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Telemetry studies of the passage route and entrainment of downstream migrating wild Atlantic salmon (*Salmo salar*) smolts at two hydroelectric installations on the Exploits River, Newfoundland, Canada

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Abstract

The Exploits River is the largest river in insular Newfoundland, Canada, supporting an anadromous wild Atlantic salmon *(Salmo salar* L.*)* population of up to 30,000 returning adults annually. Since 2001, telemetry studies have been conducted at hydroelectric plants at Bishops Falls and Grand Falls-Windsor, 10 and 22 km upstream from the mouth of the river respectively, to address downstream fish passage issues. In 2001, studies were focussed on smolt passage at Bishops Falls and 35 tagged smolt were released 100-200 m above the facility from June 6 to 23 in 7 separate releases. Nineteen (19) of these fish entered the forebay while the remaining 16 fish remained in the river mainstem and passed over the dam in spillage. Fish remained in the forebay on average 14.1±3.0 hours (mean ±s.e.). Fish spent most of their time (9.0±2.1 h) in a quiet water area in the proximity of a bypass and lesser time in other locations (0.05±0.05 h in front of the trashracks; 0.3±0.3 h in the middle of the forebay; 4.5±2.1 h below the entrance gates to the forebay). Thirteen (13) fish exited the forebay through the bypass facility (reverse fishway). Three (3) fish were determined to have passed through the turbines and survived turbine passage. In 2002, 23 smolt were released 5.0 km upstream of the Grand Falls facility from June 3 to 18 in 5 separate releases. Fish took an average of 78.8±12.8 hours to reach the dam and/or power canal of the plant. Twelve (12) fish subsequently went over the dam and 11 were entrained into the power canal. Of the 12 fish that went over the dam, one went through an opening specifically intended to facilitate smolt out migration while 6 transmitters were found at a gull colony below the dam indicating apparent predation. Once in the power canal, fish moved through the canal quickly, on average 11.0±2.0 minutes, before being bypassed (n=5), passing through the turbines (n=5), or swimming out of the canal entrance (n=1). These telemetry studies have been important in elucidating the various passage routes downstream migrating Atlantic salmon smolt are using at hydroelectric facilities and are part of a continuing effort by government and industry to maintain and enhance the salmon population on the Exploits River.

Introduction

Dams are barriers to movement of migratory species, such as anadromous salmonids, that must be traversed in order to maintain the population that is spawning and rearing upstream of the barrier. Loss of smolt during downstream migration represents a population reduction in a life stage that does not allow for normal biological compensatory mechanisms to mitigate the potential population loss. Mortality at the smolt stage will adversely affect adult recruitment and hence potential yield from the stock originating from spawning and rearing areas above a hydroelectric development (Ruggles *et al*., 1993). Smolt descent in rivers is a naturally hazardous period in the life history of Atlantic salmon and the passage of falls and dams, desmoltification, and predation from other fishes,

birds, and mammals are major sources of mortality for migrating juveniles that has the potential to seriously affect the sustainability and viability of salmon populations (Hvidsten and Johnsen, 1997). Understanding the potential for turbine entrainment and design and operation of fish bypasses at hydroelectric installations requires knowledge of swimming ability and behaviour, environmental cues for migration, and orientation and direction of movement. Fish have several potential passage routes as they approach and move past a hydroelectric facility. They can enter the forebay or turbine intakes (e.g. penstocks), where they can be directed to a bypass or pass through the turbines, or they can pass over the dam and/or spillways, depending on the design and operation of the power plant. A fundamental behaviour pattern of salmon smolts approaching dams is that they are surface oriented and generally follow the maximum flow patterns, therefore, fish may be more readily passed in spillage during high flow periods and may have to actively avoid entrainment during lower flows, when more of the bulk flow is directed to the power plant (Coutant and Whitney, 2002). Passage of downstream migrating juveniles has been a particularly difficult aspect of hydroelectric development to manage and efforts to divert smolts from turbines by spills or bypasses have met with varying degrees of success (U.S. Congress, 1995). Smolt must reach salt water in a defined time period or they may cease their migration and desmoltify and significant delays associated with passage of hydroelectric facilities may be important in initial smolt survival when they first encounter the sea (Ruggles, 1980). Fish guidance systems are influenced by fish behaviour and behaviours that lead to successful guidance will vary by species, fish size, physiological condition, etc. Mechanical, structural, and operational features of hydropower installations are important primary features that will influence potential for successful guidance and downstream passage. Studies are needed to relate fish behaviour and movements to hydraulic (flow direction and velocity) and other environmental cues encountered by fish as they approach a dam and enter forebays, bypasses, or turbine intakes (Coutant, 1999).

