FISH CONVEYANCE AND MIGRATION IN THE INTERNATIONAL ST. CROIX RIVER

PREPARED FOR THE INTERNATIONAL JOINT COMMISSION

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Introduction

The Passamaquoddy Ancestral Territory is located in present day New Brunswick, Canada and Maine, United States (Figure 1). Its borders span along the coast from what is now Pt. LePreaux, New Brunswick to Mt. Desert Island, Maine, and inland to the Chiputneticook Lakes, and it includes the Passamaquoddy Bay (Figure 2). Nestled within this territory is the St. Croix Watershed, which empties through the Passamaquoddy Bay into the larger Gulf of Maine (Figure 3). The St. Croix River, which drains the watershed, is considered the heart of the Ancestral Homeland, was home to ancient Passamaquoddy fishing villages, and now serves as the international before between the United States and Canada. Today, it connects the three Passamaquoddy Reservations, located at Pleasant Point, ME, Indian Township, ME, and St. Andrews, N.B. (Figure 4). It is still relied upon for traditional and cultural uses, including fishing, hunting, and recreational activities.

The St. Croix, a 185 km river constricted by ten dams, drains an area of 4,271 km^2 into a 24 km estuary, influenced twice daily by 7 meter tides (FB Environmental 2008). The main stem of the St. Croix River begins at the convergence of the East and West branches near Grand Falls Dam in Kellyland, ME, and continues for a stretch of 29 km until head of tide, near St. Stephen, N.B., and Calais, ME (Table 1; FB Environmental 2008). Largely due to the construction of dams, fish passage has been an ongoing obstacle in the system for multiple generations (Figure 5).

The St. Croix River has been industrialized and the ecosystem decimated over time, resulting in a loss of species diversity and ecosystem function. In particular, the loss of river herring (alewife/gaspereau, and blueback herring), from the system is thought to have precipitated declines in populations of groundfish and other species in the region. River herring are a keystone species, considered the “fish that feeds all”. They are an important prey species for higher trophic levels in the food web, and a source of nutrient input to lakes in the upper watershed. Evidence of river herring use and consumption was found in archaeological digs of Passamaquoddy villages in the St. Croix Watershed. Their loss has affected the cultural and traditional practices of the Passamaquoddy people, and limited their access to traditional food resources. Industrialization and the construction of dams along the St. Croix River are obstacles to both fish passage and harvesting for traditional practices. The Passamaquoddy, inhabiting the river’s shores, are dedicated to returning the fish to their native waters and providing “alewife in the millions”, benefiting and restoring the entire ecosystem and preserving a culturally important species for future generations.

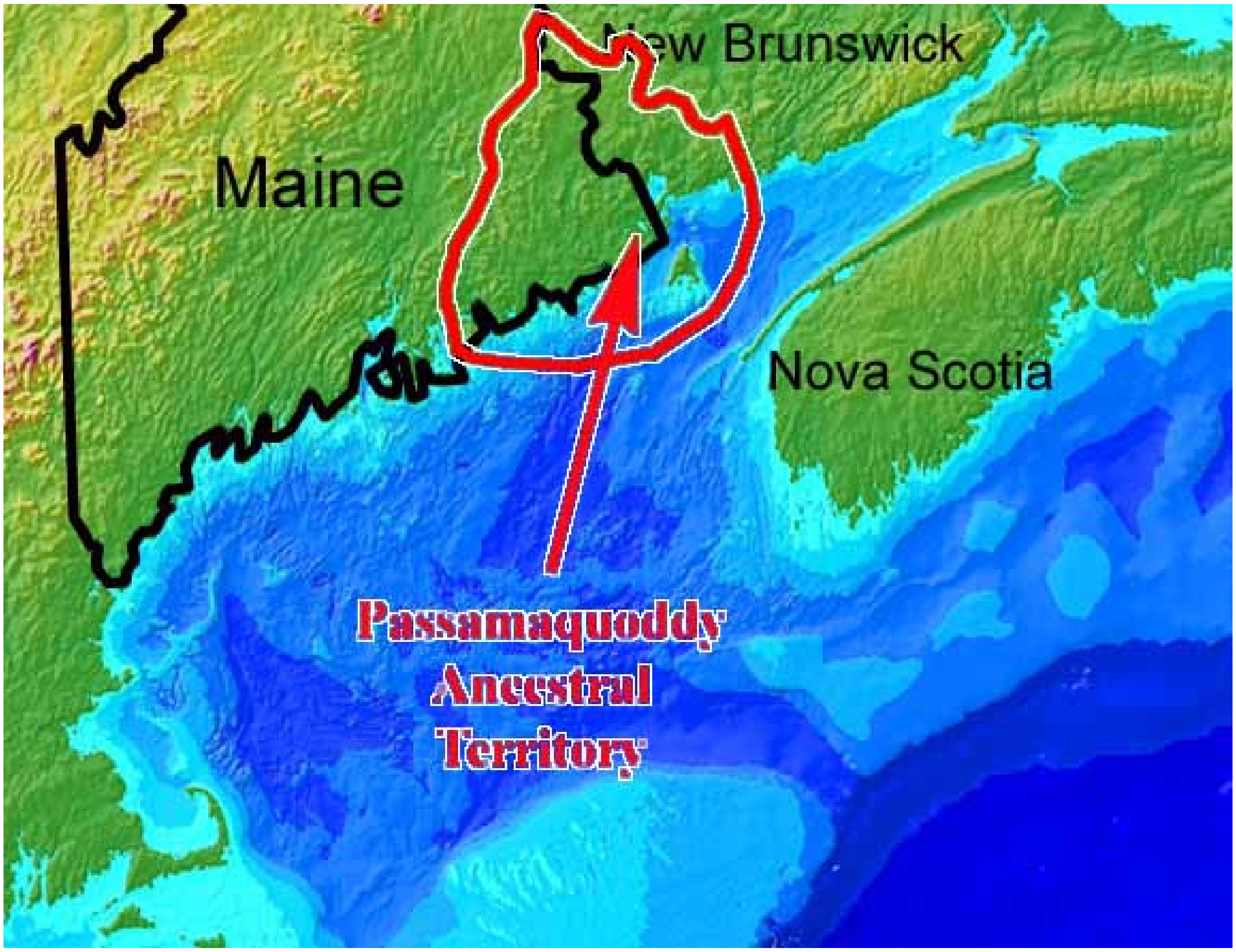

Figure 1: Passamaquoddy Ancestral Homelands, in present day New Brunswick, Canada, and Maine, United States. Map credit: Passamaquoddy Tribe at Pleasant Point.

Figure 2: The boundaries of Passamaquoddy Ancestral Territory span internationally, from what is now Pt. LePreaux, N.B. to Mt. Desert Island, ME, and back to the Chiputneticook Lakes. The Passamaquoddy Bay falls within the Traditional Homeland and connects to the larger Gulf of Maine. Map credit: Edward Bassett (SED).

