Assessing the Feasibility of PIT Tracking to Monitor Atlantic Whitefish Recovery Activities in Petite Rivière, Nova Scotia

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Table of Contents

ABSTRACT

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Barriers to fish passage are an important consideration when addressing recovery targets for riverine fish populations such as Endangered Atlantic Whitefish (*Coregonus huntsmani)* inhabiting the Petite Rivière watershed, Nova Scotia. We developed in-stream passive integrated transponder (PIT) detection arrays at fishway structures and tested their application with a proxy species. Pass-through and pass-over antennas were tested on land. Six antennas were further tested *in situ,* followed by a tagging study using 300 Alewife (*Alosa pseudoharengus*) tagged internally with 12-mm PIT tags. Three detection arrays were deployed on or near fishways, including three pass-through antennas mounted directly on fishway structures, and three pass-over antennas deployed downstream of a small dam. Equipment malfunction precluded estimating detection efficiencies for the pass-over antennas, however, land trials indicated an 8-foot wide circular design using 8 gauge wire was most efficient at detecting PIT tags. Pass-through antennas were successful at detecting 219 of the tagged alewives. Detection efficiency of the downstream array was 95% for the downstream antenna and 43% for the upstream antenna. About 30% of tagged fish made it to the upstream array, consisting of a single antenna. Further work is necessary to design pass-over antennas that may be employed on the river outside of the primary fishway structures for future monitoring of Atlantic Whitefish.

RÉSUMÉ

Tsitrin, E., Breen, A., and Broome, J. 2023. Assessing the feasibility of PIT tracking to monitor Atlantic Whitefish recovery activities in Petite Rivière, Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 3536: iv + 17 p.

Afin de permettre la surveillance future des projets de rétablissement du corégone de l'Atlantique (*Coregonus huntsman*)*,* une espèce en voie de disparition dans la Petite Rivière, en Nouvelle-Écosse, nous avons développé des réseaux de détection par transpondeur passif intégré (PIT) dans les structures des passes à poissons, et nous avons évalué leur utilisation avec une espèce de substitution. Des antennes détectant le « passage au travers » et le « passage par-dessus » ont été évaluées sur terre. Six antennes ont été évaluées *in situ,* suivies d'une étude de marquage du gaspareau (*Alosa pseudoharengus*). Au total, 300 gaspareaux ont été marqués avec un marquage PIT de 12 mm dans leur organisme. Trois réseaux de détection ont été établis, dont trois antennes de passage au travers montées directement sur la structure des passes à poissons, et trois antennes de passage par-dessus installées en aval d'un petit barrage. Un mauvais fonctionnement de l'équipement nous a empêchés d'estimer l'efficacité de la détection des antennes de passage par-dessus, mais un modèle circulaire de 8 pieds de large utilisant un fil de calibre 8 s'est avéré le plus efficace pour détecter le marquage PIT pendant les essais sur terre. Les antennes de passage au travers ont réussi à détecter 219 des gaspareaux marqués. L'efficacité de détection du réseau en aval était de 95 % pour l'antenne en aval et de 43 % pour l'antenne en amont. Environ 30 % des poissons marqués ont pu se rendre au réseau situé en amont, composé d'une seule antenne. D'autres travaux sont nécessaires pour terminer la conception d'antennes de passage par-dessus qui pourraient être utilisées dans le fleuve, hors de la structure primaire des passes à poissons, pour la surveillance future du corégone.

INTRODUCTION

Atlantic Whitefish (*Coregonus huntsmani*) is an anadromous fish species currently restricted to the three upper lakes (Minamkeak, Milipsigate, and Hebb) of the Petite Rivière watershed in southwestern Nova Scotia, Canada. Under Schedule 1 of the Species at Risk Act (SARA), the Atlantic Whitefish (AWF) is classified as Endangered (in facing imminent extirpation or extinction), and as such, recovery actions are required by law (DFO 2018a). Accordingly, the AWF Recovery Strategy was adopted, with the overarching goals to: stabilize the population, re-establish the anadromous (sea-going) form, and ultimately expand the population beyond its current range (DFO 2018a). To promote near-term recovery, the AWF Action Plan recommends to: monitor the fish passage facility constructed at Hebb Lake Dam, implement fish passage at Crousetown Dam, as well as improve other passage impediments in the Petite Rivière (DFO 2018b). The interim recovery objective is thus aimed to promote anadromy on the Petite Rivière by improving fish passage.

To address this objective, we developed and tested in-stream passive integrated transponder (PIT) detection arrays at existing fishway structures at Hebb, Crousetown and Cranberry Dams. As part of the AWF Recovery Strategy, the fish passage facility at Hebb Dam has been monitored since its construction in 2012 during spring and fall migration runs by members of the eNGO Coastal Action, in collaboration with Fisheries and Oceans Canada (DFO), and with funding awarded through the Habitat Stewardship Program (HSP). In the first season of operation, the passage facility intercepted 19 AWF (between October 21 and November 2, 2012), which are thought to be captive-bred fish released in 2008 (Cross 2012). Since then, no AWF have been observed in the Hebb Dam fishway. Other salmonids that have been recorded include: one male Atlantic Salmon in 2014 (Breen and Risto, 2019) and 20 Brook Trout (average of 1.2 per year, except for 2014 which recorded 10 individuals (Feener et al. 2021: Russell et al. 2022). Fall monitoring activities of the Hebb Dam fishway were halted in 2019, but resumed in 2022 following the summer release of captive-spawned juvenile AWF. An unidentified salmonid was captured on November 1, 2022 and released after tissue samples were taken.