The Exploits River is the largest river in insular Newfoundland, Canada, supporting an anadromous wild Atlantic salmon population of up to 30,000 returning adults annually. Upstream fish passage facilities have been installed at several major natural and man made barriers on the river to provide access to most of the watershed. Two hydroelectric plants were developed in the early 1900s in the lower reaches of the river at Bishops Falls and Grand Falls-Windsor, 10 and 22 km upstream from the mouth of the river, respectively. In the mid-1990's a downstream fish protection system (floating louver and bypass) was installed at Grand Falls-Windsor and the effectiveness of that system has been assessed since 1997 (Scruton *et al*., 2002b). In 2001, telemetry studies were conducted at the Bishops Falls hydroelectric plant to address entrainment into the forebay, residency in the forebay, passage routes including turbine entrainment, and potential migratory delays. This work was conducted as a precursor to a major refit of this power plant in 2002/2003, including installation of a new surface bypass system, in order to consider existing downstream migration routes in the design and operation of this new bypass. In 2002, a similar telemetry study of smolt entrainment and passage was conducted at the Grand Falls-Windsor facility, in order to provide comparable information to further improve the operations of the plant and bypass system to optimize downstream passage success. This paper reviews the results of these telemetry studies in the context of the comprehensive resolution of downstream fish passage issues on the Exploits River.

Materials and methods

Exploits River

The Exploits River is the longest river (246 km in length) and largest drainage basin (11,272 km^2) on the island of Newfoundland and has a mean annual discharge of approximately 290 m^3s^{-1}. The river sustains one of the largest runs of wild adult Atlantic salmon in North America which was developed through a major enhancement program including adult transfers and stocking of unfed fry

throughout the drainage (Taylor and Bauld, 1973). The river was originally obstructed to upstream migration at Bishop's Falls and Grand Falls, approximately 10 and 20 km from the estuary, respectively, and several major tributaries were also obstructed, and, prior to enhancement, only 10% of the watershed was accessible and the adult run was estimated at 1600 fish (1960) (O'Connell and Bourgeois, 1987). A fishway was constructed at Bishop's Falls (1958) providing access to major tributaries and the returning adult population grew to about 16,000 fish (1985). Fish passage was subsequently provided at Grand Falls (1991) and Red Indian Lake (1989) permitting access to much of the watershed. Adult production potential, based on habitat productive capacity, was estimated at 80-100,000 fish and returns at Bishop's Falls peaked at 33,000 fish in 1996, and have averaged 22,000 over the 1990s (O'Connell *et al*., 2003).

Hydroelectric facilities, at Bishop's Falls and Grand Falls-Windsor, were installed by Abitibi Consolidated Company of Canada (ACCC) in the early 1900's to supply power to a pulp and paper mill at Grand Falls-Windsor (Fig. 1). At Grand Falls, the water supply to the generating facility enters a forebay through a series of vertical gates and then through a power canal with submerged intake gates leading to Francis turbines operating under a 'run of river' regime. Flows under normal operating regimes are 183 m^3s^{-1} (ranging from 160 to 210 m^3s^{-1}) and during the smolt run, 28.3 m^3s^{-1} of water is spilled over the dam through 21.3 m opening and at the north end to facilitate smolt migration ('smolt water'). Passage routes for downstream migrating smolts are: (i) over the dam, (ii) through the 'smolt' opening in the dam, (iii) through spillway gates in the dam (only during the early part of the run), (iv) into the power canal and bypassed back into the river, and (v) into the power canal but past the louver guidance system and through the turbines (Fig.2).

At Bishops Falls, the water supply to the generating facility enters a forebay through a series of

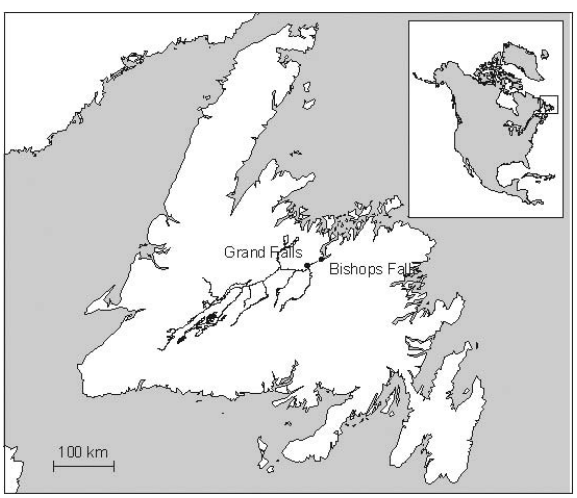

Fig. 1 – Map of the Exploits River watershed, insular Newfoundland, Canada showing the location of the Bishops Falls and Grand Falls generating stations.

