Evaluating the Climate Change Resiliency of Atlantic Salmon (Salmo Salar) Fry and Parr Habitat in The East River East Branch Pictou County Nova Scotia

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Introduction

The global Atlantic salmon (*Salmo Salar*) population has seen significant population decreases over the last half century. In 1985 the global Atlantic salmon population numbered roughly 9 million. Over the next decade the population saw a drastic decline with the total population falling to roughly 3.5 million, a 60% decline in 10 years.

Since 1995, the population has somewhat stabilized at roughly 3 million.(NASCO, 2019) The decline in wild Atlantic salmon populations across the globe is a complex issue which is not the result of one singular factor but rather a multitude of effecting factors. Overfishing has been thought to be one of the factors leading to the decline of the mid 80s. In response to this concern, governments across the Atlantic salmon's range took action, ending or at least heavily reducing the commercial Atlantic salmon fishery.

In 1973 the commercial harvest peaked with a total of 3.5 million salmon harvested. In recent years, the total harvest, including commercial, recreational and subsistence fisheries, has remained below 0.5 million salmon annually, yet the population remains threatened(NASCO, 2019).

On top of the harvesting issues, the North Atlantic Conservation Organization list five other key stressors on wild Atlantic salmon populations and they are as follow; the introduction of invasive species, the spread of disease or parasites, either naturally occurring or the result of aquaculture or industry, improper stocking practices and habitat degradation(NASCO, 2019). These five stressors as well as overharvesting have been proven to have negative effects on Atlantic salmon populations and bear significant responsibility for the decline of global Atlantic salmon populations.

One of the unique aspects of an Atlantic salmon's life cycle is that it will return to spawn in the exact same river and even the specific tributary which it was born. Over time, salmon adapt to the rivers they come from and eventually each river's salmon become genetically different from each other (Vähä et al., 2007). While we look at the global salmon population as a total population of one species, this is somewhat of an oversimplification. More accurately, the total of wild Atlantic salmon is the cumulative value of over 2000 subspecies(NASCO, 2019) . Due to these differences and each population's reliance on a very specific geographical location, it can be very valuable to study specific populations and their ecosystems instead of the population as a whole.

Salmon spend the majority of their lives in the oceans, yet the majority of studies and conservation work is done in the rivers (NASCO, 2019). This is due to the fact that we have more access to the salmon while they are in the rivers and we can infer a lot about their sea life from simply monitoring their birth and return rates (Dempson et al., 2017). Rivers also offer smaller scale solutions such as restoration projects that can see beneficial outcomes for a relatively low cost (Jonsson & Jonsson, 2009). Generally speaking, improving the survival rate of salmon at sea requires massive changes that necessitate huge investments of money, time and cooperation (Saloniemi et al., 2004).

The North Atlantic Salmon Conservation Organization, as well as many local and national partner agencies, have been collecting data and monitoring salmon and salmon rivers for decades. In total, there are 2,359 rivers across North America and Europe known to have or have had wild Atlantic salmon populations. Of these populations, 14% are considered "sustainable", 7% no longer have salmon populations, 36% have "insufficient data" and 43% are "currently at risk".

One of the rivers listed as “currently at risk” is the East River in Pictou County, Nova Scotia (NASCO, 2019). (Figure 1 & 2) This river has seen its salmon population decline significantly since the 1980s and is home to one of the few remaining salmon populations in mainland Nova Scotia (Biron & Breau, 2015; NASCO, 2019). This decline can be credited to a combination of factors over the years but as of late, rising water temperatures due to climate change have become increasingly threatening to the current population. If current climate change projections are accurate and large-scale habitat restoration projects are not conducted, what will be the state of future salmon populations in the East River?

Background

Climate Change:

Climate change is the looming threat of the 21st century. It is not inherently a new issue as there have always been changes in the earth’s climate. Historically, it has been an extremely slow process, requiring tens of thousands of years and or massive geological or meteorological events such as the eruption of super volcanos and or meteor strikes. The climate change of the 21st century is unlike that of the past (Parmesan et al., 2022; Robock, 2000). There has not been a massive eruption or a meteorological strike, yet global temperatures are increasing at an unprecedented rate. The beginning of this trend of global warming is usually considered to have begun simultaneously with the start of the industrial revolution in the mid to late 18th century. In the centuries following the industrial revolution, the earth’s human population has seen unprecedented growth (Parmesan et al., 2022). Prior to the industrial revolution, the global population numbered less than one billion while now in 2024, it has risen to above eight billion. In the last 20 years alone the world’s population has grown by almost two billion. Consider that in 1927 that the world's population first reached 2 billion so what once took tens of thousands of years now takes two decades (Statista, 2023).

This rapid population growth is a major stressor on the world's natural environments. The inventions of the industrial revolution have guided society away from the predominantly agricultural and artisanal societies of the past to a new fast paced extremely industrialised society. With this has come a heavy reliance on dirty fuels which produce greenhouse gasses (GHG). These gasses trap the sun's rays inside the earth's atmosphere, increasing the earth's average temperature(Parmesan et al., 2022). While there is some debate over the degree to which humans are to blame for climate change, the vast majority of scientists believe human activity is the root cause and this is the theory this study operates under.

Climate change is not selective in its effects. No region of the world will be untouched by the effects of climate change, but some regions and species are more susceptible to the effects of climate change than others. In the polar regions, average temperatures are rising at the highest rates on earth and the equator is seeing the slowest rates of change. While there are other influences such as topography, ocean and atmospheric currents and human activity, it is a general rule that the closer a region is to a pole, the faster the rate of climate change (Parmesan et al., 2022). It is also very important to note that while climate change will over time increase the average temperatures around the world, this does not mean ever single year will be warmer than the previous in every region of the world (Parmesan et al., 2022).