The fishway at Crousetown Dam historically consisted of a series of stone pools leading up to a narrow channel. While the fishway was reported to provide upstream access to anadromous alewife and Atlantic salmon, concerns were raised over the deteriorated state of the structure causing a partial barrier. Coastal Action, in collaboration with Nova Scotia Salmon Association's Adopt a Stream program, completed restoration efforts in 2017 and 2018, consisting of modifications to widen pools and the installation of the new Denil fishway structure. The efficiency of these fishway modifications have not been formally evaluated.

Antennas were designed and range tested in 2021, followed by *in-situ* trials with tagged Alewife (*Alosa pseudoharengus*) in 2022. Alewife were used as stand-in for AWF due to their abundance in the same watershed, use of fishways during migration, and previous experience with PIT tagging of the species. PIT tags are preferable to alternative tracking methods, such as acoustic tags, as lack of an internal battery affords a relatively small size (reduced effects of tagging on fish) and provides an indefinite tag life (potential tracking over a lifetime). The tags operate on radio frequency to transmit an alphanumeric code unique for each tagged fish, powered as they pass through the electromagnetic field emitted by an antenna, and with their presence recorded and stored locally (Prentice et al. 1990).

The Petite Rivière primarily flows through rural settlement and hosts a number of recreational activities (e.g. fishing, rafting, swimming), which pose a challenge to traditional PIT detection systems that require vertical antennas extending above the water's surface and stretched across the full width of a waterway. Additionally, any vertical structures are susceptible to damage during periods of high water flow, such as might occur in the fall, when AWF activity might be expected. Therefore, in addition to pass-through antennas, commonly used in fishways, we developed and tested pass-over designs that may be deployed on river bottom in areas where pass-through antennas are impractical or impossible. Tagging trials with alewife were used to assess detection efficiency of the various antenna designs at sites of interest for future AWF monitoring, as well as to gain insight on impediments to passage in the system.

METHODS

STUDY SITES

Hebb, Cranberry and Crousetown Dams are situated on the main channel of the Petite Rivière in Lunenburg County, Nova Scotia (Figure 1). Hebb Dam is a concrete flow-control structure situated at the outflow of Hebb Lake, approximately 21 river km (rkm) upstream of the river mouth, used to manage the water supply for the Town of Bridgewater. A fishway (80-m long concrete structure with 26 stepped pools) was completed in 2012. Cranberry Dam is a small structure of concrete and wood, located approximately 100 m downstream of Hebb Dam, that is used to conduct seasonal irrigations of a commercial cranberry operation. Fish passage at Cranberry Dam is provided via a notch (similar to a slot fishway) in a single section of the barrier, which was added to the structure in 2016. Crousetown Dam is a 2.4-m high timber structure, located approximately 14 rkm downstream of Hebb Dam, fitted with a run-around fishway of stone pools leading to an aluminum Denil ladder installed in 2017 (3-m long, 0.9 x 0.6 m opening at the top of fishway). Images of the dam structures are shown inAppendix Figures A1 and A2.

PIT DETECTION SYSTEM TRIALS (2021)

Antenna development

The primary detection system trialed herein used an RFID Half Duplex (HDX) Multiple Antenna PIT Tag Reader (Oregon RFID Inc.), capable of operating up to four antennas. Antennas were constructed of copper wire threaded through PVC conduit (1-inch diameter) (Figure 2). Each antenna was then connected to a tuning capacitor linked with twin axial cable to a reader, all powered by a 12-V deep-cycle battery (Figure 2). Detection system trials involved land-based testing of various combinations of antenna size (0.8 to 5.8m), shape (rectangular *vs*. circular), and wire gauge (8, 10, and 12 AWG) to determine the most effective configuration.

The detection range for each antenna configuration was determined by manually passing 12-mm and 23-mm PIT tags through the detection field. The intention was to design an antenna that would maximize detection efficiency in a pass-over (horizontal) position, wherein the antenna lies on the bottom of the stream channel and decode tags as fish swim above rather than through it, therefore antennas were tested with tags positioned parallel to the plane of the antenna electromagnetic field. Average or reliable detection range was defined as the vertical distance from the antenna at which a given tag was consistently detected both at the edges as well as near the antenna center. Maximum detection range was defined as the highest vertical distance at which a given tag could be detected, however, such detections were few, and generally only happened directly above the antenna edges, with almost no detections made in the antenna center. In this orientation, the magnetic charge is not as strong, as only the field above the antenna is used, therefore detection efficiency generally decreases. However, it enables the installation of antennas in areas where a swim-through (vertical) orientation would be impractical, for example where recreational use of the river may prevent the installation of vertical structures. Pass-through antennas are most used in areas where existing structures provide support, such as on fishways and culverts.

Field testing

Six antennas were further tested *in situ* at the aforementioned field sites. The detection system generally followed Figure 2, though with some site-specific antenna configurations (guided by earlier land-based testing), as detailed below.

At the Crousetown and Hebb Dam, rectangular pass-thorough antennas was adopted given the confined fishways (Figure 3A), each consisted of three turns of 12 AWG (7 strand, 600 V) copper wire. The Crousetown fishway had two rectangular antennas (0.6 x 0.9 m) mounted to wooden frames at both the upstream and downstream end (Figure 3A); a single rectangular antenna was mounted at the downstream end of the Hebb Dam fishway (0.8 x 0.8 m). A 23-mm sentinel tag, set to transmit at 15-minute intervals, was mounted in-air within the detection field on the frames of each antenna. Detection ranges were additionally tested using 12-mm ad 23-mm tags held in hand, perpendicular to the antenna field (pass-through orientation) and slowly moved towards the antenna.

