Assessing the Climate Change Vulnerability of Freshwater Fishes in Newfoundland and Labrador

by

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ABSTRACT

Freshwater fish populations are rapidly declining globally due to the impacts of rapid climate change and existing non-climatic anthropogenic stressors. In response to these threats, freshwater fishes are responding by shifting their distribution range, altering the timing of migration and spawning and through demographic processes. To mitigate the future negative consequences, managers require novel tools that provide useful information on fish vulnerability to climate change to develop appropriate responses. A trait-based vulnerability assessments methodology was applied in this study to assess the vulnerability of 7 freshwater fishes in Newfoundland and Labrador of recreational and ecological importance. Twelve vulnerability indicators were developed and 26 freshwater fish experts were consulted using an online questionnaire survey to assesses each species vulnerability. Analysis of the survey results showed one species to be high/very highly vulnerable, two species were highly vulnerable while four species were moderately vulnerable to future changes with moderate confidence from the experts. Lake trout a native species showed the highest vulnerability while was rainbow trout a non-native species showed the lowest vulnerability to future changes. The results presented in this study are significant to resource managers because findings will allow for adaptive responses targeted at each species unique vulnerability drivers.

ACKNOWLEDGMENT

I am eternally grateful to God for the opportunity to study in Canada, it's indeed been for me a story that resonates with the phrase 'started from the bottom now I'm here'. I dedicate this to my lovely parents who have invested their substance and without whom this research would be unattainable. My deepest appreciation goes to Dr. Michael Van Zyll de Jong, for being very supportive as my supervisor; your unique ideas, guidance and patience was significant in preparing and producing this research. I attest to the fact that you have been awesome throughout the program. I also would like to recognize and thank Dr. Blair Adams for his support as my thesis committee member. I thank Dr. Vodden for her course on Research methodology which was useful in developing the ideas that initiated this study. It's highly impossible to pass through the Environmental policy institute without experiencing the goodness of our EPI momma - Nadia Simmons – who works tirelessly yet notably an icon of joy, happiness and fun. I'm also thankful to awesome people like Paula, Myron, Dr. Foley, Dr. Klinke and Dr. Gabriella. Finally, I am happy to have met awesome friends during my study. Thank you all.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ARM Adaptive Resource Management

ASF Atlantic Salmon Federation

CCVI Climate Change Vulnerability Index

COSEWIC Committee on the Status of Endangered Wildlife in Canada

DFO Department of Fisheries and Ocean

EBM Ecosystem-based management

IPCC Intergovernmental Panel on Climate Change

LPR Living Planet report

MUN Memorial University of Newfoundland

NMFS National Marine Fisheries Services

SAVS System for Assessing Vulnerability of Species

SIVVA Standardized Index of Vulnerability and Value

Chapter 1 Introduction

1.1 Background: Climate change impacts on Freshwater fishes

Globally, climate change threatens freshwater fish populations and their habitats (Harrod, 2015; Chessman, 2013; Sharma et al., 2011). There is scientific agreement that global climate change is accentuated by increasing greenhouse gas emissions (Harrod, 2015; Intergovernmental Panel on Climate change (IPCC), 2007). One of the consequences of past and current greenhouse gas emissions could be a rise in atmospheric temperature of about 6.4oC by the end of this century (Harrod, 2015; Stangeland, 2007) even in the presence of strict mitigation policies. Several implications in terms of direct and indirect impacts have been cascaded down to global freshwater fish populations and their habitats (Abdel-Fattah, 2016; Lynch et al., 2016; Harrod, 2015; Xenopoulos et al., 2005). Climate-induced impacts in temperate regions are predicted to occur through increasing water temperatures, alterations in precipitation regimes, flow rates, onset and duration of ice cover, frequency of disturbances such as wild fires, floods, insect infestations (Abdel-Fattah, 2016; Williams et al., 2015; Prowse et al, 2009; Ficke et al., 2007). Because freshwater fishes are ectotherms, the effects of increasing water temperature could lead to higher physiological stress, increased metabolic demand which directly affects growth, survival, metabolism, reproduction and productivity (Trumbo et al., 2014; Isaak et al., 2012; Warren et al., 2012). Alterations in global precipitation patterns could affect seasonal stream flow and phenology (Ward et al., 2015). Critical life stages and population dynamics of some freshwater fishes are dependent on predicted seasonal flow patterns (Poff et al. 2002). Hence, some freshwater fish populations could experience declining reproductive success, shifts in species composition and local extirpation due to projected precipitation effects (Sievert, 2014; Heino et al., 2009; Brooks, 2009; Rahel & Oden, 2008; Nunn et al, 2007). Some indirect impacts could occur through changes in biotic processes in freshwater ecosystems such as increased invasive species (Lawrence et al., 2014; Muhlfeld et al., 2014; Rahel and Olden, 2008), increased competition, predation (Abdel-Fattah, 2016) and higher risk of diseases and parasites (Karvonen et al., 2010). Altogether, this could transform fish communities, food webs and ecosystems (Abdel-Fattah, 2016; Vindenes et al., 2014; Dove-Thompson et al., 2011).

A variety of non-climatic anthropogenic stressors such as deforestation, overexploitation, habitat degradation and modification, water pollution, flow modification, and hydropower generation (Williams et al., 2015; Strayer & Dudgeon, 2010; Woodward et al., 2010; Cowx & Gerdeax.,

2004) are existing drivers of global freshwater fish decline (Living Planet Report (LPR), 2016; Pittock et al., 2008; Dudgeon et al., 2006; Collares, Pereira & Cowx, 2004). The impacts of existing non-climatic stressors on freshwater fishes is predicted to become compounded by climate change (Williams et al., 2015). The study further noted that the consequences of the synergies between climatic and non-climatic stressors 'will vary depending on the conditions of local fish populations' and interactions of 'climate, biological and geological processes acting together'.

1.2 Freshwater Fish responses to Climate Change

According to Lynch et al. (2016), the reponses of freshwater fishes in relation to climate change impacts in temperate regions have been demonstrated in several empirical studies. Some fishes respond through evolutionary processes or inheritable traits i.e. their ability to evolve. For example, Crozier et al (2011), suggests that early adult migration in sockeye salmon (*Oncorhynchus nerka*, Walbaum, 1792) populations, could be an evolutionary response to climate change. Another observed response strategy of freshwater fishes is changes or alterations to demographic processes such abundance, growth and recruitment (Lynch et al., 2016) in relation to changing climatic factors. Murdoch and Power, (2013) reported that decreased growth and abundance of some cold-water species like Arctic char was linked to increasing water temperature while Kovach et al., (2014) showed it increased recruitment and abundance of Sockeye salmon (*Oncorhynchus nerka*). Spatial distribution shifts constitute another important response of freshwater fish population (Lynch et al., 2016). Alofs et al., (2014) noted that increasing water temperature is linked to an increase in the abundance and distribution of warm and cool water fish species in mid-latitudes, where cold water species experienced range contractions (Lynch et al., 2016). Freshwater fishes also respond by adjusting the timing of seasonal migration and spawning as a response to climate change. In mid-latitude, Atlantic salmon has been recorded to exhibit earlier spring migration as a result of warmer springs and summer temperatures (Lynch et al., 2016). Broadly, species are known to respond in a spatially heterogeneous manner to climate change (Morrison et al., 2015). However, species lacking the ability to outpace the rate of current and future climate change could experience extinction or extirpation (Hannah, 2008; Hannah et al., 2005). Extinction rates of freshwater fishes in North America, is recorded to be the highest in the world accounting for about sixty-nine percent of total freshwater fish extinction (Burkhead, 2012). Future climate models which projects increasing climate change influence in North America (Saha et al., 2006) reflects an urgent need for resource managers at various regional and local scales to mitigate future risks through climate change adaptation.

1.3 Adaptation planning and Vulnerability assessments

Adaptation planning involves identifying pragmatic strategies to reduce or ameliorate the negative effects of climate change (Fischlin et al., 2007). The term 'adaptation planning' can be differentiated from the biological adaptation which describes the process by which species evolve over time in response to the environment and other organisms (Mawdsley et al., 2009). The former relates to human activities intended to minimize the dangerous consequences of climate change to human and natural systems (species and ecosystems) (Mawdsley et al., 2009; Fischlin et al., 2007). In recent past, traditional fish conservation management actions have been implemented at various scales (local, regional and national) to tackle a myriad of anthropogenic threats to aquatic environments. However, more recently resource managers and policy makers accept that some of these approaches may be insufficient or obsolete in dealing with new threats from climate change (Shoo et al., 2013; Kittel, 2013; Reside, 2011). Hence, managing both species and ecosystems in the future would require expanding the scope of current management practices to incorporate climate change information (Shoo et al., 2013). Understanding vulnerabilities fill this need and now constitutes the mantra of several conservation goals and objectives (Kittel, 2013).

In conservation science and climate policy the ‘vulnerability approach’ can be employed by resource managers engaged in conserving the integrity of species and ecosystems (Kittel, 2013; Kittel et al., 2011). Determining the vulnerability of species and ecosystems reflects a bottom-up approach whereby information on climate change threats and other environmental stressors are consolidated and an integrated strategy is devised to enhance the adaptive capacity of the conservation target (Game et al., 2010). Climate change vulnerability assessments (CCVA) serve as a vital tool designed under this approach to facilitate the understanding of vulnerability or risk of harm to a species under predicted climate change (Glick et al. 2011). It is regarded in the literature as an initial step in the development of ‘planned adaptation for target species (Young et al., 2015; Cross et al. 2012; Pittock et al., 2008; Füssel et al, 2007). It involves quantifying vulnerability to climate change stressors (Reece & Noss, 2014; Dubois et al., 2011). Information from CCVAs can potentially identify highly vulnerable species, potential sources of vulnerability, and triages management actions to minimize the threat (Staudinger et al., 2016; Stortini et al., 2016; Füssel et al, 2007). Resource managers and conservation agencies are increasingly resorting to the use of vulnerability assessments as it is perceived to be cost effective, efficient, does not require large datasets and can incorporate expert judgments and local knowledge (Glick et al. 2011; Johnson & Welch, 2009). Already, vulnerability assessments have been incorporated in emergent conceptual approaches like ecosystem-based management (EBM) and adaptive resource management (ARM) to information for adaptation planning (Glick et al. 2011).

1.4 Research Purpose and Objectives

Finnis (2013) provided detailed information on how the climate of Newfoundland and Labrador is likely to change by the middle of this century (2038 - 2070) using an ensemble of seven regional climate models (RCM) simulations. In this model, mean daily air temperatures was projected to increase between 2 to 3°C in Newfoundland and 3 to 4°C in Labrador, depending on assumptions of future emissions (Fig. 1 & 2). Temperature shifts is expected to be greatest during the winter months and smaller in summer and autumn with strong latitudinal variations increasing in northern Labrador (Finnis, 2013). In a number of studies, increasing air temperature has been shown to correlate with a rise in surface water temperature (Bond et al., 2015; Webb & Nobilis, 2007) in freshwater ecosystems. This could decrease the availability of habitats to which cold-water fishes are adapted to, creating fragmented distributions in suitable areas (Williams et al., 2015). Mean daily precipitation was also projected to increase in all locations (Fig. 3 & 4), with modest increases anticipated during the winter and spring, but much smaller during summer (Finnis, 2013). Furthermore, increased intensity is also projected for Newfoundland and Labrador, with most events favoring rain over snow in several regions (Finnis, 2013). This could lead to increased stream flow, less ice cover during winter, drier summers with higher rates of evaporation, hence, this could pose important implications for cold water fishes and their habitats. For instance, suitable habitats could be lost for cold water fish communities as suitable conditions may favor species adapted to warmer waters (Williams et al., 2015). The projections therefore raise various questions in the context of regional scale adaptation of freshwater fish species: for instance, to what extent will freshwater fishes be vulnerable to projected changes including the ability to respond? What factors could influence freshwater fish climate change vulnerability? What are the potential socio-economic implications to Newfoundland and Labrador (NL)?

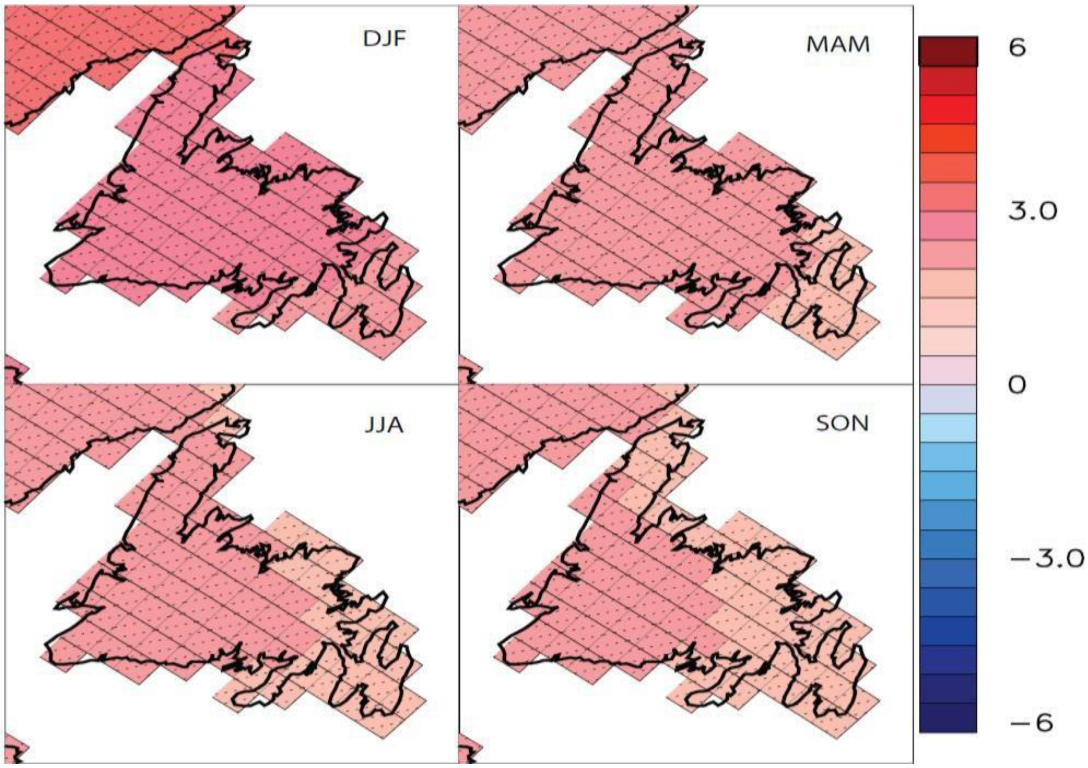

Figure 1: Changes in daily mean temperature (oC) projected for Newfoundland by 2038 – 2070 (Finnis, 2013)

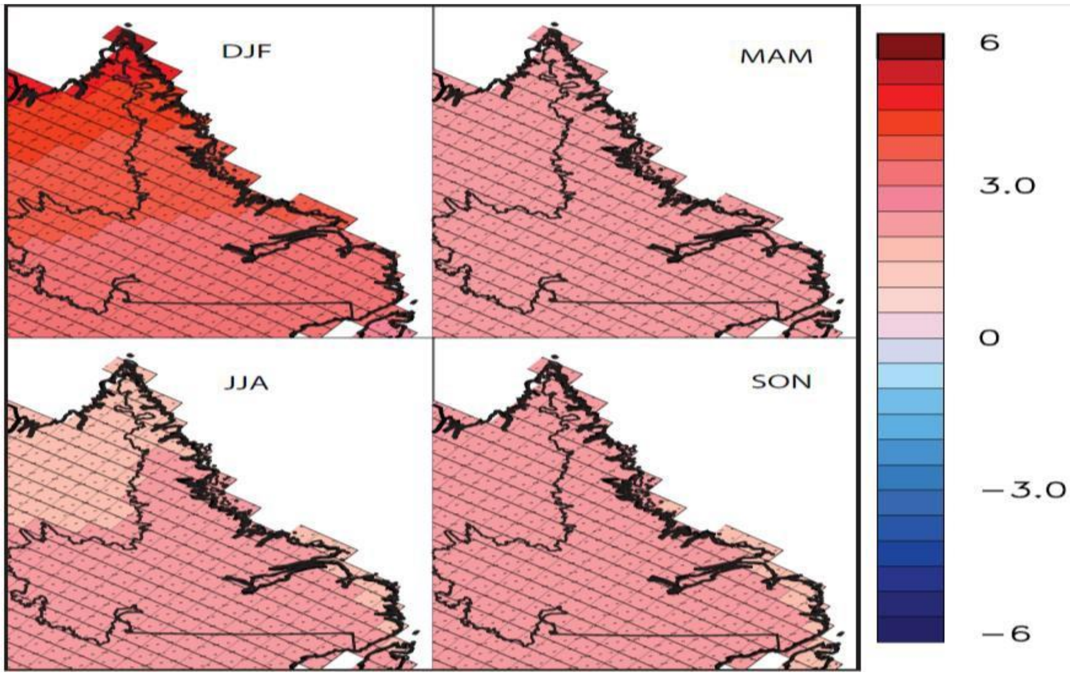

Figure 2: Changes in daily mean temperature (oC) projected for Labrador by 2038 – 2070 (Finnis, 2013)