Wild Atlantic salmon

As referenced above, wild Atlantic salmon are at risk as a whole but when broken down in to specific regional and river populations, this threat can be significantly intensified. Mainland Nova Scotia is a prime example of this. Of the more than 120 rivers known to have at one time held salmon populations, none are considered to have sustainable populations and only two, Barneys River and Sutherlands River, have populations categorized to be of low risk. In this case, they are both rivers known to have historically had low salmon populations that have not seen as significant population decline as the other rivers. Their populations combined, however, equal only roughly 100 salmon (NASCO, 2023).

Interestingly enough, these rivers are located in the same county as the East River which is the focus of this study. They are located only a few dozen kilometers to its east, yet their conditions are less dire than the larger East River(NASCO, 2019). This is likely the result of habitat destruction in the East River as the climate conditions are essentially identical. (Lundin et al., 2019). While the rivers may be located in close proximity, one major difference between the rivers, other than their size, is the source of their water. While the East River is primarily lake-fed, the Sutherlands and Barneys Rivers are mostly stream fed. As well as the differences between being lake and stream fed, Barneys and Sutherlands Rivers are located in significantly under populated areas with only a few houses and farms located along their banks. The East River is also primarily in rural areas, but large portions of the river have seen significant deforestation due to agriculture and the towns of New Glasgow, Stellarton and Trenton which are located at the mouth of the river which flows into Pictou Harbour. While these towns have relatively small populations numbering a cumulative 18,000 people, they do have a history of heavy industry and environmental degradation (Statistics Canada, 2016).

Stellarton has historically been a coal mining town, while New Glasgow and Trenton have historically been home to significant shipbuilding and steel milling, all industries that have been situated along the river (McCann, 1994; Thompson, 2012). Throughout the history of the East River, it has been used by the lumber industry to transport logs and to power lumber mills as well as to transport coal by barge. Water has been diverted to bolster agriculture and trees have been cut to improve farmlands and build infrastructure (Sandberg, 1985). A now decommissioned rail line once ran along the entire bank of the mainstem and the east branch of the river, transporting coal, iron, lumber and various other resources from the mills and mines of the East River Valley. It is also important to note that Pictou Harbour, where the East River meets the sea, was previously the site of a heavily contentious pulp mill which had been pouring effluent into the harbour and massive quantities of smoke and exhaust into the air between 1967 and 2020 (Hoffman et al., 2017).

The current status of the East River's salmon population is listed as at "moderate risk," which is better than the majority of the rivers in Nova Scotia which have seen their populations go extinct or at least no longer self-sustaining. The conservation limit for the East River, meaning the number of returning adult salmon needed to maintain this same listing is 242 (NASCO, 2019). This is a small sum for a salmon population that was once known to feed the villages along its banks (Saltwire, 2016).

As referenced in the previous section, climate change is an increasing threat to wild salmon populations. It is resulting in higher water and air temperatures around the world. This trend is most prevalent in the polar and sub polar regions which happens to also be the entire range of the Atlantic salmon (Post et al., 2019). Salmon are a cold-water species. They spend their winters in the North Atlantic mostly off the coast of Greenland and between Iceland and the Faro Islands where the water temperature is around zero and food is abundant. It is only during their time spent in the rivers and estuaries where they experience warm water conditions. Unfortunately, these are also the phases of their life where they are the most vulnerable.

In many locations, adult salmon return to the rivers in the summer when water temperatures are at their highest. This is a major issue in some rivers in Atlantic Canada, such as the Margaree located in Cape Breton, NS, and the Miramichi in neighbouring New Brunswick, both rivers being home to some of the largest wild salmon populations in Atlantic Canada(NASCO, 2023). Fortunately for the salmon population in the East River, there is not a summer salmon run and the adults return in the fall when water temperatures are lower. With the increasing rate of climate change, this could be a major issue in the East River in the future but as of right now it has yet to be identified as a concern. The water temperature threat in this river is mostly associated with the survival of salmon parr fry and smolt. Historically, Atlantic salmon have always had a low rate of survival. To balance this salmon lay and fertilize a tremendous number of eggs. In the years prior to 1990, for every 1,000 fertilized eggs only one salmon would survive over a year at sea and reach reproductive age between 2007 and 2016(NASCO, 2019). This number has dropped to 0.5 mature salmon, meaning it would require 2,000 fertilized eggs to have one adult salmon. While the ASCO's research is not yet concluded, its preliminary hypothesis suggests the number of fertilized eggs required to produce one adult salmon has continued to grow and will continue to do so. This is a major issue as the species cannot evolve fast enough to meet the egg demand to sustain its own population. While the at sea, survival rate of Atlantic salmon is low and considered to be one of the largest contributors to the decline of salmon populations globally.

The decrease in freshwater fry and parr survival is also a major threat. This threat is most applicable to salmon population at the southern range of the species habitat, which happens to be Nova Scotia(NASCO, 2019). The data is clear that salmon populations at the southern species range are on average significantly more threatened than that of the central and northern ranges.

The marine habitat of Atlantic salmon across the world is essentially equal in quality as all Atlantic salmon winter in the same two locations but there is a massive variation in their freshwater habitat. This is why it is negligent not to divide the species into regional categories when assessing threats to their survival.

