Supporting Alewife Restoration in the St. Croix/Skutik Watershed – Anadromous Fish Telemetry Project

Contract number: P2300053 – International Joint Commission, Canadian Section

Abstract

The St. Croix (Skutik) River has been a focus of recovery for river herring and other sea-run fishes in recent years. With increasing numbers of river herring reaching the first dam impoundment on the river, and with passage required at several other mainstem impoundments to reach spawning habitat, data on fish passage at dams is needed to inform future planning in the watershed around river herring recovery. With the decommissioning of the Milltown Generating Station (MGS) anticipated to begin in 2023, this information will become increasingly useful to assess the success of river restoration on the overall river herring population. To assess these important questions, Passive Integrated Transponder (PIT) tags were utilized to tag 525 river herring (Alewife and Blueback Herring) and opportunistically tag 8 American Shad at the MGS fish trap in 2022. These individuals, along with others tagged in previous years were tracked through PIT antenna arrays located at MGS, Magurrewock Stream, Woodland dam, Grand Falls dam, and Vanceboro dam. Data was downloaded from the antenna arrays on a daily to weekly basis and was compiled and manipulated in RStudio® computer software. 629 Fish (some tagged in previous years) were detected exiting MGS, 89 fish were detected exiting the Woodland fishway, and 51 fish were detected exiting the Grand Falls fishway. No fish were detected at the Vanceboro dam. Evidence of stream infidelity was found with river herring tagged in previous years at Dennis stream (Canada) and Magaguadavic River (Canada) that were detected in the Skutik River in 2022.

Introduction

River herring (alewife and blueback herring) are an anadromous fish species found throughout the northeastern United States and Atlantic Canada, and are considered a keystone species within river systems, delivering marine derived nutrients to the freshwater ecosystem, providing forage to predators, functioning as hosts to some freshwater mussels, and acting as a predation buffer to other anadromous fish species (Hare et al., 2021). The St. Croix/Skutik river forms the eastern boundary between Maine, USA, and New Brunswick, Canada, and forms the largest watershed between the Penobscot and Saint John/Wolastoq river drainages. Damming along the Skutik river's mainstem began in the 1800's, with five dams currently spanning the mainstem and East branch (international branch): Milltown Generating Station (MGS), Woodland dam, Grand Falls dam, Vanceboro dam, and Forest City dam. Annual river herring counts at MGS during the Spring spawning migration have been conducted since 1981 following the construction of a new fishway. Significant declines in river herring counts at

MGS were recorded after closures to upstream fishways located at Vanceboro, Grand Falls, and Woodland dams between 1987 and 1995. Following the reopening of the Woodland fishway in 2008 and the Grand Falls fishway in 2013, river herring counts have increased at MGS, with 712,878 fish counted in 2022.

It is estimated that the Skutik watershed has the potential to support the largest river herring spawning migration in North America (Limnotech, 2020; Gibson et al., 2017). Alewife (*Alosa pseudoharengus*) migrate upstream to spawn in ponds and lakes, while blueback herring (*Alosa aestivalis*) prefer flowing water of rivers and streams for spawning (NMFS, 2019). The majority of available spawning habitat for alewives (98%) lies upstream of the Grand Falls dam located on the mainstem of the Skutik river (Billard and Hoar, 2021). It is above the Grand Falls dam in Grand Falls Flowage where the East (international) and West branches of the Skutik River meet. To gain access to critical spawning grounds, river herring and in particular, alewives, must ascend the first three dam impoundments found on the mainstem of the Skutik river: MGS, Woodland dam, and Grand Falls dam. Past studies on river herring in the Skutik watershed have examined the ability of the mainstem impoundments to pass migrating river herring. It is estimated that only 50% of the total river herring spawning population can ascend the fishway at MGS, between 25.2%-65.5% of the fish that passed MGS were able to pass the Woodland dam, and between 48.1%-83.3% of the fish that passed Woodland were able to pass the Grand Falls dam (Peskotomuhkati Nation at Skutik, 2019).

With the scheduled decommissioning of MGS in 2023, as well as planned improvements to fish passage at Woodland and Grand Falls dams, data collected in assessing river herring passage at these dams will help with understanding the dynamics that large scale restoration efforts can have on the overall river herring population. In efforts to monitor the present potential barriers, the St. Croix International Waterway Commission (SCIWC), Sipayik Environmental Department (SED), Passamaquoddy Tribe at Indian Township, and Peskotomuhkati Recognition Group Inc. (PRGI), representing the Peskotomukhati Nation at Skutik used Passive Integrative Transponder (PIT) tags along with detection antennas placed along 5 fishways within the river to study movement and passage of river herring. Tagging and data collection efforts in the Skutik began in 2017, with SED tagging river herring below MGS using cast nets. SED tagged 592 fish in 2018, with 27 fish tagged by SCIWC in Magurrewock Stream, a tributary to the Skutik located in the Moosehorn National Wildlife Refuge, outside Calais, Maine. In 2019, SCIWC tagged a total of 465 river herring at the Magurrewock Stream fishway. In 2021, SCIWC in partnership with PRGI and Passamaquoddy Tribe at Indian Township tagged a total of 503 fish at the MGS fish trap located near the fishway exit. Also in 2021, PRGI began PIT tagging as part of their Quoddy Region River, Estuary, and Coastal Restoration Plan, tagging 17 fish, which included river herring, American Eel, and American Shad in the Skutik river basin, 174 river herring at the St. George dam located at the head of tide of the Magaguadavic River (Canada), and 127 river herring at Middle Lake dam located on Dennis Stream (Canada), which flows into the Skutik estuary.

Methods

TAGGING

Tagging was staggered throughout the river herring upstream migration, beginning in early May, and ending in late June. The number of fish tagged per week increased coinciding with increasing counts at MGS, and tagging efforts decreased with decreasing counts (Table 1). The first fish were tagged on May 4, 2022, and the last fish were tagged on June 30, 2022. 8 American Shad were tagged between May 26, 2022, and June 30, 2022. PIT tags were inserted into river herring and American Shad through a small incision made behind the pelvic fin with a surgical scalpel sanitized with rubbing alcohol (Figure 1).

Figure 1. PIT tag being inserted into river herring (left) and fish placed in recovery tote following tagging (right).

Tagging occurred at the top of the MGS fishway at the fish trap. A screen was inserted to close the exit of the trap and fish were captured using a dip net one at a time, fish were placed into a holding tote containing a general clove oil anesthetic mixed with water from the fishway. Anesthesia was used to avoid stress during handling and tagging. Once the fish were visually calm, fork length and weight were recorded, scale samples were collected dorsally between the dorsal fin and lateral line, followed by the insertion of the pre-recorded PIT tag before placing the fish into a recovery tote that allowed for slow flowing river water to pass through the tote (Figure 1). Fish were released into the fishway trap without the exit screen when fish were observed to have normal swimming and schooling behaviour.