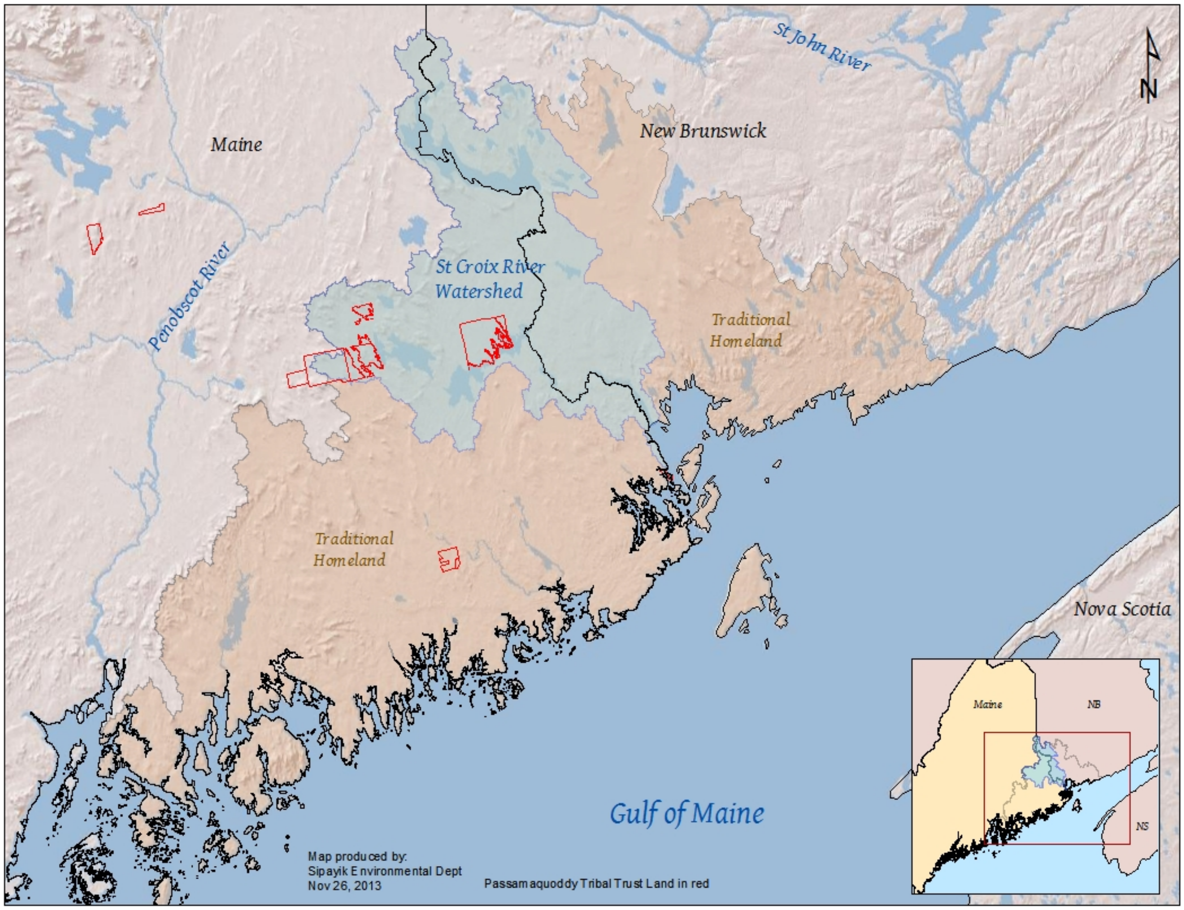

Figure 3: The St. Croix Watershed is nestled in the heart of the Traditional Homeland. It is drained by the St. Croix River, which serves as the international border between New Brunswick and Maine, and empties into the Passamaquoddy Bay and Gulf of Maine. Tribal trust lands are shown in red. Map credit: Edward Bassett (SED).

Figure 4: Locations of the Passamaquoddy Reservations at Pleasant Point, Indian Township, and St. Andrews, in relation to the St. Croix River (yellow line). The St. Croix River forms the border between the U.S.A. and Canada (yellow line), prior to its split into two branches at Kellyland, ME. Indian Township rests on the shores of the West Branch (white line). The East Branch of the St. Croix River continues to follow the international border.

Table 1: The 185 km St. Croix River drains an area of 4,271 km^2 into a 24 km estuary influenced twice a day by 7 meter tides. The river is broken into three parts: 1) the East Branch, from Spednic and East Grand Lakes to Kellyland, ME; 2) the West Branch, from Sysladobsis and West Grand Lakes to Kellyland, ME; and, 3) the Main stem, from the convergence of the East and West branches to head of tide, near Milltown, N.B and Calais, ME.

St. Croix River System	**Location**	**Length (km)**
Estuary	Head of tide to Passamaquoddy Bay	24
Main stem	Kellyland, ME to head of tide	29
Total St. Croix River	East and West branches and Main stem	185
St. Croix Watershed	Entire drainage area	4271 km^2