In recent years the effect of climate change on the world's oceans and freshwater systems has been clear. Temperatures are increasing. Between 1991 and 2021, the North Atlantic has warmed by roughly 0.3° per decade. This trend is only expected to increase as the century continues(Post et al., 2019). The East River is not exempt from this trend. A local conservation group, Pictou County Rivers Association has been monitoring water temperatures in Pictou County rivers since 2014. In 2021 and 2022, the East River set new highs for summertime temperatures and its temperature is increasing at a rate faster than any other river in the county. During the summer months of July and August, the river is consistently above 23° and temperatures as high as 30° have been recorded (PCRA, 2023). This is extremely dangerous as Atlantic salmon cannot withstand such warm water temperatures. The ideal temperature for fry and parr, meaning young salmon which are in the early stages of life, after hatching and absorbing their yolk sack but prior to growing to a size cable of migrating to sea, is between 16° and 20°. In this range they are able to grow most efficiently. When water temperatures reach 23°, growth stops. At 27.8° the temperature becomes lethal for most salmon if they are not able to find colder water. Once the water temperature reaches 33° absolute mortality occurs. (Thorstad et al., 2021) The East River is already exceeding lethal temperatures and is quickly approaching absolute mortality temperatures. If this trend continues, it is fair to expect the extinction of East River Atlantic salmon.

Methodology

The research method selected for this study is a Habitat Suitability Index (HSI). I have selected this research method as I believe it is the most valuable method of research and data collection to determine the quality of Atlantic salmon (*Salmo Salar*) habitat in Nova Scotia, Canada. As well as being the local industry standard for determining Atlantic salmon habitat quality and quantity, HSI is also a valuable tool for studying habitat for a wide array of species ranging from algaes to alligators(Allen et al., 2020). The following sections will go on to review what HSI is, how it works and why it is a valuable research method.

An HSI is a numerical index ranging from 0 to 1 which represents the overall quality of a given geographical location to support a selected species (Kellner et al., 1992). This quality is based strictly on habitat attributes and the relationships between habitat attributes and the selected species, allowing the quality estimate to be determined without any direct contact with the selected species. This is important as Atlantic salmon are a species at risk and any direct interaction between humans and salmon has the potential to negatively impact the salmon's health.

Following the data collection and analysis, a score is allocated to the geographical location. As referenced above, HSI works on a 0 to 1 scale with zero representing an unhabitable location for the selected species and 1 representing an optimal habitat (Kellner et al., 1992). For example, if Atlantic salmon retuned from sea to a river habitat scoring 0.1 HIS, it is likely there will be a very low spawning rate and many fish may not even make it to their redds to spawn. In the case of an Atlantic salmon returning to a river habitat scoring 0.8 HSI it is likely there will be a successful spawning season with a high number of fish making it to their redds to spawn and a successful rearing season for its offspring (Koljonen et al., 2013).

With HIS, it is extremely important for the scoring index to be specifically designed for the species or even subspecies, which is being targeted, as even slight variations in preferred conditions can lead to noticeably inaccurate outcomes (Smialek et al., 2021). This is why I have decided to use the HSI field methods and scoring system provided by Nova Scotia Adopt a Stream. Adopt a Stream is an international non-governmental organization focused on marine ecosystem restoration which has partnered with the Nova Scotia Government and the Canadian Department of Fisheries and Oceans. The Nova Scotia Adopt a Stream HSI field methods and scoring system has been specially designed to best represent the optimal conditions of Nova Scotia watercourses for Nova Scotia Atlantic salmon subspecies and have been updated recently in 2018 to reflect modern science. This system is the industry standard for Atlantic salmon HSI in Nova Scotia (NSHSI, 2018).

This method consists of seven pillars. The first of which is transect calculations. Due to the size and various conditions in a river system, this method divides the total study space into a series of transects. Transects are two bank full widths. On average, rivers in Nova Scotia are over widened by 20% due to degradation. The banks full width will also vary heavily throughout the survey space, to account for these factors, Nova Scotia Adopt a Stream has created a mathematical formula to determine proper stream width on average throughout the survey site as opposed to basing transects on the heavily variable banks. Bank full width is calculated by measuring the total watershed area of the site location through GIS as well as the annual runoff. These values can then be plugged into the Nova Scotia Adopt a Stream Width and Flow calculator which will provide a bank width value. Once doubled the sum is the length of the required transects. The following pillars are conducted at every transect.

The second research pillar is water quality testing. This is conducted with a YSI water quality monitoring meter or similar device. The parameters that need to be recorded are air and water temperatures, PH level, conductivity, dissolved oxygen, and total dissolved solids.

The third research pillar is a channel cross-section measurement to determine in-field bank full width for the specific location as well as wetted depth and thalweg depth. During this section measurements are also taken of the bank full height and flood plains if applicable. Location specific bank full width is likely to vary from the initial calculated bank full width, as the initial calculation is an average for the total river system as opposed to location specific and a river's width varies throughout its course.

The fourth research pillar is substrate cover determination. To do so, a description of the stream conditions is recorded as well as GPS quadrants. Stream conditions can be categorized as riffles, runs, pools, or steps. Following this, a quadrant is placed in the stream along each quarter of the bank full width. This is done to determine stream bed composition. If present, a stone is removed from the bed to determine embeddedness. Finally, if stream cover is observed, researchers place dowels under the stream cover to simulate adult and juvenal salmon. The total number of dowls which fit under the cover is then recorded.(The Nova Scotia Fish Habitat Suitability Assessment A Field Methods Manual Nova Scotia Freshwater Fish Habitat Suitability Index Assessment NSHSI, 2007)

The fifth research pillar is riverbank and riparian area calculations. Researchers take estimations of the rate of erosion along the transect location as well as the riparian vegetation. The researchers also take estimates of the total stream shade provided by vegetation. The final step of this section is to measure the height of any ice scaring in the transect location. (The Nova Scotia Fish Habitat Suitability Assessment A Field Methods Manual Nova Scotia Freshwater Fish Habitat Suitability Index Assessment NSHSI, 2007)

Pool measurements are the sixth pillar of this research process. When a pool is located anywhere along the survey site, it must be measured. The pools are measured by width, length and depth then categorized into classes. Class A pools are what is considered to be ideal salmon pools, having a depth of above 1m and above 30% cover. Class B pools have a depth of 15cm and 5-30% coverage, while class C pools have a depth of below 15cm and below 5% cover (Moir et al., 1998).