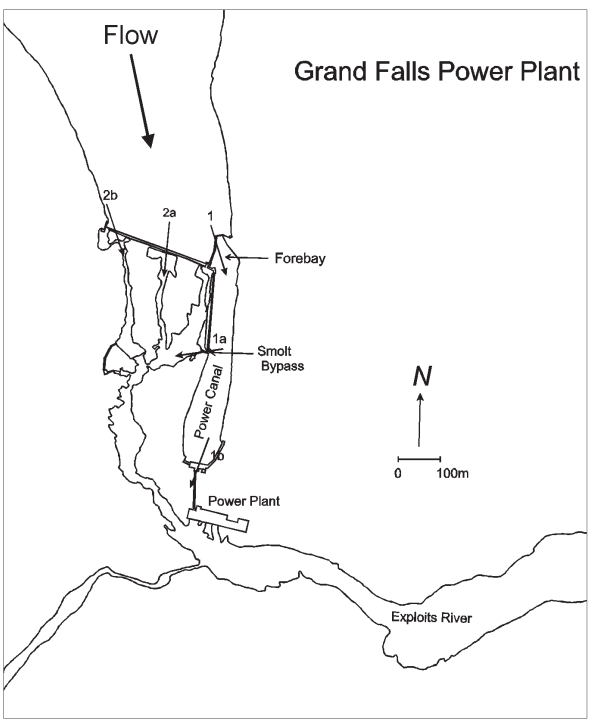

Fig. 2 – Configuration of the Grand Falls dam and power plant in the Exploits River showing the various passage alternatives for downstream migrating Atlantic salmon (*Salmo salar*) smolt. 1) entry into the forebay and power canal, 1a) turbine passage, 1b) passage through louver and bypass (reverse fishway), 2a) passage over the dam, 2b) passage over the dam through smolt water opening.

bottom opening vertical gates and then directly into the turbine intakes. During the smolt run, 28.3 $m^3s^{-1}$of spillage is provided through a 17.3 m opening on the north end of the dam to facilitate smolt migration ('smolt water'). A reverse fishway at the south end of the turbine intakes was installed as a downstream passage alternative for fish entering the forebay. Bottom opening control gates for spillage are located on the southeast end of the dam. Passage routes for downstream migrating smolts are: (i) over the dam, (ii) through the 'smolt' opening in the dam, (iii) through spillway gates in the dam (only during the early part of the run), (iv) into the forebay and bypassed back into the river through the reverse fishway, and (v) through the turbines (Fig 3).

Bishops Falls Smolt Tracking 2001

In 2001, studies were focused on downstream smolt passage at Bishops Falls and 35 radio tagged smolt were released 100-200 m above the facility from June 6 to 23, 2001. Seven separate releases, involving five fish per release, were staggered over the 17 day study period to allow maximize coverage by the fixed stations. Fish were initially captured at the fish protection system (floating louver, bypass) at the Grand Falls power canal where radio transmitters were surgically implanted. After recovery fish were transported in insulated containers to their release point.

Smolt were surgically implanted with radio transmitters (Advanced Telemetry Systems, model F1420, 7 mm in diameter, 18 mm long, 1.3 g in water) after procedures described in Scruton *et al*.