TRACKING

To detect the tagged fish, 10 antennas were set up at five fishways along the river: MGS, Magurrewock Stream, Woodland dam, Grand Falls dam, and Vanceboro dam. Three antennas were installed at MGS, one antenna at Magurrewock, three antennas at Woodland, two antennas at Grand Falls, and one at Vanceboro dam (Figures 2-3). There were two more antennas installed in 2022 than in 2021. The addition of third antennas at MGS and Woodland dams were installed to help increase chances of detection and to better detect fish at the true entrance/exits of the fishways for analysis of passage efficiency. All antennas were built as pass-through antennas using 12G AWG stranded copper wire to an inductance ranging from 41.8 to 78 µH and housed inside PVC pipe with an average of three loops (Table 2).

Table 1. Summary of PIT antenna and monitoring equipment installed in the Skutik River in 2022.

Location	Antenna	Inductance (µH)	Marker Tag	Reader Name	Power Source
MGS	Entrance (A1)	60.9	Yes	Milltown Entrance	Outlet
	Old Exit (A1)	78	Yes	Milltown Exit	Outlet
	New Exit (A2)	53.7	Yes		Outlet
Magurrewock	Exit (A2)	58.8	No	Magurrewock Exit	Marine Battery
Woodland	Entrance (A1)	42.0	Yes	Woodland Entrance	Outlet
	Second (A2)	42.8	Yes		Outlet
	Exit (A1)	42.6	Yes	Woodland Exit	Outlet
Grand Falls	Exit	41.8	Yes	Grand Falls Exit	Outlet
	Entrance	43.4	Yes	Grand Falls Entrance	Outlet
Vanceboro	Middle - Exit (A1)	73.9	No	Vanceboro	Outlet

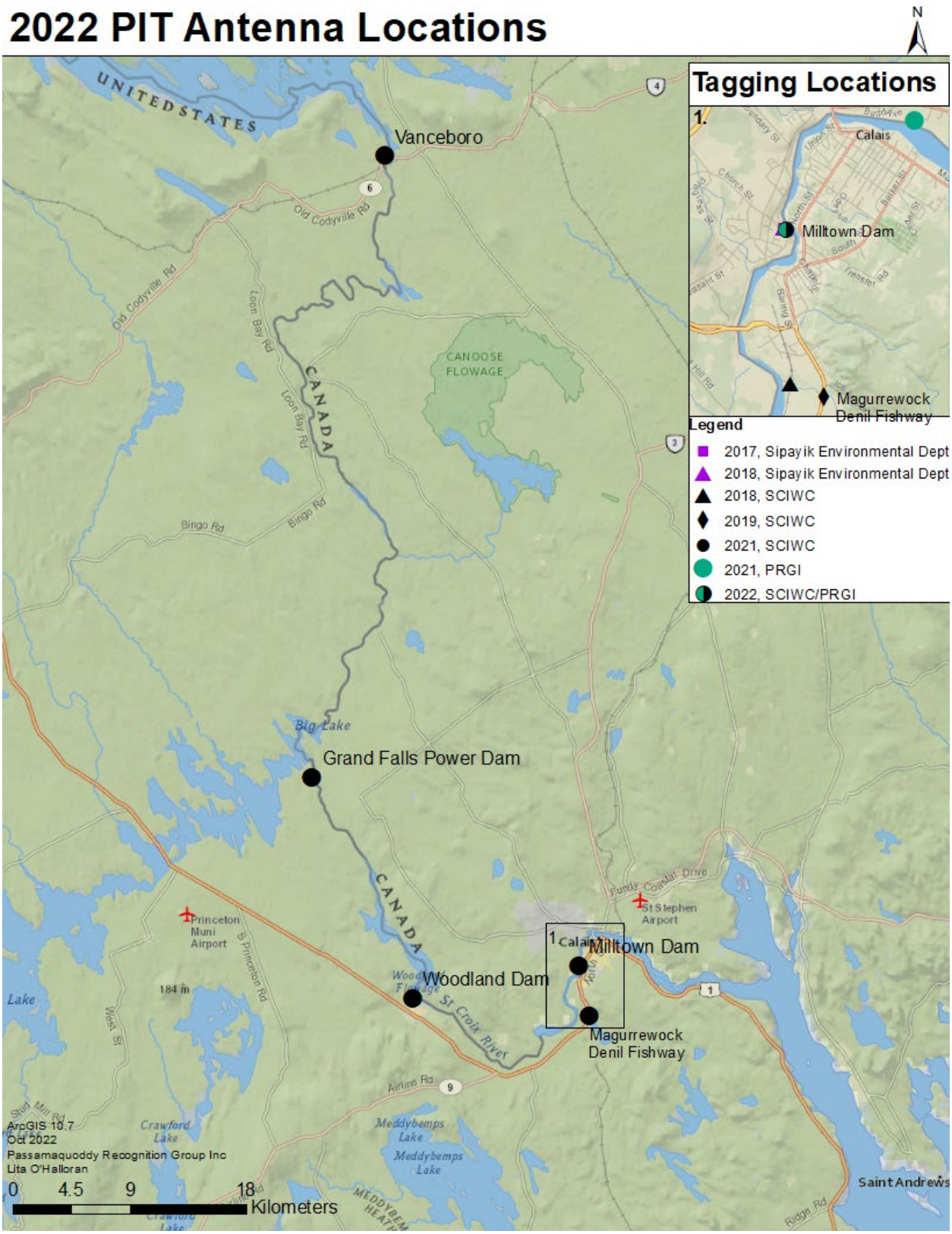


Figure 2. Locations of PIT antenna arrays and tagging locations.

