the trace task tool in network analyst was used. This tracing option
allows for upstream accumulation to be chosen and calculated from each dam location (Figure 3.2).
Figure 3.2 Example of method used to calculate upstream length from dam locations.

Calculation of blocked stream length upstream from dam locations in the SU and IBoF is considered conservative, as assumptions were made in order to maintain consistency and to avoid overrepresentation of aquatic habitat loss in Nova Scotia due to dam construction. Assumptions made are as follows:

1. Fish passages assumed to be in adequate working condition, therefore no upstream loss was calculated.
2. If more than one possible accessible route upstream was present at a dam site, no upstream loss was calculated.
3. No habitat loss was calculated at sites where it was indicated that the dam had been breached.
4. Lake dimensions were removed from upstream calculations as only streams and rivers are considered critical habitat for Atlantic salmon in Nova Scotia (Gibson et al. 2010).
5. Dams in which year of construction were unavailable were included in total upstream loss but were omitted for temporal analysis.

3.6 Analysis

Once the occurrence and presence of dams and upstream lengths was mapped in ArcGIS, the extent of aquatic habitat loss and the relationship between aquatic habitat loss and changes in Atlantic salmon populations in the SU and IBoF region of Nova Scotia were determined.

3.6.1 Extent of Aquatic Habitat Loss

The total combined length of stream loss per decade from 1800-2010 was calculated using GIS summary statistics for the SU region and IBoF region. Upstream lengths from dams with no associated year of construction were also summed.

3.6.2 Atlantic Salmon Population Data

Catch per unit effort was calculated using recreational fisheries data provided from DFO for the IBoF Atlantic salmon population (1954-2002) and for the SU Atlantic salmon population (1983-2007). Catch per unit effort was calculated as follows:

Equation 1: \( \text{Catch per unit effort} = \frac{\text{Catch} + \text{Retained}}{\text{Effort}} \) (rod days).

Catch per unit effort was summed from all rivers in order to define an overall trend. Indicator
rivers and rivers containing a large amount of dams were assessed individually in order to determine if
total catch per unit effort is representative of all rivers.

### 3.6.3 Characteristics of Dams in Nova Scotia

In order to increase general knowledge concerning barriers in freshwater ecosystems in Nova Scotia, the metadata was used to summarize characteristics of dams. Relevant parameters which were used include: year of construction, primary function of structure, and existence of fish passage.

### 3.7 Limitations and Delimitations

Time was the main limitation experienced throughout this project, hindering both the scope and depth of research (Appendix B). In order to ensure that the study was adequately addressed, within the given time frame, the study focused specifically on aquatic habitat loss due to the implementation of dams in SU and IBoF regions. Two Atlantic salmon endangered aquatic species were the focus of this study, however, results from this study may be valuable for research regarding other endangered aquatic species in Nova Scotia. Limitations also exist in light of the willingness and availability of information and databases that can be provided by individuals from the government, concerning Atlantic salmon populations.
4.0 Results

4.1 Characteristics of dams in Nova Scotia

The NSWCD contains a total of 586 dams as of September, 2010. 410 of the 473 dams that contain coordinates are within the SU and IBoF regions. A total of 279 dams exist in the SU and 131 in the IBoF. The majority of dams that did not contain associated coordinates (76 of 111) are located within the Cumberland County, Colchester County, and Hants County, which are within the IBoF boundaries and twenty dams are within the SU region. Eleven dams without coordinates are located in Cape Breton.

Evidence shows that a large proportion of dams in the SU are concentrated in the Mersey and Annapolis watersheds. The Gaspereau and St. Croix watersheds within the IBoF also contain a large concentration of dams. Figure 4.0 illustrates the spatial distribution of dams throughout Nova Scotia with coordinates and subsequent stream loss for dams located within the SU and IBoF regions.

Eighty-four of the 586 dams across the province were found to possess fish passage technologies. No information is available on working condition of fish passages. The most common primary function of dams with coordinates built in Nova Scotia is forwater impoundment (78%) which, are primarily used for hydropower production (21%). Other common primary functions of dams include agricultural, water supply, wildlife conservation, aquatic recreational enhancement, and
municipal water supply.