The final section is benthic macroinvertebrate monitoring. This section requires significant previous knowledge of benthic macroinvertebrates. The researcher lifts a large stone out of the river to examine the stone for macroinvertebrates. The presence of macroinvertebrates can give the researchers valuable insights into stream conditions as they are a food source for fish species but more importantly, many species are very intolerant to deteriorating stream conditions while others even favour streams that have conditions unsuitable for salmon (Borisk, 2007).

Following the completion of this study process, the data collected can then be analysed and compared to the ideal conditions put forward by Nova Scotia Adopt a Stream to determine the HSI score. The data from each section can also be cross referenced with the other transects along the survey section to determine areas with the highest HSI score as well as the less suitable habitats.

The HSI study provides an accurate assessment of the quality of salmon habitat within the survey location serving as a bassline for the counited research. The water and air temperature data collected by our research team, Pictou County Rivers Association and the Mi’kmaq Conservation Group in recent years is used to formulate a connection between air temperature and water temperature (Ozaki et al., 2003). Following the determination of this factor, I will apply the factor to the Nova Scotia Department of Climate Change’s projections for Pictou County for the years 2030, 2050 and 2080 (Nova Scotia, 2022). This allows for accurate future water temperature projections. Which provides important insight into how the salmon habitat in the East River will change win the coming decades.

Findings Reporting

% Pools	Pool Class Rating	% Instream Cover (fry)	% Instream Cover (parr)	Dominant Substrate Type in Riffle-Run Areas	Avg % Vegetation Along the Streambank	Avg % Rooted Vegetation and Stable Rocky Ground Cover	Summer Rearing Temp During Growing Season	pH	Spawning Present	Substrate for Spawning and Incubation	% Fines in Spawning Areas	Fry Water Depth	Parr Water Depth	Stream Order	% Stream Shade		Quadrents	Start cordinents	
0.29	0.39	0.98	0.81	0.76	1	0.82	0.7	0.99				0.58	0.65	0.9	0.78		1 to 10	45.43.252N	W62.61.048
0.196	0.4	1	0.6	0.88	1	0.98	0.34	0.99				0.72	0.76	0.9	0.66		11 to 20	45.43.121N	W62.59.319
0.12	0.3	0.92	0.35	0.8	1	0.84	0.14	0.99				0.85	0.97	0.9	0.64		21 to 30	45.42.245N	W62.58.806
0.12	0.3	0.99	0.54	0.8	1	0.88	0.2	0.95				0.94	0.96	0.9	0.88		31 to 40	45.45.417N	W62.57.389
0.218	0.39	1	0.8	0.88	1	0.71	0.36	0.94				0.94	1	0.9	0.68		41 to 50	45.45.414N	W62.56.119
0.12	0.3	0.97	0.59	0.84	1	0.88	0.39	0.93				0.62	0.69	0.9	0.52		51 to 60	45.45.410N	W6255.357
0.217	0.42	0.95	0.48	0.88	1	0.87	0.5	0.87				0.96	1	0.9	0.9		61 to 70	45.40.912N	W62.54.268
0.332	0.46	1	0.52	0.84	1	0.93	0.63	0.84				0.8	0.95	0.9	0.66		71 to 80	45.40.571N	W62.53.568
0.12	0.3	0.94	0.59	0.8	1	0.84	0.81	0.5				0.64	0.8	0.9	0.55		81 to 90	45.40282N	W62.52.868
0.12	0.33	0.79	0.15	0.8	1	0.91	0.95	0.51				0.81	0.96	0.9	0.52		91 to 100	45.40.353N	W62.52.281
0.32	0.42	0.92	0.49	0.84	1	0.91	0.95	0.4				0.82	0.89	0.9	0.6		101 to 110	45.40.256N	W62.51.262
0.12	0.33	0.92	0.44	0.88	1	0.96	0.83	0.49				0.86	0.95	0.9	0.71		111 to 120	45.40.151N	W62.50.141
0.195	0.39	0.81	0.37	0.84	1	0.94	0.86	0.77				0.96	1	0.9	0.69		121 to 130	45.39.925N	W62.49.370
0.198	0.39	0.95	0.34	0.7	1	0.91	0.97	0.76				0.95	0.97	0.9	0.79		131 to 140	45.56.729N	W62.64.507
0.19185714	0.36571429	0.93857143	0.505	0.82428571	1	0.88428571	0.61642857	0.78071429				0.81785714	0.89642857	0.9	0.68428571		Averages		

(HIS scoring by quadrant. Image 1)

Between July 3rd and August 26th, 2023, my team with assistance from the Nova Scotia Department of Inland Fisheries and Aquaculture, The Nova Scotia Salmon Association and the Pictou County Rivers Association and conducted 136 HIS surveys in the East River East Branch Pictou County. These surveys began at the confluence of the East branch and Black Brook, located just below the Bridgeville bridge at 45.43258N, 62.61003W and we then worked upriver to the confluence of the East Branch and an unnamed brook at 45.39838N, 62.47988W. The total distance surveyed was just over 10.4km. This survey site encompassed an array of various habitats, runs, pools, tributaries, and rapids. Throughout the site the quality of salmon fry and par habitat varied but in total the average HSI score across the site was 0.7266. With the lowest quality quadrant (set of ten consecutive transects) scoring 0.65 and the highest quality quadrant scoring 0.768. While there was significant variation between the effecting factors in each quadrant as a whole there was not much deviation between quadrant scores. These scores suggest there is substantial Atlantic salmon habitat throughout the system but, this is by no means exemplarily habitat for Atlantic salmon fry and parr.

