Downstream Passage of Atlantic Salmon (_Salmo salar_) Smolts at Cabot Station, Turners Falls Project, Turners Falls, Massachusetts, 1994

INTRODUCTION

A program to restore anadromous fish to the Connecticut River basin, now under the direction of the Connecticut River Atlantic Salmon Commission (CRASC), has been underway since 1967. In support of this program, Western Massachusetts Electric Company (WMECO) has provided routes for downstream passage at the Turners Falls Project (FERC Project No. 1889) since 1981, passing emigrating adult American shad (_Alosa sapidissima_) downstream through a log sluice adjacent to Cabot Station. Since then the sluice has also been opened to allow downstream passage of Atlantic salmon smolts and juvenile American shad.

In 1990, CRASC, its member agencies, and WMECO signed a Memorandum of Agreement (MOA) concerning downstream passage of anadromous fish. WMECO agreed to provide downstream passage facilities at the Turners Falls Project by 1994 or 1995, depending on progress of a similar program at the Holyoke Project, Holyoke, Massachusetts. WMECO began development of the Turners Falls facilities in 1990; this report is another in a series on the progress of this effort. The purpose of this report is to describe an evaluation of the effect of modifying the Cabot Station intake racks and adding a light at the entrance to the log sluice on downstream passage of Atlantic salmon smolts. It includes: a description of the Turners Falls site; a summary of past studies; the objectives of this study; the methods used to attain the objectives; the results of testing at Cabot Station; and a discussion of those results.

STUDY SITE

The Turners Falls Project is located at river mile 117 on the Connecticut River, Massachusetts, and consists of Turners Falls Dam, a canal gatehouse structure, a 2.1 mile canal, Turners Falls No. 1 Station, and Cabot Station (Figure 1). The Project is 31 mi upstream of the Holyoke Dam.

The canal gatehouse, situated on the east side of the river, directs up to approximately 15,000 cfs into a 2.1 mi power canal leading to Turners Falls No. 1 and Cabot Stations. Turners Falls No. 1 Station is located approximately 0.5 mi

downstream from the gatehouse, on a branch canal (Figure 1), and is generally operated only when river flow exceeds the hydraulic capacity of Cabot Station. The hydraulic capacity of No. 1 Station is 2,500 cfs.

Cabot Station, an integral-intake powerhouse, is located at the downstream end of the power canal. The Station has six identical Francis turbines with a total nameplate rating of 51 Mw at a head of 60 ft. Water is delivered to each turbine through a three-bay intake which is joined to the penstock. The intakes are protected by steel racks with bars spaced 4 in apart. The top 11 ft of the rack was modified during 1994 by reducing the spacing to 1 in. The hydraulic capacity of the Station is 12,500 cfs.

A 16-ft wide by 12-ft high log sluice gate adjacent to Cabot Station admits water into a log sluice that discharges to the river immediately downstream of Cabot Station. The entrance to the log sluice was modified in 1991 (Harza and RMC 1992a) to accommodate the installation of a sampling facility in the sluice, and further modified in 1992 to refine the sampler design. A bulkhead was inserted in the sluice gate stop log slots, providing an opening 4-ft deep by 11-ft wide leading to the sluice sampler.

The log sluice sampler (Nguyen and Hecker 1992) consists of a horizontal stainless steel profile bar screen, a flume section, and a sorting table. A 27.5 ft long screen section extends from the sluice gate bulkhead to a 3/4-barrel shaped transition to the flume. When it is deployed, the screen sheds most of the water flowing onto it and conducts virtually all (Harza 1994) fish into a 31-ft long, 1-ft wide flume. The flume leads to a sorting table where fish samples are processed. Water flows across the sorting table and back into the log sluice via a 12-in diameter pipe.

BACKGROUND

Evaluation of downstream fish passage at Cabot Station began in spring 1991, when hatchery-reared salmon smolts were radiotagged and released upstream of the gatehouse at Turners Falls Dam (Harza and RMC 1992b). Other than the deployment of a surface boom to deflect smolts from the entrance to the branch canal serving Turners Falls No. 1 Station, Project works were not modified for this study. The log sluice gate was opened from 2 to 2.5 ft to allow downstream passage. Of the 87 radiotagged smolts that approached Cabot Station during this study, 57 (66%) passed by way of the log sluice.