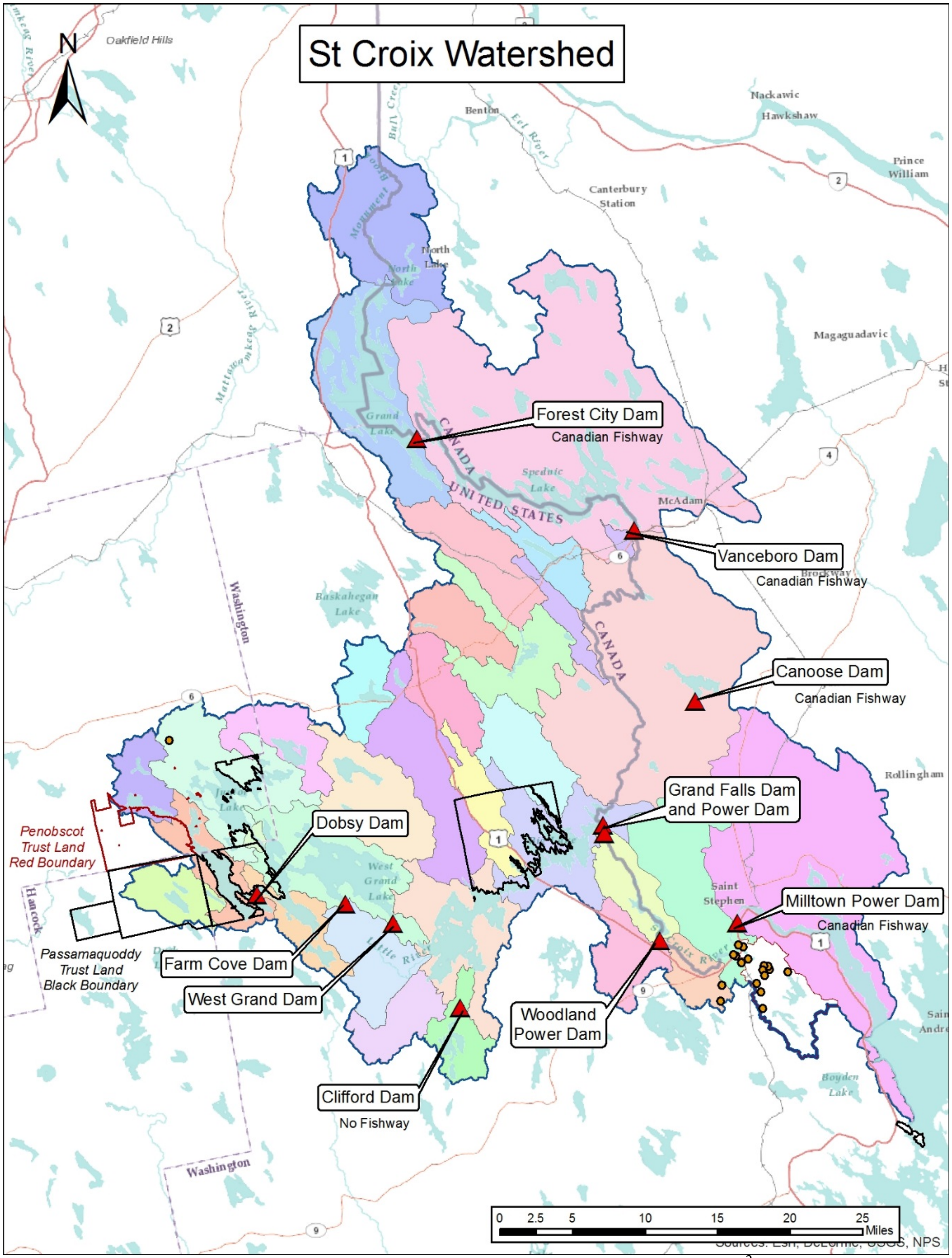

Figure 5: The 185 km St. Croix River contains 10 dams and drains an area of 4,271 km^2 into the Passamaquoddy Bay. The focus of this study is the three dams along the main stem of the river – Milltown Dam, Woodland Dam, and Grand Falls Dam. Map Credit: Edward Bassett (SED).

Project Objective

The Sipayik Environmental Department (SED) of the Passamaquoddy Tribe at Pleasant Point, ME, has undertaken a multi-year study to track the efficiency of fish ladders in the St. Croix Watershed. Efficient fish passage is imperative for migrating fish to reach their spawning grounds in the lakes of the watershed. The SED will determine the proportion of river herring that find, enter and successfully pass through fishways, and evaluate areas within the fish ladders that may slow or prevent their passage. These efforts will contribute to improving the overall understanding of fish conveyance in the St. Croix River, and the ability of river herring to migrate from the St. Croix Estuary to the upper reaches of the St. Croix River.

Identifying Priority Fishways

In order to access the upper reaches of the river, fish must navigate through three dams along the main stem of the St. Croix River – Milltown, Woodland, and Grand Falls. River herring must successfully pass over these three dams in order to access ~98% of their spawning grounds (Figure 6; Flagg 2007). These dams are the first obstacles that river herring and other fish encounter in the St. Croix Watershed, and are hypothesized to be significant barriers to their upstream migration.

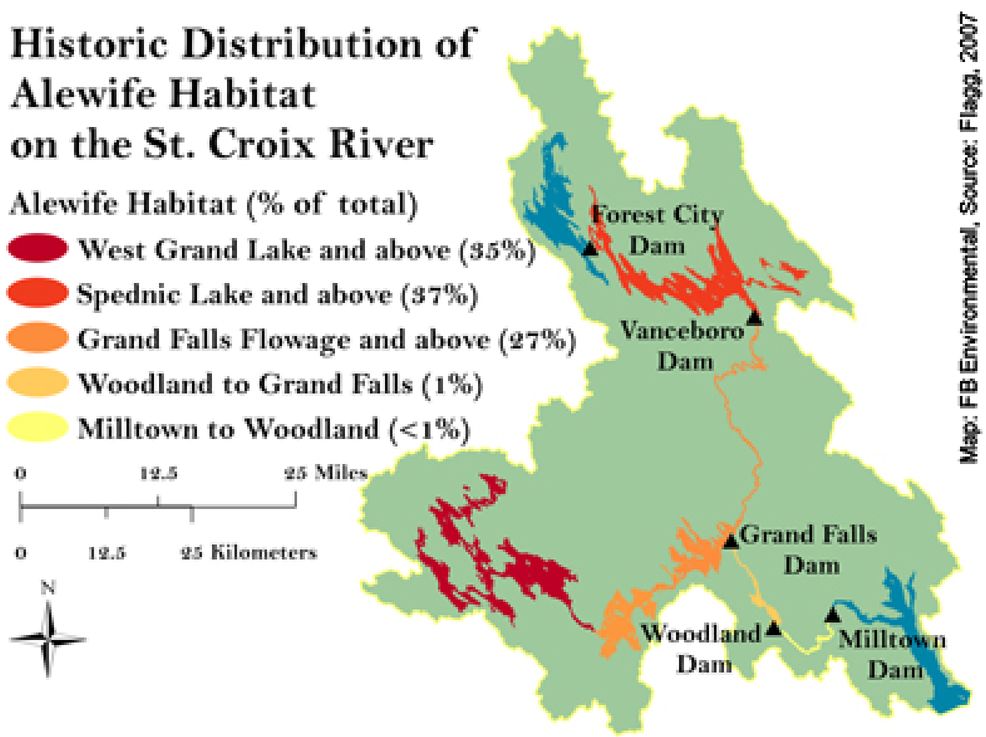

Figure 6: Map featuring the main impoundments preventing access to historic alewife habitat in the St. Croix Watershed. Dams pose significant challenges to fish migration, and alewife must successfully surmount these obstacles to access ~98% of their spawning habitat.
Not pictured: West Grand Dam, located at the convergence of Grand Falls Flowage (orange) and West Grand Lake (dark red). Photo credit: FB Environmental 2008.

Milltown Dam

Built in 1881, Milltown Dam, located 1 km from sea just above head of tide in Milltown, N.B., and Calais, ME, presents the first manmade obstacle to fish passage on the St. Croix River (Figure 7). Its hydroelectricity was used to power the looms of the St. Croix Cotton Mill. In 1887, turbine generators brought electricity to the mill and local users (Flagg 2007). The St. Croix Cotton Mill was one of the largest cotton mills in the world, and helped in the early economic development of St. Stephens, N.B. (Flagg 2007; Parks Canada n.d.). Milltown Dam, formerly Cotton Mill Dam, is the oldest hydroelectric facility in Canada, and was designated a Local Historic Place in 2006 (Anonymous 1988; Parks Canada n.d.). Currently owned and operated by New Brunswick Power (NB Power), power generated at 3.9 mw/hr is sold to the grid (FB Environmental 2008). An antiquated fish ladder, dating back to 1960, was replaced with an updated pool-and-weir style fishway in 1980, improving the potential for river herring passage over Milltown Dam (Anonymous 1988). NB Power maintains and operates the fishway on the Canadian shores of the St. Croix River (Table 2).

Figure 7: A postcard depicting the St. Croix Cotton Mill, located between Calais, ME, and Milltown, N.B. The current Milltown Dam is the oldest hydroelectric facility in Canada, and was designated a Local Historic Site in 2006. Photo credit: St. Croix Historical Society.