Rather than mounting an antenna on Cranberry Dam, three 8-foot (2.4 m) diameter circular pass-over antennas were instead employed: two that consisted of 2 turns of 10 AWG (7 strand, 600 V) copper wire and one that consisted of 2 turns of 8 AWG (7 strand, 600 V) copper wire. Antennas were deployed in 0.6 m of water, mounted approximately 12 cm off the bottom, and secured using cement blocks and/or rebar. The 8 AWG and one of the 10 AWG antennas were connected to the same reader set to a multiple antenna scan sequence, with the second 10 AWG antenna connected to an independent reader (Figure 3B; Appendix Figure A3). Detection range was tested using 12-mm and 23-mm tags mounted to small pieces of wood. The mounts were either allowed to float downstream in current or were pulled upstream by a thin cord over the antennas at the water's surface. Antennas were connected to a tuner box linked with twin axial cable to a multi-antenna HDX reader powered by a 12 volt deep cycle battery.

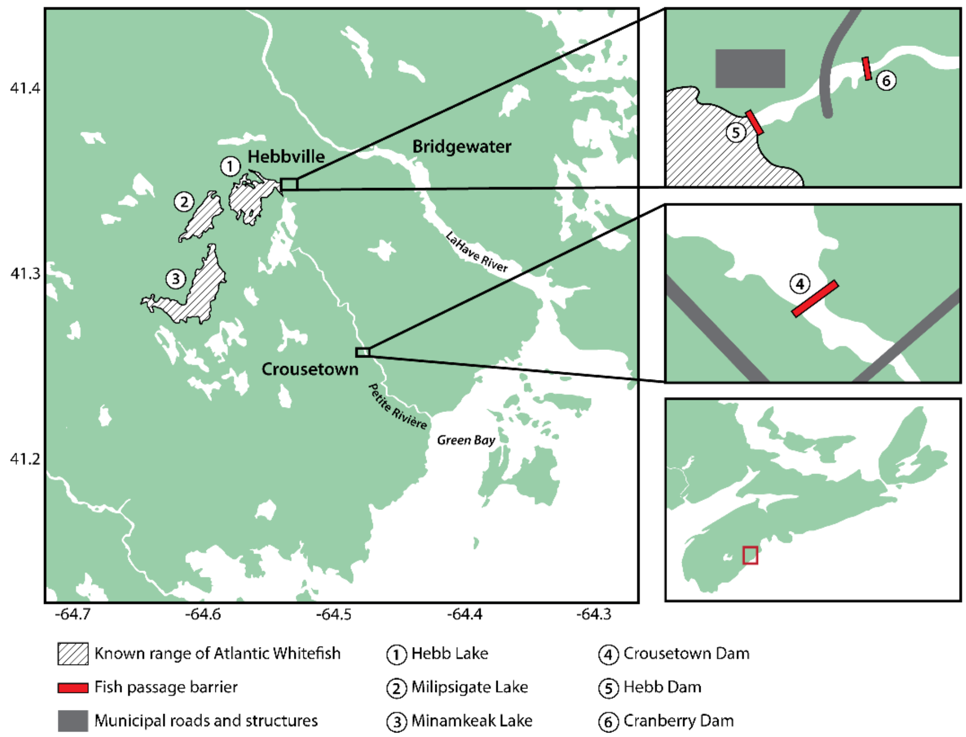

Figure 1. Map of Petite Rivière system with locations of antenna deployment sites. Alewife capture and tagging occurred at Crousetown Dam (4).

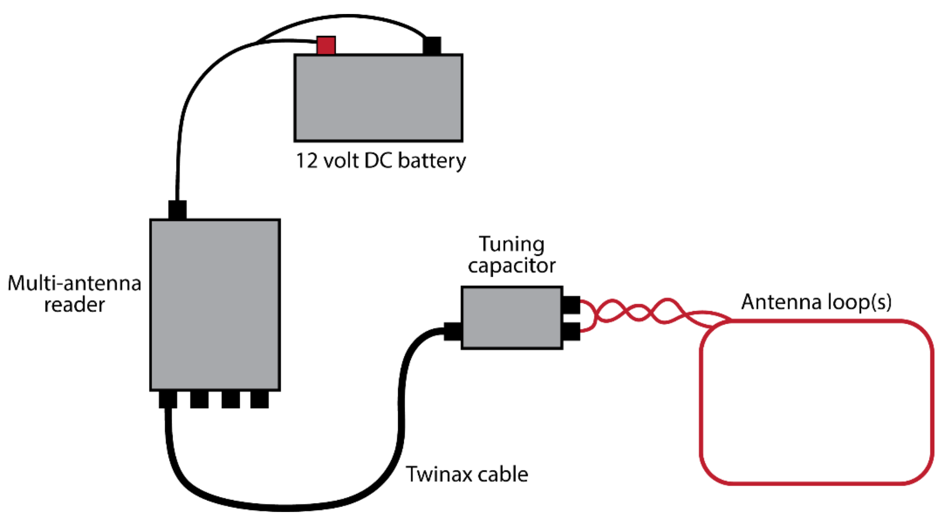

Figure 2. Diagram of the PIT detection system indicating primary components.