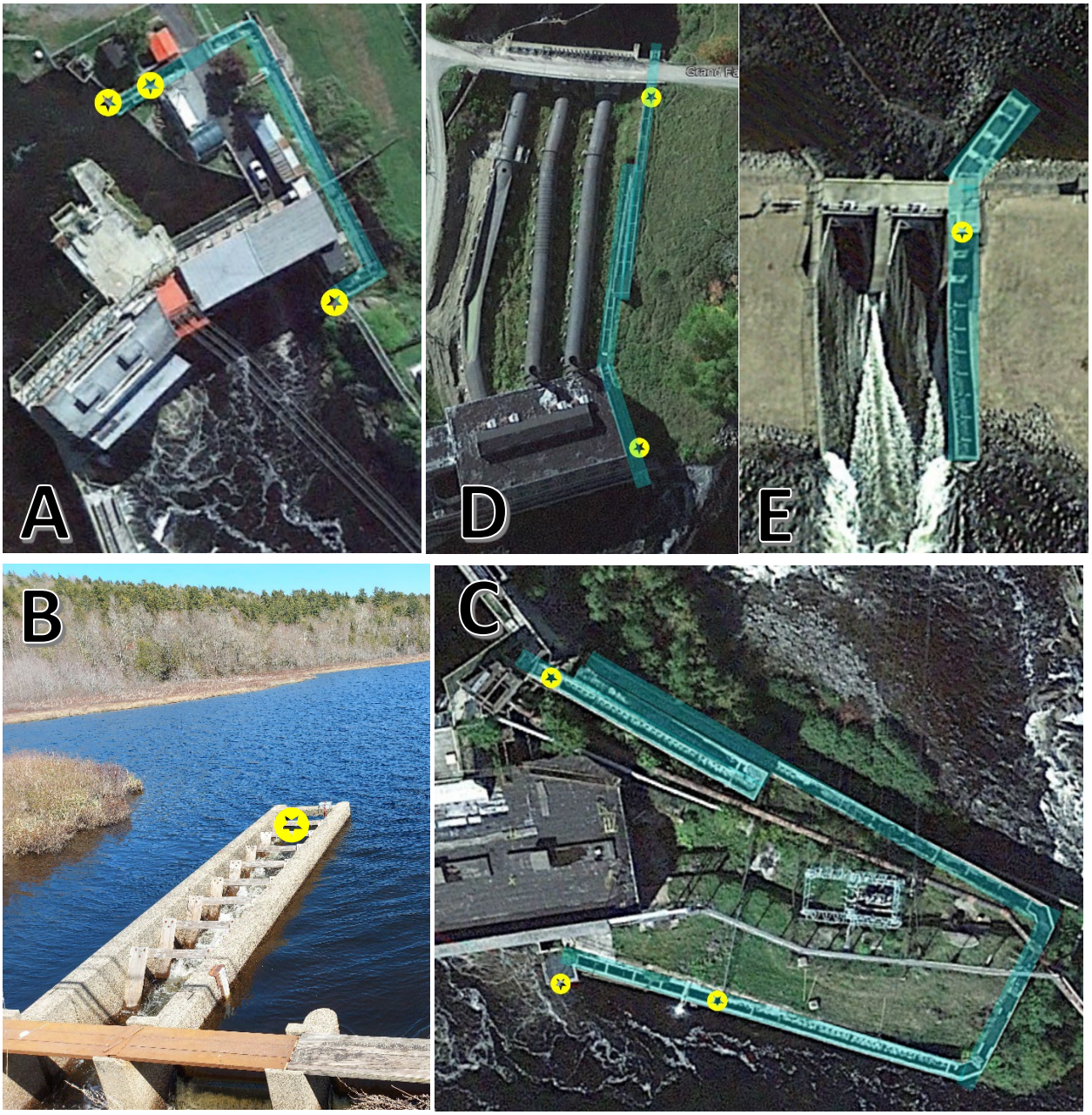


Figure 3. Location of antennas noted by the yellow star at A) Milltown Generating Station, B) Magurrewock Stream, C) Woodland dam, D) Grand Falls dam, and E) Vanceboro dam. Fishways are highlighted in blue.

At MGS, the first antenna was located at the fishway entrance on a sluice gate and installed on May 4, 2022, the second antenna was located at the weir upstream of the research trap where tagging occurred, and the third at the fishway exit (Figure 3-A). Tagged river herring at MGS were released from the recovery tote in groups. Given that antennas are only able to detect one tag at a time, it was possible that grouped tagged fish could go undetected by the middle antenna (Figure 3-A). To resolve

this issue the third antenna 'New Exit' (Figure 3-A) was installed this year to increase the probability of detection, and to determine if the fish truly exited the fishway and did not just pool in the fishway trap and drop downstream. At the Magurrewock fishway, located under Route 1 in Calais, Maine, one antenna was installed at the fishway exit (Figure 3-B). The Woodland dam had a total of three antennas installed; one antenna located at the true entrance of the fishway, a second antenna several weirs above the entrance to differentiate fish that were pooling at the entrance from fish actively attempting ascension of the fishway, and a third antenna at the exit of the fishway (Figure 3-C). Grand Falls dam was equipped with a total of two antennas. The first antenna was installed at the entrance of the fishway, followed by a second antenna at the exit (Figure 3-D). One exit antenna was installed at the Vanceboro dam, approximately four weirs downstream of the true exit (Figure 3-E). This location was chosen due to safety concerns of installing the antenna at the true exit. At MGS, Woodland, Grand Falls, and Vanceboro dams, antennas were supplied with power from an outlet. The Magurrewock fishway is not equipped with a power source, therefore parallel run marine batteries were used as a power supply. Marker tags were utilized to verify active antenna function. Tags were installed at all antennas at MGS, the first antenna and exit antenna of the Woodland fishway, as well as at both antennas at Grand Falls. Marker tags installed at Grand Falls were not functional and inaccessible to be replaced during the study period. No marker tag was installed at Magurrewock due to concerns of draining the batteries powering the antenna. Vanceboro was not equipped with a marker tag, due to marker tags being on backorder and unsafe water levels for installation. In addition to marker tags, staff kept record of antenna function during visits, recording any instances in which antennas were not functioning, and any adjustments and regular maintenance executed.

DATA ACQUISTION AND MAINTENANCE

At the beginning of the 2022 study period, any data from previous years was cleared from the readers to ensure maximum storage availability. Readers were set up to record tags in decimal format. Throughout the field season, readers were visited a minimum of once a week, though usually visits occurred twice a week. Raw detection data was uploaded onto a Panasonic Toughbook laptop utilizing the terminal software 'PuTTY', using the settings of all session output for session logging, and a serial speed of 57600. Filenames were saved according to location, antenna name, and date downloaded which was prepopulated by the PuTTY software (e.g., "Milltown_entrance05172022141735.PUTTY"). Raw data files were uploaded to a fileshare, sorted by dam, and reviewed using Notepad software. During site visits, antenna functionality was tested by tuning all antennas using a tuning indicator tool, and detection ability by using a test tag. In addition, date and time was checked and adjusted if time was drifting. If during a site visit a reader was non-functioning due to disturbance or power supply issues, this was noted in a field book and the issue was resolved. When readers were found to be potentially damaged, they were replaced with a spare reader to minimize loss of data for the remainder of the study period.

DATA QUALITY AND ANALYSIS

All data collected underwent cleaning and analysis by PRGI. Data cleaning included confirming all data on scale envelopes matched data recorded in field books for tagged fish and confirming that there were no typos in the date, tag number, or scale number (fish number). Fork lengths and weights were reviewed for outliers. This was completed by the tagging staff after tagging was completed on the same day. Data entered in the database was cleaned again and analyzed in the coding program RStudio. Database cleaning in RStudio including checking for typos, confirming data was consistently recorded, double checking for outliers, and checking that fish ID numbers were unique. Once tag data was cleaned, all downloaded detection data from the PIT readers were merged into one flatfile. Antennas were ordered from lowest downstream to highest upstream to calculate fish direction/timing. Detection data from marker tags, test tags, and reader operational data were removed. Tag data from both 2022 and previous tagging years was merged using the R packages 'PITR', 'tidyr', 'dplyr', and 'lubridate' with the reader data to allow for analysis of both detected and undetected river herring.

Results

FISH TAGGED

A total of 525 river herring were tagged in 2022, as well as 8 American shad, for a total of 533 fish tagged. For river herring, a relatively even distribution of males and females were tagged with 292 females (55.6%), 227 males (43.2%), and 6 unidentified (1.1%) fish. Tagging efforts were concentrated during the time of peak spawning migration, with less fish tagged during the start and end of the spawning migration (Table 1).

Table 2. 2022 River herring tagging schedule at Milltown generating station.