Woodland Dam

Located 14.5 km upstream in Baileyville, ME, Woodland Dam was built in 1906 to house the St. Croix Paper Company (Figure 8; Anonymous 1988). The facilities are currently home to Woodland Pulp, LLC., and St. Croix Tissue, Inc. These self-sufficient operations run entirely on thermal (36 mw/hr) and hydro (11.6 mw/hr) power generation (Kleinschmidt 2015). A 227-m denil style fish ladder was completed in 1965, with no existing fish passage capabilities prior to that time. The ladder, designed to meet safety clearance standards under high voltage power lines traversing the river, is considered one of the longest of its kind worldwide (Anonymous 1988). Woodland Pulp, LLC., is responsible for the maintenance and operation of the fishway (Table 2).

Figure 8: The St. Croix Paper Company. Foreground: The mill pond, holding logs driven downstream after the spring thaw. Background: The Woodland Mill. Photo credit: Penobscot Marine Museum.

Grand Falls Dam

Constructed in 1915, 30.6 km upriver in Kellyland, ME, the Grand Falls Dam is the last manmade barrier to fish passage on the main stem of the St. Croix River, prior to its split into the East and West branches (Figure 9). The hydropower facility generates 9.5 mw/hr to power operations at Woodland Pulp, LLC., and St. Croix Tissue, Inc. (FB Environmental 2008; Kleinschmidt 2015). In 1965, construction was completed on a 182.9-m denil style fishway (Anonymous 1988). Woodland Pulp, LLC., is responsible for the maintenance and operation of the fishway at Grand Falls Dam (Table 2).

Figure 9: The Grand Falls Dam, looking down from the top of the 182.9-m fish ladder. The Grand Falls and Woodland Dams are owned and operated by Woodland Pulp, LLC., and generate hydroelectricity to power mill and operations. Photo credit: The Portland Herald Press 2012.

Table 2: The three dams along the main stem of the St. Croix River are the first manmade obstacles that river herring encounter on their upstream migration to spawning grounds. The Milltown, Woodland, and Grand Falls Dams are power generating, producing a total of ~25 mw/hr (FB Environmental 2008; Kleinschmidt 2015). Fishways were constructed in the 1960's, and updated passage facilities were installed at Milltown Dam in 1980.

					Fishway Specifications			
Dam	**Owner**	**Distance from head of tide (km)**	**Year constructed**	**Hydropower capacity (mw/hr)**	**Year opened**	**Type**	**Length (m)**	**Country of operation**
Milltown	N.B. Power	1	1881	3.9	1960; updated in 1980	Pool and weir		Canada
Woodland	Woodland Pulp, LLC.	14.5	1906	11.6	1965	Denil	227	USA
Grand Falls	Woodland Pulp, LLC.	30.6	1915	9.5	1965	Denil	182.9	USA

Study Design

Passive Integrated Transponder (PIT) Tracking

Passive Integrated Transponder (PIT) technology is a reliable, cost-effective methodology used to gather a wide variety of individual and community level data, including animal movement, population interaction, and growth information. PIT tags are permanent markers, each with a unique identification code. They are often inserted into the body cavity of an animal, and remain dormant until in the presence of a handheld or automated reader. When they interact at close range, an electromagnetic field activates the tag and transmits its code, giving researchers the ability to distinguish between individuals in a population (Gibbons and Andrews 2004).

The SED used PIT technology to determine fish behavior during their residence in the fishways, identify areas with potential passage problems, and gauge the length of passage time. This movement data helped to assess the overall, in-ladder passage efficiency of river herring migration over the main stem dams in the St. Croix River. Multi-year data collection could help identify incidences of repeat spawning amongst the river herring population.

Water Quality

Temperature, dissolved oxygen (D.O.) content, pH, and nutrient levels all play an important role in the fitness and health of fish populations. Fish have adapted to survive within certain tolerance limits for these and other parameters, with peak performance occurring under optimal circumstances within this range (Behar 1997; Randall and Braunder 1991). Even subtle shifts in these conditions can have a significant impact on metabolic activity, swimming ability, growth, reproduction, and survival (McKenzie and Claireaux 2009; Karr and Dudley 1981).

According to the State of Maine, the St. Croix River from Grand Falls Flowage to the Woodland Impoundment is class GPA, or of such quality that it could be designated as a drinking source after disinfection, and provides natural habitat for fish and aquatic life. Class GPA waters must have a stable or decreasing trophic state, as measured by chlorophyll *a* concentration, transparency, and total phosphorous and e. coli counts. These waters have been designated as a no discharge zone (Waters and Navigation 2017).

The St. Croix River from the Woodland Impoundment to head of tide (everything below Grand Falls Dam until the estuary), is a Class C river. Class C waters must also be a sufficient source of drinking water after disinfection, and must provide suitable habitat for fish and aquatic life. The 30-day average D.O. content must not be less than 5 ppm or 60% of saturation; however, special standards apply to protect the growth of indigenous fish. These standards ensure that the 30-day average D.O. never drops below 6.5 ppm under certain temperature conditions. Discharges into Class C waters may cause changes to aquatic life, but must not affect the overall ability of the system to support all indigenous species of fish and maintain the resident biological community (Waters and Navigation 2017).

Monitoring throughout the field season provided important information about water quality and habitat health for migrating fish. Dams are a known origin of non-point source (NPS) pollution. Sampling from both the head pond and tailrace of each dam helped gauge dam effects on water quality. Assessing changes in water quality may help managers identify potential sources of pollution, locate fish habitat, and prioritize areas for restoration. In addition, it may help managers predict and prepare for future climatic impacts on water quality and fishway operations.

The SED plans to lead a multi-year assessment in the St. Croix Watershed to better understand the effects of dams on water quality. This includes the collection of a more robust dataset, including monitoring for total dissolved solids (TDS), continuous temperature and D.O. data, and testing for heavy metal pollution. The SED hopes to conduct outreach programs to educate the public and to guide other organizations on NPS pollution management strategies (Table 3).

Funded under the EPA's Clean Water Act 319 and section 106 assessment plan, short term water quality monitoring goals include: 1) obtain reliable data to understand the full extent of NPS pollution in the St. Croix Watershed; 2) identify NPS pollution and use Best Management Practices (BMPs) to reduce pollution loads; and, 3) form partnerships with the US Environmental Protection Agency (EPA), Maine Department of Environmental Protection (DEP), Bureau of Indian Affairs (BIA), St. Croix International Waterway Commission (SCIWC), and other stakeholders and municipalities on the St. Croix Watershed (Longfellow 2017).

The SED's section 106 assessment plan identifies longer term monitoring outcomes, including: 1) measureable reductions in NPS pollution on the St. Croix Watershed; 2) a restored and healthy ecosystem for native fish and plant species; and, 3) Tribal government, tribal members, surrounding municipalities, the general public and stakeholders taking a proactive stance in protecting the St. Croix Watershed so that all lifeforms can benefit from a healthy ecosystem (Longfellow 2017).

Table 3: Key objectives and timeline for the SED's implementation a NPS pollution monitoring program, under the EPA's Clean Water Act 319 and section 106 assessment plan. Table from Longfellow 2017.