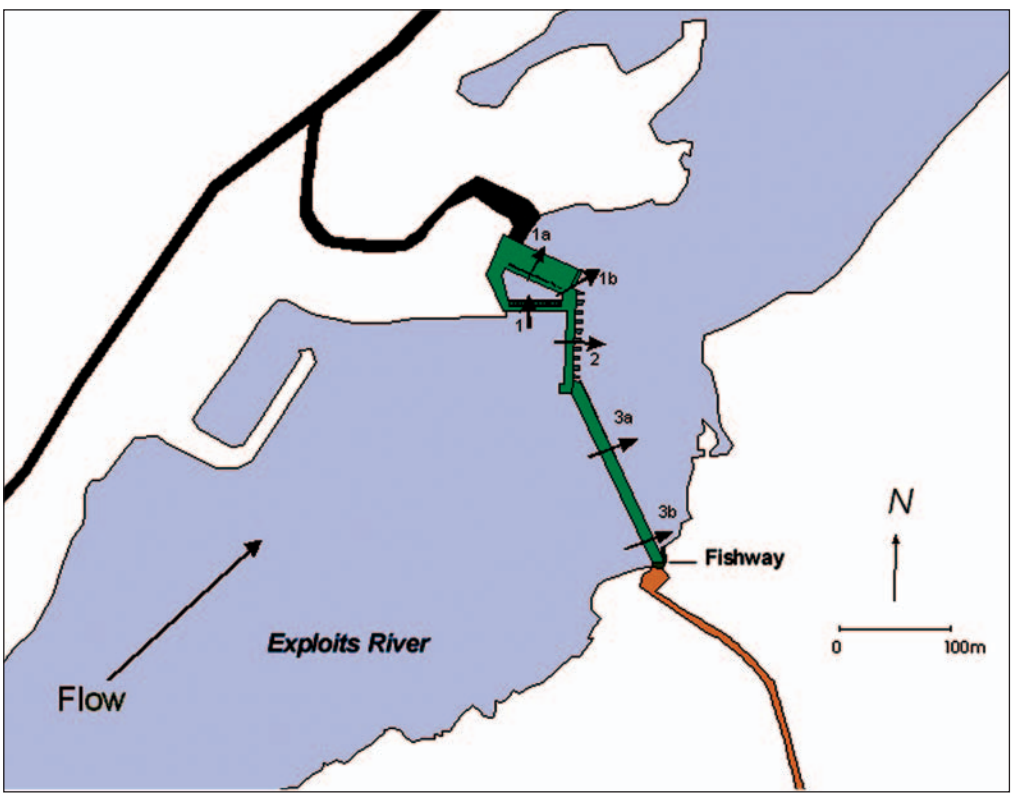

Fig. 3 – Configuration of the Bishops Falls dam and power plant in the Exploits River showing the various passage alternatives for downstream migrating Atlantic salmon (*Salmo salar*) smolt. 1) entry into the forebay, 1a) turbine passage, 1b) passage through bypass (reverse fishway), 2) passage through spillway gates, 3a) passage over the dam, 3b) passage over the dam through smolt water opening.

(2002a). Fish were anesthetized in 10 l of river water with 1-2 ml clove oil/ethanol solution as described in Anderson *et al*. (1997). After regular opercular movement had ceased and fish had lost equilibrium (approximately 2 min), fork length (FL, centimeters) and weight (WT, grams) were determined. Fish were then placed dorsal side down on foam padding which kept them moist and held them in position during surgery. A 1 cm incision was made posterior to the pelvic fin. Using an 18 G hypodermic needle, a small puncture wound was made just below and lateral to the incision, through the body cavity. The antenna of the transmitter was threaded through the body wall using the hypodermic needle. The transmitter was then inserted into the body cavity and the incision closed with 2 sutures of 4-0 Ethicon braided silk. Upon completion of surgery, fish were placed in insulated holding containers and were allowed to recover for a 12 hour recovery period.

A combination of both manual tracking and fixed stations were used to monitor fish movements. Three automatic data logging stations (Lotek Wireless Inc. SRX_400 receivers with a combination of coaxial [underwater] and Yagi antennas) were setup to monitor discrete areas in the forebay and other parts of the power plant and dam. Set up with calibration delineated 4 discrete areas in the forebay: (i) in front of the submerged entrance gates to the forebay, (ii) in the main area (middle) of the forebay, (iii) at the trash racks in front of the submerged turbine entrances, and (iv) in a quiet water area near the spillway gates and the downstream fishway (Fig. 4). Additional antennae monitored potential passage over the dam and spillways as well as turbine passage. Fixed station data were downloaded daily. Scanning rate varied by receiver and in relation to the transmitters deployed and the maximum scan time was 2 minutes at any one receiver. Manual tracking from both the river shoreline and boat, was conducted each evening after release, and opportunistically, during