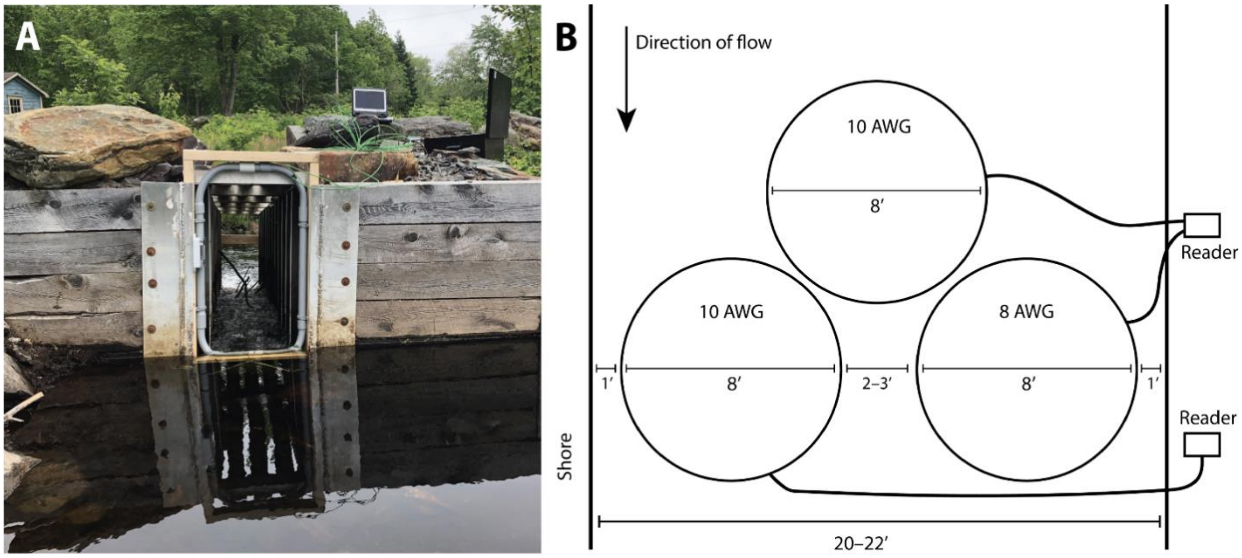

Figure 3. Positioning of upstream antenna at Crousetown Dam (A) and schematic of pass-over antennas downstream of Cranberry Dam (B).

TAGGING TRIALS (2022)

Antenna deployment

For the 2022 field season, antennas were deployed in largely the same configuration and placement as the 2021 field trials. Rectangular pass-through antennas were re-deployed at Crousetown and Hebb Dam fishways on May 17, 2022. However, the upstream antenna at Crousetown was repositioned: in 2021 it was slipped into the aluminum slots at the fishway mouth (see Figure 3A); in 2022, detection efficiency was improved by attaching the wooden frame supporting the antenna to the outside of the structure. A 23-mm sentinel tag, set to transmit at 30-minute intervals, was mounted on the frame within the detection range at Crousetown (upstream) and Hebb Dam antennas. However, the sentinel tag at Hebb Dam failed 10 days after the start of the trial.

At Cranberry Dam, two 8-ft (2.4-m diameter) circular antennas were re-deployed downstream on May 24. Both antennas consisted of two loops of 8 AWG wire. In the field, all antennas were powered by a 12-volt battery, connected to a solar panel (Renogy 100 or 200 watt suitcase panel), and monitored every 2-3 days for the first two weeks, after which they were checked weekly until removal on July 19.

Water temperature loggers (UA-002-64 HOBO Pendant) were deployed at Hebb and Crousetown Dam on May 18. Data on water levels were available from the nearby LaHave River Weather Station (01EF001; extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site: https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html on 20 October 2022).

Alewife collection and tagging

Alewife, in their upstream migration, were captured by dip netting the first holding pool below the Crousetown fishway (approximately 30 m from fishway opening) between May 19 – 27, 2022. Prior to tagging, fish were held in a 70-L plastic tote containing oxygenated river water. No more than 10 fish were held at a given time, and water was replenished after each group was tagged. Individuals were sexed, measured for fork length (FL) to the nearest millimeter, and weighed to the nearest gram. A 12-mm HDX PIT tag [Oregon RFID Inc. (2.0 mm, 0.1 g), Biomark (2.12 mm, 0.1 g)] was inserted into the peritoneal cavity using a pistol grip injector (Oregon RFID Inc.), with the PIT ID recorded. Tagged individuals were held for observation in a second 70-L tote until all fish from the given batch were tagged (~5 min), and the group was then released into the upper holding pool immediately below the fishway (approximately 3 m from fishway opening) to continue their upstream migration. No more than 100 fish were tagged on a single day to reduce the possibility of tag signal collisions. In total, 300 alewives were tagged.

DATA MANAGEMENT AND ANALYSES

PIT ID, timestamp, and antenna number were recorded by each reader box, with data download occurring at antenna inspection (~3 times a week for the first two weeks, once weekly for the remainder of the study period). The array at Cranberry Dam failed on May 27 due to a SD card malfunction, and these data could not be recovered.

All analyses were performed in the R statistical environment (R Core Team, 2021), using the tidyverse (Wickham et al. 2019) and ggpubr (Kassambara 2020) packages. Fork length and mass of tagged alewife were compared between the detected and undetected groups using t-test (length) and Mann-Whitney test (mass) based on the distribution of the measurements (tested for normality with Shapiro-Wilk test). Detection efficiencies (expressed as a percentage) were calculated for the two Crousetown Dam antennas as the total number of individuals detected by a given antenna divided by the number of individuals detected further upstream (Nau et al. 2017).

RESULTS

PIT DETECTION SYSTEM TRIALS (2021)

Configuration of antennas

Land-based trials were aimed to maximize the detection range of PIT tags in pass-over antennas. Although various configurations of antenna size (0.8 – 5.8 m), shape (rectangular *vs*. circular), and wire gauge (8, 10 and 12 AWG) were attempted, not all combinations were tested herein (Table 1).

Overall, a circular design had improved performance in detection range to a rectangular design in the pass-over (horizontal) position (Table 1). In this orientation, tags were detected best when they were directly over the wire, so two separate detections per pass were possible, although this was at a cost of detection efficiency near the center. Detection efficiency decreased as antenna size increased, however, detection range above the edges was consistently greater for circular antennas compared to rectangular ones. The optimal performance of circular antennas was observed at a size range of 1-3 m (Figure 4). As more wire gauge configurations were attempted at these sizes, further comparisons are limited to this size range.