St. Croix River Watershed BMPs	2017	2018	2019	2020
Evaluate St. Croix River Watershed for NPS Pollution Sites	x	x		
Define Pre-BMP water chemistry at NPS Pollution sites.		x		
Describe Pre-BMP Biological Aspects of NPS Pollution sites.		x		
Rank NPS Sites by Importance	x	x	x	x
Identify and Install on the Ground BMP at Tribal Boat Landings		x	x	
Compile past and present data from other Partners for NPS Pollution Sites.	x	x		
Help Guide other Municipalities in Water or Waterbodies to adopt NPS pollution management strategies.			x	x
Develop and implement Education and Outreach Programs for NPS Pollution on Watershed basis that deal with Lawns, Pets, gardens, driveways, household chemicals, agricultural, forestry practices, boating and invasive species.		x	x	x
Monitor for Invasive Species.	x	x	x	x
Remove or control Invasive Species through BMP.		x	x	x
Monitor Effectiveness of BMPs	x	x	x	x

Electronic Fish Counters

Electronic fish counters are commonly used to provide river herring population assessments in areas with monitoring limitations or passage bottlenecks, including fish ladders. In Maine, the Department of Marine Resources (DMR) requires several years of counts to re-open or establish new river herring fisheries. Since river herring are an important cultural species for the Passamaquoddy Tribe and the primary bait species for the lobster fishery, local stakeholder groups are collaborating to monitor river herring status throughout the state.

In partnership with DMR, Maine Sea Grant, and the Downeast Salmon Federation (DSF), the SED is involved in fish counting efforts on several smaller, local riverine systems. On the St. Croix River, Milltown Dam was an ideal site for a pilot project using electronic counters, as the SCIWC conducts an annual hand count from the fish trap at the top of the fishway. The hand count could be used to calibrate the automated data, and, if appropriate, eventually replace the need for a 24/7 onsite technician.

At Woodland and Grand Falls Dams, the installation of electronic counters provided the first river herring population estimates in the upper main stem in decades. Knowing the percentage of the total population that successfully makes it over each dam helps broadly identify areas of decreased passage and priority areas for restoration. This information can be applied to future fisheries management decisions, contributing to the Tribe's goal of "alewife in the millions."

Methodology

PIT Antenna Installation and Monitoring

In spring 2016, the SED installed PIT antennas at Woodland Dam and Grand Falls Dam on the St. Croix River. Antennas were installed at the entrance (bottom) and exit (top) of the fish ladders at both dams. They were also installed on baffles at the entrance and exit of resting pools within the fish ladders. This design was chosen to assess overall passage time, use of resting pools, and areas of inefficiency within the fish ladders. No more than three antennas were connected to a single data logger, to avoid slowing down system cycling and missing detections.

In August, 2016, wooden frames were installed on five of the metal baffles in the fish ladder at Milltown Dam, for use in the 2017 field season. Two wooden frames were also braced between concrete walls at the entrance to the ladder and in the exit channel. Prior to the fishway being opened on April 15, 2017, the upper two frames were wired with 12 gauge AWG stranded wire for tracking efforts. NB Power also extended their electrical lines to provide power for the tracking systems at three locations along the fish ladder. Due to spring flooding, the bottom of the fish ladder was inaccessible throughout the monitoring season. In preparation for 2018, wiring was completed after the closing of the fish ladder.

At Woodland Dam, a total of seven antennas were created by stapling wire directly to the wooden baffles in the fish ladder. The antenna at the entrance of the ladder was constructed on a wooden frame, which fit into the metal framing behind the gate to the entrance pool.

Antennas at Grand Falls Dam were also stapled directly onto the existing wooden baffles. Due to safety concerns and the compromised structure of several of the baffles, the SED only installed antennas on the lower and upper portions of the fish ladder. A total of three antennas were stapled directly onto the wooden baffles, and an additional two were constructed on wooden frames. The first frame was placed behind the gate at the entrance pool, and the second fit into an empty stop log slot at the exit of the fish ladder.

The PIT tracking systems were monitored for the duration of the river herring migration season (May-August) to ensure they had continuous power and that the antennas remained in tune, defined as monitoring at the same frequency as the PIT tags. Testing was conducted with a tag attached to a piece of PVC pipe, which was steadily moved towards the antenna until multiple detections occurred (as indicated by several beeps on the reader). Data was uploaded regularly, and connections were checked to ensure the PIT system received continuous power.

In 2017, the detection field of individual antennas was determined by moving a test tag towards the antenna field until multiple beeps were heard and the tag code appeared on the data logger. The distance from this point to the antenna was then measured. This additional step made it easier to diagnose problems with the antenna arrays.

PIT Tagging Procedure

River herring were collected directly from the Milltown Dam fish trap, with permission from the Department of Fisheries Oceans, Canada (DFO) under the appropriate scientific license. The SCIWC technicians assisted with sampled collection and tagging procedures. They also provided temperature readings on tagging days. Fish were tagged throughout the migration season to capture changes in behavior and passage success at different stages in the run.

Fish were randomly sampled five at a time and held in a bucket with water that was regularly refreshed to maintain safe temperature and oxygen levels. Each fish was briefly examined to determine its condition, and any abnormalities documented (i.e. hemorrhaging, missing scales, claw marks). Length measurements, the unique PIT tag code, and any observations were recorded. Tags were inserted into the peritoneal space through a small incision located between the ribs behind the pelvic fin. Fish were then returned to a different bucket with clean water. Handling was minimal, and their total time out of water was approximately 30 seconds.

In 2016, the fish were transported one kilometer upstream and held in a net pen for one hour to acclimate prior to release. This was deemed unnecessary in 2017, and instead fish were released onsite immediately after tagging.

Known mortalities were sexed and their tag codes recorded. Tags were recovered and reused.

Water Quality Parameters

To assess dam effects on water quality at Woodland and Grand Falls Dams, the SED periodically collected surface data throughout the migration season directly from the top and bottom of the fish ladders. At Milltown Dam, the SCIWC recorded daily temperature readings. In addition, Environment and Climate Change Canada (ECCC) and the United States Geological Service (USGS) have remote water quality monitoring stations located up and downstream from Milltown Dam. This data is publicly available.

Throughout the season, the SED tested for surface temperature, D.O., conductivity, pH, turbidity, nitrates, phosphates, and TP (Table 4). Surface grab samples collected using a Van Dorn Bottle were analyzed at the SED's onsite lab, in accordance with the Environmental Protection Agency's (EPA) protocols and quality control measures. The results provided important information about water quality, pollution control, and habitat health for migrating fish. They could also be used to identify preferred river herring spawning grounds, and to prioritize certain areas for restoration efforts.

Table 4: Sampling equipment used to measure surface water quality parameters. In 2017, the SED made equipment upgrades to a YSI Pro DSS multimeter. All water samples were collected with a Van Dorn Bottle.

	Method	
Parameter	**2016**	**2017**
Temperature	YSI 85	YSI Pro DSS
Dissolved Oxygen	YSI Pro D.O.	YSI Pro DSS
Conductivity	YSI 85	YSI Pro DSS
pH	Hach pH meter	YSI Pro DSS
Turbidity	Hach TSS meter	YSI Pro DSS
Nitrates	Hach TNT 835	Hach TNT 835
Phosphates	Hach TNT 843	Hach TNT 843
Total Phosphorous	Hach TNT 843	Hach TNT 843

Electronic Fish Counters

In order to assess the St. Croix River overall efficiency of the St. Croix fish ladders to upstream river herring passage, the SED installed one Smith-Root 1601 electronic fish counter in the exit channel of each dam. DMR trained staff from the DSF and the SED on construction of a 4x4 counter tube array and material guidelines, so the counters were comparable to others located around the state. DSF and the SED collaborated to construct the counter tubes and framing. Each frame was designed to accommodate the unique features of the individual fishways.