It is important to note the summer of 2023 in Nova Scotia was by no means a usual summer. The late spring and early summer consisted of a long drought and historic wildfire season with wildfires raging throughout the southern portion of the province. Which was followed by historic rainfalls in late July. These rainfalls had a significant effect on my team's ability to conduct surveys due to high water conditions in the river. In the interest of safety, I chose to pause our surveying for close to two weeks at the end of July. This was far from ideal as it reduced the total survey length and significantly changed the conditions in the river. While this was not ideal this is unfortunately an accurate representation of the river conditions we should expect in the future as a result of the environmental instability that climate change brings.

Based on the Pictou County Rivers Association's years of water temperature monitoring data. As a whole this year's water temperatures were significantly below previous summers. Normally the warmest temperatures are observed in mid-summer late July to early August (PCRA, 2023). Due to the historic rainfalls occurring in this period as well as a cool summer as a whole, water temperature were significantly cooler than they had been in recent years. The warmest temperatures were actually observed in early and late summer. As referenced above climate change causes instability in the climate making it very hard to predict changes from year to year. Yet due to the earths average temperature increasing it is fair to assume these low temperatures are unlikely to consistently occur and the temperature on average is going to increase assuming mitigation efforts are not conducted (Parmesan et al., 2022). This trend is exemplified by PCRA's water temperature data over the last few years which shows a trend of water temperature increasing overall PCRA, 2023).

This year's cooler temperatures suggest there was a lower rate of fry and parr thermal mortality then the previous year's multiple days of lethal temperatures.

Water temperature plays a key role in salmon fry and parr growth and survival. The East River has been experiencing dangerously high-water temperature over the last few years and even this year with abnormally cool water temperature. The water temperature was still dangerously high at points of the summer (PCRA, 2023).

While high water temperatures are a putting the salmon population at risk pH is likely the biggest immediate threat to fry and parr survival in the East Branch. The pH varies throughout the system and in many locations most notably the downstream portions of the survey site the pH is quite healthy consistently scoring 0.99 HSI for the first three quadrants in these areas the pH was consistently in the high 6's which is ideal for salmon. Unfortunately, this trend did not continue as we moved upriver. The middle portion of our survey location saw alarmingly low pH levels. The area between Glencoe and Sunnybrae consistently demonstrated low pH levels hovering around 5.0. This is not suitable habitat for salmon fry and parr. According to the Canadian department of Fisheries and Oceans in waters with a pH level of 5.0 salmon fry and parr mortality is (19-71%) While Smolt mortality is significantly lower at (1-5%) (Farmer, 2000). Over 40 transects almost entirely withing this section between Glencoe and Sunnybrae had pH levels in the low 5's. Six transects all located within a few hundred meters of the

Sunnybrae bridge had pH scores below five. To be exact these scores ranged between 4.77-4.87pH. According to the DFO salmon fry and parr have a mortality rate of 72-100% when pH is 4.7 or below and egg survival is decreased once pH falls below 4.8 (Farmer, 2000). It is important to note these areas were measured for pH multiple times with two separate YSI systems to increase confidence in these measurements. These YSI systems were both calibrated multiple times and tested in other areas in the river which have better pH levels to make sure these readings were correct. I can say with complete confidence these readings were correct.

This suggest it is more than probable that a substantial amount of salmon fry and parr are dying because of this low pH. There are two tributaries that flow into the East Branch in this area of extreme pH both located just before the Sunnybrae bridge. One flows from the left side of the river, and one flows from right. In both tributaries the pH values were in the mid 6'es suggesting the root cause of the pH values is much closer to the East Branch itself. I had initially thought the cause of low pH could potentially be a result of built-up acidity in soils surrounding the river potentially from acid rain which has been a problem in nearby sheet harbour, but the pH did not continue to decrease after heavy rains which decreases my confidence in this hypothesis (Rotteveel, L., 2018). According to geological maps of the area there are significant iron deposits in this location that have been mined in the past (DNR, 2021). This could likely be playing a role in the low pH but the drastic decrease in pH surrounding the community of Sunnybrae (one of the larger settlements in the area) is questionable. Unfortunately, due to the lack of data I am unable to come to any substantial hypothesis regarding the cause of these pH levels.

The effects of climate change are already affecting the salmon habitat in the East River East Branch. While temperatures were generally lower this year with the highest temperature recorded by my team being 24.8° which is high, scoring a 0.13HSI but a significant decrease from the above 30° temperatures which PCRA had recorded in the previous years (PCRA,2023). This is still too high for proper fry and parr growth and could potentially lead to a mortality event if salmon are unable to find a cooler location to rest (Thorstad et al., 2021). The Nova Scotia department of Environment and Climate Change's projections suggest temperatures on average will increase significantly over the coming century, especially if significant steps are not taken to reduce our GHG emissions (DECC, 2022). This will inevitably lead to increased water temperatures in the East River. Even this year with unseasonable low temperatures I observed dozens of dead salmon fry in the system. These fry had been trapped in disconnected puddles following highwater events and the sun had raised the temperature in these shallow puddles leading to the fries inevitable mortality. Fortunately, I did not observe any dead fry or parr in the main system. This is contrary to the previous year where PCRA observed a large parr mortality event in the mainstem of the East River in Stellarton. It is reasonable to assume this parr kill was the result of the 30° water temperature that had been observed at this location as no other water quality measurements raised any concern (PCRA, 2023). Unfortunately, these temperature educed mortalities are likely to become increasingly common throughout the century as temperatures continue to increase. While the East Branch does have a number of tributaries the base of the system is the large but relatively shallow Eden Lake. Being a lake fed system the East River is increasingly susceptible to high temperatures. Due to the stagnant nature and lack of shade in the water increases at a faster rate than in the river system but this means the water is already warm when it enters the river as opposed to a system where the majority of the water comes from ground water which is generally cooler than surface water (Keery, 2007). Fortunately, in general we found the temperatures in the tributaries to be slightly cooler than in the main stem which offers salmon cool water to rest and reduce their internal temperatures.