Generally, the higher the wire gauge (i.e. smaller diameter wire), the lower the detection range: 8 and 10 AWG wire performed better than 12 AWG at all sizes (Figure 2). Detection range also decreased (35-50 cm for the 23 mm tag, 7-10 cm for the 12 mm tag) when multiple 8-foot (2.4 m) diameter antennas were operated on the same reader. A trial was also undertaken placing one 4-foot (1.2 m) wide antenna inside of an 8-foot one, but detections were inconsistent, with tags only being detected in areas of the circles sporadically.

Regardless of wire gauge or size, the 23-mm tag was detected at a higher range than the 12-mm tag. Although 23-mm tags were tested, the 12-mm size is more likely to be adopted for future AWF tracking studies, given the reduced potential for tag effect in fish of smaller size.

Table 1. Specifications for tested PIT detection antennas with respective maximum and average reliable detection ranges (cm) for 23-mm and 12-mm PIT tags. Trials of rectangular vs circular antennas are separated by a horizontal line. Trials marked by a dash line were attempted but were not successful (i.e. antenna did not tune, and/or tag was not detected).

Wire gauge	Size (m)**	Wire turns	Inductance (µH)	Max range* 23 mm tag	Reliable range 23 mm tag	Max range 12 mm tag	Reliable range 12 mm tag
12	12.2 x 2.1	2	148	-	-	-	-
12	23.8 x 2.1	1	89	-	-	-	-
12	18.3 x 1.2	1	59	46	41	-	-
12	19.5 x 0.6	1	58	46	36	-	-
12	9.8 x 0.6	2	-	56	51	18	15
12	6.4 x 0.6	3	-	53	51	8	8
12	3.7 x 3	2	31	61	56	20	18
12	0.9 x 0.6	3	42	63	50	30	20
12	0.8	3	22	86	76	-	-
12	1.2	2	16	86	81	41	31
12	2.4	2	42	97	91	31	23
12	5.2	1	-	41	30	-	-
12	5.8	2	101.3	-	-	-	-
12	5.2	2	97.5	-	-	-	-
12	2.4	2	38.6	71	61	31	20
10	4.6	2	76.8	-	-	-	-
10***	3.7	2	48.9	-	-	-	-
10***	2.9	2	39	61	56	10	8
10	2.4	2	40.6	81	76	41	30
8	4.4	1	22.9	61	56	-	-
8	2.4	2	34	102	97	46	41

Reliable range refers to the distance vertically above the antenna where tags were consistently detected; detections at max range generally only occurred at antenna edges, and sometimes only one detection was made at this distance.
***Antenna size is given as length x width for rectangular antennas, and diameter for circular antennas.*
****Issues with equipment wiring may have affected the results of some tests, potentially affecting the antennas' ability to tune and/or detection range.*

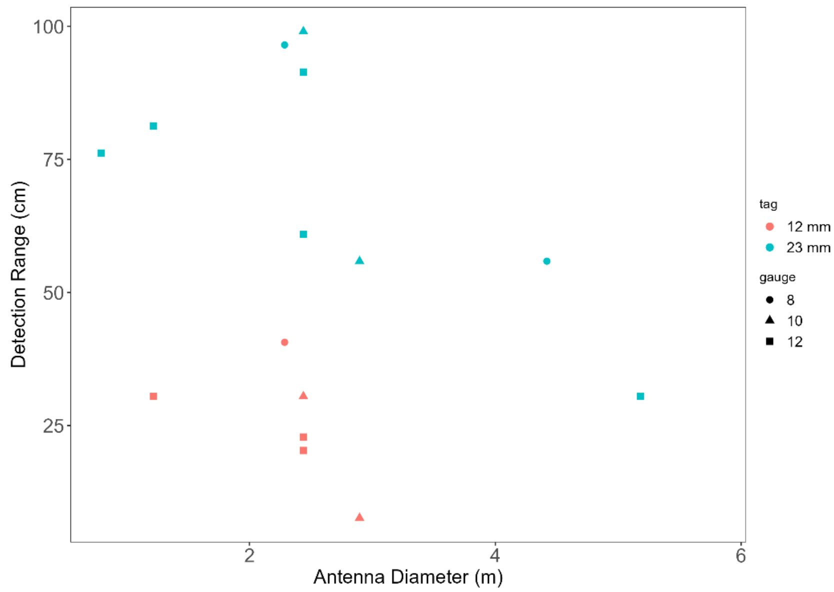

Figure 4. Reliable detection range of circular antennas based on diameter. Tag size is indicated by colour, while antenna wire gauge is indicated by shape.

Sentinel tags

At the Crousetown Dam fishway, both antennas (upstream and downstream) successfully detected a 23-mm sentinel tag at the expected times (30-minute intervals). Detection range of hand-held tags was determined to be approximately 63 cm and 30 cm for the 23-mm and 12-mm tag, respectively. Sentinel tag test results were similar at the Hebb Dam fishway, where a similar antenna configuration was employed.

At Cranberry Dam, the detection range of the 10 AWG antennas was 50-76 cm and 15-25 cm for the 23- and 12-mm tag, respectively, though few detections were made in the circle center. Detection range of the 8 AWG antennas was 76 cm and 30 cm for the 23- and 12-mm tag, respectively, with some detections made in the antenna center.