Results from the fish counters were compared to the hand count conducted by the SCIWC at Milltown Dam, providing a rough estimate of the percentage of the river herring population that successfully navigated through the main stem of the St. Croix River.

Results and Discussion

I. 2016

In 2016, three data loggers were deployed at Woodland Dam from May to August. No more than three antennas were connected to a single data logger, forming an array. Two data loggers were deployed at Grand Falls Dam. The antennas were deployed from May to August, for the duration of the river herring migration.

The erratic run in 2016 prevented the SED from tagging fish throughout the season. Flow conditions and water temperature may have contributed to the erratic timing and size of the migration. According to hand counts coordinated by the SCIWC at the Milltown Dam fish trap, the run size was small compared to 2015, but still higher than the 10- year average for the system (Table 5; Goreham and Almeda 2016). The SED was on-call with the SCIWC and only able to tag when larger numbers of fish appeared in the trap. This resulted in two tagging days over the entire migration period, after which the run size declined (Table 6; Goreham and Almeda 2016). The first event was unsuccessful, and 51 river herring died prior to release. The second tagging event was successful, and 104 river herring were released into the St. Croix River (Table 7).

Unfortunately, results from the 2016 season are skewed due to non-random sample selection by fish trap operators. This has been discussed and will be corrected in the approaching season.

In early June, 2016, the SED collected, PIT tagged and released 155 river herring from the fish trap at Milltown Dam in two tagging events. Tags with unique codes were inserted into the peritoneal space through a small slice between the ribs, and length measurements were recorded (Appendix A). River herring were transported one km upstream and held to acclimate for one hour in a net pen with untagged fish prior to release.

In the 2017 season, the SED hopes to increase the sample size of tagged river herring for a more comprehensive understanding of fish passage through these ladders. If possible, fish will be tagged throughout the migration season to capture changes in behavior and passage effectiveness at different stages in the run.

In addition, the SED hopes to test various tagging and release methods, including but not limited to: 1) capture, tag and release; 2) capture and truck fish one kilometer upstream, tag, and release; 3) capture, tag, truck, and release fish one kilometer upstream; 4) release fish directly below Woodland Dam; 5) release fish directly below Grand Falls Dam, and 6) repeat these methods with and without a one hour holding period. River herring will be taken directly from the Milltown Dam fish trap, as well as collected with dip nets and cast nets below Milltown Dam.

Milltown Dam Fishway

The 2016 season was delayed, and monitoring will commence in spring 2017.

Woodland Dam Fishway

Successful passage was determined by detection on the entrance (bottom) antenna and subsequent detection on the exit (top) antenna. Of 104 tagged river herring, a total of 12 were detected on the Woodland Dam antennas, with nine detected at the exit of the fish ladder. Passage success was calculated at 75%, or 9 of 12 fish. Using binomial expansion, the data shows, with 97% confidence, that fish passage is >51% at Woodland Dam (Appendix B). The maximum likelihood estimate is 75%, with a 50-90% probability of successful passage; however, preliminary results show that river herring appear to stay in the ladder for long periods of time, reducing overall passage efficiency.

Problems with the lower antennas may have caused reduced detection rates as fish entered the ladder. Although these antennas were tested with the same frequency and success as the upper arrays, when compared to detections on other antennas, data was sparse and only appeared later in the season. In the upcoming season, the addition of beacon tags will help diagnose problems within the antenna arrays. Combined with increased monitoring frequency, these methods should help with early detection and correction of these issues.

A complete shutdown, including power outages and no access to the dam, of Woodland Pulp operations during migration season may have resulted in data loss, if fish were using the ladder during this period. This may be an unavoidable situation, but will be discussed in detail with management prior to the 2017 season.

Grand Falls Dam Fishway

No fish were detected at Grand Falls Dam.

The lack of detections at Grand Falls Dam could be due to a number of issues, including poorly maintained passage facilities or power issues with the PIT tracking equipment. Many baffles in the fish ladder were broken or missing, potentially restricting fish passage. This was brought to the attention of the operators prior to the beginning of the 2016 run, and will hopefully be repaired for the 2017 season.

All antennas performed well when tested throughout the season; however, the lower antennas were often without power. The frequency of power outages on these antennas could have prevented data collection; however, the lack of detection on upper antennas indicated no fish were successfully passing through the Grand Falls Dam fish ladder. Once power was reset to the upper antennas, no other outages occurred. In spring 2017, backup power will be supplied by deep cycle marine batteries, frequently monitored for charge.

Water Quality

Preliminary data suggests a temperature difference between the top and bottom of the dams. D.O. and nutrient levels are within a healthy range. Although inconclusive, this data suggests these locations are clean as a surface water resource (Appendix C).

Electronic Fish Counters

The Smith-Root fish counters were scheduled to be installed in 2017.

II. 2017

Milltown Dam Fishway

The 2017 season was delayed, and monitoring will commence in spring 2018. This was largely due to spring run-off that prevented access to the bottom of the fish ladder, creating high water levels and unsafe conditions.

Two antennas were connected at the second bend in the ladder; however, heavy rain events flooded the electrical source and prevented continued monitoring. The SED chose to forego establishing an alternative power supply for the season, as no fish could be caught from below Milltown Dam given the unsafe conditions at the bottom of the ladder.

Of the antennas installed, two were removed at the request of NB Power to improve flow of water through the ladder. These included the entrance to the ladder and the first frame in the ladder, out of the entrance pool. Not having this information will be a significant gap in analysis and fish passage efficiency and timing estimates.

Woodland Dam Fishway

Grand Falls Dam Fishway

Table 5: Number of river herring per year in the Milltown Dam fish trap. Data from Goreham and Almeda 2016, 2017.

Year	No. of fish
2014	27,312
2015	93,503
2016	33,016
2017	157,750
Ten-year avg. (2008-2017)	47,142

Table 6: Grouped river herring counts for the 2016 and 2017 Season. The peak of the migration is in bold. Data from Goreham and Almeda 2016, 2017.

Date Range	2016	2017
April 14 – April 29	0	-
April 30 - May 2	0	0
May 3 – May 9	0	0
May 10 - May 16	125	369
May 17 – May 23	269	29946
May 24 - May 30	**14304**	**44110**

May 31 - June 6	12781	42406
June 7 – June 13	3038	27681
June 14 - June 20	2000	8790
June 21 – June 27	471	3787
June 28 - July 4	27	571
July 5 – July 11	1	69
July 12 – July 18	-	21
July 19 – July 25	-	0
July 26 - Later	-	-
Total	33016	157750

Table 7: Date, number tagged, and total known mortalities in the 2016 and 2017 seasons.

Date (2016)	**No. of fish tagged**	**Total mortalities**
June 1	51	51
June 9	104	0
Total	155	51

Date (2017)	**No. of fish tagged**	**Total mortalities**
May 23	140	7
June 6	159	1
June 21	98	0
Total	397	8

Water Quality:

Throughout the season, the SED collected water quality data from above and below Grand Falls and Woodland Dams. Measurements were taken in the head pond and tailrace directly in front of the fish ladder entrance and exit. Preliminary data indicates water quality was consistent and did not exceed reportable limits for nitrates or TP. River temperatures peaked in early August. Readings were consistent between sites (Appendix D).