Openings were cut into a trough leading to the sluice located behind the intake racks in 1992 to raise the percentage of smolts passing around Cabot Station (Harza and RMC 1994). Two different spill configurations, one providing a wide, shallow entrance to the sluice, the other providing a deeper, narrower entrance, were also tested. Radiotagged, hatchery-reared smolts were released upstream of the gatehouse at Turners Falls Dam and monitored as they passed through the canal. Although interpretation of the data was difficult because of overlapping antenna ranges, of 81 smolts that passed either through the sluice, the trough, or the units, only 31 (38%) bypassed Cabot Station. Neither the openings into the trough nor the shape of the spill configuration were shown to have a beneficial effect on overall passage of the radiotagged smolts.

The sluice sampler was installed in 1992. In spring 1993, hatchery-reared and stream-reared smolts were marked and released in the canal, either 1.5 mi upstream of Cabot Station or immediately upstream of the Station forebay (Harza 1994). One of the trough openings was used and the bulkhead at the entrance to the sluice provided a 4-ft deep by 11-ft wide opening. Results were highly variable and passage was generally lower than it had been in previous studies.

In fall 1993, the effect of overhead lighting at the entrance of the sluice on the downstream passage of juvenile clupeids was evaluated (RMC 1994). The use of lights had a marked effect on passage; passage was enhanced by the use of a light under the walkway at the entrance to the sluice and by cycling an overhead light on and off at 20-min intervals.

The low passage rates attained in 1992 and 1993 led to the reduction of the intake rack bar spacing at Cabot Station in 1994. After receipt of the results of the 1993 tests of the effect of lighting on the passage of juvenile clupeids, it was decided to conduct testing of the effect of lighting on passage of salmon smolts as well.

OBJECTIVE

The objectives of the 1994 study were to determine:

- o the proportion of radiotagged smolts passing downstream by way of the log sluice with reduced intake rack bar spacing at Cabot Station; and

- o the effect of overhead lighting on the proportion of radiotagged smolts passing through the sluice.

METHODS AND MATERIALS

A series of eleven combined mark-recovery and radiotelemetry releases was conducted between May 9 and May 21, 1994. A substantial number of radio tags were recovered at the log sluice bypass collection facility. Thus, a series of three supplemental radiotelemetry releases (no mark-recovery component) was conducted between May 24 and May 27, 1994 to assess passage of smolts over the sluice gate without the collection facility in operation.

Test Conditions

Rack bar spacing in the upper 11 ft of the intake racks was reduced from 4 in to 1 in clearance by inserting polyethylene bars and spacers between the existing steel bars of the upper trash rack sections. The rack bar spacing remained the same during all tests.

The Cabot Station intake area is normally lighted by two overhead high pressure sodium lamps at the north and south (nearest the sluice entrance) ends of the forebay (Figure 2). The lights are oriented toward the trash racks, serving to illuminate the platform and walkways above the penstocks. Areas of brightest illumination along the face of the trash racks occur at either side of the forebay. The footbridge over the entrance of the sluiceway places the area immediately upstream of the sluice entrance in shadow under normal light conditions. The modified lighting condition was provided by turning off the north forebay overhead light and turning on a 400-watt mercury vapor lamp suspended under the footbridge immediately upstream from the entrance of the log sluice. The modified lighting condition resulted in the areas of brightest illumination being located near the Unit 1 intake and at the sluiceway entrance. The modified lighting condition was alternated with the normal lighting condition during the primary series of tests. Only the modified lighting condition was evaluated during the supplemental series of tests.

The sluice gate may be used to control flow onto the screen section of the bypass collection facility. During the releases prior to May 18, debris loads were relatively heavy and the sluice gate was opened 30-40%, depending on debris-loading of the screen. This mode of operation resulted in the water depth at the sluice entrance opening varying between approximately 2.2 and 3.5 feet (typically 3.0 feet), depending on canal elevation. For the four releases of May 18 through 21, the sluice gate was opened 100% resulting in a depth of 3.6 to 3.9 feet (typically 3.8 feet) at the sluice entrance opening.

During the four supplemental, radiotelemetry-only releases of May 24-27, the sampler was not operated and the bulkhead and horizontal screen were removed. For those releases, the sluice gate was opened 35%, resulting in a water depth at the sluice entrance of 2.5-3.0 ft (typically 2.8 ft). Without the bulkhead in place, the width of the sluice opening was 16 ft.