TAGGING TRIALS (2022)

A total of 219 out of 300 tagged alewife (73%) were detected in the Petite Rivière system across two PIT detection arrays. Overall, 218 fish were detected by the Crousetown array (between May 19th to June 1st), and 61 were detected at Hebb Dam (between May 21st and June 11th). When taken together, the Crousetown antennas detected 60 of 61 fish that were later detected at Hebb, which corresponds to a 98% detection efficiency. The downstream antenna on its own had a 95% detection efficiency, having detected 58 of 61 fish that were subsequently detected by the upstream antenna and/or the Hebb antenna. In contrast, the upstream antenna alone detected only 26 of 61 fish later detected at Hebb, corresponding to a 43% detection efficiency. One fish that made it upstream was never detected by either of the Crousetown antennas (Table 2).

Tagging took place on 5 separate days (hereafter referred to as tagging cohorts). The proportion of fish detected at Hebb Dam was lower from the first and last two cohorts (May 19, 26, and 27) at <20%, compared to 28-32% for the May 20 and 25 cohorts (Table 3). The mean travel time between the two arrays was 2.75 (±2.51) days (Figure 7).

Of the 300 alewives tagged, 137 (46%) were male, 82 (27%) female, and 81 (27%) were undetermined; of the 219 detected fish, 104 (47%) were male, 56 (26%) female, and 59 (27%) undetermined. The length distribution of detected fish was representative of the length distribution of all fish tagged (Figure 5). Fork length (t-test) and mass (Mann-Whitney) of tagged fish also did not differ statistically between the detected and undetected groups ($p>0.05$). However, tagged females were found to be significantly larger than males (Figure 6; Mann–Whitney, $W=8539$, $p=0.000$).

Table 2. Summary of detection period, number of detection days, and individuals detected at each fishway.

	Crousetown Dam*			**Hebb Dam**	**Total**
	Downstream	**Upstream**	**Both antennas**		
Detection period	05/19 – 06/01	05/19 – 06/01	05/19 – 06/01	05/21 – 06/11	-
Detection days	14	11	14	16	18
Total fish detected	213	71	66	61	219
Fish also detected at Hebb Dam	58	26	26	-	60

*The same tag might be detected by both the downstream and upstream antennas

Table 3. A summary of individuals detected based on tagging and release date.

Tagging Date	**Crousetown downstream**	**Crousetown upstream**	**Hebb Dam**	**Total detected**	**Total tagged**
May 19	13	7	3	13	20
May 20	31	19	14	37	50
May 25	32	8	16	32	50
May 26	79	37	20	79	100
May 27	58	0	8	58	80

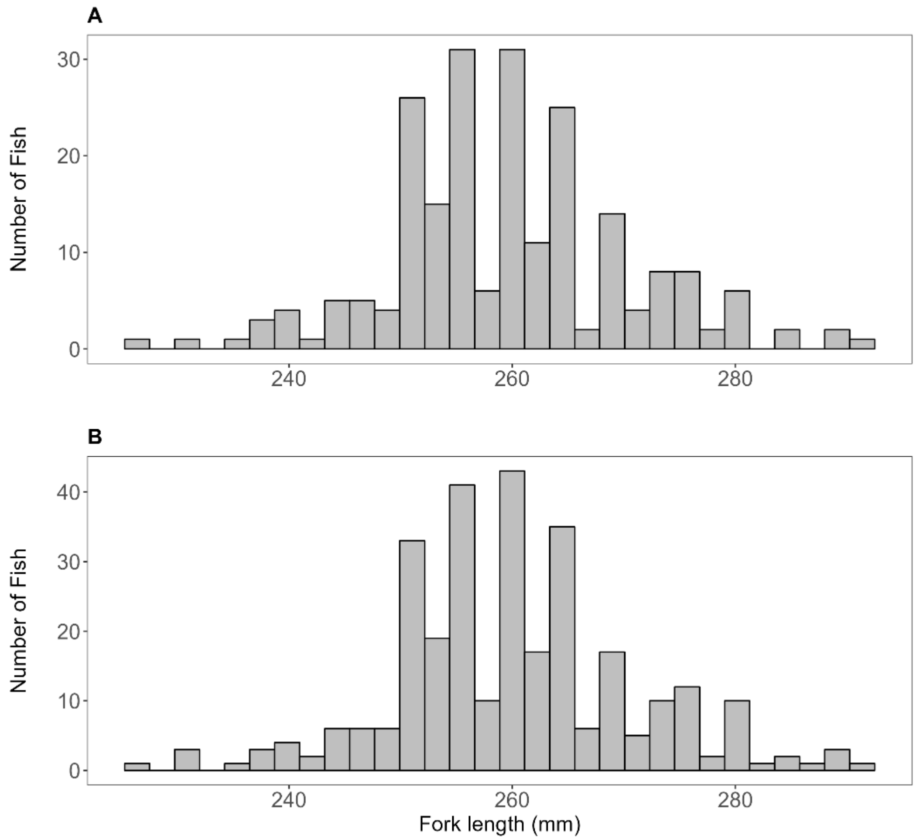

Figure 5. Fork length (mm) distribution of Alewife detected (A) compared to all fish tagged (B).