In 2017, the SED planned to deploy HOBO U26 temperature and D.O. sensors in the head pond and tailrace of each dam for the duration of the season. Unfortunately, the loggers were backordered and arrived after the season. They will be deployed in 2018. In addition, HOBO Pro-V2 continuous temperature sensors were deployed along the St. Croix River on August 23, 2017. These will provide valuable data on yearly temperature regimes in the system. A planned collaboration with the SCIWC and the Passamaquoddy at Indian Township will provide a more robust dataset and a deeper understanding of water quality dynamics in the St. Croix Watershed.

Electronic Fish Counters:

The Sipayik Environmental Department installed an automated tube counter at the top of the Milltown fishway within the exit channel; fish would pass through the count immediately after being hand counted and released from the trap. Numbers from the automated counter were compared to the numbers acquired during hand counting. On May 20th the amount of fish being released from the trap exceeded the space available for schooling in front of the automated counter. The counter was closed for the rest of the fish run. On June 7th the fishway was dewatered at low tide and the automated counter was removed. The fishway was dewatered for less than 1.5 hours.

Unfortunately, the percentage of river herring that enter Moosehorn Wildlife Refuge or spawn between Milltown and Woodland Dams is unknown. This would contribute to the
Visual counts calibration

Conclusion

Despite challenges in the field, the 2016 season provided a successful introduction to PIT tagging studies on the St. Croix River. The tagging protocol proved effective, as determined by the detection of 12 fish on the PIT tracking system. Although no results were obtained from Milltown Dam and Grand Falls Dam, the results from Woodland Dam indicate that river herring are passing with a 75% success rate (9 of 12 fish) at that dam. Although this indicates a high success rate, fish appear to be lingering in the ladder, reducing overall passage efficiency.

The SED is excited to take lessons learned in 2016 and apply them to the 2017 season. All three dam owners have granted permission for PIT tracking studies and fish counter installation. The addition of fish counters will help determine population estimates of river herring in the St. Croix River. The counters may also assist in the diagnosis of issues with the PIT tracking equipment or methodology. For example, if the counters are showing high numbers of passing fish, and the PIT system shows no detections, this may indicate a problem within the antenna arrays or an increase in post-tagging mortality or fallback (downstream migration spurred by stress). The data collected from the fish counters and the PIT tracking study may be used to extrapolate passage efficiency to the entire river herring population in the St. Croix River.

River herring face many challenges during their upstream migration. In the St. Croix River, a series of three dams block access to ~98% of their spawning grounds. These dams each have fish passage facilities that are in varying states of disrepair and have not been assessed for passage efficiency in decades. These facilities are imperative to successful upstream migration of anadromous fish. Low passage efficiency may significantly delay or impair migration to spawning grounds, potentially impacting the overall size and reproductive success of the river herring population. In addition, river herring are an important food fish for all trophic levels, input nutrients into lake systems, are economically valuable to the local fishing industry, and are a culturally important species for the Passamaquoddy people in Maine. The restoration of this species will benefit the overall ecosystem and protect a traditional food source for future generations.

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Appendix A Raw data from tagging events, 2016

Table 8: Raw data from the tagging event on June 1, 2016. All river herring died post-surgery. Mortality was deemed unrelated to the tagging procedure.

Tag number	Length (mm)	Sex (M/F/Unknown)	Notes: (all fish died, one possibly made it)
200	265	F	
201	240	F	
202	240	M	large incision
203	280	U	
204	250	F	
205	264	M	
206	272	F	
207	269	F	
208	264	M	
209	269	F	
210	270	M	
211	244	M	
212	264	F	
213	229	U	Feisty (tried to escape multiple times)
214	242	M	
215	218	M	
216	250	M	already bleeding before tagging
217	256	M	bird damage along one side
218	255	M	
219	250	M	
220	260	M	
221	240	M	
222	274	F	
223	255	M	
224	270	U	
225	268	M	
226	270	F	
227	250	M	
228	250	M	
229	250	M	a little over 250mm
230	248	M	
231	250	F	
232	250	M	
233	252	M	red mark near place of incision (present before incision was made)

Tag number	Length (mm)	Sex (M/F/Unknown)	Notes: (all fish died, one possibly made it)
234	255	F	
235	260	F	
236	255	U	
237	235	M	
238	261	U	
239	255	F	
240	270	M	
241	236	M	damage around pelvic fin
242	255	M	
243	250	M	
244	235	F	
245	240	M	
246	260	M	
247		F	
248	260	M	
249	250	U	
250	240	M	

Table 9: Raw data from the tagging event on June 9, 2016. River herring were successfully tagged, transported 1 km upstream from their collection site at Milltown Dam, held for an hour in a net pen, and released.

Tag number	Length (mm)	Notes
101	240	incision tore, hemorrhaging
102	255	large incision
103	270	
104	260	
105	255	
106	245	
107	272	
108	255	claw marks pelvic to anal fin
109	245	missing scales
110	230	claw marks, missing scales, incision tore
111	235	large incision
112	252	
113	270	
114	274	
115	285	
116	262	hemorrhaging on side
117	260	hemorrhaging
118	230	incision tore
119	250	
120	270	
121	245	
122	255	hemorrhaging
123	245	
124	265	
125	250	
126	260	incision tore
127	245	little more blood
128	260	
129	270	
130	250	
131	255	
132	240	
133	265	missing scales
134	235	
135	260	
136	240	
137	250	

Tag number	Length (mm)	Notes
138	270	healed claw marks
139	275	
140	250	
141	232	big incision
142	240	hemorrhaging
143	245	missing scales
144	240	
145	265	tail fin half rapped off, large incision
146	265	
147	255	
148	245	scales missing, incision tore
149	270	
150	265	
151	265	scales missing, large incision
152	265	
153	240	hemorrhaging
154	260	
155	238	
156	255	missing scales, damage on tail fin/anal fin
157	250	tail chewed up
251	245	
252	262	bled when incision was done (deep)
253	260	
254	270	
255	242	deep incision
256	219	
257	250	
258	265	
259	240	
260	270	
261	255	
262	250	
263	280	fell on ground & lap
264	265	
265	265	tore incision (big)
266	250	
267	250	
268	221	
269	262	incision bled
270	260	tore incision
271	230	
272	248	tore incision
273	245	
274	265	
275	250	

Tag number	Length (mm)	Notes
276	240	hemorrhaging on side
277	230	
278	250	missing scales
279	245	
280	246	regenerating scales/ hemorrhaging
281	270	
282	250	hemorrhaging
283	273	
284	250	large incision
285	260	
286	240	
287	208	
288	240	regenerating scales
289	240	claw mark by pelvic fin, anal fin had a slice
290	255	
291	245	
292		
293		
294	246	hemorrhaging on side, missing scales
295	255	
296	260	missing scales
297	255	
298	276	
299	245	

Appendix B Binomial distribution for Woodland Dam, 2016

Table 10: Select results of the binomial expansion of a 75% passage rate (9 of 12 fish) at Woodland Dam. This shows with 97% confidence that fish are successfully passing through the ladder >51% of the time. The probability that a fish will pass successfully is between 50-90%. Worksheet provided by Theodore Castro-Santos (USGS).