Study Design

The planned evaluation of downstream passage involved two integrated study components, radio telemetry and mark- recovery. The mark-recovery component was intended to provide a series of relatively precise estimates of the effectiveness of the log sluice bypass facility. Calculation of bypass efficiency (i.e., the proportion of smolts bypassed) based solely on mark-recapture data involves the assumption that all smolts that are not recaptured in the sluice pass through the turbines. However, studies conducted at Cabot Station in 1991 and 1992 showed that some fish may remain in the canal for extended periods of time prior to exiting the canal. The radiotelemetry component, while suitable for estimating bypass efficiency, was intended to provide additional information on the fate of smolts released in the canal. This information was to be used to assess the fate of the released smolts and, if necessary, to adjust estimates of bypass efficiency to account for smolts that did not exit the canal, or that exited at locations other than the turbines and log sluice.

The original design called for release of ten groups of hatchery-reared smolts. Eleven releases were conducted because the south forebay overhead light failed during the first release, resulting in atypical illumination of the forebay. Each group consisted of approximately 200 marked smolts and 12 radiotagged smolts. The release site was at a railroad bridge that crosses the Turners Falls canal approximately 0.75 mi downstream from the gatehouse. Passage routes of radiotagged smolts were identified. Mobile monitoring of the canal was conducted on the day following each release of radiotagged smolts to determine whether smolts that were unaccounted for had remained in the canal.

All the combined radiotelemetry and mark-recovery releases were conducted when water temperatures were between 10°C and 15°C. Table 1 lists the flow and temperature conditions that existed during these releases.

Upon completion of the combined radiotelemetry and mark-recovery releases, enough radiotags had been recovered at the sluice sampler to allow the supplemental radiotelemetry

Table 1. River flow, flow through Cabot Station, flow over Turners Falls Dam, and water temperature, Connecticut River, May 9-23, 1994.

Date	Average river flow (cfs)	Average flow through Cabot Station (cfs)	Average flow over Turners Falls Dam (cfs)	Average water temperature (C)
May 9	24,448	9,626	14,830	10.5
May 10	24,156	14,131	10,025	10.8
May 11	18,677	14,064	4,613	11.4
May 12	18,509	14,440	4,099	12.0
May 13	18,906	14,394	4,514	11.6
May 14	17,808	13,855	3,951	11.6
May 15	15,872	13,497	2,375	-
May 16	16,144	13,743	2,399	12.0
May 17	25,526	13,690	11,842	11.7
May 18	24,045	14,226	9,818	10.7
May 19	22,273	14,288	7,952	10.6
May 20	19,053	14,105	5,056	10.9
May 21	17,937	14,347	3,545	11.6
May 22	12,990	12,633	358	12.5
May 23	11,680	11,310	370	14.8

releases. This provided the opportunity to assess bypass effectiveness without the sluice sampler in place.

Radiotelemetry System Set-up and Preparation

The radiotelemetry antenna system at Cabot Station comprised a combination of underwater whip, aerial whip, and aerial Yagi antennas. The antenna configuration for each monitored location was selected based on tests of reception areas and noise levels conducted prior to commencing releases of radio-tagged fish. For each antenna, high quality, double-shielded coaxial cable was used for the transmission line from antenna to receiver. Transmission lines were attached to their antenna and frequency-tuned (cut to proper length) using a precision standing wave ratio analyzer (SWR). Where in-water antennas were used, each individual antenna drop was made with #12 gauge insulated twisted core electrical wire soldered to a section of double-shielded coaxial cable for connection to the receiver. These antennas were frequency-tuned using the SWR and impedance-matched to the receiver. In instances where several antennas were connected to the same receiver, impedance-balanced splitter-combiners were used to connect tuned antenna leads to a common lead connecting all antennas to the receiver.

The monitoring system used five Lotek SRX-400 receivers for monitoring passage at fixed locations. An ATS R2000 tracking receiver was used for mobile operations. The following provides a verbal description of the antenna locations:

Forebay (Figure 3: #1)
This was a series of three underwater antennas suspended from a rope stretched across the forebay approximately 50 ft upstream from the trash racks. The antennas were spaced equidistant from each other at approximately 60-ft intervals beginning approximately 30 ft from the north end of the forebay. The antennas were joined through a splitter-combiner to a single receiver.

Sluice entrance (Figure 3: #2)
An underwater whip antenna monitored the area immediately upstream from the log sluice. The antenna was suspended from the downstream side of the footbridge at the sluice gate.