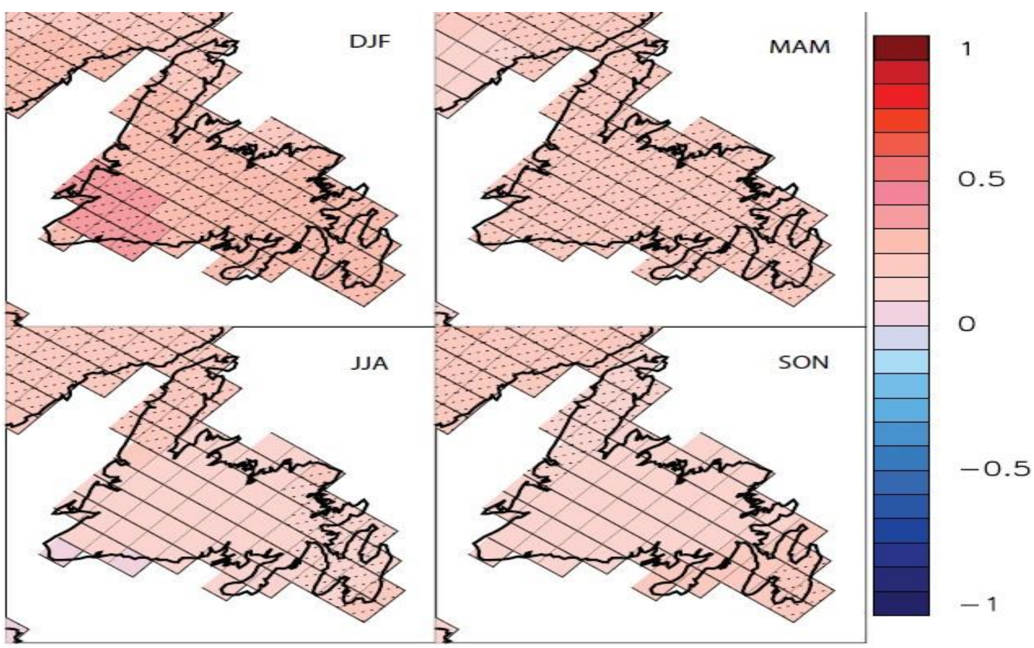

Figure 3: Changes in daily mean precipitation (mm) projected for Newfoundland by 2038 - 2070. (Finnis, 2013)

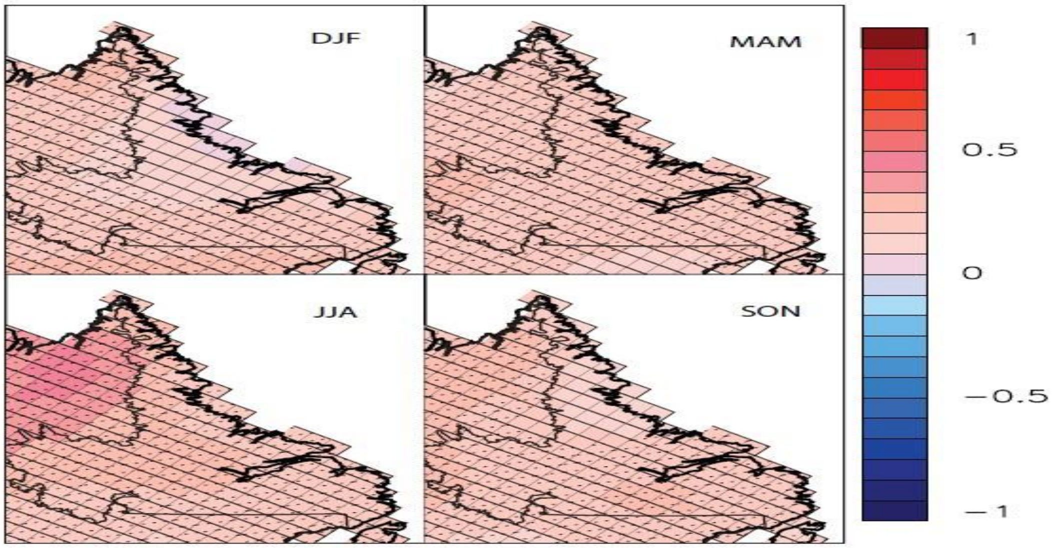

Figure 4: Changes in daily mean precipitation (mm) projected for Labrador by 2038 - 2070. (Finnis, 2013)

While, this study seeks to answer the first two questions, it should be noted that historically, climate change has played a role in defining the marine fishery industry in NL, for example it has been suggested to be an actor in the collapse of Cod populations (Brander, 2010; Rose, 2003). More recently, conservation monitoring efforts by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) suggest that some freshwater fish populations are already in a vulnerable state due to impacts from multi-faceted threats (COSEWIC, 2010). The absence of effective policy and adaptation management interventions, could potentially limit the adaptability of freshwater fish to projected climate change. For instance, increasing influence from development activities, habitat modification activities from forestry, dam projects and mining (McKay et al., 2013), could truncate stream connectivity, and close migratory corridors thereby impeding migration to suitable climatic environments (Hall et al., 2011; Jansson et al., 2007). A first step should be to assess the vulnerability of freshwater fishes in NL to projected climate change. The results could be essential to future management actions including triaging species for further monitoring or research (Glick et al., 2011). In recognition of this need, this study aims to assess the climate change vulnerability of freshwater fish species in Newfoundland and Labrador. This scope of this study will focus on recreational freshwater fish species because of their socio-economic importance to the province. The objectives of this research are as follows:

1. To describe a methodology for assessing the climate change vulnerability of freshwater fishes.
2. To assess the vulnerability of some freshwater fish species to projected climate changes in Newfoundland and Labrador.
3. To describe the drivers of freshwater fish vulnerability to climate change.

Chapter 2 Literature Review

2.1 Approaches for conducting Climate Change Vulnerability Assessments (CCVA) for species

The concept of vulnerability used in non-climate science disciplines have contributed to its present knowledge and application in climate change literature (Adger, 2006). Vulnerability has evolved with various interpretations and approaches (top-down or bottom-up) across climate adaptation literature (Williams et al. 2008; Fussel and Klein 2006; Fussel, 2007) depending on the type of knowledge and policy response desired (O'brien et al., 2007). The most cited definition by the IPCC defines vulnerability as the 'degree to which a system is susceptible to and is unable to cope with adverse effects of climate change' (Adger, 2006 pg 269). Dawson et al. (2011) refers to it as the extent to which a species is threatened with population decline, genetic loss, or extinction because of climate change and therefore comprises of three factors: exposure, sensitivity and adaptive capacity. Glick et al., (2011) points out that climate change vulnerability lies in the intersection of each of these factors. Thus, exposure refers to the magnitude and rate of climate change experienced by a species (Hare et al., 2016; Morrison et al., 2015). For example, exposure for fish species could include effects from changes in temperature, precipitation, and extreme events. Sensitivity to climate change refers to the degree to which a species' survival and persistence, depends on changes in specific climate factors (Hoving et al., 2013). Sensitivity reflects the ability of a species to withstand changes in climate, hence more sensitive species will possess limited survivability as climate changes (Dawson et al., 2011). Adaptive capacity refers to a species ability to adapt or move to suitable habitats and could depends on the potential for behavioral changes, dispersal ability, and genetic variation (Dawson et al., 2011). Assessing species vulnerability to climate change involves evaluating a combination of the three components with some studies not differentiating between sensitivity and adaptive capacity (Morrison et al., 2015). Pacifici et al., (2015) and Young et al., (2015) provide in-depth categorizations of available methods for species vulnerability assessments in literature. Butt et al., (2016) noted that these methods have rapidly evolved due to computational and methodological advances. Guidelines on applying these methods have also been documented by Rowland et al., (2011). One method is correlative modelling, which relates a species' current realized niche or distribution with current environmental variables and then predicts possible future outcomes based on future climate projections (Brander, 2010; Pearson & Dawson, 2003).

Another is the mechanistic modelling developed from the previous methods used to models a species' vulnerability by incorporating several functional traits, tolerances, and energy-balance equations to define a species niche (Kearney & Porter, 2009) These methods referred to as fine-filter approaches (Johnson, 2014) have been applied to assess fish vulnerability (Wenger et al. 2013; Wade et al. 2013; Wenger et al. 2011; Kennedy et al. 2009). A third method - trait-based assessments referred to as the course filter approach (Johnson, 2014) uses species' biological characteristics or traits as indicators of extinction risk due to climate change (Young et al., 2015; Foden et al. 2014; 2013; Bagne et al. 2011). The hypothesis in this method is that 'general or specific trait factors' relating to life history or ecological parameters governs a species vulnerability (Barber et al., 2015; Foden et al., 2013; Chessman, 2013; Schloss et al., 2012) and could either predispose a species to extinction or mediate the effects of threats including climate change (Garcia et al., 2014; Pecl et al. 2014; Foden et al., 2014; 2013). In other terms, these traits serve as an indicator of vulnerability. Considering this, several studies use biological trait characteristics as a proxy to capture the observed variances between different species' degree of vulnerability to climate change (Chevin et al., 2010; Williams et al., 2008). Chin et al., (2010) developed 10 trait-based indicators and applied them to assess the vulnerability of shark and ray species in Australia's Great Barrier Reef.

2.2 Trait-based Vulnerability assessments

The scale of trait-based vulnerability assessments (TVA) in literature have either been focused on single species level i.e. conducted across various life history stages (McDaniels et al., 2010), or applied to multiple species or taxa (Young et al; 2015; Foden et al., 2014). Foden et al (2014) using the multi-species approach assessed the climate change vulnerability of 16,857 species of birds, amphibians and corals. The work of Schröter et al., (2005) was one of the first studies to iterate several criteria and procedures for vulnerability assessments. A review of this paper and other recent literature on species vulnerability assessments (Pacifici et al., 2015; Moyles et al., 2015; Foden, 2014; Kittel, 2013), reveal two critical requirements that are contingent to the successful assessment: selecting appropriate trait indicators to match the right taxa and identifying uncertainty of the assessment. Incorporating these aspects into an assessment involves quantitative or qualitative analysis with the results intended to inform adaptation planning. In terms of applicability, TVA methodologies are generally perceived to be relatively easy to implement by a number of conservation and government agencies (Pacifici et al., 2015; Morrison et al., 2015; Young et al., 2014;

Gleeson et al., 2011; U.S. Environmental Protection Agency (EPA), 2009). Though, Butt et al., (2016) discussed several challenges that pertains to the ambiguity of vulnerability assessments results in conservation planning, several methodologies and frameworks are still in use across North America. Some of the common methodologies employed are the NatureServe's Climate Change Vulnerability Index (CCVI) (Young et al., 2015); Integrated Risk-based approaches (Chin et al., 2010), A System for Assessing Vulnerability of Species to Climate Change, (SAVS) (Bagne et al. 2011); Standardized Index of Vulnerability and Value, SIVVA (Reece and Noss, 2014) and the National Marine Fisheries Service NMFS) climate change vulnerability framework (Hare et al., 2016). The following chapter employs NMFS framework to assess the vulnerability of freshwater fishes in Newfoundland and Labrador. The method employed is thus described with the aim that it would be relevant to future assessments.

Chapter 3 Methods

The National Marine Fisheries Service (NMFS) climate-change vulnerability framework is applied here to assess freshwater fish vulnerability to climate changes projected by mid-21st century (2050). Unlike some existing methodologies, this approach better suits the current study's objectives since it does not require technical skills to accomplish. Rather, the framework represents basic repeatable steps which is applicable to rapidly assess and compare vulnerabilities among multiple species while providing transparent information to decision makers (Hare et., 2016). Several features of the framework were modified and comprises three phases as shown in Fig. 5. At the scoping phase, the spatial and temporal scale of the study was determined, provided a rationale for the species selection, determined the relevant indicators relating to climate exposure factors, sensitivity, adaptive capacity indicators and finally, selected experts to participate in the study. The assessment phase involved designing an online questionnaire survey and the expert elicitation process. The third phase involved analyzing expert scores and determined the relative vulnerability of the freshwater fishes to future climate change.

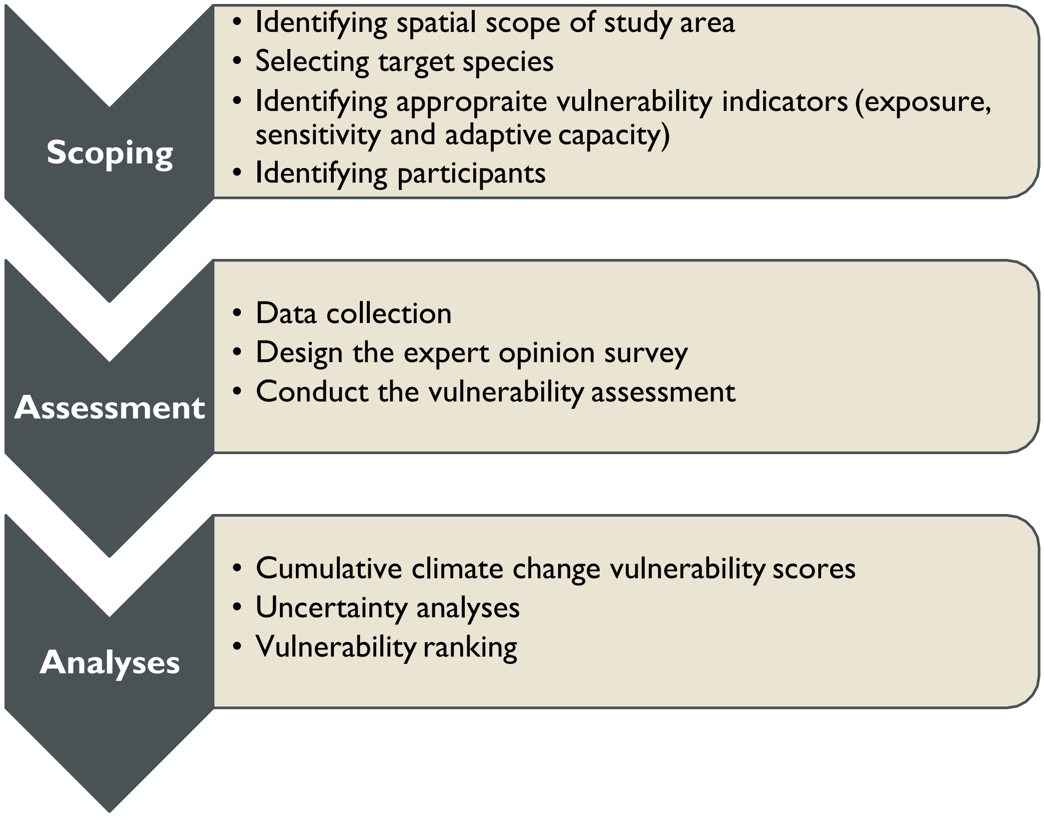

Figure 5: Modified climate change vulnerability framework adapted from National Marine Fisheries Service (NMFS) (Hare et al., 2016)

3.1 Study Area and Species Selection

The study area is Newfoundland and Labrador which features freshwater lakes, natural and regulated rivers, pristine wetlands and boreal forests that provide habitat to anadromous and landlocked freshwater fish populations (NRCan, 2010). The freshwater fish fauna of NL has been previously described in literature (Van Zyll de Jong et al., 2004; Bradbury et al., 1999). Fifteen native freshwater fishes have been reported in insular

Newfoundland dominated by salmonids while twelve species have been recorded in Labrador (Van Zyll de Jong et al., 2004; Bradbury et al., 1999). Five non-native salmonid species were introduced in the 1880s due to early fishery policies (Van Zyll de Jong et al., 2004; Bradbury et al., 1999). The present assessment focuses on seven game fish species: Atlantic salmon (*Salmo sala, Linnaeus, 1758*), Brook trout (*Salvelinus fontinalis, Mitchill, 1814*), Lake trout (*Salvelinus namaycush, Walbaum, 1792*), Brown trout (*Salmo trutta, Linnaeus, 1758*), Arctic char (*Salvelinus alpinus, Linnaeus, 1758*), Northern pike (*Esox Lucius, Linnaeus, 1758*) and Rainbow trout (Oncorhynchus mykiss, *Walbaum, 1792*). This selection represents native and non-native fishes that are recreationally, economically, and culturally important species in the study area as well as being priority species to several conservation and resource management efforts.

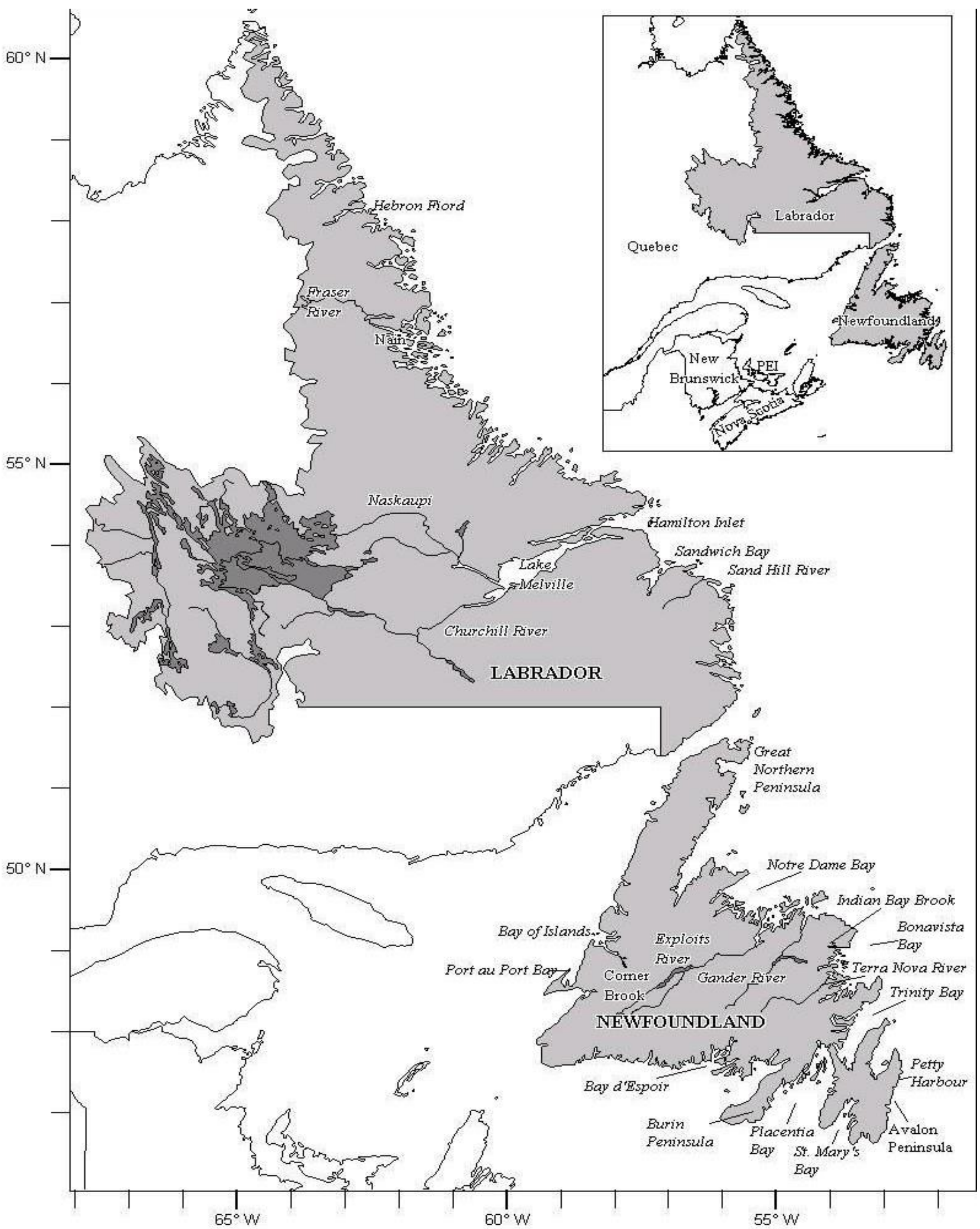

Figure 6: Map of the study area, Newfoundland and Labrador showing some common freshwater environments

3.2 Vulnerability Indicators

'Vulnerability' applied in this study refers to the interplay of a freshwater fish's exposure to projected climate factors (extrinsic factor), its sensitivity to the climate factors (based on intrinsic traits) and ability to adapt (intrinsic traits) (Foden et al., 2013). A review of published literature was employed to identify the vulnerability factors described above as it relates to the potential vulnerability of freshwater fish to future climate change. Based on the study objectives it was necessary to define future vulnerability or the time-frame considered in this assessment. Some assessments employ a relatively longer time-frame such as the end of this century. However, a relatively short time-frame (mid-21st century is employed since it is more relevant to conservation planning (Morrison et al., 2015). Water temperature and precipitation constitute the dominant climatic exposure factors for freshwater habitats identified from the review of several literature (Moyles et al., 2015; Whitman et al., 2013). This study relied on projections provided by Finnis (2013) for the study area. In addition, the Nature Conservancy's climate wizard tool which uses an ensemble of statistically downscaled Global circulation models (to a 0.5-degree grid) to project average annual temperature and precipitation changes by mid-21st century (Maurer, et al., 2007) provided spatially explicit visual maps for the study area. Sensitivity and adaptive capacity factors for freshwater fishes were identified and refined from previous CCV assessments (Stortini et al., 2016; Moyles et al., 2015; Morrison et al., 2015; Foden et al., 2014). Nine sensitivity and adaptive capacity indicators were developed following a review of these studies. A list of the indicators and their definitions are provided in Appendix A. An additional indicator was included to account for the effects of other non-climatic stressors on freshwater fishes. Overall, twelve vulnerability indicators were developed for the purpose of this assessment.