Unfortunately, in some cases these cooler water tributaries are quite spaced out an in some locations there are simply no areas for cold water salmon refuge within close proximity. We did also observe three locations where there was significant cold ground water upwelling within the main stem. These upwelling locations could potentially be the sites of river restoration projects such as cold water refugia systems similar to that of the projects being conducted in the Miramichi River in New Brunswick (Kurylyk, 2015).

While this year's conditions did not give much insight into the coming effects of increased temperatures it did give a lot of insight into the effects of high-water events. The Department of Climate Change and Environment's "Weathering What's Ahead" report on the risks of climate change suggests the biggest risk to Nova Scotia in the coming years is historic floods and high-water events (ECC,2022). As previously mentioned, Nova Scotia did receive historic floods and extreme rainfall. This had mixed effects on the salmon habitat of the East Branch. The high-water levels did keep the rivers flow high allowing for good oxygen levels and contributed to the years cool water temperatures. These effects certainly benefited salmon fry and parr. But it also had some negative effects. High water is not ideal for fry and parr and while the systems scored a good 0.82 HSI for fry depth and a 0.90 HSI for parr depth the low scores were more often the result of high-water depths as a opposed to low. It is reasonable to assume in the coming years there will be even higher water events which could lead to a decrease in habitat quality. A second threat that is posed by the increased flooding that will come with climate change is erosion. With heavy rainfall come increased discharge and flow rates. The increased flow puts additional pressure on the river's banks (Yusoff, 2013). The banks off the East Branch are already heavily eroded and in almost all of the 140 transects the river was significantly over widened. The increased erosion will lead to decreased vegetation along the banks reducing stream shade and instream cover for fish. The increased over widening can have a multitude of negative effects. In summer conditions it can lead to increased water temperatures and reduced oxygen levels as the flow rate will decrease. It also increases the probability of fry and parr becoming stranded in disconnected puddles in low water events or following high water events. In winter conditions the over widened streams reduce the space between ice and the stream bed which can lead to decreased egg survival (Whalen, 1999).

The increased erosion will also lead to stream straightening which is already a large problem in the East Branch. As a whole the survey location is already very straight. This leads to a reduction of pools. The system already has very few pools with it scoring 0.19 HSI. This was by far the lowest scoring HSI category. Of the 14 quadrants six had no pools whatsoever. In some locations the distance between pools exceeded 1.4km. This significantly complicates the spawning salmon's ability to make their journey up stream. If restoration projects are not done to prevent erosion or to introduce new pools the number of pools in this system will continue to drop only further complicating the spawning journey.

One of the categories in which the East Branch scored highly in was the percentage of riparian rooted vegetation. The HSI score was 0.88 this is a good score especially considering throughout the province many of the river valleys have been converted to agricultural land. While their system does have some agricultural lands along its banks in most cases the riparian zones are still heavily treed. These trees provide valuable shade from the sun helping to fight against the hot summer temperatures as well as providing fish cover from arial predators. The integrated web of roots also helps to prevent further erosion. Unfortunately, these well vegetated riparian zones are at threat from climate change (Simon, 2002). While flooding is the largest environmental risk in the coming years. Forest fires are also a huge risk and are supposed to surpass flooding as the number one environmental risk by the 2050's (ECC,2022). This year southern Nova Scotia experienced extreme forest fire conditions and droughts effected the entire province. Fortunately, the Northern portion of the province was spared from these disasters but it is unlikely that this luck will continue. The Department of Climate Change and Environment's "Weathering What's Ahead" report also lists Northern Nova Scotia as being one of the areas in the province most at risk of forest fires (ECC,2022). In the event of a forest fire these riparian zones could be destroyed. The fires surrounding the river and heavy smoke would also drastically decrease the water quality threating the survival of all fish in the area. The damage that forest fires cause cannot be easily remedied, and it would take decades for the riparian zone to properly recover all the while the effects of climate change will continue to worsen, further damaging the quality of salmon habitat.

Conclusion

In conclusion the effects of climate change in salmon fry and parr habitat in the East River East Branch will be significant and have the potential for total population collapse over the coming century. Unfortunately, the specific effects of climate change are extremely hard to predict as it will lead to a much more irregular climate. But we do know already high water temperatures will continue to rise further threating survival. Storms will erode the banks accelerating stream widening and the healthy riparian zones are at risk of being destroyed by forest fires.

As referenced throughout this report there are steps that can be taken to reduce the effects of climate change in the system such as cold water refugia systems and or various pool creation methods, but I believe these projects will have little effect if steps are not taken to combat the dangerously low pH levels in the Sunnybrae area. These levels are already too low for significant fry and parr survival. If this is not addressing, further projects in the area will have minimal benefits as water temperature or pool quality are relevant when the water is to acidic to support life.

Work Cited

Adopt a Stream. (2018). *The Nova Scotia Fish Habitat Suitability Assessment A Field Methods Manual Nova Scotia Freshwater Fish Habitat Suitability Index Assessment NSHSI*.