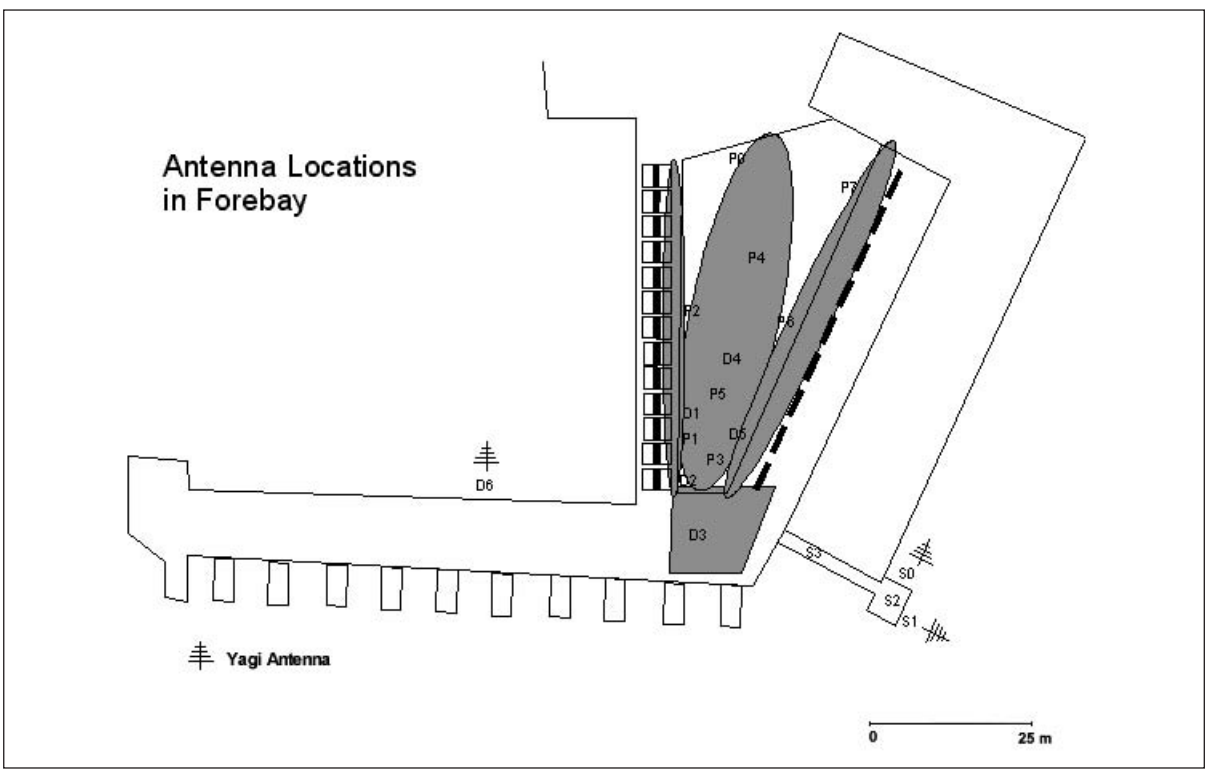

Fig. 4 – Bishops Falls forebay showing the location of coaxial and Yagi antennae and the discrete detection zones used in the fixed station telemetry monitoring of smolt movements.

daylight hours. Manual tracking was also used to locate fish and follow movement downstream after having passed through the facility to determine survival after turbine passage.

Grand Falls Smolt Tracking 2002

In 2002, studies focused on downstream smolt passage at Grand Falls and 23 radio tagged smolt were released from June 3 to 18, 2002. Five separate releases, involving three to twelve smolt per release, were staggered over the 15 day study period. Fish were captured from the fish protection system (floating louver, bypass) at the Grand Falls power canal and radio transmitters were surgically implanted as described above. After recovery fish were transported in insulated containers to their release point, approximately 5.0 km above the entrance to the Grand Falls forebay. Fish were released at 3 locations, from the right hand bank (looking upstream) (n=10), from the left hand bank (n=13), and from mid-river (n=9), to determine if release location (i.e. migration trajectory) had any influence on entrainment into the Grand Falls facility.

Again, a combination of both manual tracking and fixed stations were used to monitor fish movements. Three automatic data logging stations (Lotek Wireless Inc. SRX_400 receivers with a combination of coaxial [underwater] and Yagi antennas) were setup to monitor discrete areas along the dam, the entrance to the forebay, and the floating louver, fish handing and bypass system (Fig. 5). Fixed station data were downloaded daily. Scanning rate varied by receiver and in relation to the transmitters deployed and the maximum scan time was 30 s at any one receiver. Manual tracking, as above, was also used to track fish from their release point until detected by the fixed stations.

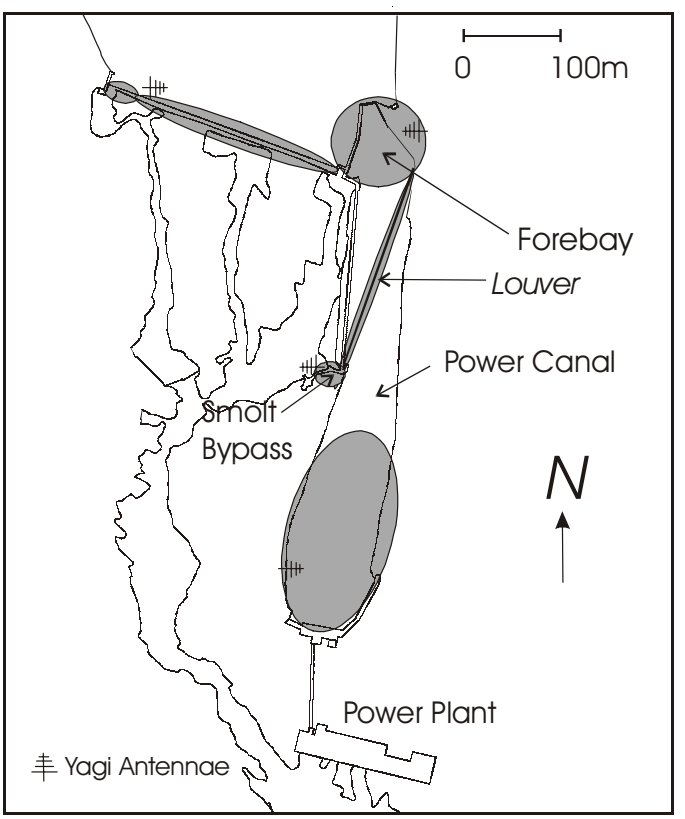

Fig. 5 – The approach to and the Grand Falls forebay and power canal showing the location of discrete detection zones used in the fixed station telemetry monitoring of smolt movements.