3.3 Expert selection

Expert opinion is considered a useful tool applied in situations where data or other secondary literature is insufficient and in this study, it facilitates a rapid approach to assess several species using best available information (Staudinger et al., 2016). With guidance from the study committee twenty-six species experts were identified and selected through the internet. Selected experts were invited to participate in the assessment process. Participants consisted of freshwater fish biologists and ecologists from Department of Fisheries and Oceans (DFO), Wildlife division, Atlantic salmon federation (ASF), and academic professors from Memorial University of Newfoundland (MUN). Participants were selected on the basis of having extensive research and working experience with freshwater fish species in Newfoundland and Labrador and all had Ph.Ds. Justification for the choice of participants was in line with an expert definition provided by Meyer & Booker (1991). Several assumptions were made in our choice to fill the need for providing participants with background knowledge of species distribution and species profile as practiced in several vulnerability assessments (Hare et al., 2016). Firstly, we assumed our experts had adequate technical knowledge of all selected species including their population status, management and distribution across Newfoundland and Labrador. Secondly, we assumed that experts were able to obtain new and existing information on all species with which to make sound judgments to core vulnerability. Lastly, it was assumed that experts had the ability to articulate the justification behind the scores they provide (EPA, 2009).

3.4 Data collection

In some assessments, expert consensus is solicited through workshop-based Delphi approach (Staudinger et al., 2016). While this approach and the benefits of expert consensus is acknowledged in this study, we opted to use online surveying with the expectation that outcomes will be a synthesis of independent qualitative expert opinion. An online questionnaire survey was designed to facilitate the vulnerability assessment process and experts were required to assess each question relating to the vulnerability indicators previously developed.

Participants accessed the online questionnaire through Survey monkey (an online survey tool). The questionnaire was designed into five sections consisting of twelve survey questions each relating to a vulnerability indicator. The first section assessed the magnitude of each fish species exposure to projected water temperature and precipitation (stream flow change) changes likely to occur by mid-21st century. Access to data for climate change projections from Finnis (2013), Thistle & Cassie (2013), and a link to the Nature Conservancy's climate wizard tool was incorporated into the questionnaire to aid expert scoring. The second and third sections assessed sensitivity and adaptive capacity indicators respectively for all species. The fourth section assessed the cumulative effects of non-climatic stressors across each species distribution range. The final section required participants to include species-specific factors not included in the survey.

Experts were required to provide three types of ordinate scores: an indicator score (for exposure, sensitivity, adaptive capacity and cumulative non-climatic factors), weight scores (to determine the relative importance of an indicator to the overall species vulnerability) and level of confidence scores (to account for uncertainty in the scoring). A scoring scales of low, moderate, high and very high were provided and applied to all indicators. A different scoring scale of low, moderate and high, were applied to the weight scores and level of confidence scores.

3.5 Data Analyses

Quantitative analysis was applied to estimate the climate change exposure index, sensitivity index, adaptive capacity index, and cumulative climate change vulnerability score of the seven freshwater fishes. Uncertainty was estimated by scoring the level of confidence in each vulnerability indicator.

3.5.1 Climate Change Vulnerability Analysis

The cumulative climate change vulnerability score for the seven freshwater fish was estimated using additive combination of the vulnerability components:

$$V = f(E, S, AC)$$

Where, V= cumulative vulnerability score, E = exposure index, S = sensitivity index and AC = adaptive capacity index.

Numerical values of 0 to 4 was attributed to the predefined indicator scales used in the questionnaire (i.e. low, moderate, high and very high). Therefore, predefined scales for exposure and sensitivity indicator scale had values corresponding to low = 1, moderate = 2. High = 3 and very high = 4. With this the higher the exposure and sensitivity index for any species the higher the vulnerability to climate change. The numerical values assigned to the scoring scale of adaptive capacity indicators were reversed since it acts against vulnerability (Dawson et al., 2011). Therefore, adaptive capacity was scored as low = 4, moderate=3, high = 2, very high = 1. Using this, the higher the adaptive capacity index (i.e. low vulnerability) the higher the climate change vulnerability.

Each indicator score was calculated using the weighted means of the expert's scores. The exposure, sensitivity and adaptive capacity index scores were derived by averaging the respective indicator scores. Averaging indicators has been suggested to de-emphasize the effects of high scoring indicators on a species vulnerability (Morrison et al., 2015). Hence, to account for the significance of high scoring indicators, a modified logic rule applied in Hare et al., (2016) is employed to develop an adjusted exposure, sensitivity and adaptive capacity index were applicable. Based on the logic rule, where more than two indicator score in a given component (i.e. exposure, sensitivity and adaptive capacity) is >3.0 the final component score is adjusted by 0.5. The justification for using this model is that it enables the assessment pull out 'species with multiple risk's or have 'life history requirements where environmental change could impact through multiple mechanisms' (Morrison et al., 2015).

The final cumulative vulnerability scores for each species was computed by adding the scores for exposure, sensitivity and adaptive capacity index such that final scores ranged from minimum of 3 to a maximum of 12. Species with higher scores were considered to be the relatively more vulnerability to future climate change. Seven rank levels were developed to categorize the vulnerability score. No specific standard currently exists in literature to set vulnerability thresholds (Gardali et al., 2012), hence to present an easy mechanism to communicate vulnerability and to develop the ranks, the categories were evenly sub-divided (Table 1). Potential climate impacts are usually defined in terms of the exposure and sensitivity of a species to climate change. A scatterplot is used to highlight the relationship between the species potential climate impact and their adaptive capacity determined by their specific traits. A Mann-Whitney U rank test was conducted on expert's vulnerability scores to determine if there were significant differences between scores for native and non-native species. Also, a Kruskall-Wallis test was conducted on expert's indicator scores to ascertain the factors driving vulnerability of freshwater fish to climate change. All computations were derived using Microsoft office Excel 2013 and Minitab® Statistical Software.

Table 1: Vulnerability ranking categories for freshwater fish species

Vulnerability score	Rank Category
3 - 5	Low
5.1 – 5.9	Low – moderate
6 - 8	Moderate
8.1- 8.9	Moderate – High
9 – 10	High

10.1-10.9	High - very high
11 - 12	Very high

3.5.2 Uncertainty analyses

Uncertainty was estimated by averaging expert's level of confidence scores for each indicator. Numerical values were assigned to the predefined scales provided for level of confidence scores (where low confidence =1, medium confidence = 2, and highly confident = 3).

Chapter 4 Results

Eleven experts representing 47% of the invited participants returned their surveys. Three percent of the returned surveys had all sections completed, while 27% had several sections unanswered. This study analyzed only completed surveys.

4.1 Vulnerability component scores

4.1.1 Exposure Index

Exposure scores for all the species was determined by the weighted average of three indicators: future exposure to temperature, future exposure to variation in precipitation and stream flow changes, and exposure to non-climatic and anthropogenic stressors. The final scores showed a linear pattern (Fig. 7) across the seven species with mean exposure score computed as 2.62 (out of a possible 4 points). Fig. 7 shows the relative exposure score for the assessed species. Experts scored Atlantic salmon as having the highest exposure to projected climate change (3.6) while Northern Pike was scored with the least future exposure score (1.5). Lake trout, Arctic char, Brook trout, Brown trout and Rainbow trout had final exposure scores of 3.4, 3.1, 2.5, 2.3 and 2.0 respectively.

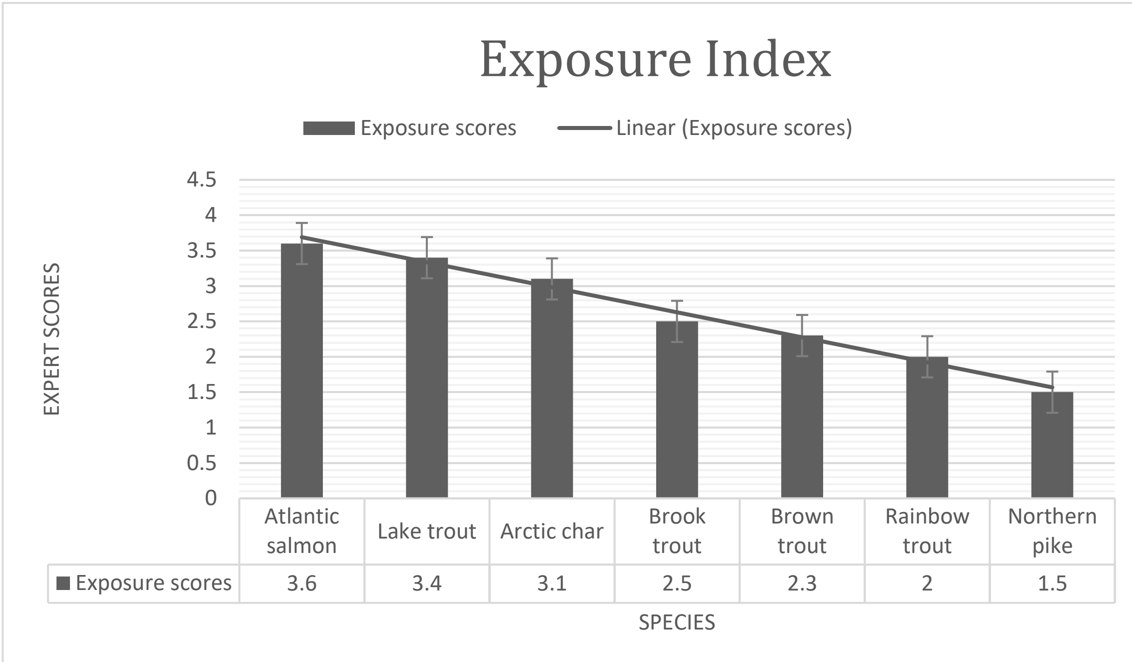

Figure 7: Expert scores for the climate change exposure of 7 freshwater fish in Newfoundland and Labrador

4.1.2 Sensitivity Index

Sensitivity index was estimated using weighted scores for six indicators as shown in Fig. 8. Mean sensitivity scores showed moderate - high sensitivity to projected climate change (2.5 out of 4) across the assessed species. Experts rated Atlantic salmon and Arctic char similarly with the highest sensitivity (3.2) while Northern Pike scores the lowest in sensitivity (1.7) to projected changes. Lake trout, Arctic char, Brook trout, Brown trout and Rainbow trout had final sensitivity scores of 3.1, 3.2, 2.3, 2.0 and 1.9 respectively. Fig. 8 shows the relative sensitivity scores for all the species.

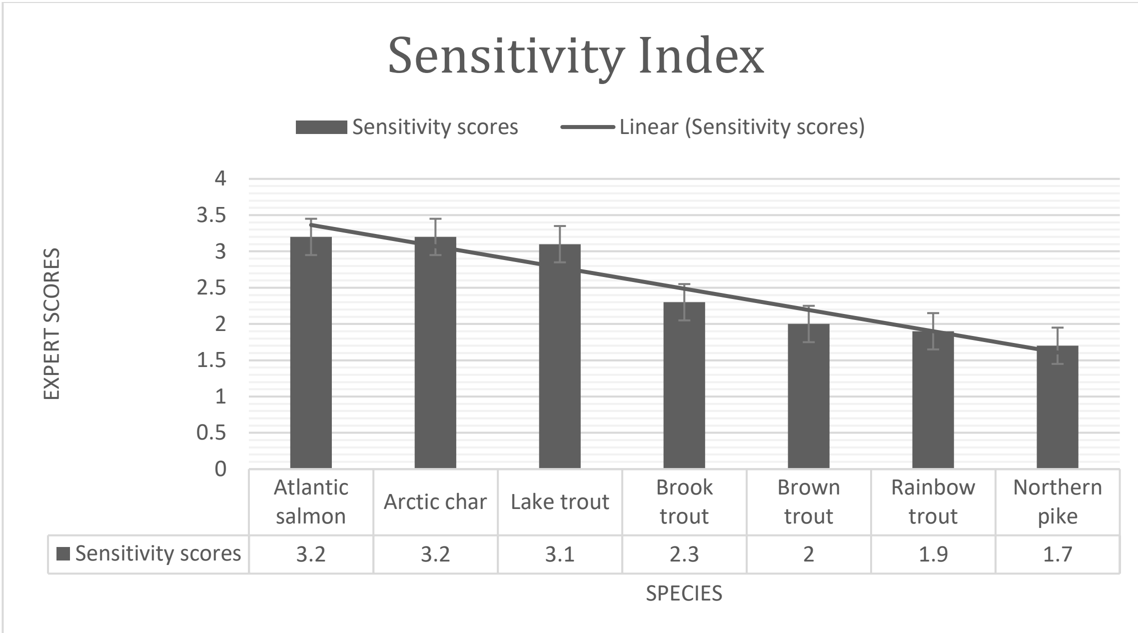

Figure 8: Expert scores for the climate change sensitivity of 7 freshwater fish in Newfoundland and Labrador

4.1.3 Adaptive Capacity Index

Adaptive capacity index was estimated from the weighted scores of three indicators: genetic plasticity, dispersive capability and inherent resilience. The analysis showed that mean adaptive capacity score for all species was computed as 2.3 i.e. indicating some level of moderate adaptability across the species. Experts scored Lake trout and Northern pike with the lowest adaptive capacity (i.e. indicative of the high score for the species) while Atlantic salmon, Brown trout and Rainbow trout tied scores with relatively having the highest adaptive capacity (indicated by the lowest score). Arctic char and Brook trout had adaptive capacity scores of 3.0 and 2.6 respectively (Fig. 9).

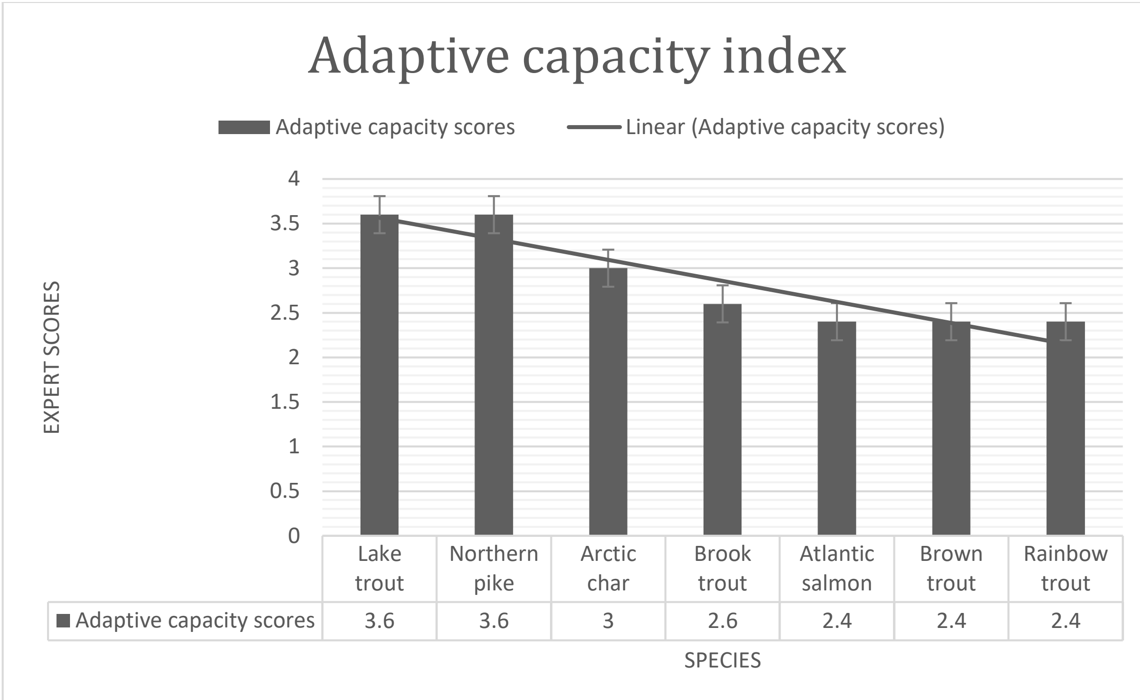

Figure 9: Expert scores for the adaptive capacity of 7 freshwater fish in Newfoundland and Labrador

4.2 Cumulative Vulnerability scores

Final computation of vulnerability scores across the game fishes showed a mean score of 7.9. Overall, vulnerability scores ranged from 10.1 with Lake trout showing the highest vulnerability to 6.3 where Rainbow trout was estimated to have lowest potential for climate change vulnerability. Atlantic salmon, Arctic char, Brook trout, Brown trout and Northern pike were assessed with final vulnerability scores of 9.2, 9.3, 7.4, 6.7 and 6.8 respectively (Fig. 10). Comparison between native and non-native game species showed that mean vulnerability scores were higher for native species (8.6) than non-native species (6.5) indicating that native species may be more vulnerable than exotic species. Mann-Whitney U rank sum test showed a statistically significant difference between experts scores for native and non-native species ($p=0.003$) also indicating that experts scores suggests higher vulnerabilities for native fishes. Fig. 11 shows species likely to experience higher climate impacts were observed at the upper side of the scatterplot and vice versa for species likely to experience lower potential climate impact. On the other hand, species towards the right exhibit lower ability to adapt to potential climate impacts. Hence, most vulnerable species can be found at the uppermost right while species with the least vulnerability can be found at the lower let of the scatterplot.