Allen, Y., Kimmel, K., & Constant, G. (2020). Using Remote Sensing to Assess Alligator Gar Spawning Habitat Suitability in the Lower Mississippi River. *North American Journal of Fisheries Management*, *40*(3), 580–594. https://doi.org/10.1002/nafm.10433

Biron, M., & Breau, C. (2015). *Canadian Science Advisory Secretariat (CSAS) Status of Atlantic salmon (Salmo salar L.) stocks in rivers of Nova Scotia flowing into the Gulf of St. Lawrence (SFA 18), 2012-2013*. http://www.dfo-mpo.gc.ca/csas-sccs/

Borisko, J. P., Kilgour, B. W., Stanfield, L. W., & Jones, C. F. (2007). *An Evaluation of Rapid Bioassessment Protocols for Stream Benthic Invertebrates in Southern Ontario, Canada*.

Darimont, C. T., Paquet, P. C., & Reimchen, T. E. (2008). Spawning salmon disrupt trophic coupling between wolves and ungulate prey in coastal British Columbia. *BMC Ecology*, *8*(1), 1–12. https://doi.org/10.1186/1472-6785-8-14/FIGURES/6

Dempson, B., Schwarz, C. J., Bradbury, I. R., Robertson, M. J., Veinott, G., Poole, R., & Colbourne, E. (2017). Influence of climate and abundance on migration timing of adult Atlantic salmon (Salmo salar) among rivers in Newfoundland and Labrador. *Ecology of Freshwater Fish*, *26*(2), 247–259. https://doi.org/10.1111/EFF.12271

Denny, S. K., & Fanning, L. M. (2016). A Mi'kmaw Perspective on Advancing Salmon Governance in Nova Scotia, Canada: Setting the Stage for Collaborative Co-Existence. *The International Indigenous Policy Journal*, *7*(3). https://doi.org/10.18584/IIPJ.2016.7.3.4

Farmer, G.J., (2000) Effects of Low Environment pH on Atlantic Salmon (Salmo Salar L.) In Nova Scotia, Department of Fisheries and Oceans Canada. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/244788.pdf

Google Earth. (2023). *East River Pictou County Mainstem and East Branch*. Google Earth.

Hoffman, E., Guernsey, J. R., Walker, T. R., Kim, J. S., Sherren, K., & Andreou, P. (2017). Pilot study investigating ambient air toxics emissions near a Canadian kraft pulp and paper facility in Pictou County, Nova Scotia. *Environmental Science and Pollution Research*, *24*(25), 20685–20698. https://doi.org/10.1007/S11356-017-9719-5/FIGURES/6

Jonsson, B., & Jonsson, N. (2009). *Restoration and Enhancement of Salmonid Populations and Habitats with Special Reference to Atlantic Salmon Effects of early experiences on ecological traits of salmonid fishes View project Climate change effects on salmonids View project*. https://doi.org/10.1007/978-94-007-1189-1_11

Keery, J., Binley, A., Crook, N., & Smith, J. W. (2007). Temporal and spatial variability of groundwater–surface water fluxes: Development and application of an analytical method using temperature time series. *Journal of Hydrology*, *336*(1-2), 1-16.

Koljonen, S., Huusko, A., Mäki-Petäys, A., Louhi, P., & Muotka, T. (2013). Assessing habitat suitability for juvenile atlantic salmon in relation to in-stream restoration and discharge variability. *Restoration Ecology*, *21*(3), 344–352. https://doi.org/10.1111/j.1526-100X.2012.00908.x

Kurylyk, B. L., MacQuarrie, K. T., Linnansaari, T., Cunjak, R. A., & Curry, R. A. (2015). Preserving, augmenting, and creating cold-water thermal refugia in rivers: Concepts derived from research on the Miramichi River, New Brunswick (Canada). *Ecohydrology*, *8*(6), 1095-1108.

Lundin, J. I., Spromberg, J. A., Jorgensen, J. C., Myers, J. M., Chittaro, P. M., Zabel, R. W., Johnson, L. L., Neely, R. M., & Scholz, N. L. (2019). Legacy habitat contamination as a limiting factor for