Results

Bishops Falls Smolt Tracking 2001

In 2001, studies on downstream smolt passage at Bishops Falls involved the release and tracking of 35 tagged smolt from June 6 to 23 in 7 separate releases. Smolt used in telemetry studies ranged in length from 144 to 233 mm (mean of 175.3, s.e.±2.99) and in weight from 30-103 g (mean of 50.4, s.e.±2.33). Nineteen (19) of these fish entered the forebay while the remaining 16 fish remained in the mainstem of the river and passed over the dam (Fig. 6). Fish remained in the forebay from 0.2 to 42.0 hours (average 14.1±3.0 hours). Fish spent most of their time, from 0.1 to 30.0 hours (average 9.0±2.1 hours) in a quiet water area in the proximity of the bypass. Fish spent a lesser time in the other locations; from 0.0 to 1.0 hours (average 0.05±0.05 hours) in front of the trashracks; from 0.0 to 5.0 hours (average 0.3±0.3 hours) in the middle of the forebay; and from 0.0 to 35.0 hours (average of 4.5±2.1 hours) below the entrance gates to the forebay. One fish was detected at the entrance gates to the forebay for a total of 102 hours, and may have been injured or dead, and the data on this fish was removed from more detailed analyses. Thirteen fish exited the forebay through the bypass facility (reverse fishway) and 3 fish were determined to have passed through the turbines. Manual tracking downstream of the power plant determined these 3 fish had survived turbine passage as fish were verified to be continuing their migration in the lower reaches. Monitoring frequency did not permit a rigorous assessment of survival of turbine passage.

Grand Falls Smolt Tracking 2002

In 2002, a total of 23 smolt were released 5.0 km upstream of the Grand Falls facility from June 3 to 18 in 5 separate releases. Smolt used in telemetry studies ranged in length from 161 to 209 mm (mean of 180.4, s.e.±1.83) and in weight from 40-77 g (mean of 50.7, s.e.±1.56). Fish took an average of 78.8±12.8 hours to reach the dam and/or power canal of the plant. Twelve (12) fish subsequently went over the dam and 11 were entrained into the power canal. Of the 12 fish that went over the dam, one went through an opening specifically intended to facilitate smolt out migration while 6 transmitters were found at a gull colony below the dam indicating predation (either active on live smolt, or passive on smolt that may have been killed during dam passage) (Fig.7). Once in the power canal, fish spent on

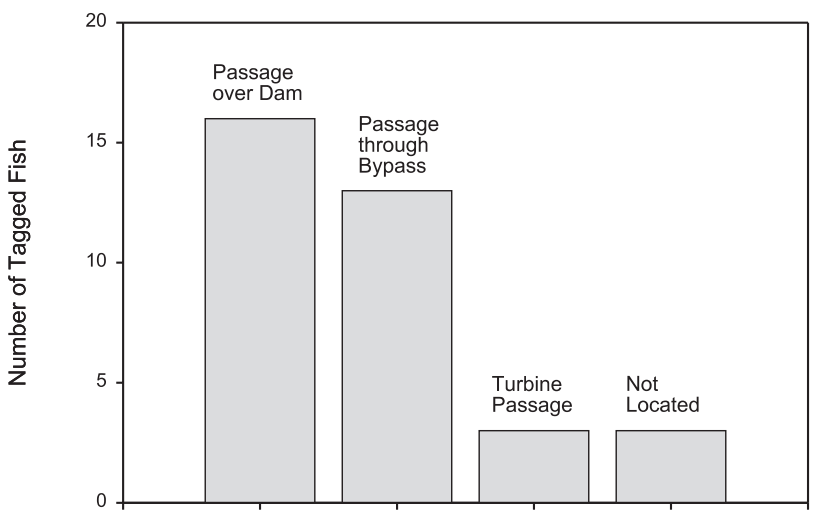

Fig. 6 – Proportion of downstream migrating Atlantic salmon (*Salmo salar*) smolt using various passage alternatives at the Bishops Falls dam and power plant in telemetry studies in 2001.

average 11.0±2.0 minutes in the canal before being bypassed (n=5), passing through the turbines (n=5), or swimming out of the canal entrance (i.e. returning to the forebay/main river; n=1).