Figure 4.0. Spatial distribution of dams in Nova Scotia and habitat loss in the SU and IBoF watersheds from damming.
4.2 Associated Stream Loss

Total length of accessible streams for potential salmonid habitat in the SU region was found to be 32,414 km. Findings indicate that 3,008 km of stream length has been potentially lost from 1800-2000, which is equivalent to approximately 9.28% of total stream length of the SU region (Table 4.0). The most extensive loss occurred from 1920-1930, with 47 dams constructed, resulting in a loss of 1,564 km of stream length. This decade alone accounts for approximately 52% of total loss.

The total length of stream in the Inner Bay of Fundy was found to be 18,242 km. Findings indicate that 1,299 km of stream length has been potentially lost from 1850-2010, which is equivalent to approximately 7.1% of total stream length (Table 4.0). The largest amount of loss occurred from 1930-1940, in which eight dams were constructed, resulting in 585 km of stream length being lost.
Table 4.0. Total length of accessible streams for potential salmonid habitat lost due to dam construction in the SU and IBoF from 1800-2010.

<table>
<thead>
<tr>
<th>Year of Construction</th>
<th>Number of dams constructed</th>
<th>Length of upstream loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SU</td>
<td>IBoF</td>
</tr>
<tr>
<td>1800-1810</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1810-1820</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1820-1830</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1830-1840</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1840-1850</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1850-1860</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1860-1870</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1870-1880</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1880-1890</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1890-1900</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1900-1910</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>1910-1920</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1920-1930</td>
<td>47</td>
<td>3</td>
</tr>
<tr>
<td>1930-1940</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>1940-1950</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>1950-1960</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>1960-1970</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>1970-1980</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>1980-1990</td>
<td>43</td>
<td>18</td>
</tr>
<tr>
<td>1990-2000</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2000-2010</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Unknown</td>
<td>95</td>
<td>68</td>
</tr>
</tbody>
</table>

TOTAL: 279 | 131 | 3008 (9.3%) | 1299 (7.1%)

Total Stream Length: 32414 | 18242

### 4.3 Sufficiency of Fish Data

Decreasing trends in recreational fisheries catch and effort data is evident from 1983-2007 for the SU Atlantic salmon population (Appendix C). Figure 4.2 illustrates the relationship between cumulative habitat loss and catch per unit effort for the SU Atlantic salmon. Total catch per unit effort from 1983-1990 ranges from values of 8-12. From 1990-2000, total catch per unit effort decreases with the exception of a peak in 1996. In 1997 total catch per unit effort continues to decline again.
8.4 and decreases furthermore to 4.79 in 1998. In 2000, total catch per unit effort is reduced to 1.7.

The overall trend in catch per unit effort data within the SU does not represent each river individually. For example different trends were found in the St. Mary’s River and the LaHave River which are index rivers for the SU Atlantic salmon population and are minimally impacted by dam construction. Both of the index rivers exhibit increase overtime in catch per unit effort. The maximum catch per unit effort value for the St. Mary’s River is 0.9 in 1996 and the LaHave River maximum catch per unit effort value is 0.6 in 2002 (Appendix C). In contrast, the Mersey River is heavily impacted by dams and exhibits a decreasing trend since 1983. The Mersey maximum value in catch per unit effort occurred in 1999 was 0.2.
Figure 4.1. Length of cumulative habitat loss (km) from 1800-2000 and total catch per unit effort data for the SU Atlantic salmon populations from 1983-2007.

A declining trend in total catch per unit effort is evident for the IBoF Atlantic salmon population from 1954-2010, based upon recreational fisheries data (Appendix D). Figure 4.2.b shows the relationship between cumulative habitat loss in the IBoF region and catch per unit effort for IBoF Atlantic salmon. No catch or effort was recorded until 1960. Total catch per unit effort from 1960 to 1964 for the IBoF Atlantic salmon population was low with values ranging from 0.006 to 0.08. The early 1960’s trend is evident in some individual rivers such as the Stewiacke River, which is the index river within Nova Scotia for the IBoF Atlantic salmon. This river is not impacted by habitat loss caused by dams. However, rivers which are impacted by dams such as the Gaspereau River possess larger
catch per unit effort values for this time period 0.1-0.22 (Appendix D). Some rivers such as the Economy River do not contain data for this time period. A general peak occurs in the majority of rivers from 1960-1970. Exact time of peak differs within rivers. For example, in the Stewiacke River this occurs in 1965 with a value of approximately 1.5 and in the Gaspereau River this occurs in 1961 with a value of approximately 0.2. A general decreasing trend occurs from 1970-1990 overall in the IBoF region. This trend is evident in the Stewiacke River however, within the Gaspereau River values remain relatively constant overtime until 1990. Values do not exist for any rivers after 1999 as the fishery closed.
4.4 Data Limitations