Weeks	Fish tagged per week	Proportion of fish tagged per week	Proportion of total weekly counts at MGS
May 3– May 9	10	1.9%	1.1%
May 10 – May 16	89	16.9%	35%
May 17 – May 23	58	11.0%	20.9%
May 24 – May 30	118	22.6%	31.0%
May 31 – June 6	121	23.0%	10.0%
June 7 – June 13	90	17.1%	1.0%
June 14 – June 20	0	0.0%	1.0%
June 21 – June 27	13	2.5%	0.0%
June 28 – July 4	26	5.0%	0.0%
July 5 – July 11	0	0.0%	0.0%

Antenna Functionality

Marker tags were installed at every antenna except for the Magurrewock and Vanceboro antennas. Marker tags at Grand Falls entrance and the second entrance antenna at Woodland did not function either due to water damage, or dead batteries. These marker tags could not be safely accessed in order to fix these issues. Marker tags helped to assess when fish were going undetected because of antenna/reader functionality or due to the lack of tagged fish present. Based on analysis of marker tag detections and antenna detections, there were some antenna functionality issues noted at the MGS final exit antenna at the end of May, and some potential for missed detections at Woodland entrance at the end of April (Figure 5).

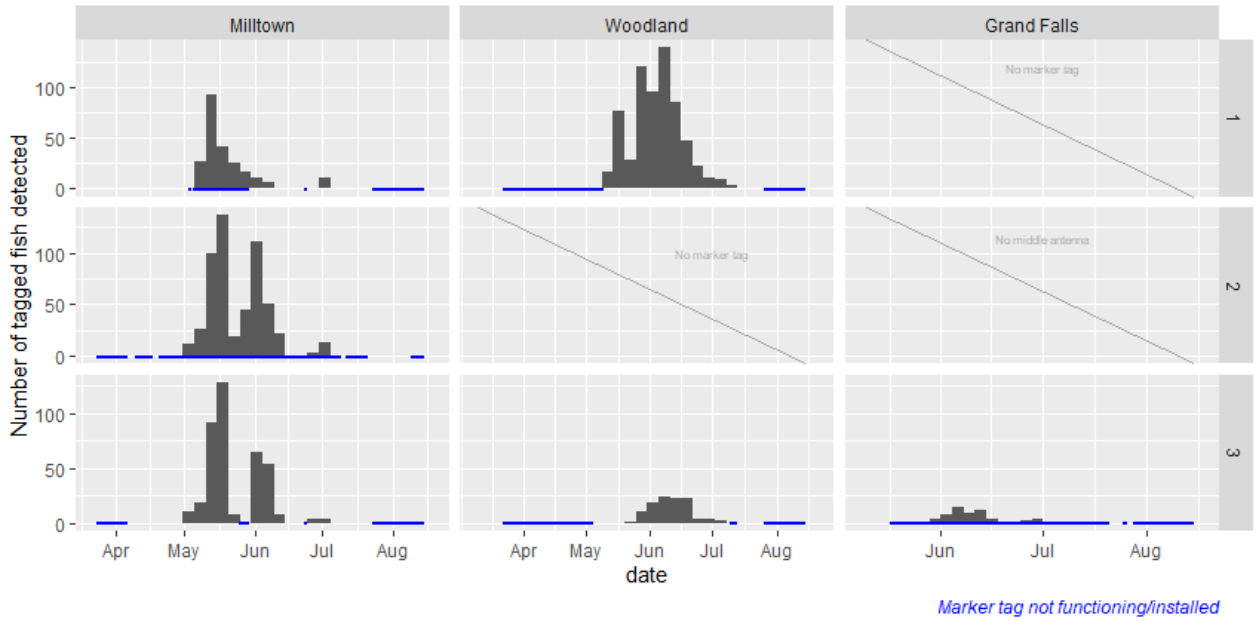


Figure 4. Number of fish detected per dam and antenna with marker tag functionality. Blue lines indicate time periods where marker tags were non-functional or not installed. Note: numbers on right axis indicate antenna number ranging from lowest downstream (1) to highest upstream (3).

Since the Magurrewock antenna was powered by batteries, there were instances where the batteries died before the subsequent site visit which resulted in gaps in functionality. In total this antenna was not operational for 206 hours of the study period. However, there were only two instances where there was no power for more than 24 hours (May 9-11, and June 4-6). Even though there were minor power outages, the antenna was functional for much of the study period. At Magurrewock, only two tagged fish were detected (Figure 6). The antenna at Vanceboro was functional for 62 of the 70 days it was installed (88.5%) from May 17 to July 26. However, during the period of June 16-30th a test tag was mistakenly placed withing detection range of the antenna. This severely impacted the ability to detect

fish as the test tag was constantly being read and would not have picked up any other tags during this time. This reduced antenna functional days to 53/70 days (75.7%) (Figure 7).

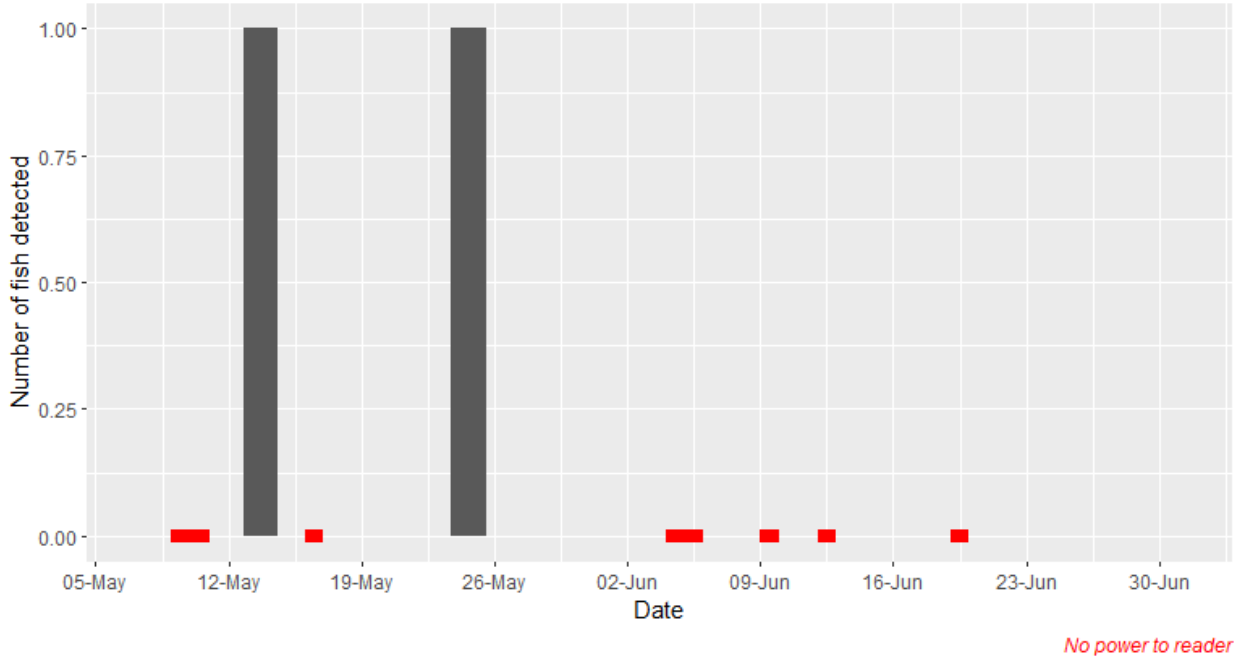


Figure 5. Number of fish detected and power supply functionality at the Magurrewock Stream denil fishway. Red bars indicate periods of time where there was no power to the antenna.