Discussion

In the 2001 Bishops Falls study, 19 (54%) of 35 fish released entered the power plant forebay while the remaining 16 fish were deemed to have passed over the dam. Fish passing into the forebay would have to sound some 1.2 m below the water's surface to do so. Generally, many species of salmon smolt are reluctant to sound to submerged outlets at dams (Ruggles and Murray, 1983). Orientation of smolt in the upper portion of the water column will result in them having a greater likelihood of being deterred from bottom opening entrance gates or deep turbine intakes and finding alternative surface passage routes (Haro *et al*., 1998). Fish generally do not descend into the lower two-thirds of the water column in dam entrances or forebays, unless there is no alternative passage route, and several studies have demonstrated that migrating salmonids only sound to great

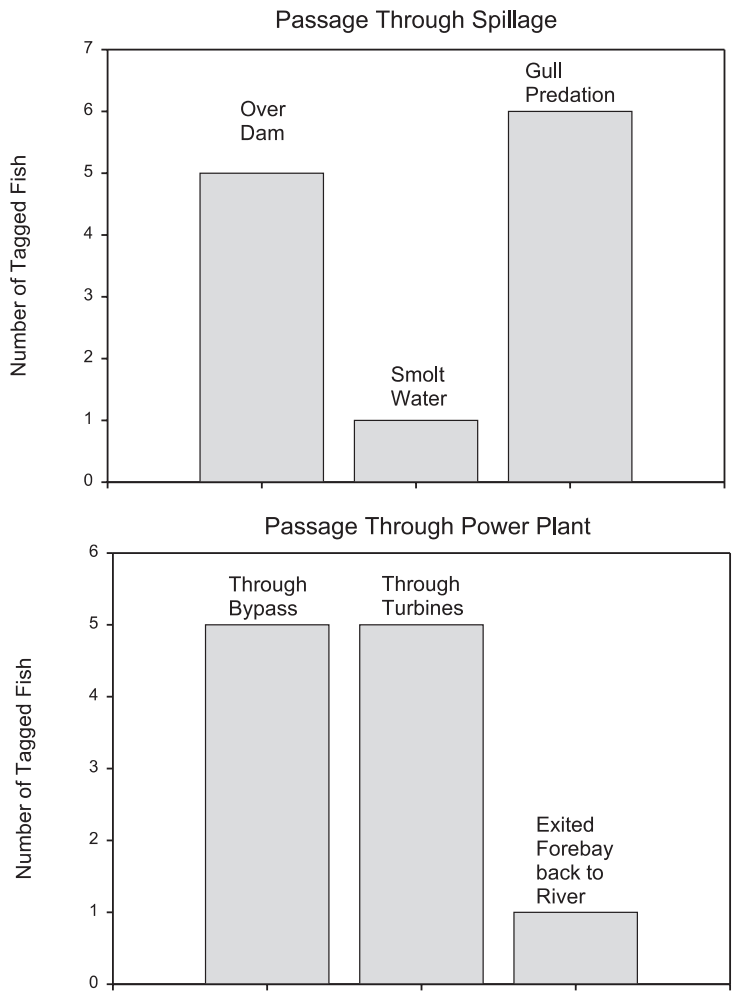

Fig. 7 – Proportion of downstream migrating Atlantic salmon (*Salmo salar*) smolt using various passage alternatives at the Grand Falls dam and power plant in telemetry studies in 2002.

depths as a last resort (Coutant and Whitney, 2002). Salmon smolts are able to sound to considerable depth to escape from reservoirs however their migration can be delayed for considerable periods (Ruggles and Murray, 1983).

Fish will use alternative pathways for downstream migration, other than turbine passage, if suitable conditions can be provided for fish to locate and use alternative routes. In both the 2001 Bishops Falls studies and the 2002 Grand Falls studies, 45% and 56% respectively, used alternative passage routes other than going through the power plant infrastructure. Atlantic salmon smolts that did enter the forebay at Bishops Falls resided in the forebay from 0.2 to 42.0 hours (average of 14 hours) and did not appear to demonstrate any significant delay in their migration. At Grand Falls in 2002, smolts spent, on average, 79 hours to traverse the 5.0 km from their release location to the power plant, however, once they were entrained into the forebay and power canal, took an average of 11.0 minutes to be bypassed. Salmon smolt migration is often interrupted once fish reached impounded waters associated with a hydroelectric dam and the general pattern is also for smolt to be delayed in the surface waters of forebays (e.g. Giorgi *et al*., 1988). The time taken by smolts to reach Grand Falls power plant, from release, suggest they may have been delayed owing to an impoundment associated with Goodyear's Dam, approximately 3.5 km above the power plant. Once fish passed Goodyear's dam they arrived at the Grand Falls power plant very quickly. Atlantic salmon smolt can also be delayed at bypass systems and have been observed to gather in large numbers before being bypassed *en mass* as a school (Nettles and Gloss, 1987). This appears to be the situation for fish that entered the Bishops Falls forebay in 2001. Once in the forebay, fish appeared to locate the quiet water area in front of the smolt bypass locations (reverse fishway) and large accumulations of smolt were observed in this area. Tagged smolt resided in this area for 9.0 hours on average before 13 of them were subsequently bypassed, mostly at night.