Data limitations exist within the recreational fisheries data for the IBoF and SU Atlantic salmon in Nova Scotia. Data is non-existent prior to 1954 for the IBoF population or prior to 1983 for the SU population. No effort has been documented after year 2000 as fisheries were closed. A total of 54 rivers were monitored within the SU region and 46 rivers within the IBoF region, however, data does not exist every year for each river as rivers were closed to fisheries at various times. Limitations therefore arise when assessing correlation and causation of decline and the current status of Atlantic salmon.
Quality of data is questionable as various biases are associated with recreational fisheries data as described in section 3.2.

5.0 Discussion

5.1 Spatial Occurrence of Dams in Nova Scotia

Results of this research allowed for the identification of the presence and patterns of dam occurrence, purpose, and extent in Nova Scotia, due to the recent development of the NSWCD.

The NSWCD is an on-going project, therefore, the total amount of dams across Nova Scotia is yet to be determined. No national inventory of dams for Canada exists (Environment Canada 2008).

Development of a dam inventory for each province across Canada such as the NSWCD would greatly benefit management and protection implications regarding freshwater aquatic habitat across Canada.

Results of presence and patterns of dam occurrence within the SU and IBoF can be assumed to be underestimated for two reasons; 1) the database is incomplete, and 2) only 473 dams contained coordinates, the remaining amount of dams could not be analyzed.

Results of this research illustrating the spatial occurrence of dams throughout Nova Scotia could be used to target rivers or watersheds containing extensive dam construction for restoration via implementation of fish passage or dam removal. For example, results clearly indicate that the Southern
Uplands region is highly impacted by dam construction, especially in the Mersey River and the Annapolis River. Intense dam construction in these rivers may be resulting in subjecting negative impacts on already depressed Atlantic salmon populations, therefore, these regions should be targeted for the rehabilitation of river connectivity.

5.2 Implications for Endangered Salmon Populations

Correlation between salmon population data and cumulative habitat loss overtime within the SU and IBoF regions remain inconclusive as catch and effort data only extends into the 1950s and therefore cannot capture the effect of the 1920-1940 extensive dam construction and subsequent habitat loss. However, evidence shows that dams have impacted an extensive amount of freshwater habitat in Nova Scotia which should not be considered negligible.

Currently, freshwater habitat is not considered to be limiting the recovery of both the endangered SU and IBoF salmon populations (Gibson 2010; DFO 2010). However, results of this study suggest that the loss of connectivity amongst critical habitats in freshwater ecosystems may be a limiting factor in Atlantic salmon recovery as a large extent of upstream habitat is potentially inaccessible to salmon. Research has shown that inaccessibility to upstream habitats has led to extirpation of species and may lead to eventual extinction (Cote et al. 2009; Schick & Lindley 2007).
Therefore, loss of spatial connectivity throughout freshwater habitats should be acknowledged as a serious threat to the recovery for salmon populations, especially within the SU region as freshwater habitat is already depressed.

**5.3 Indicator Rivers**

Results show that indicator rivers which are used to analyze population abundances, distributions, and trends (St. Mary's River, LaHave River, and the Stewiacke River) for both the SU and IBoF Atlantic salmon populations are minimally impacted by dams or not at all. Results also indicate that catch per unit effort in indicator rivers vary considerably from rivers which are heavily impacted by dams such as the Mersey River and the Gaspereau River. Therefore, indicator rivers are not representative of all rivers within the region.

Due to the misrepresentation of the rivers within both regions, current indicator rivers may be providing inaccurate results regarding Atlantic salmon population dynamics throughout the ecosystem, which could lead to ill-informed management decisions and restoration action. Rivers which are impacted from dam construction should be assessed similarly as current indicator rivers are which includes being regularly electro-fished. Implementing monitoring of rivers impacted by dams may gain insight into if there are any outstanding differences in salmon population dynamics in rivers.
which are impacted by dams and those that are not and to would aid in developing a better 
representation of all the rivers within the region. This information may lead to improved management 
and conservation policies regarding endangered Atlantic salmon populations.

**5.4 Restoration Implications**

The recent progress of the NSWCD has led to valuable findings regarding the extent and 
ocurrence of dam construction and associated habitat loss within Nova Scotia. This study shows 
irrefutably that habitat loss due to dam construction within Nova Scotia is not negligible, therefore, an 
opportunity exist throughout the SU and IBoF regions to restore connectivity in endangered Atlantic 
salmon freshwater habitat.