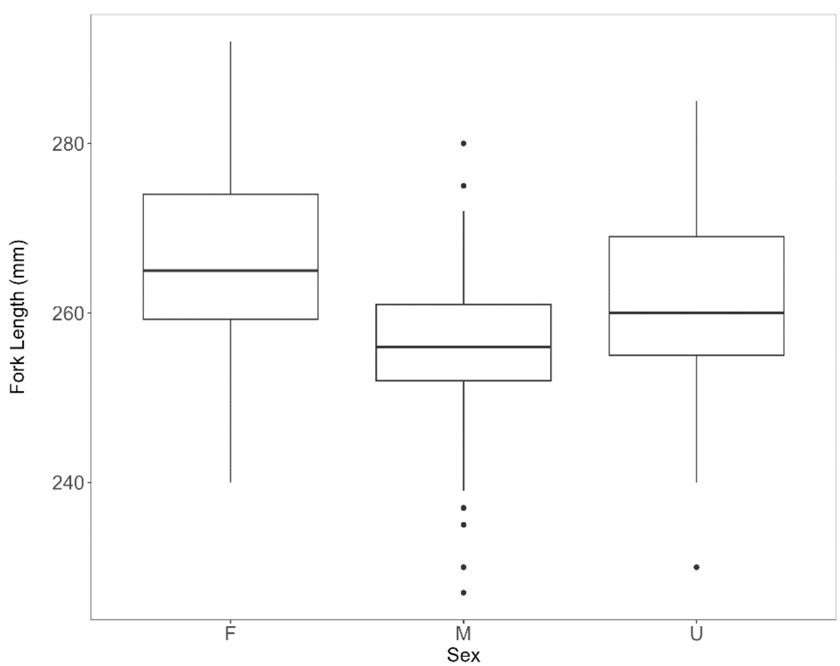

Figure 6. Fork length (mm) distribution of tagged Alewife by sex.

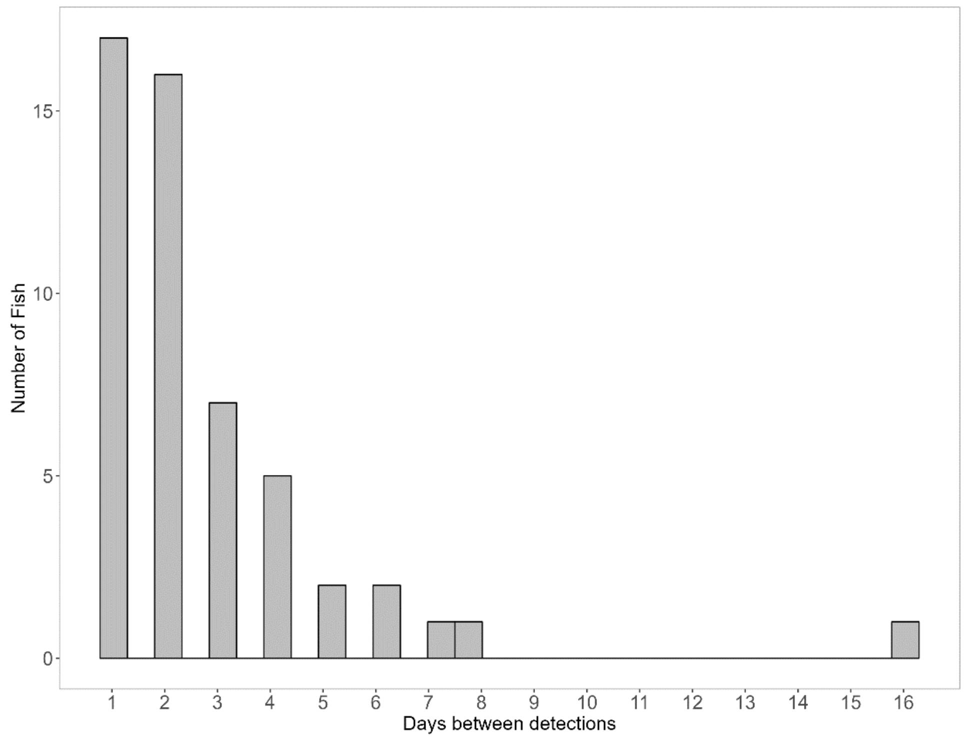

Figure 7. Time, in days, between the last detection at Crousetown Dam and the first detection at Hebb Dam, for the 61 individuals detected at both locations.

DISCUSSION

From land-based trials, it was determined that circular pass-over antennas had a higher detection range when compared to rectangular ones. An 8-foot diameter was the size selected for further testing, as it balanced maximizing detection efficiency with the number of antennas required to cover the width of the stream. Unfortunately, *in situ* trials of these antennas were not completed due to failure of the equipment. The short interval for which circular antennas were operational downstream of Cranberry Dam revealed certain challenges: namely, that a single multi-antenna reader was not able to operate more than two such antennas, despite being designed to function with up to four. It is unclear whether this shortfall was caused by a greater power requirement from the circular antennas compared to smaller rectangular ones, or if the reader had some other unknown electronic malfunction.

Despite these challenges, approximately two thirds of the tagged alewife were detected by the remaining two arrays, though fate of those undetected remains unknown. As tagging took place after the start of the alewife spawning run, and was spread out over two weeks, it is possible that some of the tagged fish had spawned and were downstream migrants. This would also explain the high proportion of individuals that could not be sexed (i.e., undetermined), although there was no observed difference in weight between groups. Further, the distance between Crousetown and Cranberry Dams includes access to Fancy Lake, which provides suitable spawning habitat for alewife, and thus may have diverted some of the upstream migrants from reaching Hebb Lake. It is also not known whether spawning can occur below the capture and release location at Crousetown Dam.

The size, weight and sex ratios of detected and undetected fish did not differ significantly, suggesting that neither river ascent nor detection efficiency are size or sex dependent. Other possible reasons for undetected individuals include: tag expulsion, delayed tagging mortality, predation, capture in fisheries, initial downstream movements ("fallback") post-tagging, and/or environmental factors, which will be further considered below.

Tag expulsion and delayed tagging mortality are both documented in alewife; however, values are generally low (99% tag retention) and thus unlikely to account solely for the number of undetected individuals in this study (Castro-Santo and Vono, 2013; Eakin 2017). In terms of predation, illegally introduced invasive species, such as Smallmouth Bass (*Micropterus dolomieu*) and Chain Pickerel (*Esox niger*), are important in the Petite Rivière system, and may have consumed tagged alewives before array detection. These predators are also considered to be amongst the principal factors impeding the survival and recovery of the AWF population (COSEWIC 2010), however predation levels have not been evaluated empirically. Removal of undetected fish may also be possible through the recreational alewife fishery, with a popular fishing location at Conquerall Mills, upstream of the release location at Crousetown Dam.