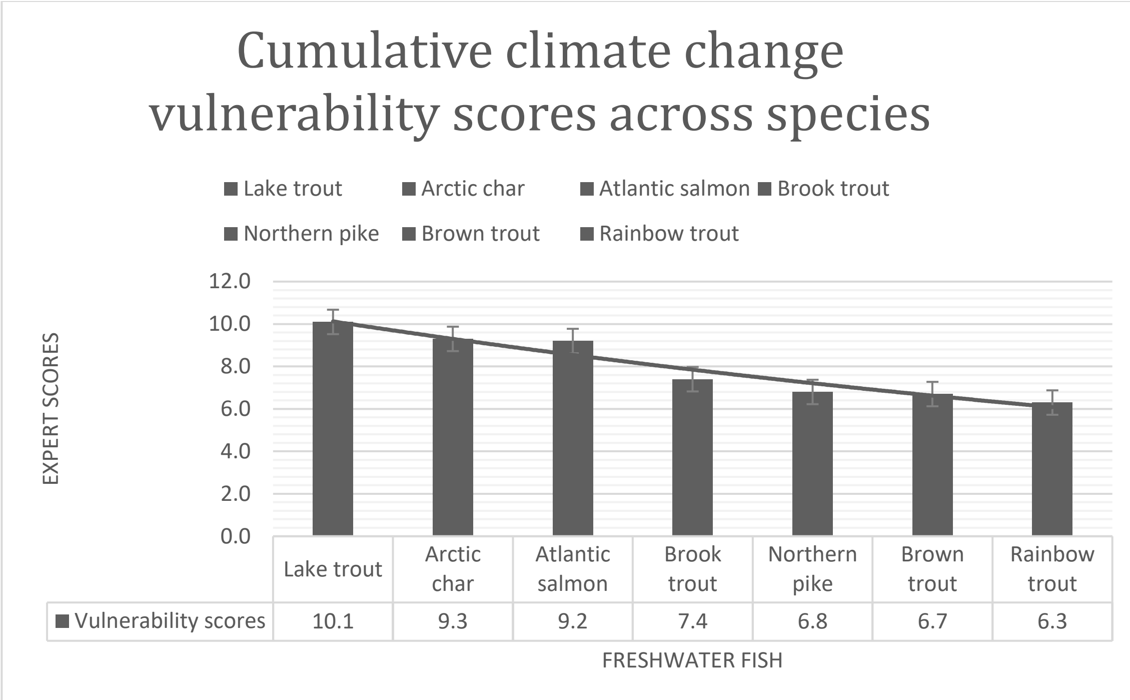

Figure 10: Expert scores for the adaptive capacity of 7 freshwater fish in Newfoundland and Labrador

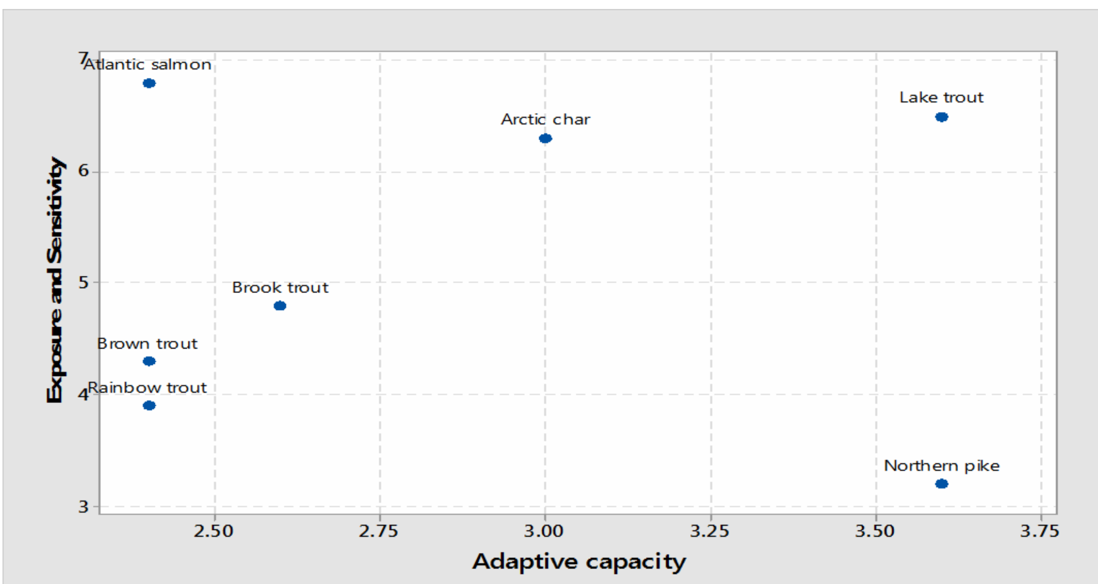

Figure 11: Scatterplot showing the relationship between exposure/sensitivity (potential climate change) and adaptive capacity of Freshwater fishes

Following the predetermined ranking category developed in table, each species was grouped into the following vulnerability categories (Table). In summary, for native species Lake trout was categorized as having potential for high – very highly vulnerability (i.e. at a transition point). Atlantic salmon and Arctic char were categorized with high potential for vulnerability, while Brook trout and Northern pike were categorized as moderately vulnerable. Both non-native species i.e. Rainbow trout and Brown trout were moderately vulnerable.

Table 2: Vulnerability rankings across assessed fish species

Species	**Category**
Lake trout (Salvelinus namaycush)	High - very high
Arctic char (Salvelinus alpinus)	High
Atlantic salmon (Salmo salar)	High
Brook trout (Salvelinus fontinalis)	Moderate
Northern pike (Esox lucius)	Moderate
Brown trout (Salmo trutta)	Moderate
Rainbow trout (Oncorhynchus mykiss)	Moderate

4.3 Experts uncertainty

Analysis of confidence scores showed that experts were moderately confident (mean confidence scores of 2.3) in the vulnerability ratings across all species. Experts seem to have shown higher confidence in scoring Atlantic salmon (mean confidence = 2.4) showing the highest scores across the exposure, sensitivity and adaptive capacity components. Conversely, experts showed the least certainty in scoring Northern pike (mean confidence = 2.0). Expert's confidence scores showed higher ratings for the adaptive capacity of the species compared to other vulnerability factors. There appeared to be no apparent difference in the expert's confidence scoring between native and non-native species.

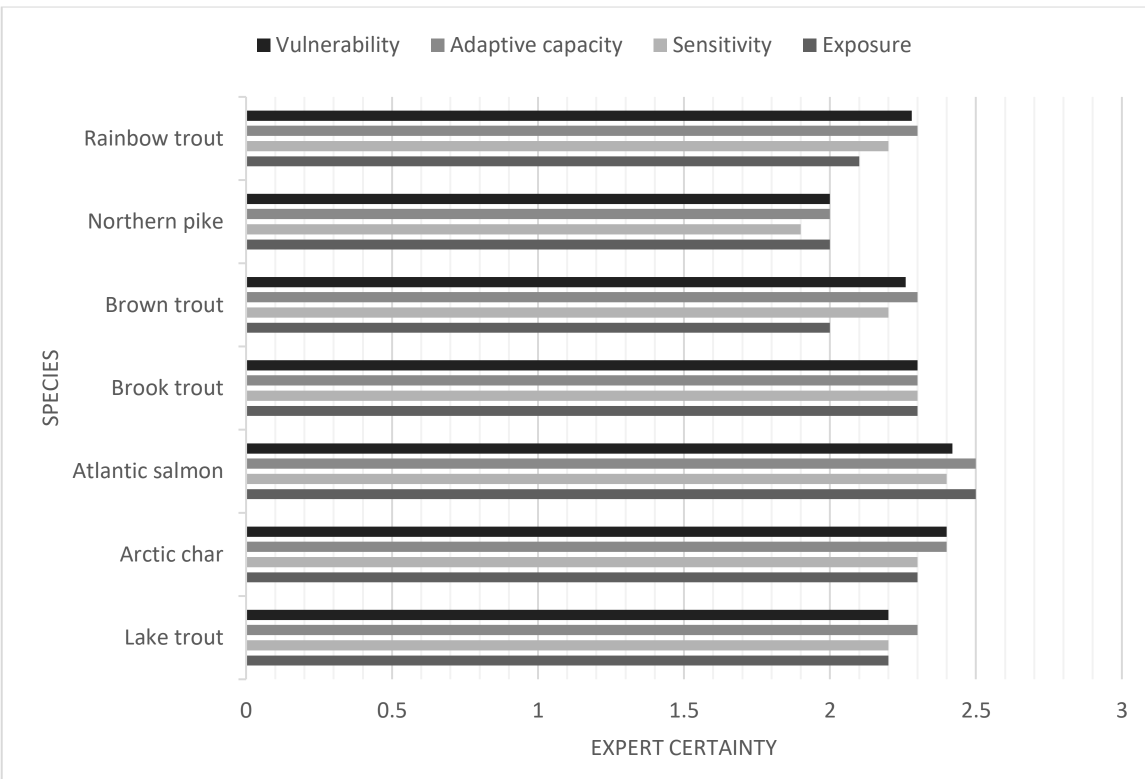

Figure 12: Experts certainty scores for the exposure, sensitivity, adaptive capacity and cumulative vulnerability of assessed fish species

4.4 Attributes driving freshwater fish climate change vulnerability

The Kruskal-Wallis test to determine the major drivers of the assessed freshwater fish vulnerability indicated a significant difference ($p = 0.027$) between the indicators suggesting that certain indicators were more influential in driving species climate change vulnerability in this assessments. Therefore, from a general perspective, the test analysis showed that based on expert scores, inherent resilience, dispersive capability, dependence on environment cues impacted by climate change, exposure to temperatures and genetic plasticity were found to be the major determinants in this assessment. Fig. 13 shows the major determinants of future climate change vulnerability across the species. Freshwater fish's inherent resilience which represents the generation time, size and age at maturity, and fecundity or productivity was considered to highly influence vulnerability (Fig. 13). Prey specificity was considered the least influential but important factors. From a species-specific perspective, varying factors can be shown to determine vulnerability. For example, Lake trout ranked with the highest relative climate change vulnerability can be noted to be mostly influenced by the combination of 8 factors (Fig. 14). Conversely, Rainbow trout ranked with the least relative vulnerability (moderate) is influenced by 6 factors (Fig 20).

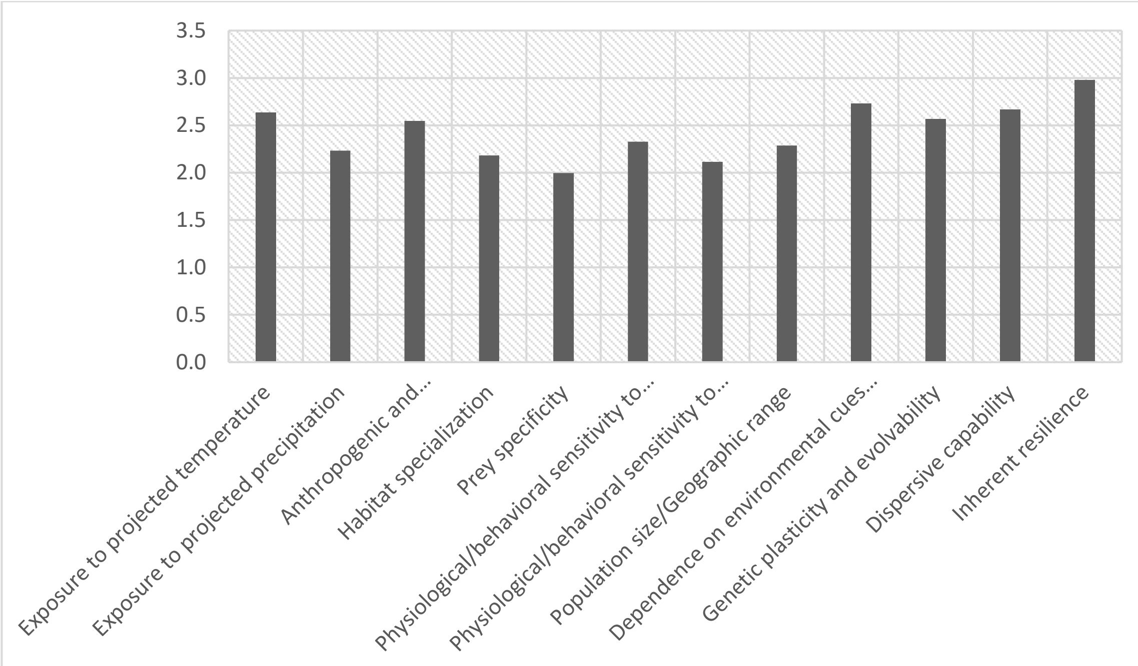

Figure 13: Trait factors majorly influencing future climate change vulnerability across seven freshwater fishes. Most important drivers are highlighted in red

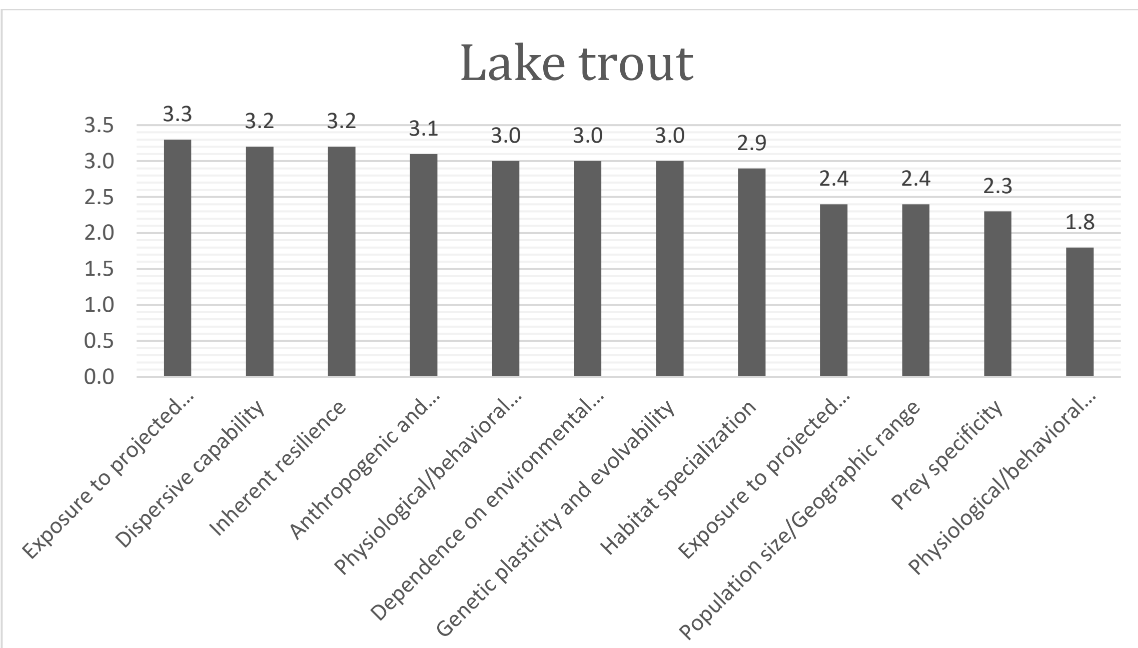

Figure 14: Trait factors affecting Lake trout's climate change vulnerability highlighted in red