Various research has concluded that the loss in spatial connectivity amongst riverine systems 
has been a primary determinant in the extirpation and extinction of fish species, therefore, restoring 
connectivity amongst riverine system should be of high priority for restoration opportunities (Locke et 
al. 2003; Bunn & Arthington 2002; Schick & Lindley 2007).

As the NSWCD has led to identifying barriers to fish passage in freshwater habitats and 
subsequent habitat loss in the SU and IBoF, areas can be prioritized for mitigation in order to ensure 
that freshwater habitat will not pose a limiting factor for the potential recovery of Atlantic salmon
populations. Restoration efforts should be focused on improving salmon migration throughout freshwater habitats which may result in re-colonization of previously disturbed upstream habitats.

Decreasing trends in recreational fisheries catch and effort data and decline in recruitment is wide ranging despite closures of fisheries are considered to be due to low marine survival and acidification of freshwater habitats (Marshall et al. 2005; DFO 2009). Acidification, especially in the SU has been intensely studied and it is well documented that acid rain has substantially reduced the capacity of rivers to contain salmon populations (DFO 2009). For example, twenty rivers have lost 90% of their past known Atlantic salmon populations and thirty rivers contain populations classified as threatened (Figure 5.0) (ASF 2011). Acid rain has also killed fish populations within fourteen rivers throughout the SU (ASF 2011). Loss of connectivity amongst habitats overtime due to dam construction may have increased vulnerability of fish species to acidified waters.

It has been estimated that extirpations of Atlantic salmon populations are likely to occur in 85% of rivers within the SU alone in the near future due expected ecological regime shifts in temperatures, predators, and chemical impacts (Marshall et al. 2005). As of 2000, approximately 50% of salmon populations have already been extirpated from rivers within the SU and the numbers of vulnerable populations are increasing (Marshall et al. 2005). Therefore, it is evident that the magnitude of
cumulative effects throughout freshwater habitats is potentially inhibiting the recovery of Atlantic salmon.

An opportunity also exists to correlate findings from this research with established acid rain data in order to prioritize areas of restoration highly impacted by multiple stressors which may significantly help in rehabilitating sustainable populations. For example, results from this study have shown that the Mersey, Meteghan, and the Sissiboo/Bear watersheds within the SU are heavily impacted by dam construction. Past research has concluded that these watersheds are also impacted by acidification of freshwater, therefore they should be prioritized for restoration via dam removal, fishway implementation, and liming.

Restoring areas highly affected by multiple stressors could lead to successfully increasing quality and quantity of freshwater habitat available to Atlantic salmon. Restoration efforts focusing on areas impacted by multiple stressors would likely be effective in promoting recovery of endangered species populations.
5.5 Implication of Assumptions and Limitations

As previously mentioned various assumptions and limitations were made and placed upon the research in order to maintain consistency, accuracy, and in order to avoid portraying an unrealistic representation of habitat loss in Nova Scotia due to dams. Implications of the assumptions and limitations produced conservative results (Section 3.5). Amount of dams and subsequent habitat loss in Nova Scotia can therefore be estimated to be of a larger degree than what is portrayed throughout this research. However, this research does result in a justifiable representation using current available information for the province and can be considered as a baseline study for future research regarding loss of connectivity due to dam construction within the SU and IBoF regions of Nova Scotia.
5.6 Conclusions and Future Work

The recent progress of the NSWCD has led to valuable findings regarding the extent and occurrence of dam construction and associated habitat loss within Nova Scotia. Results indicate that dams have caused a widespread upstream loss of freshwater habitat in Nova Scotia however fish population data do not exist to examine the direct impact of dam construction on the IBoF and SU Atlantic salmon populations in Nova Scotia. Because of the large extent of rivers behind dams, this research suggests that dam construction and subsequent lost connectivity amongst river systems may have contributed to the decrease of Atlantic salmon populations or may be currently inhibiting recovery of salmon stocks in Nova Scotia. This study shows irrefutably that habitat loss due to dam construction within Nova Scotia is not negligible, therefore, restoration actions should be taken to re-establish connectivity amongst river systems in order to ensure that the quality and quantity of freshwater habitat does not limit recovery of endangered Atlantic salmon populations in Nova Scotia.