218 unique IDs were detected by the Crousetown array, however only 71 of these were ever detected by either the upstream or the Hebb Dam antennas. The remaining 147 fish may indicate some proportion of unsuccessful passage attempts or fallback behaviour. All fish were released into the upper holding pool, where they might have come into close enough proximity for detection by the downstream antenna without directly attempting passage. The small proportion of fish detected by the upstream antenna suggests either low detection efficiency, or failure to attempt passage (in which case, tagged fish may have dropped down to lower pools or downstream of the dam). Fallback behaviour following tagging has been documented in studies of anadromous species in other river systems (Frank et al. 2009; Nau et al. 2017). It is possible for fallback to result from the tagging procedure, but also due to environmental conditions, such as low water level and higher water temperature. It was observed that water levels on the nearby LaHave River decreased from an average of 1.9 m in May to a June average of 1.6 m, with the exception of a short bout of heavier rainfall (June 9-11). Field observations between May 20-26 noted that water levels in the holding pool at Crousetown Dam were low and fish were having difficulty accessing the first stepped pool, which could have impeded the upstream passage of tagged individuals if they had dropped down below that point. At the same time, average daily water temperatures increased from 18°C to 21°C in May through June, which may have further stressed the alewives and led some to cooler waters downstream. The number of tagged individuals that were detected upstream was lower for the last two cohorts, however 10-20% still made it at least as far as the base of the Hebb Dam fishway.

Aside from the aforementioned biological reasons why fish may have been undetected, there were technological limitations that may have also led to reduced detection efficiency of antennas. For instance, the Crousetown Dam array (consisting of 2 antennas) had a high detection efficiency overall; however, when considered separately, the downstream antenna had a higher detection efficiency compared to the upstream antenna. A possible explanation for this could be the difference in exposure time that each antenna experiences. The downstream antenna likely experienced longer duration and higher numbers of tagged individuals present within the detection range, due to fish holding in the pool before upstream passage. The upstream antenna, contrarily, can only detect fish as they swim through it. Once passage is attempted, alewife typically burst swim up the fishway, which may result in lower detection efficiency as the tags are only present within the detection field of the upstream antenna for a short time. Lower detection efficiencies for antennas located nearer the top of fishways has been observed in other PIT tracking studies (e.g. Nau et al. 2017). Another reason could be due to poor electrical connection, caused by greater water flow and accumulation of debris at the upstream passage mouth, or the presence of the metal support of the fishway directly behind the antenna mounting, which is the side from which fish approach the antenna when passing through.

One individual, a male tagged on May 20, was never detected by the Crousetown array, but was later detected upstream at Hebb Dam. As no other upstream passage exists on the Petite Rivière, this fish is assumed to have transited the Crousetown fishway undetected. Of the 50 fish tagged on that day, 37 were subsequently detected in the system, including many detections on the day of tagging, therefore technical failure of the array is unlikely. This is also not a case of false positive detection, as many detection events of the individual were made at Hebb Dam over three days. It is therefore concluded that the individual passed undetected at Crousetown Dam due to issues with detection efficiency discussed above.

Given the low detection efficiency of the Crousetown upstream antenna, it is possible that more fish made it past Crousetown Dam, and their fate is unknown. Concern was raised as water level in the Hebb Dam fishway decreased near the end of May that the lower end of the wooden frame supporting the antenna was forming an obstacle, based on several observations of unsuccessful passage attempts. The frame was modified, and the antenna repositioned, but this may have delayed some upstream passage at Hebb Dam.

Hydraulic conditions within fishways may present different challenges to AWF than alewife. While a direct comparison between alewife and adult AWF is not possible at this time, this work can help identify possible challenges and develop monitoring methods before trials are attempted with the sensitive species. Establishing fish passage is deemed a significant step towards ensuring the survival of the wild AWF population and re-establishing anadromy within the Petite Rivière watershed. Our results demonstrate the possibility of using PIT monitoring arrays in the Petite Rivière to study movement of native fishes. However, technical challenges must be addressed in order to establish a robust system capable of monitoring passage rates through fishways. This is an important consideration for AWF recovery, as fishway type (e.g., run-around, Denil, slot, stepped pool) and design are known to have a significant effect on passage rates (Bunt et al. 2012; Noonan et al. 2012), and passage rates may vary by species (Mallen-Cooper and Brand, 2007; Noonan et al. 2012).

Following the results described herein, the next steps towards development of a dedicated PIT detection system in Petite Rivière are to deploy and test the detection efficiency of pass-over antennas. Land-trials suggest that this design can be successful for detecting 12-mm PIT tags, however, estimate of detection efficiency are needed to enable the application of these antennas to assessment of passage rates through fishways. Therefore, more work is necessary to finalize a design for pass-over antennas that may be employed outside of the primary fishway structures. The low detection efficiency of the upstream antenna at Crousetown Dam must also be addressed so that meaningful estimates of fish passage through the fishway can be made. Furthermore, the PIT tagging methods must be trialed and validated in AWF prior to a large-scale tagging study taking place. The development of a PIT detection system at strategic locations in Petite Rivière will provide the tools necessary to monitor the effectiveness of AWF recovery efforts, such as demonstrating whether fishways can allow the passage of AWF, identifying fish passage needs, addressing questions of riverine habitat use, dispersal, and migration timing.

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APPENDIX

Figure A1. Crousetown Dam (A) showing stepped pools (B) and inside of Denil ladder (C).

Figure A2. Cranberry Dam (A) and Hebb Dam (B) showing base of fish ladder.

Figure A3. In-stream deployment of circular pass-over antennas.