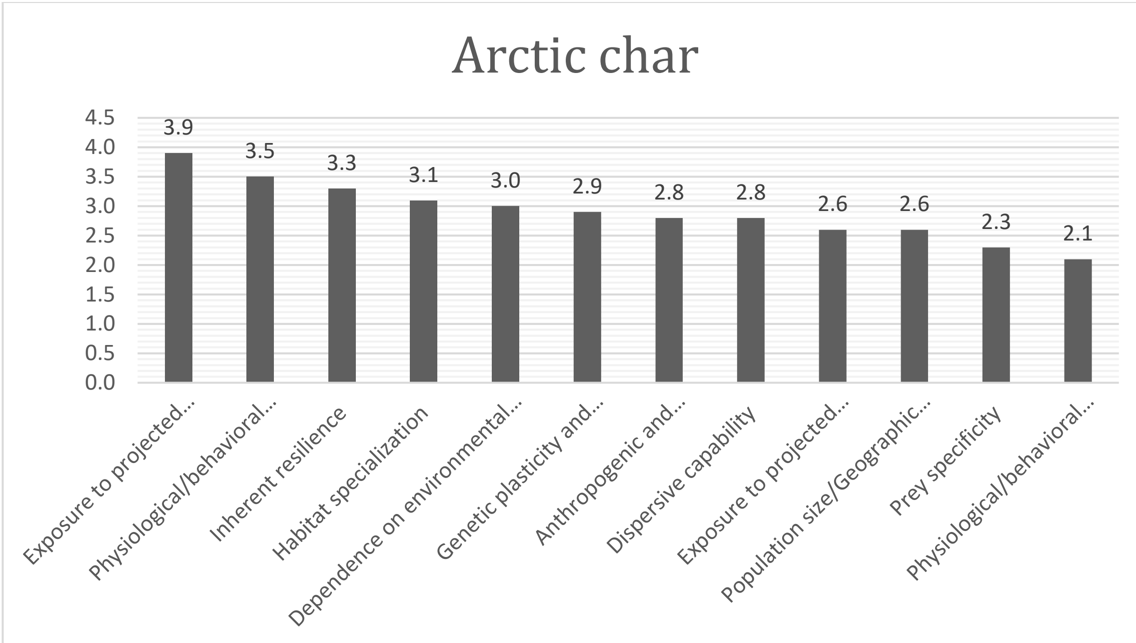

Figure 15: Major factors driving Arctic Char's climate change vulnerability highlighted in red

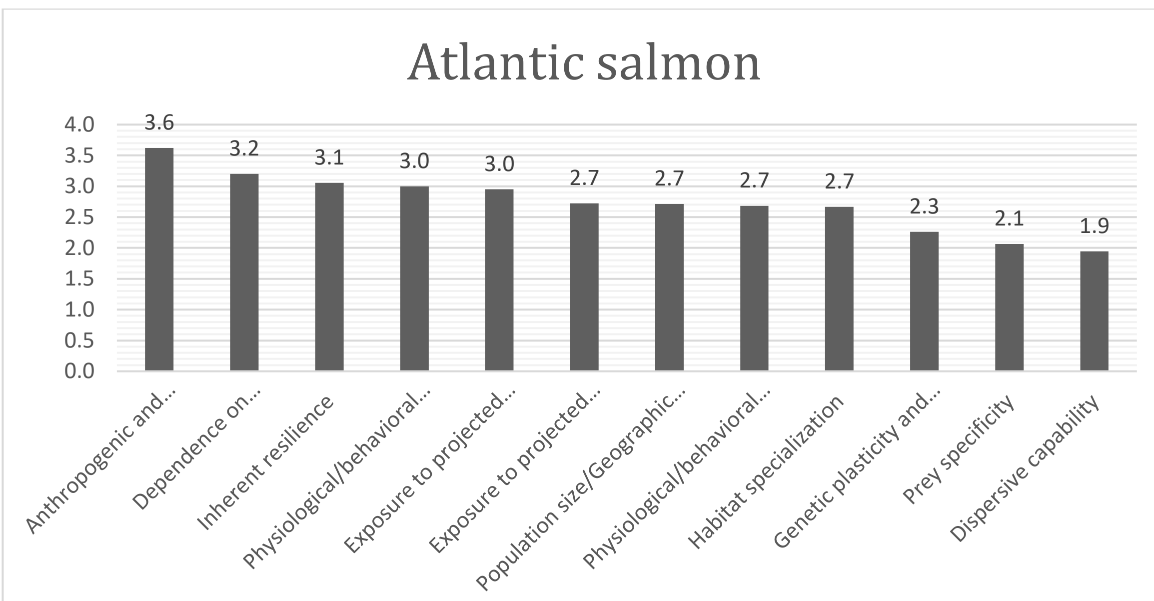

Figure 16: Major factors affecting Atlantic salmon's climate change vulnerability highlighted in red

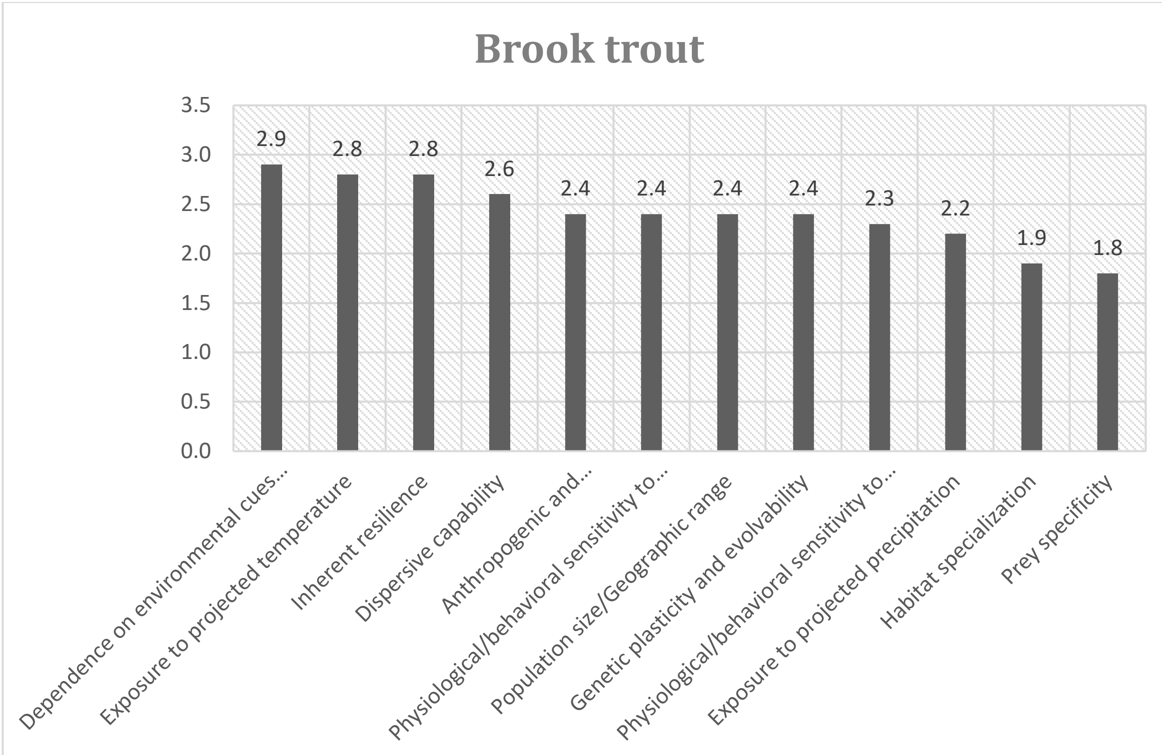

Figure 17: Major factors affecting Brook trout's climate change vulnerability highlighted in red

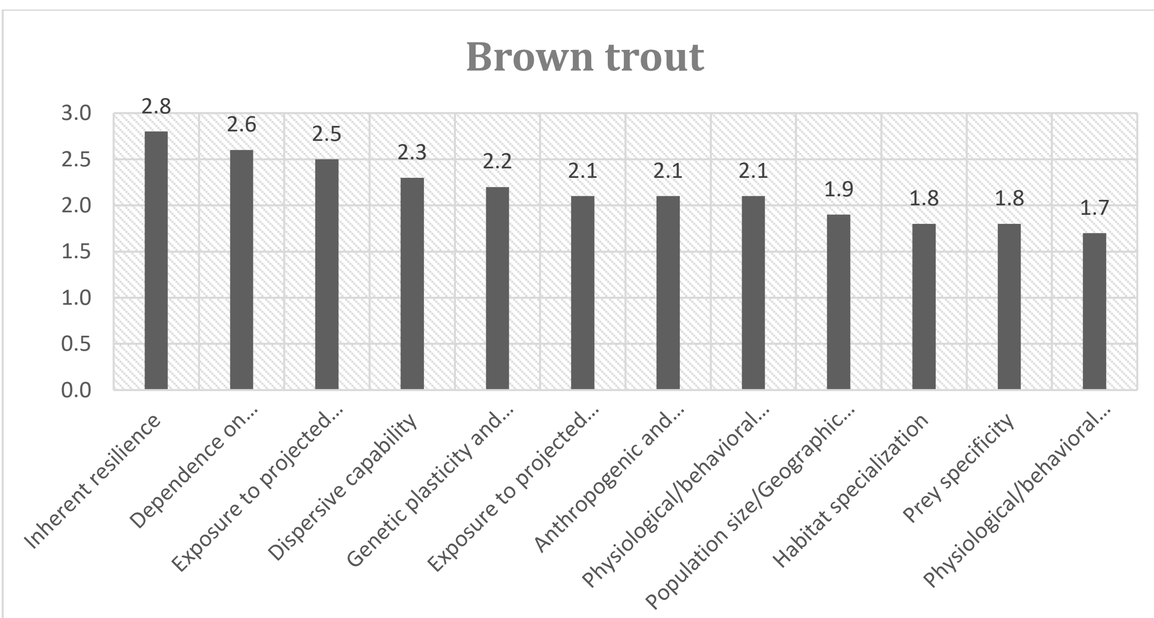

Figure 18: Major factors affecting Brown trout's climate change vulnerability highlighted in red

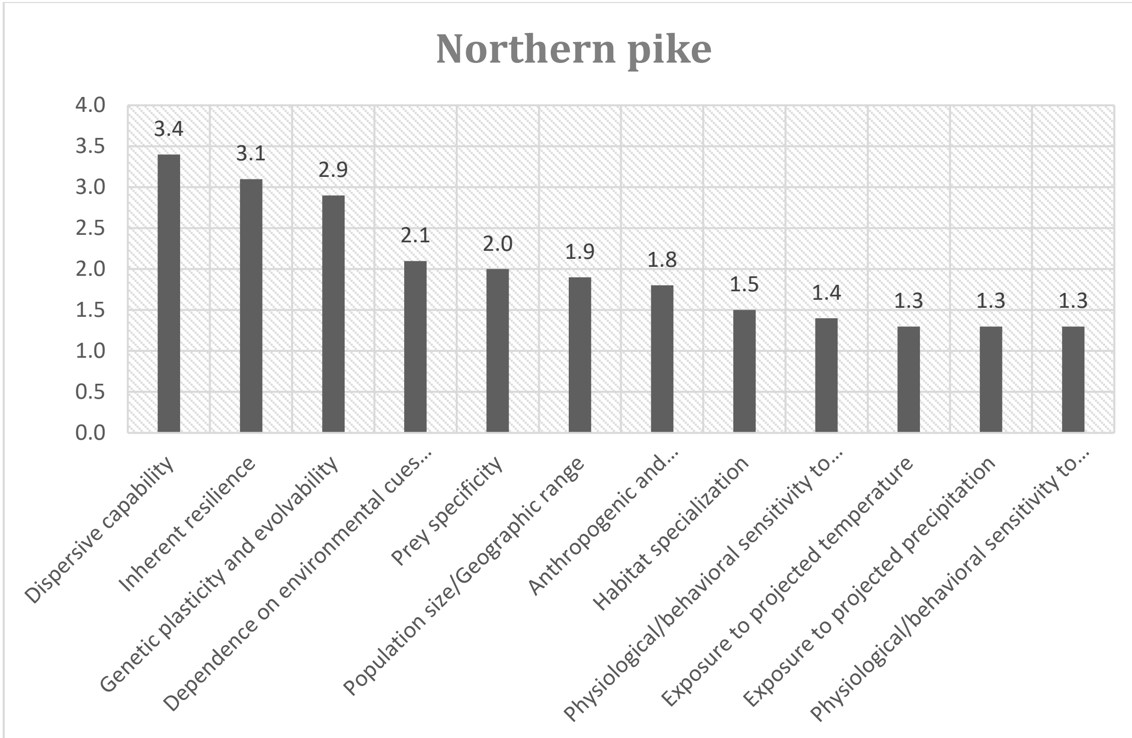

Figure 19: Major factors rated to influence Northern pike's climate change vulnerability highlighted in red

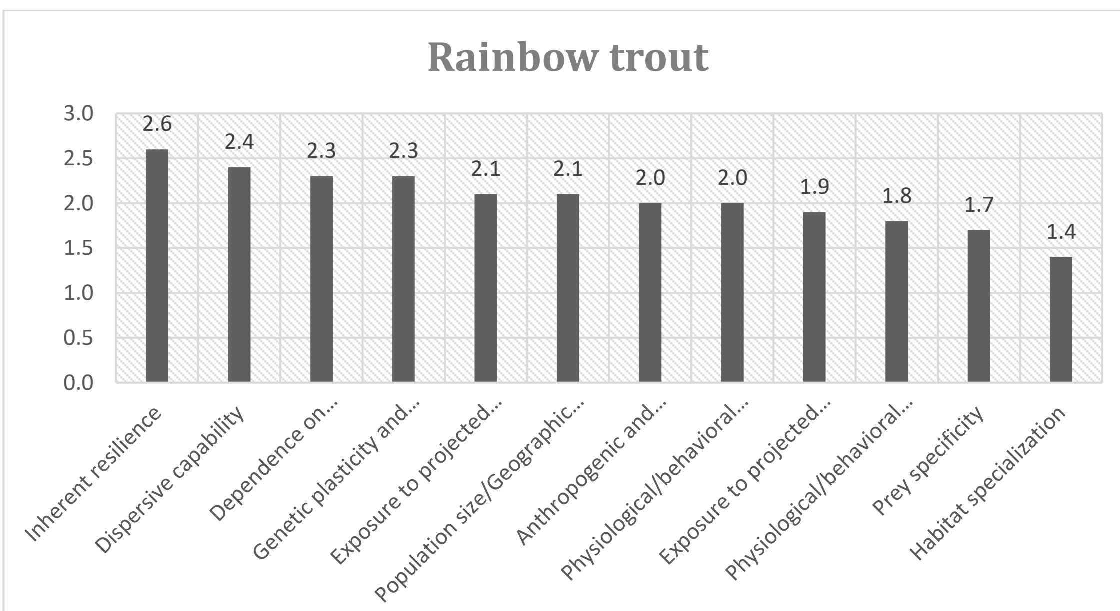

Figure 20: Major factors rated to influence Rainbow trout's climate change vulnerability highlighted in red

Anthropogenic non-climatic stressors to the species were also analyzed and Fig. 21 provides a breakdown of expert responses. From expert's responses, habitat loss related activities pose the greatest threats to game fish vulnerability. For instance, out of a total of 24, 14, 21 individual threats iterated for Atlantic salmon, Lake trout and Brook trout respectively, 33%, 50% and 38% of the response categories mentioned habitat loss as a threat to each species respectively. Appendix shows a breakdown of the responses.

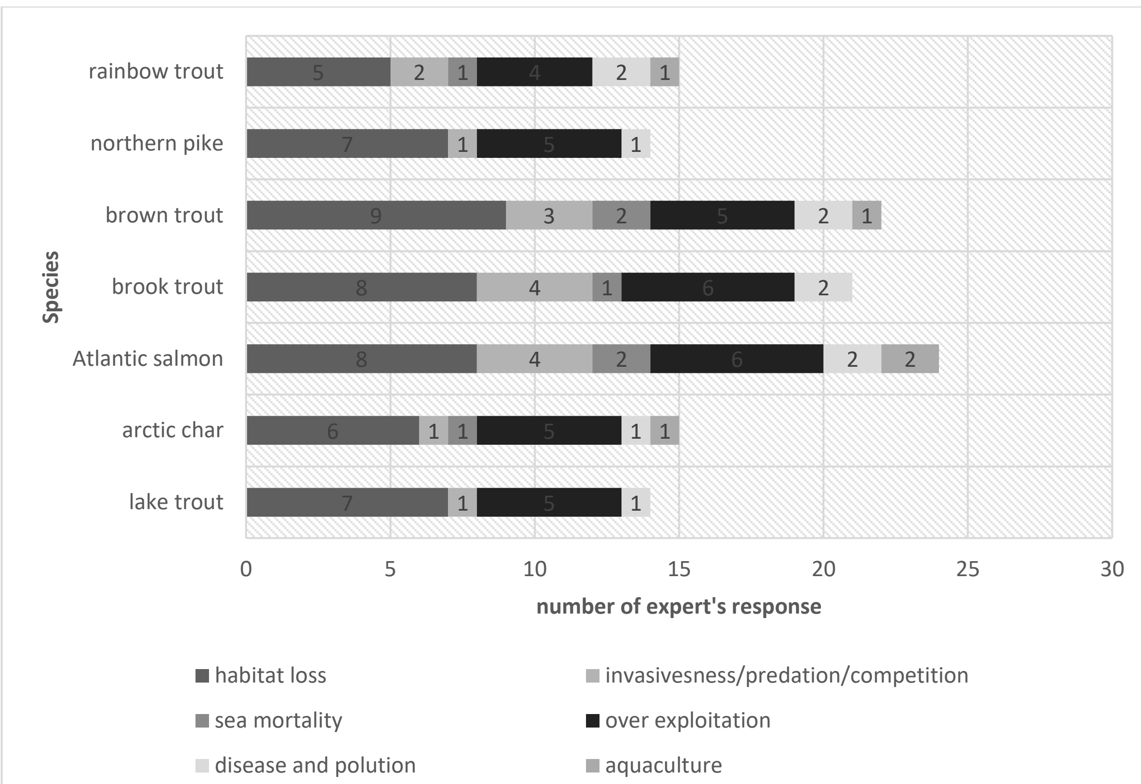

Figure 21: Experts response showing the anthropogenic threats as drivers of the vulnerability of 7 freshwater fishes

Chapter 5 Discussion

Results from this assessment suggests that game fish species in Newfoundland and Labrador will experience some measure of vulnerability to climate change as projected in Finnis (2013). Vulnerability is used here refers to the possibility that negative climate change and non-climatic impacts could lead to drastic fish population loss, extirpation or extinction by the middle of this century. Out of the seven species assessed, none showed low vulnerability to climate change. This may indicate that in general, experts showed consensus that future climate change will pose negative impacts across all game species. From a broad perspective of expert's scores, game fish would likely experience a range of moderate to very high vulnerability to climate change depending on the species. Results from analysis of expert judgment also suggests that native species would likely be more vulnerable to future climate change than non-native species. Since the assessment did not cover all freshwater fish recorded in Newfoundland and Labrador, it is indeterminate if similar trend will reoccur in a broad scale assessments of all freshwater fish species. However, previous studies conducted in other regions have shown similar conclusions that non-native species especially warm or cool water fish species will likely expand their northward range

(Abdel-Fattah, 2016). Non-climatic factors were also highlighted to contribute moderately (Northern pike) or highly (Atlantic salmon) to game fish vulnerability to climate change. Non-climatic stressors identified as threats to the species were placed into 5 categories. Among the categories, habitats destruction/modification and over-exploitation were noted to be playing a leading role in increasing vulnerability to climate change.