Forebay bathymetry often results in turbulent flow conditions and will determine smolt distribution, both vertically and horizontally, under these conditions. Conditions in the Bishops Falls forebay are extremely turbulent and, during the peak smolt run, fish were observed to be buffeted in the standing waves in the forebay and, on occasion, have been seen to be tossed into the air. Fish spent very little time in the highly turbulent areas in front of the entrance gates, in the middle of the forebay and in front of the trash racks and were able to locate and remain in the quiet water areas of the forebay. Despite the apparent disorientation of smolts related to water turbulence at the Bishops Falls forebay, the majority of the tagged fish were able to locate and utilize the downstream bypass system. Of the three fish that went through the turbines, they spent more time in the forebay (average of 18.3 hours), and considerable time (average of 10.6 hours) in the quiet water area, before turbine entrainment. It is unclear why these fish selected turbine passage and were unable to find and use the downstream bypass.

The location of fish as they approach hydro power installations, in relation to possible passage through spillage routes, is important in the context of overall passage of hydroelectric facilities, and the particular physical configuration of power plants and spillways will play a large role in the overall effectiveness of spillage in passage. A large proportion of the tagged smolts at Bishops Falls and Grand Falls were not entrained into the power plant's infrastructure (i.e. forebays and power canal) and utilized spillage over the dams as the preferred downstream migration route. At both facilities, water is released throughout the smolt run, in addition to openings in the dams on the opposite side of the river from the power plants, specifically for the purpose of encouraging smolt to use these passage routes.

At Grand Falls, half of the fish that went over the dam (6 of 12) were predated upon by herring gulls (*Larus argentatus*). A large gull colony has been established at Grand Falls presumably, at least in part, because of food supply from migrating smolts during the nesting period. Additionally, the configuration of Grand Falls, with most water spilling on top of rock outcrops, would result in a high natural rate of mortality. Stress associated with tagging, or possibly the obvious appearance of the antennae, could also have made tagged fish more susceptible

to predation. If rates of mortality and/or predation are a true indication mortality associated with dam passage, the preferred passage route in terms of overall survival may be through entrainment into the power canal, and subsequent bypass back into the river from the louver protection scheme as previous studies have determined a bypass efficiency up to 75% (Scruton *et al*., 2002b). This observation may result in modifying the current operation of the facility, which spills water during the smolt run to encourage fish to use alternative passage routes, to increasing entrainment into the power canal for subsequent bypass. The apparent high rate of mortality and/or predation is of importance and may warrant additional study.

Migration delays can potentially cause smolts to de-smoltify and reside in the river for an additional year, could delay there entrance into the ocean resulting in exposure to unfavourable environmental conditions, can result in depletion of energy reserves, and could expose fish to increased rates of predation (Ruggles, 1980). Reductions in the delay that smolt experience as they enter forebays and are bypassed by hydroelectric projects is considered a critical element of enhancing fish passage and survival (Haro *et al*., 1998). The telemetry studies at Bishops Falls in 2001 and Grand Falls in 2002 suggest no major migration delays associated with passage of the two facilities. Further, school integrity during downstream migration and passage of hydroelectric facilities will reduce stress and predation risk (Haro *et al*., 1998) and downstream passage can be inhibited by obstacles that prevent fish from maintaining schools (Bakshtansky *et al*., 1993). Accumulation of smolt, through schooling behaviour, may be playing a role in the successful bypass of fish entering the Bishops Falls forebay.

The telemetry studies conducted at Bishops Falls and Grand Falls, in 2001 and 2002 respectively, have been important in elucidating the various passage routes downstream migrating Atlantic salmon smolt are using at hydroelectric facilities on the Exploits River. These studies, in addition to assessing the effectiveness of existing fish protection schemes at these facilities, will be important in determining the overall successful downstream passage of smolts from the watershed. Additionally, with a knowledge of the utilization of the various passage alternatives, the operation of the two facilities, including discretionary spillage during the smolt migration period, can be optimized to improve overall successful passage of hydroelectric facilities. These studies are part of a continuing effort by government (Canadian Department of Fisheries and Oceans) and industry (Abitibi Consolidated Company of Canada) to maintain and enhance the salmon population on the Exploits River and to minimize the impacts of hydroelectric development on migrating fish.

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