Chinook salmon recovery in the Willamette Basin, Oregon, USA. *PLOS ONE*, *14*(3), e0214399. https://doi.org/10.1371/JOURNAL.PONE.0214399
McCann, L. D. (1994). Fragmented Integration: The Nova Scotia Steel and Coal Company and the Anatomy of an Urban-Industrial Landscape, c. 1912. *Urban History Review / Revue d'histoire Urbaine*, *22*(2), 139–158. https://doi.org/10.7202/1016714AR
Moir, H. J., Soulsby, C., & Youngson, A. (1998). Hydraulic and sedimentary characteristics of habitat utilized by Atlantic salmon for spawning in the Girnock Burn, Scotland. *Fisheries Management and Ecology*, *5*(3), 241–254. https://doi.org/10.1046/j.1365-2400.1998.00105.x
Nova Scotia, D. of C. C. (2022). *Weathering What's Ahead: Climate Change Risk and Nova Scotia's Well-being*.
Nova Scotia Department of Environment and Climate Change, (2022) Weathering What's Ahead: Climate change Risk and Nova Scotia's Well-being.
Nova Scotia Department of Natural Resources, (2021), Iron Deposits of Nova Scotia. https://novascotia.ca/natr/meb/pdf/75egs01.asp
Ozaki, N., Fukushima, T., Harasawa, H., Kojiri, T., Kawashima, K., & Ono, M. (2003). A Statistical Study on Influence of Meteorological Variations on River Water Quality. Monitoring and analysis on lake environmental changes View project Statistical analyses on the effects of air temperature fluctuations on river water qualities. *Process*, *17*, 2837–2853. https://doi.org/10.2208/jscej.1999.629_97
PCRA, (2023) Pictou County Water Quality Data, ER1.https://atlanticdatastream.ca/explore/#/dataset/a2ac7b8b-88cd-4d57-b691-30b04e13344d/?ref=map&locations=1769&guideline=&percentiles=&characteristic_media=Surface%2520Water&characteristic_characteristic_name=Temperature%252C%2520water&characteristic_method_speciation=&characteristic_sample_fraction=&characteristic_field=true&characteristic_unit=%25C2%25B0C&tab=statistics&endDate=2023-08-17T23:59:59.000Z
Post, E., Alley, R. B., Christensen, T. R., Macias-Fauria, M., Forbes, B. C., Gooseff, M. N., Iler, A., Kerby, J. T., Laidre, K. L., Mann, M. E., Olofsson, J., Stroeve, J. C., Ulmer, F., Virginia, R. A., & Wang, M. (2019). ENVIRONMENTAL SCIENCES The polar regions in a 2°C warmer world. *Sci. Adv*, *5*. https://data.
Rotteveel, L. (2018). Effects of partial-catchment helicopter liming on stream water chemistry in West River Sheet Harbour, Nova Scotia.
Saloniemi, I., Jokikokko, E., Kallio-Nyberg, I., Jutila, E., & Pasanen, P. (2004). Survival of reared and wild Atlantic salmon smolts: size matters more in bad years. *ICES Journal of Marine Science*, *61*(5), 782–787. https://doi.org/10.1016/J.ICESJMS.2004.03.032
Saltwire. (2016). Fishing the East river . *Saltwire*.
Sandberg, L. A. (1985). *The deindustrialization of Pictou County, Nova Scotia: capital, labour and the process of regional decline, 1881-1921.*
Smialek, N., Pander, J., & Geist, J. (2021). Environmental threats and conservation implications for Atlantic salmon and brown trout during their critical freshwater phases of spawning, egg development and juvenile emergence. In *Fisheries Management and Ecology* (Vol. 28, Issue 5, pp. 437–467). John Wiley and Sons Inc. https://doi.org/10.1111/fme.12507
STATE OF NORTH ATLANTIC SALMON. (2019). *North Atlantic Salmon Conservation Organization*. www.nasco.int
Simon, A., & Collison, A. J. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth surface processes and landforms*, *27*(5), 527-546.

Statistics Canada. (2016). *Census Profile, 2016 Census - New Glasgow [Population centre], Nova Scotia and Nova Scotia [Province]*. https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=POPC&Code1=0577&Geo2=PR&Code2=12&SearchText=New%20Glasgow&SearchType=Begins&SearchPR=01&B1=All&GeoLevel=PR&GeoCode=0577&TABID=1&type=0

Thompson, P. (2012). Extraction, Memorialization, and Public Space in Leo McKay's Albion Mines. *Studies in Canadian Literature / Études En Littérature Canadienne*, *37*(2), 96–116. https://id.erudit.org/iderudit/scl37_2art05

Thorstad, E. B., Bliss, D., Breau, C., Damon-Randall, K., Sundt-Hansen, L. E., Hatfield, E. M. C., Horsburgh, G., Hansen, H., Maoiléidigh, N., Sheehan, T., & Sutton, S. G. (2021). Atlantic salmon in a rapidly changing environment—Facing the challenges of reduced marine survival and climate change. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(9), 2654–2665. https://doi.org/10.1002/AQC.3624

Vähä, J. P., Erkinaro, J., Niemelä, E., & Primmer, C. R. (2007). Life-history and habitat features influence the within-river genetic structure of Atlantic salmon. *Molecular Ecology*, *16*(13), 2638–2654. https://doi.org/10.1111/J.1365-294X.2007.03329.X

Whalen, K. G., Parrish, D. L., & Mather, M. E. (1999). Effect of ice formation on selection of habitats and winter distribution of post-young-of-the-year Atlantic salmon parr. *Canadian Journal of Fisheries and Aquatic Sciences*, *56*(1), 87-96.

Xu, C., Letcher, B. H., & Nislow, K. H. (2010). Context-specific influence of water temperature on brook trout growth rates in the field. *Freshwater Biology*, *55*(11), 2253–2264. https://doi.org/10.1111/J.1365-2427.2010.02430.X

Yusoff, N., & Abidin, R. Z. (2013). River bank erosion risk with regards to rainfall erosivity. *Infrastructure University Kuala Lumpur Research Journal*, *1*(1), 46-5.

Project Budget

Expense Category	Expenditure Items	Cost (Canadian Dollars)	Contribution			
			NSDFA	Other Sources CAD		
				Cash (cad)	In-Kind	Contributors
Labour	Field work	9,300	9,300	x	x	NSDFA
Labour	Field work	2,100	x	x	2,100	Pictou County rivers Association
Labour	Training (7 hours)	70	x	x	70	NS Salmon Association
Labour	Advising (80 hours)	800	x	x	800	Dr. Barry Taylor, St. Francis Xavier University
Mileage	Travel Mileage (Kms)	2,000	x	2,000	x	Dr. Barry Taylor, St. Francis

						Xavier University
Mileage	Travel Mileage (Kms)	1600	x	1600	x	Matthew Russell
Total		15,870	9,300	3,600	2,970	

*Project also received donated equipment from:

Equipment	Donating Organization
YSI System (3 weeks)	NSDFA
YSI System (3 weeks)	PCRA
Field Gear (waders, boots, etc.)	Dr. Barry Taylor, St. Francis Xavier University