The estimated habitat loss within the SU and IBoF regions is conservative for a variety of reasons (Section 3.5), it is therefore likely that the degree of actual habitat loss is much larger than the results presented in this study. Due to the conservative results of this study there is a need for further investigation regarding “worst case scenario” of habitat loss from dams within Nova Scotia and the
subsequent implications for endangered species populations, as it may be a contributing factor inhibiting recovery of such populations. The extent of freshwater habitat which has transformed from lotic water-bodies to lentic water-bodies due to dam construction could also be analyzed as this has important implications for native and non-native species within freshwater ecosystems.

A tangible outcome of this research is a map indicating locations of dams in Nova Scotia and associated habitat loss from dams within the SU and IBoF. The model used throughout this research could be replicated for the remaining portion of the province allowing for areas of extensive habitat loss from dams to be identified and thus potentially improve conserving and re-establishing biodiversity within riverine systems throughout Nova Scotia.
6.0 References

Allan, J., Erickson, D., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology, 37*(1), 149-161


Department of Fisheries and Oceans Canada. (2010). *Recovery strategy for the Atlantic salmon (Salmo salar), inner Bay of Fundy populations [Final].* Species at Risk Act Recovery Strategy Series. Ottawa, ON.


Esri. (2010). *ArcGIS 10.* Copyright 1995–2010 Esri. All rights reserved. Published in the United States of America


Herbert, M., & Gelwick, F. (2003). Spatial variation of headwater fish assemblages explained by hydrologic variability and upstream effects of impoundment. *Copeia* 2, 273-284


7.0 Acknowledgments

Many thanks are extended to my supervisor Shannon Sterling for support, encouragement, direction, and enthusiasm throughout this research and Peter Horne for continuous help, support, advice, and patience when it came to GIS aspects of this research. I would also like to thank Daniel Rainham for direction throughout the proposal phase and support throughout the entire research, Fred Whoriskey for advice and enthusiasm, and Ray Jahncke for GIS support. This project would not have been made possible if it wasn’t for the countless hours of work put into the Nova Scotia dam inventory by Nova Scotia Environment and for their cooperation, support, and interest in this research and from Jamie Gibson from the Department of Fisheries and Oceans for his interest and support.
8.0 Appendices

Appendix A

Attached as a pdf document.
Table B.1. Gantt chart, timeline for thesis.

<table>
<thead>
<tr>
<th>Objectives and Tasks</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis Proposal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate extent of aquatic habitat loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial comparisons between habitat loss and endangered species</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal examination of patterns between fish population declines and dam construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discussion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft Thesis Due</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Thesis Due</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare for presentation/poster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thesis Fair and HQE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintain records of inaccuracies in databases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C

Figure C.1. Total catch per unit effort of rivers in the SU region from 1983-2007.

Figure C.2. Catch per unit effort in the Mersey River from 19983-2007.
Figure C.3. Catch per unit effort in the St. Mary’s Rivers from 1983-2007.

Figure C.4. Catch per unit effort in the LaHave River from 1983-2007.
Appendix D

Figure D.1. Total catch per unit effort of all rivers in the IBoF region from 1960-1999.

Figure D.2. Catch per unit effort in the Stewiacke River from 1960-1999.
Figure D.3. Catch per unit effort in the Gaspereau River from 1960-1999.
<table>
<thead>
<tr>
<th>Table A.1. Summary of Water Structure Characteristics From the Nova Scotia Water Control Structure Database</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year Constructed</strong></td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>Project Name</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Blacks Pond Dam</td>
</tr>
<tr>
<td>Trenholm Marsh Project</td>
</tr>
<tr>
<td>Barronsfield Marsh Project</td>
</tr>
<tr>
<td>Colchester Marsh Project</td>
</tr>
<tr>
<td>Troops Marsh Project</td>
</tr>
<tr>
<td>Browns Woodlot Project</td>
</tr>
<tr>
<td>Mountain Road Marsh Project</td>
</tr>
<tr>
<td>Ryerson Brook Marsh Project</td>
</tr>
<tr>
<td>Eel Creek Marsh Project</td>
</tr>
<tr>
<td>Antigonish Marsh Project</td>
</tr>
<tr>
<td>Allex Brook Marsh Project</td>
</tr>
<tr>
<td>Gelding Brook Marsh Project</td>
</tr>
<tr>
<td>Hysons Pond Dam</td>
</tr>
<tr>
<td>Victoria Marsh Project</td>
</tr>
<tr>
<td>Lunenburg Marsh Project</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>19</td>
</tr>
</tbody>
</table>