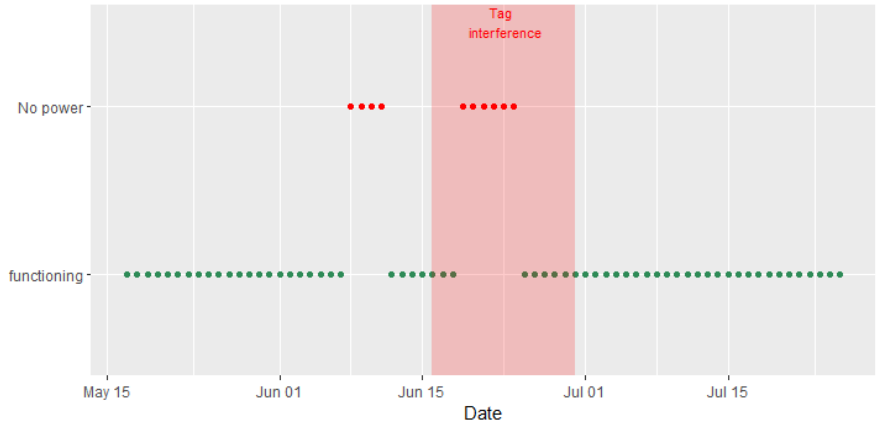


Figure 6. Vanceboro antenna functionality over the duration of the study period.

Detections

643 individual fish were detected by antennas in 2022. Of these 643 fish, 179 were found to be returns, tagged in the Skutik river in previous years (Figure 8). One of these returns was later determined to be a

river herring tagged in the Magaguadavic River basin (Canada) by PRGI in 2021 and was detected at the entrance of MGS in 2022; but did not ascend any of the fishways successfully. Of the 533 fish tagged in 2022, 464 were detected after tagging; 70 fish tagged in 2022 were not detected. Of the 8 American shad tagged in 2022, 2 were determined to have exited the fishway in Milltown successfully, no tagged shad were detected at any of the other upstream antennas.

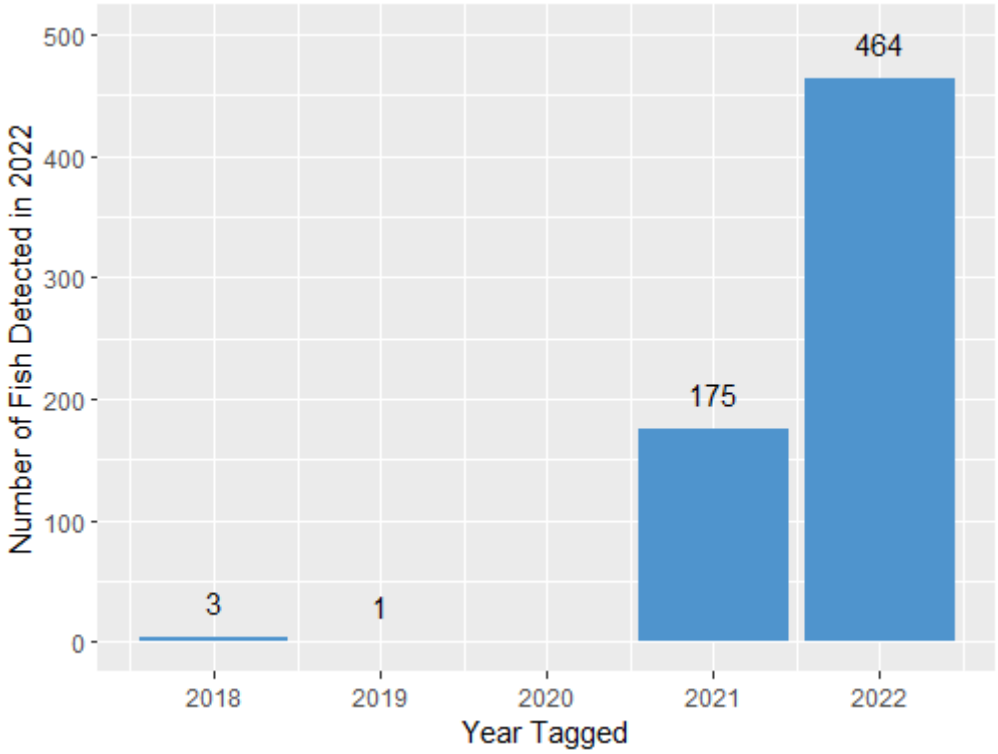
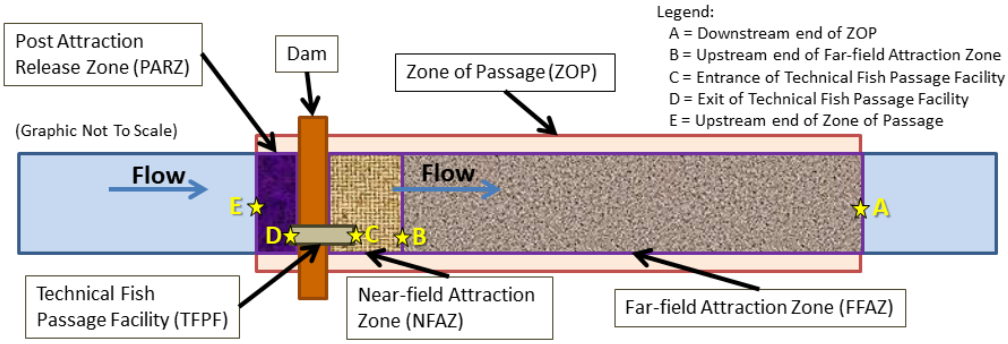


Figure 7. Fish detections in 2022 showing the year the fish were tagged in.

To understand efficiency of the fishways, exit efficiency was calculated individually for each dam that was equipped with both entrance and exit antennas, as well as calculating the percentage of tagged fish that were able to ascend subsequent fishways upstream of MGS. The term “exit efficiency” used in this report refers to the proportion of tagged fish that entered and exited the technical fish passage facility,

meaning that the fish was detected at both the entrance and exit antennas, or the exit antenna. “Exit efficiency” can also refer to “technical fish passageway efficiency” (Figure 8).



Far-field Attraction Efficiency. The proportion of the migrating population that successfully passes through the area of the Far-field Attraction Zone; e.g., the proportion of fish that start at A and travel to B.

Entrance Attraction Efficiency. The proportion of the migrating population which has passed the Far-field Attraction Zone and successfully enters the Technical Fish Passage Facility; e.g., the proportion of fish that pass B and enter C.