From a species-specific point of view, the results show variability in the influencing factors of vulnerability. For instance, Lake trout populations are reported to be distributed mostly in Southern Labrador, no population is recorded to be established in insular Newfoundland (Grant and Lee, 2004; Bradbury et al., 1999). The vulnerability of Lake trout to future climate change was rated by experts to likely transition between high and very high vulnerability (high – very high). Scores analysis showed that exposure to changing stream temperatures and high physiological and behavioral sensitivity to temperature are among the major risk factors for the species. Previous studies have already shown that adult and juvenile lake trout's have strong temperature and oxygen preferences occupying shallow lakes and rivers approximately 10°C (Grant and Lee, 2004; Bradbury et al., 1999) and deep portions when temperature exceeds 15°C (Dillon et al., 2004, Scott and Crossman, 1973). In addition, existing data from climate impacts studies in boreal shield lakes have similarly shown that future warming could impose increased thermal stress on Lake trout populations (Guzzo and Blanchfield, 2016). Experts judged that biological characteristics such as habitat specialization, low dispersal ability, low resilience and genetic plasticity would increase this risk of vulnerability for Lake trout. More than 80% of non-climatic threats identified for Lake trout were categorized under habitat degradation and over-exploitations (illegal and legal). Such threats include: instream barriers, toxins, and invasive species, also posed current and future vulnerability risk to Lake trout population. Atlantic salmon (*Salmo salar*) on the other hand was ranked as highly vulnerable to climate change showing the highest relative confidence scores across all species in the assessment. The species is reported throughout Newfoundland and southern Labrador (Grant and Lee, 2004) existing as anadromous and landlocked populations and is observed to prefer clean, cool waters with specific micro-climates (Grant and Lee, 2004; Bradbury et al., 1999). Expert's high vulnerability rank for Atlantic salmon resulted from a combination of increasing exposure to temperature changes, high physiological/behavioral sensitivity to temperature, sensitivity to precipitation and its high dependence on environment cues likely to be interrupted by climate change. This shows some parallels with existing literature and assessments. For instance, Atlantic salmon has been shown to have a maximum critical temperature threshold of about 20°C (depending on the life stage) which is threatened due to climate change (Whitman et al., 2013). Also, increasing water temperatures has been linked with changing competition and predation (Mills et al., 2013; Beaugrand and Reid. 2003), and reduced body fat content in spawning adults (Todd et al., 2008) while alterations in precipitation regimes have been predicted to lead to impaired recruitment, survival, and productivity in Atlantic salmon (Jonsson and Jonsson, 2009). Atlantic salmon's relatively high score for habitat specialization shows some limitations to its ability to colonize new habitats. About 75% of anthropogenic stressors listed by experts threatening Atlantic salmon related to habitat loss, invasive species and overexploitation of the species. Similar factors were observed in other vulnerability assessments studies (Hare et al., 2016; Sneddon and Hammerson, 2014; Whiteman et al., 2013).

Brook trout a native freshwater fish distributed across Newfoundland and Labrador (Van Zyll de Jong et al., 2002) was considered moderately vulnerable to climate change due to factors such as moderate exposure to increasing temperature and precipitation. Already, brook trout has been documented to prefer cool, well oxygenated headway streams, rivers and gravely lakes (Grant and Lee, 2004; Bradbury et al., 1999). Also, significant mortality has been shown to occur where water temperature exceeds 25°C (McCormick et al., 1972) further buttressing the high sensitivity to temperature of the species shown by expert's scores. Similarly, results from Sneddon and Hammerson (2014) showed that temperature related threats influence future brook trout populations. Further, low dispersal ability and low inherent resilience presented by expert's scores suggests biological limits to brook trout adaptability. These factors together with non-climatic stressors such as industrial development, invasiveness, competition with other salmonids, were noted as threats to brook trout's population in the study area. Brown trout on the other hand a non-native species known to exhibit similar environmental requirements with brook trout (Grant and Lee, 2004; Van Zyll de Jong et al., 2002) was ranked moderately vulnerable with expert scores showing moderate confidence ratings. Expert scores ratings suggested relatively higher physiological and behavioral tolerance to temperatures. This could indicate that brown may be presented with an opportunity for invasiveness and northward range expansion under climate change possibly out-competing fishes like brook trout or other salmonids that show higher sensitivity to temperature changes (Rahel et al., 2008). However, biological factors such as low genetic plasticity, low inherent resilience and dispersive capacity were considered to increase its climate change vulnerability. In addition, threats from instream barriers, dams, habitat modification/fragmentation, constitute some of the non-climate factors noted by experts to enhance vulnerability risk of brown trout. In general, expert's scores showed that it would likely be less vulnerable than brook trout. Rainbow trout also a non-native species in Newfoundland (Van Zyll de Jong, 2004; Bradbury et al., 1999) is recorded to be well adapted to clear cold deep lakes and have also been reported in smaller lakes, ponds and streams environments (Grant and Lee, 2004). Ranked as moderately vulnerable to climate change, experts assessed that low adaptability in terms of its inherent resilience and dispersal capability compared to its exposure and sensitivity to future changes were determinants of its vulnerability therefore, showing the least climate change vulnerability scores. Anthropogenic stressors like habitat loss and harvest (legal and illegal) could drive climate vulnerability for Rainbow trout. Actions to limit anthropogenic pressures on habitats (such as habitat protection measures) could be sufficient for conserving this brown trout (Wade et al., 2013) through enhanced resilience and dispersal capability to shift its distribution in response to climate suitability.

Arctic char's distribution extends from some parts of Newfoundland to northern coasts of Labrador (Grant and Lee, 2004; Bradbury et al., 1999).

Arctic char was considered highly vulnerable to future climate change. Exposure to rising water temperature was considered to highly increase its vulnerability. Specific trait factors such as high physiological tolerance to temperature, high habitat specialization and dependence on environmental cues were in addition important determinants of high sensitivity to future changes. Combining limited adaptability traits (low genetic plasticity, resilience) were also determined to likely enhance vulnerability to climate change. In contrast, Northern pike distributed mostly throughout southern Labrador (Grant and Lee, 2004; Bradbury et al., 1999) was rated moderately vulnerable to projected climate change. Trait factors such as high physiological/behavioral tolerance to temperature and precipitation suggests that direct thermal stress from exposure to temperature would unlikely occur (Winfield et al., 2008) reflecting some potential to expand its range. Scientific studies have observed the species to exhibit high tolerance to a wide range of environmental conditions with an upper lethal temperature limit of 29°C (DFO, 2011). Low habitat specialization and a notable prey generalist (Beaudoin et al., 1999) the species possess some potential to persist and colonize habitats under changing conditions. Conversely, Winfield et al., (2008) opined that changing prey abundance (usually other salmonids like arctic char) due to climate change could increase Northern pike's risk of climate change vulnerability. Also, the analysis showed that low relative adaptive capacity factors such as limited dispersal capability for example during adult stages (except during migration and spawning) are known to be mostly sedentary (DFO, 2011), and its early life stages is dependent on environmental cues which could increase the risk of vulnerability to climate change. Combining impacts from habitat loss/fragmentation from forestry and development coupled with fishing harvest (overexploitation) were indicated by experts as a threat to future population resilience of both Arctic and northern pike populations.

Conservation strategies for freshwater fishes could require both evolutionary and human-assisted adaptation responses to cope with climate change (Closs et al., 2015). Some of the challenges to evolutionary adaptation responses relate to the extent which different ecosystems will be destroyed, the presence of suitable thermal and flow regimes, and the dispersal capability of freshwater fish to overcome fragmentation (Heino et al., 2009). For instance, species confined to fragmented habitats without adequate evolutionary adaptive capacity may become extinct. Adaptation strategies from resource managers could be focused to address the various vulnerability drivers displayed by species through enhancing their individual adaptive capacity, though these strategies may not necessarily forestall the loss of all species (Shoo et al., 2013). Transparent decision making frameworks rooted in specific adaptation actions is recognized as critical for sustainable species management (Shoo et al., 2013). While several conservation operations are already in place for in managing a suite of anthropogenic stressors, it is realistic to note that such conventional actions will still be useful in conserving freshwater fish populations (Hunter et al., 2010). Yet, in terms of effectiveness, additional approaches may be necessary where conventional operations may be limited in addressing future vulnerabilities (Heller & Zavaleta, 2009). Shoo et al., (2013) proposed a structure decision framework applicable to freshwater fish adaptation management which involves first identifying the most vulnerable species for management interventions, followed with linking each species response scenarios such as its unique vulnerability drivers to management actions that can improve resilience. Mawdsley et al., (2009) noted direct species management strategies also applicable to sustainable fish resource management such as assisted translocation or migration of species with limited dispersal capability. This strategy is specifically useful to assist depleting species being perturbed to colonize new habitats (Mawdsley et al., 2009). Fishery managers could also focus strategies on limiting non-climatic anthropogenic stressors to enable freshwater fish evolve responses to climate change (Mawdsley et al., 2009). Strategies relating to landscape management such as riparian reforestation have been proposed by a number of scholars including Bond et al., (2015) as a tool useful in mitigating current and future warming of stream environments to benefit species highly sensitive to temperature changes. Habitat connectivity restoration is also recognized as important to provide adequate migratory corridors for fishes to shift to suitable climatic environments.

Chapter 6 Conclusion

Globally, freshwater fish are vulnerable to the effects of climate change, with native cold water species likely more vulnerable due to their dependence on cold, clean water (Williams et al., 2015). There is existing evidence to show that freshwater fish in Canada are already experiencing some negative impacts from climate change and it can be expected that this could continue in the future (Abdel-Fattah, 2016). Based on projected changes, the objective of this study was to provide a semi-quantitative estimate of seven freshwater fish's vulnerability to the negative impacts of climate change. The NMFS methodological framework (Fig. 5) presented a step by step useful guideline for the assessment. Expert's knowledge synthesized through systematic indicator scoring facilitated through an online questionnaire survey presented a unique mechanism to characterize the vulnerabilities of seven freshwater fish. Analysis of the results supported claims that native species were relatively more vulnerable to climate change. Vulnerability ranks ranged from moderate to very high vulnerability. Several limitations are recognized in this study. This assessment could represent a first step effort to quantify the climate change vulnerability of freshwater fish in the province. Future assessments could produce more refined results by employing spatially explicit vulnerability assessments with species traits

(Pacifici et al., 2015). Ultimately, the quantified results presented by this study represents a relative measure of climate change vulnerability since the results lacks capacity to serve as an absolute measure of vulnerability. However, from a planning and decision making perspective this study could be significant for conservation, to inform future climate change adaptation planning, prioritizing monitoring and further research for freshwater fish. Since climate change would likely outpace the ability of some species to shift to suitable habitats and genetically evolve, the need for proactive management responses cannot be overemphasized. Adaptation management actions such as assisted translocation or migration, removal of non-climatic anthropogenic stressors, habitat connectivity restoration, riparian reforestation are some responses that can strategically target vulnerable species and habitats.

Bibliography

Abdel-Fattah, S. 2016 [Ed.]. Impacts of climate change on fish species and aquatic ecosystems in the Great Lakes and Prairie regions of Canada: a compilation of reports. Can. Manuscr. Rep. Fish. Aquat. Sci. 3108: v + 95 p.

Adger, W. N. (2006). Vulnerability. Global environmental change, 16(3), 268-281.

Alofs, K. M., Jackson, D. A., & Lester, N. P. (2014). Ontario freshwater fishes demonstrate differing range-boundary shifts in a warming climate. Diversity and Distributions, 20(2), 123-136.

Angert et al., 2011 A.L. Angert, L.G. Crozier, L.J. Rissler, S.E. Gilman, J.J. Tewksbury, A.J. Chunco (2011). Do species' traits predict recent shifts at expanding range edges? Ecol. Lett., 14 (2011), pp. 677-689

Angert et al., 2011 A.L. Angert, L.G. Crozier, L.J. Rissler, S.E. Gilman, J.J. Tewksbury, A.J. ChuncoDo species' traits predict recent shifts at expanding range edges?

Bagne, Karen E.; Friggens, Megan M.; and Finch, Deborah M. 2011. A System for Assessing Vulnerability of Species (SAVS) to Climate Change. Gen. Tech. Rep. RMRS-GTR-257.Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Rocky Mountain

Barber, Q. E., Nielsen, S. E., & Hamann, A. (2015). Assessing the vulnerability of rare plants using climate change velocity, habitat connectivity and dispersal ability (Doctoral dissertation, University of Alberta).

Beaudoin, C. P., Tonn, W. M., Prepas, E. E., & Wassenaar, L. I. (1999). Individual specialization and trophic adaptability of northern pike (Esox lucius): an isotope and dietary analysis. Oecologia, 120(3), 386-396.

Beaugrand, G., and P. Reid. (2003). Long-term changes in phytoplankton, zooplankton and salmon related to climate. Global change biology 9: 801–817.

Bond, R. M., Stubblefield, A. P., & Van Kirk, R. W. (2015). Sensitivity of summer stream temperatures to climate variability and riparian reforestation strategies. Journal of Hydrology: Regional Studies, 4, 267-279.

Bradbury, C., M.M. Roberge and C.K. Minns. (1999). Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Lake Habitat Characteristics. Can. MS Rep. Fish. Aquat. Sci. 2485:vii+150p.

Brander, K. (2010). Impacts of climate change on fisheries. Journal of Marine Systems, 79(3), 389-402.

Brooks, R.T. 2009. Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. Clim. Change. 95(3-4): 469-483.

Brzeski, V. (2013). Adapting Atlantic Canadian Fisheries to Climate Change. Ecology Action Centre.

Buisson, L., Thuiller, W., Lek, S., Lim, P. U. Y., & Grenouillet, G. (2008). Climate change hastens the turnover of stream fish assemblages. Global Change Biology, 14(10), 2232-2248.

Burkhead, N. M. (2012). Extinction rates in North American freshwater fishes, 1900–2010. BioScience, 62(9), 798-808

Butt, N., Possingham, H. P., De Los Rios, C., Maggini, R., Fuller, R. A., Maxwell, S. L., & Watson, J. E. M. (2016). Challenges in assessing the vulnerability of species to climate change to inform conservation actions. Biological Conservation, 199, 10-15.

Casselman, J.M., S. Kunjikutty, P. Lehman, L. Marcogliese, and J. Oblak. (2011). Report –Fish, Fisheries, and Water Resources: Adapting to Ontario's Changing Climate. Report to Natural Resources Canada, Climate Change Impacts and Adaptation Directorate, Study A1367, Ottawa, Canada, in conjunction with Queen's University and Mississippi Valley Conservation. March 2011.

Chessman, B. (2013). Identifying species at risk from climate change: Traits predict the drought vulnerability of freshwater fishes. Biological Conservation, 160, 40-49.

Chevin, L.-M., Lande, R., Mace, G.M. (2010) "Adaptation, plasticity, and extinction in a changing environment: Towards a predictive theory," PLoS Biology, 8(4)

Chin, A., Kyne, P. M., Walker, T. I., & McAULEY, R. O. R. Y. (2010). An integrated risk assessment for climate change: analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. Global Change Biology, 16(7), 1936-1953.

Closs, G. P., Krkosek, M., & Olden, J. D. (Eds.). (2015). Conservation of freshwater fishes. Cambridge University Press.

Collares-Pereira, M. J., & Cowx, I. G. (2004). The role of catchment scale environmental management in freshwater fish conservation. Fisheries management and Ecology, 11(3-4), 303-312.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon Salmo salar (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 pp.

Cowx, I. G., & Gerdeaux, D. (2004). The effects of fisheries management practises on freshwater ecosystems. Fisheries Management and Ecology, 11(3-4), 145-151.

Cross MS, Zavaleta ES, Bachelet D, Brooks ML, Enquist CA, Fleishman E, Graumlich LJ, Groves CR, Hannah L, Hansen L, Hayward G, Koopman M, Lawler JJ, Malcolm J, Nordgren J, Petersen B, Rowland EL, Scott D, Shafer SL, Shaw MR, Tabor GM (2012) The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. Environ Manage 50(3):341-351

Crozier, L. G., Scheuerell, M. D., & Zabel, R. W. (2011). Using time series analysis to characterize evolutionary and plastic responses to environmental change: a case study of a shift toward earlier migration date in sockeye salmon. The American Naturalist, 178(6), 755-773.

Dawson, T.P., Jackson, S.T., House, J.I., Prentice, I.C., Mace, G.M. (2011) "Beyond predictions: Biodiversity conservation in a changing climate," Science, 332(6025), 53–58

DFO. (2011). Science Advice from a Risk Assessment of Northern Pike (Esox lucius) in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/083.

Dove-Thompson, D., Lewis, C., Gray, P. A., Chu, C., & Dunlop, W. (2011). A summary of the effects of climate change on Ontario's aquatic cosystems. Ontario Ministry of Natural Resources and Forestry, Science and Research Branch, Peterborough, Ontario, Canada.

Dubois N, Caldas A, Boshoven J, Delach A (2011) Integrating climate change vulnerability assessments into adaptation planning: A case study using the NatureServe Climate Change Vulnerability Index to inform conservation planning for species in Florida. Defenders of Wildlife.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., ... & Sullivan, C. A. (2006). Freshwater biodiversity:importance, threats, status and conservation challenges. Biological reviews, 81(2), 163-182.

Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries, 17(4), 581-613.

Finnis, J. (2013). Projected Impacts of Climate Change for the Province of Newfoundland Labrador. Newfoundland and Labrador Office of Climate Change and Energy Efficiency.