Nenter	**12.000**
Nexit	**9.000**
	0.750
0.516	0.975
0.517	0.975
0.518	0.974
0.519	0.974
0.520	0.973
0.521	0.973
0.522	0.972
0.523	0.972
0.524	0.972
0.525	0.971
0.526	0.971
0.527	0.970
0.528	0.970
0.529	0.969
0.530	0.969
0.531	0.968
0.532	0.968
0.533	0.967
0.534	0.967
0.535	0.966
0.536	0.966
0.537	0.965

Nenter	**12.000**
Nexit	**9.000**
	0.750
0.538	0.965
0.539	0.964
0.540	0.964
0.541	0.963
0.542	0.963
0.543	0.962
0.544	0.961
0.545	0.961
0.546	0.960
0.547	0.960
0.548	0.959
0.549	0.958
0.550	0.958
0.551	0.957
0.552	0.957
0.553	0.956
0.554	0.955
0.555	0.955
0.556	0.954
0.557	0.953
0.558	0.953
0.559	0.952

Appendix C Water Quality Parameters, 2016

Table 11: Water quality parameters for Grand Falls (STCR GF) and Woodland (SC WM), sampled from the top and bottom of the fish ladders. Data collected and provided by William Longfellow, Sipayik Environmental Department.

Date (MM/DD/YY)	Site ID	Depth (ft)	Lake Horizon	Temp (^oC)	pH	DO (mg/L)	Conductivity (µS)	Turbidity (NTU)	Nitrogen (NO3-N) (ug/L)	Phosphorous (PO_4^{3-}) (ug/L)	TP (PO_4-P) (ug/L)
6/14/2016	STCR GF Bottom	1.0	Surface	16.0	6.00	8.66	23.50	1.43	<230	<60	<20
7/15/2016	STCR GF Bottom	1.0	Surface	23.5	7.28	7.93	27.00	1.45	<230	<60	<20
7/18/2016	STCR GF Bottom	1.0	Surface	24.0	6.90	7.51	27.30	1.25	<230	<60	<20
8/10/2016	STCR GF Bottom	1.0	Surface	24.0		7.70	27.50	1.40	<230	<60	<20
			mean	**21.88**	**6.73**	**7.95**	**26.33**	**1.38**			
			median	23.8	6.9	7.8	27.2	1.4			
			range	8.0	1.3	1.2	4.0	0.2			
6/14/2016	STCR GF Top	1.0	Surface	16.0	6.56	8.61	28.50	1.34	246.00	<60	<20
7/15/2016	STCR GF Top	1.0	Surface	23.1	6.70	7.92	25.50	1.25	<230	<60	<20
7/18/2016	STCR GF Top	1.0	Surface	24.0	7.05	7.38	28.00	9.73	<230	<60	<20
			mean	**21.03**	**6.77**	**7.97**	**27.33**	**4.11**			
			median	23.1	6.7	7.9	28.0	1.3			
			range	8.0	0.5	1.2	3.0	8.5			
6/2/2016	SC WM Top	1.0	Surface	19.1	6.74	8.30	23.50	1.04	<230	<60	<20
6/15/2016	SC WM Top	1.0	Surface	16.3	6.64	8.49	23.10	1.35	<230	<60	<20
			mean	17.7	6.7	8.4	23.3	1.2			
			median	17.7	6.7	8.4	23.3	1.2			
			range	2.8	0.1	0.2	0.4	0.3			
6/2/2016	SC WM Bottom	1.0	Surface	16.5	6.10	8.74	22.90	4.19	<230	<60	<20
6/15/2016	SC WM Bottom	1.0	Surface	18.8	6.61	8.05	23.70	1.48	<230	<60	<20
			mean	17.7	6.4	8.4	23.3	2.8			
			median	17.7	6.4	8.4	23.3	2.8			
			range	2.3	0.5	0.7	0.8	2.7			

Appendix D Water Quality Parameters, 2017

Table 12: Water quality parameters for Grand Falls (STCR GF) and Woodland (SC WM), sampled from the top and bottom of the fish ladders. NA values indicate that the sensor was not working properly. Data collected and provided by William Longfellow, Sipayik Environmental Department.

Date (MM/DD/YY)	Site ID	Depth (ft)	Lake Horizon	Temp (^oC)	pH	DO (mg/L)	Conductivity (µS)	Turbidity (NTU)	Nitrogen (NO3-N) (ug/L)	Phosphorous (PO_4^{3-}) (ug/L)	TP (PO_4-P) (ug/L)
6/28/2017	STCR GF Bottom	1.0	Surface	22.10	6.85	8.41	27.20	0.10	<230	<60	<20
8/28/2017	STCR GF Bottom	1.0	Surface	21.60	6.58	8.29	27.20	0.10	<230	<60	<20
			mean	**21.85**	**6.85**	**8.41**	**27.20**	**0.10**			
			median	21.85	6.72	8.35	27.20	0.10			
			range	0.50	0.27	0.12	0.00	0.00			
5/31/2017	STCR GF Top	1.0	Surface	15.70	NA	8.87	25.30	1.37	<230	<60	<20
6/5/2017	STCR GF Top	1.0	Surface	16.90	6.69	8.81	20.80	0.20	<230	<60	<20
6/12/2017	STCR GF Top	1.0	Surface	16.90	6.71	9.09	21.00	0.10	<230	<60	<20
6/28/2017	STCR GF Top	1.0	Surface	21.90	6.88	8.16	26.90	0.10	<230	<60	<20
7/28/2017	STCR GF Top	1.0	Surface	22.70	7.05	7.74	27.80	1.20	<230	<60	<20
8/28/2017	STCR GF Top	1.0	Surface	21.50	7.03	8.15	26.60	1.40	<230	<60	<20
			mean	**19.27**	**6.87**	**8.47**	**24.73**	**0.73**			
			median	19.20	6.88	8.49	25.95	0.70			
			range	7.00	0.36	1.35	7.00	1.30			
5/31/2017	SC WM Top	1.0	Surface	15.70	NA	8.67	25.20	1.00	<230	<60	<20
6/5/2017	SC WM Top	1.0	Surface	17.30	6.53	8.69	21.50	0.20	<230	<60	<20
6/12/2017	SC WM Top	1.0	Surface	17.30	6.49	8.71	21.20	0.20	<230	<60	<20
6/28/2017	SC WM Top	1.0	Surface	22.10	6.94	7.88	26.90	0.10	<230	<60	<20
			mean	18.10	6.65	8.49	23.70	0.38			
			median	17.30	6.53	8.68	23.35	0.20			
			range	6.40	0.45	0.83	5.70	0.90			
6/28/2017	SC WM Bottom	1.0	Surface	21.80	7.50	7.99	27.00	0.40	<230	<60	<20
			mean	21.80	7.50	7.99	27.00	0.40			
			median	21.80	7.50	7.99	27.00	0.40			
			range	0.00	0.00	0.00	0.00	0.00			