Technical Fish Passageway Efficiency. The proportion of the migrating population that has entered the Technical Fish Passage Facility and successfully exits it; e.g., the proportion of fish that start at C and pass D.

Total Passage Efficiency. The proportion of the migrating population that successfully passes through the entire Zone of Passage; e.g.. the proportion of the fish that start at A and travel to E without falling back.

Figure 8. Diagram illustrating technical fish passage terms.

To minimize the effect of antenna functionality, as detections can be missed due to malfunction, noise, and large numbers of fish passing the antenna at once, the assumption was made that if a fish was detected at an upstream antenna, it must have passed by any antennas downstream. Using this assumption, it was found that of the 643 fish that entered the fishway at MGS, 629 (97.8%) were detected exiting MGS, 2 (0.3%) were detected entering the fishway at Magurrewock Stream, 89 (13.9%) of the fish exited the Woodland fishway, and 51 (7.9%) exited the Grand Falls fishway (Table 4). No fish were detected at the Vanceboro dam during the study period.

Table 3. Exit efficiency of individual fishways for tagged fish, as well as the proportion of tagged fish that were able to exit subsequent upstream dams.

Dam	Number of tagged fish entering fishway	Number of tagged fish exiting fishway	Calculated fishway passage efficiency (%)	Proportion of all tagged fish passing dams of initially detected Fish at Milltown Entrance (%)
MGS	643	629	N/A*	97.8%
Magurrewock**	2	N/A***	N/A***	0.3%
Woodland	326	89	27.3%	13.9%
Grand Falls	56	51	91.1%	7.9%
Vanceboro	0	N/A***	N/A***	0%

*Note: fishway passage efficiency cannot be calculated for MGS due to tagging taking place inside the fishway.

**Note: not a mainstem dam, therefore the number of fish detected at Magurrewock will be subtracted from total detections along the mainstem for calculation of passage efficiency.
*** Note: No exit antenna at these dams.

Further analysis focused on passage time. Passage time was calculated within dams using the first detection of the fish at the entrance antenna of a dam and subtracting this time from the last detection at the dam's exit antenna. This was done for any fish detected both at MGS' entrance and exit antennas,

Woodland's entrance and exit antennas, and Grand Falls entrance and exit antennas. On average fish spent 9.03 hours at MGS, 80.03 hours at Woodland Dam, and 1.25 hours at Grand Falls Dam (Figure 9).

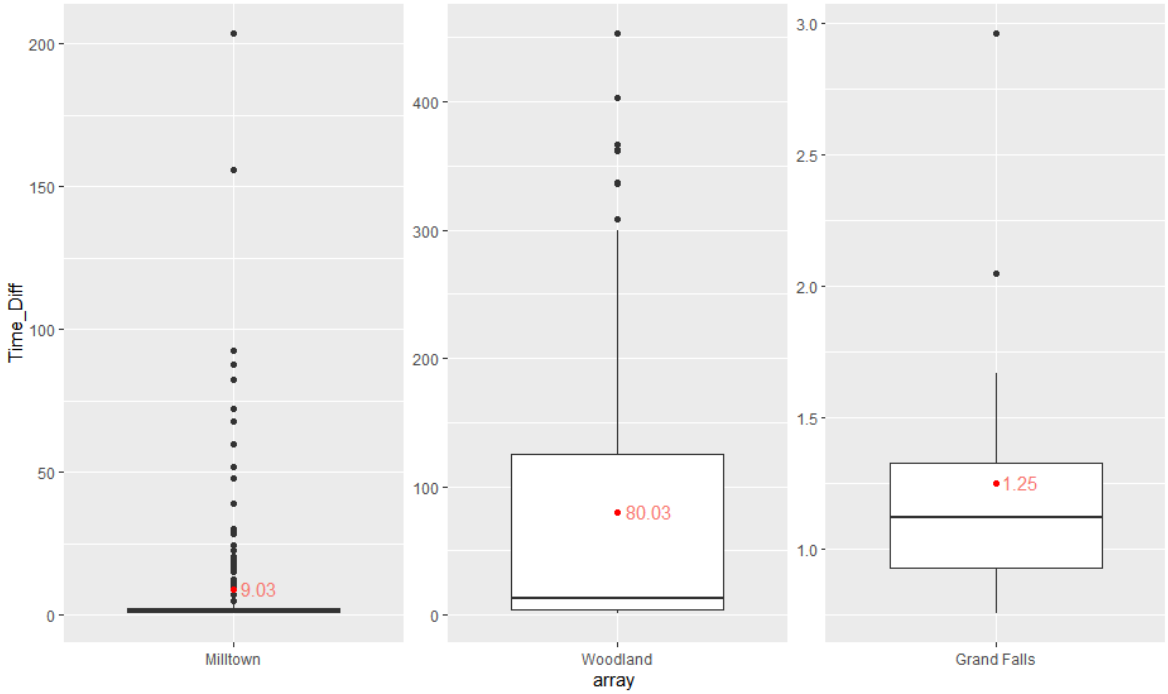


Figure 9: Time Spent at Dams (hours) with Mean Time in Red.

Biological Data

In addition to PIT tagging river herring and American shad, scale samples were taken from all tagged fish in 2022, as well as scales and fin clips from American shad for genetic analysis. 500 river herring were also lethally sampled to determine sex, species, and age. 250 otoliths from the lethal samples were aged by the Massachusetts Division of Marine Fisheries, results from all scale aging of 2022 live/lethal samples will be presented to various agencies and stakeholders once all of the scales collected from live/lethal samples are analyzed. Maine Department of Marine Resources have graciously agreed to age 200 scale samples, with aging priority given to live fish tagged as part of this study. Dr. M.J. Dadswell has aged all shad scale samples (Table 3), while fin clips from shad were sent to the Sipayik Environmental Department for genetic stock analysis at a later date.

Table 3. Biological data of American shad sampled during the 2022 study period. Note: Fish SCR-22-S02 was not tagged due to being in poor condition, fish SCR-22-S08 was a mortality during sampling. Fish SCR-22-S05 was determined to have skipped a year between spawning.

Date	Fish #	Fork Length (mm)	Weight (g)	Sex	Sex Stage (Nikolsky index)	Fin clip	Scale sample	Scale age	Previous spawn (#)
2022/05/26	SCR-22-S01	455	--	--	--	Y	Y	5	1
2022/06/02	SCR-22-S02	--	--	--	--	Y	N	--	--
2022/06/02	SCR-22-S03	444	--	--	--	Y	Y	4	0
2022/06/07	SCR-22-S04	465	--	--	--	Y	Y	6	1
2022/06/07	SCR-22-S05	485	--	--	--	Y	Y	7	2
2022/06/07	SCR-22-S06	473	--	--	--	Y	Y	5	0
2022/06/07	SCR-22-S07	344	--	M	--	Y	Y	3-4	0
2022/06/08	SCR-22-S08	408	870.6	M	3	Y	Y	7	2
2022/06/13	SCR-22-S09	450	--	--	--	Y	Y	5	1
2022/06/30	SCR-22-S10	438	--	--	--	Y	Y	5	1

Of the 500 river herring fish lethally sampled, 490 (98%) were determined to be alewife, and 10 (2%) were determined to be blueback herring. Lethal sampling efforts took place throughout the spawning migration, with more sampling effort associated with higher count days at MGS to get a representative sample of the spawning population (Table 5).