Fischlin, A., G. F. Midgley, J. T. Price, R. Leemans, B. Gopal, C. Turley, M. D. A. Rounsevell, O. P. Dube, J. Tarazona, and A. A. Velichko. (2007). Ecosystems, their properties, goods, and services. Pages 211– 272 in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Climate change 2007: impacts, adaptation and vulnerability, contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom Foden et al. 2014; 2013;

Foden, W. B. (2015). Assessing species' vulnerability to climate change (Doctoral dissertation).

Foden, W.B., Butchart, S.H.M., Stuart, S.N., Vié, J.-C., Akçakaya, H.R., Angulo, A., DeVantier, L.M., Gutsche, A., Turak, E., Cao, L., Donner, S.D., Katariya, V., Bernard, R., Holland, R.A., Hughes, A.F., O'Hanlon, S.E., Garnett, S.T., Șekercioğlu, C.H., Mace, G.M. (2013) "Identifying the

World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals," PLoS ONE, 8(6),

Füssel, H. M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability science, 2(2), 265-275.

Füssel, H-M and Klein, R.J.T. (2006). Climate change vulnerability assessments: An evolution of conceptual thinking. Climatic Change 75: 301-329. Füssel et al, 2007

Galbraith, H., & Price, J. (2009). A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. Global Change Research Program, National Center for Environmental Assessment, Office of Research and Development, US Envrionmental Protection Agency.

Garcia, r. A., Araújo, m. B., Burgess, n. D., Foden, w. B., Gutsche, a., Rahbek, c. & Cabeza, m. (2014). Matching species traits to projected threats and opportunities from climate change. Journal of Biogeography, 41, 724-735.

Gardali, T., Seavy, N. E., DiGaudio, R. T., & Comrack, L. A. (2012). A climate change vulnerability assessment of California's at-risk birds. PLoS One, 7(3), e29507.

Gleeson, J., Gray, P., Douglas, A., Lemieux, C. J., & Nielsen, G. (2011). A practitioner's guide to climate change adaptation in Ontario's ecosystems. A practitioner's guide to climate change adaptation in Ontario's ecosystems.

Glick, P., Stein, B. A., & Edelson, N. A. (2011). Scanning the conservation horizon: a guide to climate change vulnerability assessment.

Grant, CGJ. and E.M. Lee. (2004). Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Riverine Habitat Requirements. Can. Manuscr. Rep. Fish. Aquat. Sci. 2672: xii + 262p.

Guzzo, M. M., & Blanchfield, P. J. (2016). Climate change alters the quantity and phenology of habitat for lake trout (Salvelinus namaycush) in small Boreal Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences, 74(6), 871-884.

Hall, C. J., Jordaan, A., & Frisk, M. G. (2011). The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology, 26(1), 95-107.

Hannah L (2008) Protected areas and climate change. Ann New York Acad Sci 1134(1):201-212

Hannah, L., Midgley, G., Andelman, S., Araújo, M., Hughes, G., Martinez-Meyer, E., ... & Williams, P. (2007). Protected area needs in a changing climate. Frontiers in Ecology and the Environment, 5(3), 131-138.

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., ... & Chute, A. S. (2016). A vulnerability assessment of fish and invertebrates to climate change on the Northeast US continental shelf. PloS one, 11(2), e0146756.

Harrod, C. (2015). Climate change and freshwater fisheries. Freshwater Fisheries Ecology, 641-697.

Heino, J., Virkkala, R., & Toivonen, H. (2009). Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. Biological Reviews, 84(1), 39-54.

Heller NE, Zavaleta ES (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biol Conserv 142:14–32

Hoving, C. L., Lee, Y. M., Badra, P. J., & Klatt, B. J. (2013). Changing climate, changing wildlife: a vulnerability assessment of 400 species of greatest conservation need and game species in Michigan. Michigan Department of Natural Resources Wildlife Division Report, 3564.

Hunter M Jr, Dinerstein E, Hoekstra J, Lindenmayer D (2010) A call to action for conserving biological diversity in the face of climate change. Conserv Biol 24:1169–1171

IPCC (2007). Climate Change 2007.Adaptation and Vulnerability, Summary for Policymakers, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Isaak D, Wollrab S, Horan D, and Chandler G (2012) Climate change effects on stream and river temperatures across the northwest US from 1980–2009 and implications for salmonid fishes. Climatic Change 113: 499–524.

Jamie Pittock , Lara J. Hansen & Robin Abell (2008) Running dry: Freshwater biodiversity, protected areas and climate change, Biodiversity, 9:3-4, 30-38, DOI:10.1080/14888386.2008.9712905

Jansson, R., Nilsson, C., & Malmqvist, B. (2007). Restoring freshwater ecosystems in riverine landscapes: the roles of connectivity and recovery processes. Freshwater Biology, 52(4), 589-596.

Johnson, J. E., & Welch, D. J. (2009). Marine fisheries management in a changing climate: a review of vulnerability and future options. Reviews in Fisheries Science, 18(1), 106-124.

Johnson, K. A. (2014). Climate Change Vulnerability Assessment for Natural Resources Management: Toolbox of Methods with Case Studies.

Arlington, Virginia.

Jonsson, B., Jonsson, N. (2009). A review of the likely effects of climate change on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta, with particular reference to water temperature and flow. Journal of Fish Biology 75:2381-2447.

Karvonen A, Rintamaki P, Jokela J, and Valtonen ET (2010) Increasing water temperature and disease risks in aquatic systems: Climate change increases the risk of some, but not all, diseases. International Journal for Parasitology 40: 1483–1488.

Kearney, M., Shine, R., Porter, W.P. (2009) "The potential for behavioral thermoregulation to buffer 'cold-blooded' animals against climate warming," Proceedings of the National Academy of Sciences of the United States of America, 106(10), 3835–3840

Kittel, T., Howard, S., Horn, H., Kittel, G. M., Fairbarns, M., & Iachetti, P. (2011). A vulnerability-based strategy for incorporating the climate threat in conservation planning: A case study from the British Columbia Central Interior. Journal of Ecosystems and Management, 12(1).

Kennedy, T.L., D.S. Gutzler, and R.L. Leung. (2009). Predicting future threats to the long-term survival of Gila trout using a high-resolution simulation of climate change. Climatic Change 94:503–515. DOI 10.1007/s10584-008-9503-0

Kittel, T. G. (2013). The Vulnerability of Biodiversity to Rapid Climate Change. Climate Vulnerability: Understanding and Addressing Threats to Essential Resources; Pielke, RA, Ed, 185-201.

Kovach, R. P., Joyce, J. E., Vulstek, S. C., Barrientos, E. M., & Tallmon, D. A. (2014). Variable effects of climate and density on the juvenile ecology of two salmonids in an Alaskan lake. Canadian Journal of Fisheries and Aquatic Sciences, 71(6), 799-807. Lawrence et al., 2014;

Lawrence DJ, Stewart-Koster B, Olden JD, Ruesch AS, Torgensen CE, Lawler JJ, et al. (2014) The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24: 895–912.

Living Planet report (2013). Technical supplement: Ecological footprint. Prepared by Global Footprint Network

Lynch, A. J., Myers, B. J., Chu, C., Eby, L. A., Falke, J. A., Kovach, R. P., ... & Whitney, J. E. (2016). Climate change effects on North American inland fish populations and assemblages. Fisheries, 41(7), 346-361. Chicago

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy (2007), Fine-resolution climate projections enhance regional climate change impact studies, Eos Trans. AGU, 88(47), 504

Mawdsley, J. R., O'malley, R., & Ojima, D. S. (2009). A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology, 23(5), 1080-1089.

McCormick, J.H., K.E.F. Hokanson, and B.R. Jones. (1972). Effects of temperature on growth and survival of young brook trout, Salvelinus fontinalis. Journal of the Fisheries Research Board of Canada 29:1107-1112

McDaniels, T., Wilmot, S., Healey, M., & Hinch, S. (2010). Vulnerability of Fraser River sockeye salmon to climate change: A life cycle perspective using expert judgments. Journal of Environmental Management, 91(12), 2771-2780.

McKay, S. K., Schramski, J. R., Conyngham, J. N., & Fischenich, J. C. (2013). Assessing upstream fish passage connectivity with network analysis. Ecological applications, 23(6), 1396-1409.

Mills K.E., Pershing A.J., Sheehan T.F., Mountain D. (2013). Climate and ecosystem linkages explain widespread declines in North American Atlantic salmon populations. Global Change Biology 19:3046-3061. doi: 10.1111/gcb.12298

Morrison, W. E., Nelson, M. W., Howard, J. F., Teeters, E. J., Hare, J. A., Griffis, R. B., ... & Alexander, M. A. (2015). Methodology for assessing the vulnerability of marine fish and shellfish species to a changing climate. NOAA Technical Memorandum NMFS-OSF-3.

Muhlfeld CC, Kovach RP, Jones LA, Al-Chokhachy R, Boyer MC, Leary RF, et al. (2014) Invasive hybridization in a threatened species is accelerated by climate change. Nature Climate Change 4: 620–624.

Murdoch, A., & Power, M. (2013). The effect of lake morphometry on thermal habitat use and growth in Arctic charr populations: implications for understanding climate-change impacts. Ecology of Freshwater Fish, 22(3), 453-466.

NRCan (Natural Resources Canada). 2010. The atlas of Canada. Available: www.nrcan.gc.ca/earth-sciences/geography/atlas-canada.

Nunn, A. D., Harvey, J. P., Britton, J. R., Frear, P. A., & Cowx, I. G. (2007). Fish, climate and the Gulf Stream: the influence of abiotic factors on the recruitment success of cyprinid fishes in lowland rivers. Freshwater Biology, 52(8), 1576-1586.

O'BRIEN, K. A. R. E. N., Eriksen, S., Nygaard, L. P., & Schjolden, A. (2007). Why different interpretations of vulnerability matter in climate change discourses. Climate policy, 7(1), 73-88.

Pacifici, M., Foden, W. B., Visconti, P., Watson, J. E., Butchart, S. H., Kovacs, K. M., ... & Corlett, R. T. (2015). Assessing species vulnerability to climate change. Nature Climate Change, 5(3), 215.

Pearson, R.G., Dawson, T.P. (2003) “Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful?,” Global Ecology and Biogeography, 12(5), 361–371.

Pecl GT, Ward TM, Doubleday ZA, Clarke S, Day J, Dixon C, et al. Rapid assessment of fisheries species sensitivity to climate change. Climatic Change, 2014; 127(3–4): 505–520. doi: 10.1007/s10584-014-1284-z

Poesch, M. S., Chavarie, L., Chu, C., Pandit, S. N., & Tonn, W. (2016). Climate change impacts on freshwater fishes: a Canadian perspective. Fisheries, 41(7), 385-391.

Poff, N. L., Brinson, M. M., & Day, J. W. (2002). Aquatic ecosystems and global climate change. Pew Center on Global Climate Change, Arlington, VA, 44.

Prowse, T.D., Furgal, C., Wrona, F.J., and Reist, J.D. 2009. Implications of Climate Change for Northern Canada: Freshwater, Marine, and Terrestrial Ecosystems. Ambio. 38(5): 282-289.

Rahel FJ and Olden JD (2008) Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22: 521–533

Rahel, F. J., Bierwagen, B., & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology, 22(3), 551-561.

Reece, J.S., and R.F. Noss. (2014). Prioritizing Species by Conservation Value and Vulnerability: A New Index Applied to Species Threatened by Sea-Level Rise and Other Risks in Florida. Natural Areas Journal, 34(1):31-45.

Reside, (2011) Assessing climate change vulnerability: novel methods for understanding potential impacts on Australian tropical savanna birds. PhD thesis, James Cook University.

Rose, G. A. (2003). Fisheries resources and science in Newfoundland and Labrador: An independent assessment. Royal Commission on Renewing and Strengthening Our Place in Canada.

Rowland, e. L., Davison, j. E. & Graumlich, l. J. (2011). Approaches to Evaluating Climate Change Impacts on Species: A Guide to Initiating the Adaptation Planning Process. Environmental Management, 47, 322-337.

Saha, S. K., A. Rinke, and K. Dethloff. (2006). Future winter extreme temperature and precipitation events in the Arctic. Geophysical Research Letters 33(15):L15818.

Schloss, C., Nunez, T., Lawler, J. (2012) “Dispersal will limit ability of mammals to track climate change in the Western Hemisphere,” Proceedings of the National Academy of Sciences, 109(22), 8606–8611.

Schröter, D., Polsky, C., & Patt, A. G. (2005). Assessing vulnerabilities to the effects of global change: an eight step approach. Mitigation and Adaptation Strategies for Global Change, 10(4), 573-595.

Sharma, S., Vander Zanden, M. J., Magnuson, J. J., & Lyons, J. (2011). Comparing climate change and species invasions as drivers of coldwater fish population extirpations. PLoS One, 6(8), e22906.

Shoo, L. P., Hoffmann, A. A., Garnett, S., Pressey, R. L., Williams, Y. M., Taylor, M., ... & Williams, S. E. (2013). Making decisions to conserve species under climate change. Climatic Change, 119(2), 239-246.

Sievert, N. A. (2014). An assessment of stream fish vulnerability and an evaluation of conservation networks in Missouri (Doctoral dissertation, University of Missouri--Columbia).

Sneddon, L. A., and G. Hammerson. (2014). Climate Change Vulnerability Assessments of Selected Species in the North Atlantic LCC Region. NatureServe, Arlington, VA

Stangeland, A. (2007). Why CO2 capture and storage (CCS) is an important strategy to reduce global CO2 emissions. The Bellona Foundation, June, 1.

Staudinger, M. D., Hilberg, L., Janowiak, M., & Swanton, C. O. (2016). Northeast and Midwest regional species and habitats at greatest risk and most vulnerable to climate impacts. Northeast Climate Science Center.

Stortini, C. H., Shackell, N. L., Tyedmers, P., & Beazley, K. (2015). Assessing marine species vulnerability to projected warming on the Scotian Shelf, Canada. ICES Journal of Marine Science: Journal du Conseil, 72(6), 1731-1743.

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society, 29(1), 344-358.

Thistle, M. E., & Caissie, D. (2013). Trends in air temperature, total precipitation, and streamflow characteristics in eastern Canada. Fisheries and Oceans Canada.

Todd, C.D., Hughes, S.L., Marshall, C.T., Macleans, J.C., Lonerhan, M.E., Biuw, E.M. 2008. Detrimental effects of recent ocean surface warming on growth condition of Atlantic salmon. Global Change Biology. 14:958-970.

Trumbo BA, Nislow KH, Stallings J, Hudy M, Smith EP, Yun Kim D, et al. (2014) Ranking site vulnerability to increasing temperature in southern Appalachian brook trout streams in Virginia: an exposure-sensitivity approach. Transactions of the American Fisheries Society 143: 173–187.

U.S. Environmental Protection Agency (EPA). (2009) A framework for categorizing the relative vulnerability of threatened and endangered species to climate change. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/011. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

Van Zyll de Jong, M. C., Gibson, R. J., & Cowx, I. G. (2004). Impacts of stocking and introductions on freshwater fisheries of Newfoundland and Labrador, Canada. Fisheries Management and Ecology, 11(3-4), 183-193.

Van Zyll de Jong, M. C., Lester, N. P., Korver, R. M., Norris, W., & Wicks, B. L. (2002). Managing the exploitation of brook trout, Salvelinus fontinalis (Mitchill), populations in Newfoundland lakes. Management and ecology of lake and reservoir fisheries, 267-283.

Vindenes, Y., Edeline, E., Ohlberger, J., Langangen, Ø., Winfield, I. J., Stenseth,

N. C., & Vøllestad, L. A. (2014). Effects of climate change on trait-based dynamics of a top predator in freshwater ecosystems. The American Naturalist, 183(2), 243-256.

Wade, A. A., Beechie, T. J., Fleishman, E., Mantua, N. J., Wu, H., Kimball, J. S., ... & Stanford, J. A. (2013). Steelhead vulnerability to climate change in the Pacific Northwest. Journal of Applied Ecology, 50(5), 1093-1104.

Warren DR, Robinson JM, Josephson DC, Sheldon DR, and Kraft CE (2012) Elevated summer temperatures delay spawning and reduce redd construction for resident brook trout (Salvelinus fontinalis). Global Change Biology 18: 1804–1811.

Webb, B. W., & Nobilis, F. (2007). Long-term changes in river temperature and the influence of climatic and hydrological factors. Hydrological Sciences Journal, 52(1), 74-85.

Wenger, S. J., N. A. Som, D. C. Dauwalter, D. J. Isaak, H. M. Neville, C. H. Luce, J. B. Dunham, M. K. Young, K. D. Fausch, and B. E. Rieman. (2013). Probabilistic accounting of uncertainty in forecasts of species distributions under climate change. Global Change Biology 19(11): 3343–3354.

Wenger, S.J., D.J. Isaak, C.H. Luce, H.M. Neville, K.D. Fausch, J.B. Dunham, D.C. Dauwalter, M.K. Young, M.M. Elsner, B.E. Rieman, A.F. Hamlet, and J.E. Williams. (2011). Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proceedings of the National Academy of Sciences 108 (34): 14175–14180.

Whitman, A., A. Cutko, P. De Maynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. (2013). Climate change and biodiversity in Maine: vulnerability of habitats and priority species. Report SEI-2013-03. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group). Brunswick, ME.

Williams JE, Neville HM, Haak AL, Colyer WT, Wenger SJ, and Bradshaw S (2015) Climate change adaptation and restoration of western trout streams: opportunities and strategies. Fisheries 40: 304–317.

Williams, S.E., L.P. Shoo, J.L. Isaac, A.A. Hoffmann, and G. Langham. 2008. Towards an Integrated Framework for Assessing the Vulnerability of Species to Climate Change. PLoS Biol 6(12): e325.

Winfield, I. J., James, J. B., & Fletcher, J. M. (2008). Northern pike (Esox lucius) in a warming lake: changes in population size and individual condition in relation to prey abundance. Hydrobiologia, 601(1), 29-40.

Woodward, G., Perkins, D. M., & Brown, L. E. (2010). Climate change and freshwater ecosystems: impacts across multiple levels of organization. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1549), 2093–2106. http://doi.org/10.1098/rstb.2010.0055

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Märker, M., Schulze, K., & Van Vuuren, D. P. (2005). Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biology, 11(10), 1557-1564.

Young, B. E., Dubois, N. S., & Rowland, E. L. (2015). Using the Climate Change Vulnerability Index to inform adaptation planning: lessons, innovations, and next steps. Wildlife Society Bulletin

Appendix A: Definitions of sensitivity and adaptive capacity traits

Habitat specialization	This factor indicates the relative dependence of a species on a wide range of habitat or its limitation to specific habitats throughout its range (i.e. habitat specialists or generalists). It determines if a species will be able to find and inhabit suitable habitats if forced out of its current distribution as a result of possible stochastic events from climate or non-climate changes.
Prey specificity/diet choices	This factor determines on a relative scale, the flexibility of each fish species feeding habits i.e if the salmonid is a prey generalist or a prey specialist.
Physiological/behavioral sensitivity to temperature changes:	This factor determines the level of physiological and behavioral tolerance a species (at various life stage) has to prolonged temperature exposure considering the anticipated temperatures projections.
Physiological/behavioral sensitivity to changes in	This factor determines the physiological and behavioral tolerance or sensitivity to projected changes in precipitation events

precipitation or river flow:	and flow regimes which could alter spawning seasonal availability of spawning and rearing habitats and other external factors.
Population size/Geographic range:	This factor determines a specie's population health, ability to cope with negative impacts, and adapt to new conditions. Species with a diminished status, declining population/stock trend or distribution range will be likely less resilient to climate change than species with a growing population stock or distribution range. Reports from the Committee on the Status of Wildlife in Canada's (COSEWIC) can also be consulted for this factor.
Dependence on environmental cues likely to be disrupted by climate change	Specific environmental triggers or cues necessary to initiate life stages (e.g., migration, spawning etc) of freshwater fish may be altered in their timing and magnitude by projected climate change for example mismatches between advancing spring food availability peaks and hatching dates. Species relying on strict environmental cues may be more climate change sensitive. Estimate the followingspecies' sensitivity level based on this factor.
Genetic plasticity and evolvability:	This factor relates to a species current genetic variation across its population and the probability that rapid evolutionary changes can occur at the same pace with

	climate change. Species with relatively high genetic variation and capacity to evolve will likely be more adaptable to changes in climate than species with lower genetic variation. Estimate each species below based on this factor
Dispersive capability	Species with higher dispersive capabilities (adults ability to migrate beyond natural and anthropogenic barriers) and a larger distribution of eggs have greater probability to adapt to a shifting climate envelop and colonize new habitats than species with poor dispersive capability. Estimate the species relative adaptability based on this factor
Inherent resilience	This factor is determined by a specie's generation time, size and age at maturity, and fecundity or productivity. This trait is a determinant of a species adaptability and health, for example those with high fecundity and generation time will likely adapt to climate change more easily through generational evolution. Long-lived species that reproduce infrequently cannot adapt quickly.

Appendix B: Climate change vulnerability assessment survey

Assessing the Climate change vulnerability of Freshwater Fish in Newfoundland and Labrador

Section 1: Climate Change Exposure factors

This section will assess species exposure to projected changes temperature and precipitation by mid 21st century. In assessing exposure, consider the species current spatial range and life history stages.

Possible data sources to consult in this section:

1) Climate wizard is an online tool designed by Nature Conservancy which provides statistically-downscaled projections for temperature and precipitation changes by mid-21st century. Click here to access
http://www.climatewizard.org/

2) Finnis, J. (2013). Projected Impacts of Climate Change for the Province of Newfoundland Labrador. Newfoundland and Labrador Office of Climate Change and Energy Efficiency.

3) Thistle, M. E., & Caissie, D. (2013). Trends in air temperature, total precipitation, and streamflow characteristics in eastern Canada. Fisheries and Oceans Canada.

*1.

Under highest emissions climate scenario, Newfoundland and Labrador is predicted to experience a temperature increase of 2 - 3ºC across different regions and seasons by mid 21st century. Based on each species spatial distribution, estimate the exposure level of each species to temperature changes.

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of temperature to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Brook trout	**Brook trout No**	**Brook trout Low**	**Brook trout Moderate**	**Brook trout High**	**Brook trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of temperature to the vulnerability of this species** **b) What is your level of confidence**					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of temperature to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of temperature to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of temperature to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High

	No	Low	Moderate	High	Very High
	trout No				
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of temperature to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of temperature to the vulnerability of this species b) What is your level of confidence in the scores you provided above					

	No	Low	Moderate	High	Very High
For example: a=1, b=2					

*2. **Considering each species current spatial distribution in Newfoundland and Labrador, and future climate projections for precipitation events by mid-21st century, estimate the exposure level of each fish species population to precipitation events.**
The resources above provides a statistically downscaled map of precipitation projections by mid 21st century.

	No	Low	Moderate	High	Very high
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					

	No	Low	Moderate	High	Very high
Brook trout	**Brook trout No**	**Brook trout Low**	**Brook trout Moderate**	**Brook trout High**	**Brook trout Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brown Trout	**Brown Trout No**	**Brown Trout Low**	**Brown Trout Moderate**	**Brown Trout High**	**Brown Trout Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in					

	No	Low	Moderate	High	Very high
the scores you provided above For example: a=1, b=2					
Arctic Char	**Arctic Char No**	**Arctic Char Low**	**Arctic Char Moderate**	**Arctic Char High**	**Arctic Char Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	**Lake trout No**	**Lake trout Low**	**Lake trout Moderate**	**Lake trout High**	**Lake trout Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very high
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	**Rainbow trout No**	**Rainbow trout Low**	**Rainbow trout Moderate**	**Rainbow trout High**	**Rainbow trout Very high**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	**Northern pike No**	**Northern pike Low**	**Northern pike Moderate**	**Northern pike High**	**Northern**

	No	Low	Moderate	High	Very high
					pike Very high
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					

+New question

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PAGE 4

P4: Section 2: Climate change Sensitivity Factors

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Exit

Assessing the Climate change vulnerability of Freshwater Fish in Newfoundland and Labrador

Section 2: Climate change Sensitivity Factors

Sensitivity to climate change measures the degree to which freshwater fish species' population (considering relevant life stages) will be negatively impacted by projected changes in climate factors for Newfoundland and Labrador by mid-21st century.

This section assesses the relative level to which the listed freshwater Salmonids will be sensitive or susceptible to projected climate change based on 5 sensitivity indicators.

Key to using the sensitivity scoring scale:

	No	Low	Moderate	High	Very High
Sensitivity factors	**Not sensitive based to that factor**	**Low sensitivity**	**Moderately sensitive**	**Highly sensitive**	**Very highly sensitive**

1.

Habitat specialization:
This factor indicates the relative dependence of a species on a wide range of habitat or its limitation to specific habitats throughout its range (i.e. habitat specialists or generalists). It determines if a species will be able to find and inhabit suitable habitats if forced out of its current distribution as a result of possible stochastic events from climate or non-climate changes.

	No	Low	Moderate	High	Very High

	No	Low	Moderate	High	Very High
Atlantic Salmon	Atlantic Salmon No	Atlantic Salmon Low	Atlantic Salmon Moderate	Atlantic Salmon High	Atlantic Salmon Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High

	No	Low	Moderate	High	Very High
	trout No				
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above					

	No	Low	Moderate	High	Very High

For example: a=1, b=2

*2.

Prey specificity/diet choices:
This factor determines on a relative scale, the flexibility of each fish specie's feeding habits i.e if the salmonid is a prey generalist or a prey specialist. Estimate the sensitivity level of the following based on this factor.

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**

Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:

a) What is the impact or overall importance of this factor to the vulnerability of this species
b) What is your level of confidence in the scores you provided above

For example: a=1, b=2

	No	Low	Moderate	High	Very High
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern	Northern	Northern pike Moderate	Northern pike High	Northern

	No	Low	Moderate	High	Very High
	pike No	pike Low			pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

*3.

Physiological/behavioral sensitivity to temperature changes:
This factor determines the level of physiological and behavioral tolerance a species (at various life stage) has to prolonged temperature exposure considering the anticipated temperatures projections.
Estimate the sensitivity level of these species based on this factor.

	No	Low	Moderate	High	Very High
Atlantic Salmon	Atlantic Salmon No	Atlantic Salmon Low	Atlantic Salmon Moderate	Atlantic Salmon High	Atlantic Salmon Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High

Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:

a) What is the impact or overall importance of this factor to the vulnerability of this species
b) What is your level of confidence in the scores you provided above

For example: a=1, b=2

	No	Low	Moderate	High	Very High
Brown Trout **Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:** **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**	**Brown Trout No**	**Brown Trout Low**	**Brown Trout Moderate**	**Brown Trout High**	**Brown Trout Very High**
Arctic Char **Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:** **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence**	**Arctic Char No**	**Arctic Char Low**	**Arctic Char Moderate**	**Arctic Char High**	**Arctic Char Very High**

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Northern pike	**Northern pike No**	**Northern pike Low**	**Northern pike Moderate**	**Northern pike High**	**Northern pike Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

*4.

Physiological/behavioral sensitivity to changes in precipitation or river flow:

This factor determines the physiological and behavioral tolerance or sensitivity to projected changes in precipitation events and flow regimes which could alter spawning seasonal availability of spawning and rearing habitats and other external factors. Estimate the relative sensitivity of each species below.

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Brook trout	**Brook trout No**	**Brook trout Low**	**Brook trout Moderate**	**Brook trout High**	**Brook trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the**					

	No	Low	Moderate	High	Very High
vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score					

	No	Low	Moderate	High	Very High
the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Lake trout	**Lake trout No**	**Lake trout Low**	**Lake trout Moderate**	**Lake trout High**	**Lake trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

	No	Low	Moderate	High	Very High
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above **For example: a=1, b=2**					

*5. **Population size/Geographic range:**

This factor determines a specie's population health, ability to cope with negative impacts, and adapt to new conditions. Species with a diminished status, declining population/stock trend or distribution range will be likely less resilient to climate change than species with a growing population stock or distribution range.

Reports from the Committee on the Status of Wildlife in Canada's (COSEWIC) can also be consulted for this factor.

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above**					

	No	Low	Moderate	High	Very High
For example: a=1, b=2					
Brook trout	**Brook trout No**	**Brook trout Low**	**Brook trout Moderate**	**Brook trout High**	**Brook trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Brown Trout	**Brown Trout No**	**Brown Trout Low**	**Brown Trout Moderate**	**Brown Trout High**	**Brown Trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the**					

	No	Low	Moderate	High	Very High
vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score					

	No	Low	Moderate	High	Very High
the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					

	No	Low	Moderate	High	Very High
Northern pike	**Northern pike No**	**Northern pike Low**	**Northern pike Moderate**	**Northern pike High**	**Northern pike Very High**

Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:

a) What is the impact or overall importance of this factor to the vulnerability of this species
b) What is your level of confidence in the scores you provided above

For example: a=1, b=2

*6.

Dependence on environmental cues likely to be disrupted by climate change
Specific environmental triggers or cues necessary to initiate life stages (e.g., migration, spawning etc) of freshwater fish may be altered in their timing and magnitude by projected climate change for example mismatches between advancing spring food availability peaks and hatching dates. Species relying on strict environmental cues may be more climate change sensitive.
Estimate the followingspecies' sensitivity level based on this factor.

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**

	No	Low	Moderate	High	Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Brook trout	**Brook trout No**	**Brook trout Low**	**Brook trout Moderate**	**Brook trout High**	**Brook trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

	No	Low	Moderate	High	Very High
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					

P5: Section 3: Climate change Adaptive Capacity factors

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Exit

Assessing the Climate change vulnerability of Freshwater Fish in Newfoundland and Labrador

Section 3: Climate change Adaptive Capacity factors

Adaptive capacity refers to the innate ability of a species to respond to projected changes in climate factors through evolutionary changes, physical and behavioral responses.

The section assesses the level of adaptability of each freshwater fish species using 3 indicators.

Key to scoring adaptive capacity

	No	Low	Moderate	High	Very High
Adaptive capacity factors	Not adaptable or not enough data to score this factor	Low adaptability	Moderate adaptability	Highly adaptable	Very highly adaptable

*1. **Genetic plasticity and evolvability:**

This factor relates to a species current genetic variation across its population and the probability that rapid evolutionary changes can occur at the same pace with climate change. Species with relatively high genetic variation and capacity to evolve will likely be more adaptable to changes in climate than species with lower genetic variation.

Estimate each species below based on this factor

	No	Low	Moderate	High	Very High
Atlantic Salmon	Atlantic Salmon No	Atlantic Salmon Low	Atlantic Salmon Moderate	Atlantic Salmon High	Atlantic Salmon Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High

	No	Low	Moderate	High	Very High
	trout No				
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above					

	No	Low	Moderate	High	Very High
For example: a=1, b=2					

*2.

Dispersive capability

Species with higher dispersive capabilities (adults ability to migrate beyond natural and anthropogenic barriers) and a larger distribution of eggs have greater probability to adapt to a shifting climate envelop and colonize new habitats than species with poor dispersive capability. Estimate the species relative adaptability based on this factor

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**

Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:

a) What is the impact or overall importance of this factor to the vulnerability of this species
b) What is your level of confidence in the scores you provided above

For example: a=1, b=2

	No	Low	Moderate	High	Very High
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brown Trout	Brown Trout No	Brown Trout Low	Brown Trout Moderate	Brown Trout High	Brown Trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence					

	No	Low	Moderate	High	Very High
in the scores you provided above For example: a=1, b=2					
Arctic Char	Arctic Char No	Arctic Char Low	Arctic Char Moderate	Arctic Char High	Arctic Char Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Lake trout	Lake trout No	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern

	No	Low	Moderate	High	Very High
					pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

*3. **Inherent resilience**

This factor is determined by a specie's generation time, size and age at maturity, and fecundity or productivity. This trait is a determinant of a species adaptability and health, for example those with high fecundity and generation time will likely adapt to climate change more easily through generational evolution. Long-lived species that reproduce infrequently cannot adapt quickly.

Estimate the relative adaptability of each species based on this factor

	No	Low	Moderate	High	Very High
Atlantic Salmon	**Atlantic Salmon No**	**Atlantic Salmon Low**	**Atlantic Salmon Moderate**	**Atlantic Salmon High**	**Atlantic Salmon Very High**

	No	Low	Moderate	High	Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Brook trout	Brook trout No	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above					

	No	Low	Moderate	High	Very High
For example: a=1, b=2					
Brown Trout	**Brown Trout No**	**Brown Trout Low**	**Brown Trout Moderate**	**Brown Trout High**	**Brown Trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Arctic Char	**Arctic Char No**	**Arctic Char Low**	**Arctic Char Moderate**	**Arctic Char High**	**Arctic Char Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions:					

	No	Low	Moderate	High	Very High
a) What is the impact or overall importance of this factor to the vulnerability of this species **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					
Lake trout	**Lake trout No**	**Lake trout Low**	**Lake trout Moderate**	**Lake trout High**	**Lake trout Very High**
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: **a) What is the impact or overall importance of this factor to the vulnerability of this species** **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

	No	Low	Moderate	High	Very High
Rainbow trout	Rainbow trout No	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the vulnerability of this species b) What is your level of confidence in the scores you provided above For example: a=1, b=2					
Northern pike	Northern pike No	Northern pike Low	Northern pike Moderate	Northern pike High	Northern pike Very High
Using a scale of 1 to 3, where 1=Low, 2=Medium, 3=High, score the following sub-questions: a) What is the impact or overall importance of this factor to the					

	No	Low	Moderate	High	Very High
vulnerability of this species **b) What is your level of confidence in the scores you provided above** **For example: a=1, b=2**					

+New question

or Copy and paste questions

71%

P6: Section 4: Vulnerability to non-Climate change factors

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Exit

Assessing the Climate change vulnerability of Freshwater Fish in Newfoundland and Labrador

Section 4: Vulnerability to non-Climate change factors

This section assesses vulnerability to anthropogenic and non- climate change factors or threats like invasive species, over exploitation, land use changes etc that can exacerbate or interact with current and future climate change across the species current range. Consider the cumulative effects of non-climate change factors when scoring each species.

*1. **Indicate all possible anthropogenic and non-climate threat to each species and provide an estimate vulnerability level to their cumulative effects.**

	None	Low	Moderate	High	Very High
Atlantic Salmon	Atlantic Salmon None	Atlantic Salmon Low	Atlantic Salmon Moderate	Atlantic Salmon High	Atlantic Salmon Very High
List all possible threats if applicable					
Rainbow trout	Rainbow trout None	Rainbow trout Low	Rainbow trout Moderate	Rainbow trout High	Rainbow trout Very High
List all possible threats if applicable					
Brown trout	Brown trout None	Brown trout Low	Brown trout Moderate	Brown trout High	Brown trout Very High
List all possible threats if applicable					

	None	Low	Moderate	High	Very High
Brook trout	Brook trout None	Brook trout Low	Brook trout Moderate	Brook trout High	Brook trout Very High
List all possible threats if applicable					
Arctic char	Arctic char None	Arctic char Low	Arctic char Moderate	Arctic char High	Arctic char Very High
List all possible threats if applicable					
Northern Pike	Northern Pike None	Northern Pike Low	Northern Pike Moderate	Northern Pike High	Northern Pike Very High
List all possible threats if applicable					
Lake trout	Lake trout None	Lake trout Low	Lake trout Moderate	Lake trout High	Lake trout Very High

	None	Low	Moderate	High	Very High

List all possible threats if applicable

*2. **Indicate your level of confidence in the scores you provided above.**

	Low	Medium	High
Atlantic Salmon	Atlantic Salmon Low	Atlantic Salmon Medium	Atlantic Salmon High
Brook trout	Brook trout Low	Brook trout Medium	Brook trout High
Brown trout	Brown trout Low	Brown trout Medium	Brown trout High
Lake trout	Lake trout Low	Lake trout Medium	Lake trout High
Arctic char	Arctic char Low	Arctic char Medium	Arctic char High
Northern Pike	Northern Pike Low	Northern Pike Medium	Northern Pike High
Rainbow trout	Rainbow trout Low	Rainbow trout Medium	Rainbow trout High

+New question