Table 4. 2022 Biological data of lethal and live sampled river herring sampled at MGS.

	Lethal Sampled River Herring (n=500)	Live Sampled River Herring (n=525)
Average Fork Length (mm)	251	254
Average Weight (g)	218	224
Average Age	4.1 (otolith, 250 samples)	N/A, TBD
Males	223	227
Females	277	292

There was a higher proportion of female river herring in both the tagged fish, as well as the lethally sampled fish (Table 4), with 55% of the lethal sampled fish and 56% of the live tagged fish identified as female. Further analysis on scale and otolith ages of river herring in the Skutik will be completed once scales have been fully aged, including comparisons and analysis from previous years sampled.

Table 5. River herring lethal sampling schedule at Milltown Generating Station.

Weeks	Fish lethal sampled per week	Proportion of fish sampled per week	Proportion of total weekly counts at MGS
May 3– May 9	2	0.4%	1.1%
May 10 – May 16	50	10.0%	35%
May 17 – May 23	78	15.6%	20.9%
May 24 – May 30	119	23.8%	31.0%
May 31 – June 6	116	23.2%	10.0%
June 7 – June 13	123	24.6%	1.0%
June 14 – June 20	4	0.8%	1.0%
June 21 – June 27	6	1.2%	0.0%
June 28 – July 4	2	0.4%	0.0%
July 5 – July 11	0	0.0%	0.0%

Discussion

Tagging mortality was minimal in 2022 with only three (1 American shad, 2 river herring) direct mortalities recorded during tagging. For each of these mortalities, the PIT tag was removed, and the 2-river herring were used as part of the lethal sampling efforts under Department of Fisheries and Oceans Canada permit # 343928. 70 fish tagged in 2022 were not detected at any of the upstream antennas post-tagging. Reasons for this could include mortality from handling and stress, natural mortality from predation, disruption to their spawning migration from handling, or simply antenna functionality and missed detections. To understand antenna functionality, marker tags were installed at all antennas except for Vanceboro and Magurrewock. In the future, a solar panel could be added at the Magurrewock antenna to increase power capacity, and therefore accommodate a marker tag. Marker tags are a great option to understand antenna functionality. These tags are installed within detection range of antennas and were set to be detected every 30 minutes. When marker tags are not detected every 30 minutes, and no subsequent tags were detected, it can indicate a functionality issue at the given antenna. It is important to understand that marker tags can malfunction as well, as seen this year. Multiple marker tags were compromised part-way through the study period, as batteries became dislodged and drained. Some marker tag issues could not be remedied as some marker tags were inaccessible after installation. Despite this, results show that marker tags at installed antennas were functioning at least 75% of the time.

In addition to marker tags, each antenna was tested using a test tag during data downloads, which occurred frequently, and readers were re-tuned to ensure the antennas were functioning correctly. To further maximize our confidence of antenna functionality, and to recognize if there was loss of antenna

functionality, it would be beneficial to include a marker tag check during antenna visits, as well as adding marker tag functionality to the weekly analysis and checks that were taking place. In the future, marker tags must be installed so that they are accessible so that batteries can be safely replaced when needed.

This year's detection results are similar to results from 2021. One notable difference is the increasing number of tagged fish returning from the previous year. With 35% of the 503 tagged fish returning from 2021, it will be interesting to note the number of returns in 2023 and beyond, to see if the decommissioning of MGS improves the number of returning spawners. During the study period there were detections of fish interpreted as going downstream through the Woodland fishway, with detections noted at the exit then the entrance antenna. These were also fish detected previously going upstream, and the time of detection was much later than fish detected during the upstream migration. With the decommissioning of MGS, as well as a new planned fish lift at Woodland dam, future studies could focus on downstream passage efficiency and path choice to help inform future construction and alterations to fish passages. Returning spawners are older and larger, and exhibit higher fecundity, which has a greater impact on the overall population than first time spawners (Ganias et al. 2015).

Detections decrease significantly after the Woodland Dam, with approximately only 50% of the tagged fish being detected at the entrance of the fishway, and only 13.9% of the tagged fish exiting the dam. There are many possible reasons for this, including to antenna functionality potentially causing a lower detection rate at Woodland, predation may occur in the stretch between MGS and Woodland, fish mortalities due to temperature fluctuations and other reasons could have occurred, and/ or other tributaries could have been used by the fish such as Magurrewock stream and Mohannes Stream (Canada). Comparing each dams calculated exit efficiency, we see the poorest exit efficiency at the Woodland dam, passing 27.3 % of fish that made it to the entrance and therefore only passing 13.9% of the tagged fish. Poor exit efficiencies at Woodland can be due to an unsuitable fishway construction (Woodland dam fishway is one of the longest denil fishways in the world), poor attraction flows to the fishway entrance, unsuitable flows within the fishway, and other fishway flaws. It is however important to note that antenna functionality can again be a cause for lower detections. In this case, antenna function may have been compromised due to a high fish traffic event. During a high fish traffic event, antennas may be unable to detect more than one tag at a time. Woodland dam experienced such an event after a structural issue in the fishway caused a decrease in attraction flow and water levels during the peak of the spawning migration. Fish were observed pooling at the entrance of the fishway, unable to ascend due to the breach in the fishway. Once this structural issue was temporarily resolved on May 28, both fish counts and antenna detections instantly increased, demonstrating a high traffic event potentially causing a decrease in antenna detection ability. In addition to Woodland exhibiting a poor exit efficiency, fish were calculated to have the longest time spent at the fishway. Using the same method of analysis as for the other dams, where the first detection at the entrance of the fishway was used to be subtracted from the last detection at the exit antenna of the fishway, was not possible for

the Woodland fishway. This is due to observing downstream passage detections within the fishway. Therefore, the first detection at the entrance antenna was subtracted from the first detection at the exit antenna, eliminating the inclusion of spawning time and downstream passage time into the analysis. It is important to note that this could decrease the true time some fish spent at the dam, as downstream movement inside the fishway was observed as fish were attempting to ascend the fishway prior to the fix of the fishway breach. The average time spent at MGS and Woodland may be skewed due to outliers observed at these dams, showing that fish spent up to 200 hours ascending Milltown and up to 400 hours ascending Woodland. At MGS these outliers can be attributed to the closure of the research trap to be able to dip and tag fish, causing a delay in their ascent. To remedy this, it could be beneficial to minimize the utilization of the screen in the research trap during days that exhibit the highest fish density, which was implemented to some extent this year. Another reason for the analysis showing a large amount of time spent at the MGS and Woodland fishways is that the entrance antennas at these dams were located close to where fish tend to school and circulate before entering the fishway. This likely contributed to why some fish seemingly spent ~ 400h ascending Woodland. The fishway breach at Woodland caused reduced attraction flow into the fishway and not enough water in the fishway, causing a large number of fish to school at the entrance without being able to ascend the fishway.

During the study period, fish were observed ascending the Magurrewock fishway and travelling upstream. Fish were noted at various ponds throughout the Moosehorn National Wildlife Refuge that Magurrewock stream connects (pers. comm.). Beaver dams and lodges are a constant problem within inlets and outlets of the ponds connected by Magurrewock and require constant attention during the migration to not impede passage. In addition to fish being visually observed ascending the fishway, there were two detections at the Magurrewock antenna in 2022.

51 of the 643 fish that entered MGS successfully exited above Grand Falls. This approximates to 7.9% of the total tagged migration, exit efficiency at Grand Falls was calculated as being 91.1%, with 51 of the 56 fish entering the fishway being detected exiting (Table 3). It is important to note that approximately 98% of the calculated spawning habitat for alewives exists above the Grand Falls dam (Billard and Hoar, 2021). Presumably, the majority of river herring (alewives in particular) would need to successfully exit above the Grand Falls dam in order to find suitable spawning habitat. Sipayik Environmental Department (SED) conducted counts for river herring at the Grand Falls fishway in 2022, using similar methodology to the counts that SCIWC conducted at MGS. 189,560 river herring were recorded at Grand Falls (personal communication), corresponding to approximately 26.6% of the total number of river herring that were recorded at MGS (189,560/712,808). It is important to note that estimating the total proportion of fish able to make it to upstream spawning habitat using the ability of tagged fish to pass impoundment fishways does not give an accurate representation of the total population of river herring able to reach upstream spawning habitat. Reasons for this can include a small sample size, mortality; natural or otherwise, antenna functionality, etc. Time spent ascending the fishway was the

lowest of the 3 mainstem dams at Grand Falls (Figure 9). Observations of bald eagles, smallmouth, and largemouth bass feeding on river herring at the Grand Falls fishway entrance were noted during the study period. Also observed during the study period was young of the year river (YoY) herring migrating downstream through the turbines and attraction pipe. There were observed instances of mortality noted when YoY river herring migrated downstream through the turbines. Attraction flows were maintained and observed as functioning at the fishway during the study period.

No fish were detected in 2022 at the Vanceboro dam. Antennas and data checks were done weekly in Vanceboro, along with observations of the fishway. No river herring were observed during any of these weekly checks, smallmouth bass were observed utilizing the fishway, and pooling/visually feeding at the upstream exit of the fishway during the study period. It is possible that detections of tagged fish at Vanceboro could have been missed because of the tag interference noted from June 16th-June 30th (Figure 6).

Generally, the analysis repeatedly demonstrates issues in tagged river herring successfully exiting the Woodland fishway. With this dam being the first barrier that anadromous fish will encounter on their upstream spawning migration after the removal of MGS in 2023-2024, it is becoming increasingly important to understand the efficiency of fish passage, and the capacity of the existing fishway at the Woodland dam, and other dams within the watershed, to be able to accommodate the predicted increase in the spawning population after MGS removal. Additionally, as river herring return to the river, this keystone species is predicted to set the stage for other anadromous species to return. The removal of MGS will accelerate this even more, as it removes a significant barrier to passage for fish migrating upstream, allowing for species with difficulty ascending fishways to recolonize the lower mainstem river. Monitoring of anadromous fish passage is key to understanding the dynamics of fish passage in the river with the changing biological productivity of the river.

During the 2022 study period, weekly antenna detections were provided during the MGS weekly count reports. These reports were distributed to a mail list of over 60 people representing various organizations, tribal governments, federal/state/provincial government agencies and departments, and interested stakeholders. Project status was discussed with stakeholders, and people conducting fisheries related research on dams throughout the Skutik system every two weeks during the spring and summer months to ensure coordination and communication between groups. Project results were communicated with the International Joint Commission: St. Croix River Watershed Board during their board meeting on October 27th, 2022; as well as their public meeting on January 24th, 2022. Project results were also shared at the St. Croix – Next Steps Working Group, a consortium of state, tribal, federal (Canadian/USA), and NGO stakeholders working on anadromous fish restoration in the Skutik.

Lessons learned this year that could be mediated for future fish tracking in the Skutik were to ensure that marker tags are installed accessibly where possible. To try and determine an efficient solution for a

power supply at the Magurrewock antenna, which could be solved with solar energy, allowing for a marker tag to function without compromising the battery power supply. This is being investigated for the 2023 field season. Additionally, implementing a regular check on marker tags during site visits would increase confidence of the analysis on antenna functionality. Sampling of American shad in 2023 will not take place. American shad did not respond well to handling in 2022 and were visibly stressed during tagging with mortalities noted. Antenna placement at fishways will likely be tweaked in the future, to avoid interference with other dam and fishway operations, as well as to ensure optimal placement of antennas. Ensuring the fish research trap screen at MGS remains open during days of peak fish migration will avoid skewed data on time spent within the MGS dam.

Follow up fieldwork is planned for 2023, with PIT tagging resuming at MGS, with the possibility of Woodland, and antenna placements at all 5 dams continuing. Additional monitoring at the Vanceboro dam including the possibility of placing a camera within the fishway are being investigated. Monitoring the fishway at Vanceboro is critical to knowing whether river herring are entering and presumably spawning in Spednic Lake, and beyond. Partnerships that were undertaken for this study will continue in 2023, with PRGI continuing to donate time, equipment, and valuable resources to help with this study, the support of Indian Township's biologist, and SED's continued support in antenna placement, interpretation of results, and guidance. The SCIWC will continue to work with and alongside various government and tribal agencies in monitoring river herring, American shad, and other sea-run fishes that return to the Skutik river in 2023, and beyond.

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References

Billard, M., and Hoar, A.R. 2021 Alewife Spawning Habitat in the St. Croix River Watershed. 7pp. Fisheries and Oceans Canada, unpublished data.

Ganias, K., Divino, J.N., Gherard, K.E., Davis, J.P., Mouchlianitis, F., & Schultz, E.T. 2015. A reappraisal of reproduction in anadromous alewives: determinate versus indeterminate fecundity, batch size, and batch number. Transactions of the American Fisheries Society, 144(6), 1143-1158.

Gibson, A.J.F., Bowlby, H.D., and Keyser, F.M. 2017. A Framework for the Assessment of the Status of River Herring Populations and Fisheries in DFO's Maritimes Region. DFO Canadian Science Advisory Secretariat Research Document 2016/105 VI + 69pp.

Limnotech. 2021. Exploring Upstream and Downstream Fish Passage Improvements on the Lower St. Croix River. Final Report. January 28, 2021. 131 pp. Prepared for the International Joint Commission (IJC), International St. Croix River Watershed Board and Workgroup. IJC Contract Number: GS10F150BA

NMFS. 2019. Status Review Report: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*). Final Report to the National Marine Fisheries Service, Office of Protected Resources. 160 pp.

Peskotomuhkati Nation at Skutik. Skutik Watershed Strategic Sea-run Fish and River Restoration Plan. March 28, 2019, Updated February 8, 2022. 78pp.