Spillway (Figure 3: #3)

Two base-loaded whip antennas were used to monitor the canal spillway - fishway water supply channel area. The whips were mounted on a metal plate attached to a pipe clamped to the fish ladder railing (upstream antenna) or wall (downstream antenna). The whips were oriented

upside-down under the fishladder. The antennas were located over the wall that separates the attraction water spillway from the rest of the overflow spillway area. The antennas were joined to a common receiver using a splitter-combiner.

Log sluice (Figure 3: #4)

A 4-element Yagi was attached low on the downstream face of the footbridge that goes over the sluiceway below the sampler. The antenna was oriented downstream and tuned to receive signals from within the sluiceway only. This location was monitored only when the sampler was not operating. The receiver was set to monitor only the frequencies of tags that had not passed the station or that were not accounted for at the end of a 24-h sampler monitoring period.

Tailrace (Figure 3: #5)

A 4-element Yagi was located on the walkway structure above the fishway entrance gallery at the Unit 2 discharge, aimed upstream to detect fish following passage through the turbines. An underwater antenna was used to detect fish exiting Unit 1. These antennas were joined to a common transmission line using a splitter-combiner.

Downstream (Figure 3: #6)

A 9-element Yagi was used to cover the width of the river channel below Cabot Station. The antenna was oriented across the river and slightly downstream. The antenna location was approximately 350 ft downstream from the log sluice exit.

Mobile and Sluice Sampler

A tracking receiver was provided to allow daily mobile coverage of the Turners Falls Canal. Both whip (e.g., roof-mounted on a vehicle) and hand-held Yagi antennas were used to locate fish in areas of the canal that were not covered by fixed-position monitoring equipment. When available, an SRX-400 with a small omni-directional whip was located at the sampler when the sluiceway sampler was being operated to capture fish (for 24 h following each release). A portable tracking receiver (ATS Model R2000) was sometimes used in place of the SRX-400. This allowed the crew to determine the frequency and pulse rate of tags recovered at the sampler.

Lotek SRX-400 receivers using either W9 or W18 software were used at Cabot Station. Once antennas had been installed, receivers were calibrated through seven functions: RF gain (sets the receiver sensitivity), scan rate (length of time receiver monitored a given frequency), time out (length of time a radiotag's signal must be absent before detection events are logged as separate), group size (number of detected pulses needed to considered the detection a valid event), global noise (number of noise events detected to cause automatic reduction of gain), noise blank level (minimum signal strength to be recorded as an event), and pulse rate window settings.

The RF gain setting for each receiver was established by placing an activated transmitter at the greatest desired detection range; at depths of 3 and 10 ft (typical for migrating smolts). The gains of receivers were set to detect tags in the intended coverage area without undue noise interference and to minimize detection of tags in the coverage areas of other receivers.

Scan rates (durations of time each frequency was monitored during a scan cycle) were set at the minimum time necessary to detect a valid pulse from a tag (typically, 0.8 sec). If a pulse was detected, the system would interrupt scanning until sufficient time had passed to detect a valid group of pulses.

Time out allowed multiple detection events to be combined into a single record indicating continuous fish presence in an area. This reduced data storage requirements for locations where fish remained for extended periods (e.g., forebay). Time out periods of less than one scan cycle length caused each detection of a tag to be recorded as a discrete event record. Time out periods of one-to-two scan cycle lengths combined detections of a tag during consecutive scan cycles into a continuous record. Time out periods that were greater than two times the scan cycle length combined intermittent detections into a continuous record until the receiver failed to detect a tag during a number of consecutive cycles equal to the time out period. Time out was typically set to 1 min (i.e., two scan cycles with tags present on all frequencies) to provide the relatively fine time discrimination necessary to determine passage routes, while minimizing excessive generation of event records.

Group size (typically 3), global noise, and noise blank levels were set on a receiver-by-receiver basis to optimize the data collection process and minimize recording of noise and spurious data.

Once individual receivers had been calibrated, the overall system configuration was tested. Emphasis was placed on reducing areas of potential antenna coverage overlap. Receiver calibrations were adjusted to balance coverage areas and minimize any potential problems due to overlapping coverage.

Smolt Marking/Tagging and Handling

Smolts in both the mark-recovery and radiotelemetry portions of the study were handled similarly. Handling procedures were similar to those used in 1993 (Harza 1994).

Groups of 200 hatchery smolts were marked at the Cronin National Salmon Station (Cronin) up to 48 h prior to their planned release. Smolts were marked using a Panjet marker and India ink. Fish were collected from the raceway at Cronin and anaesthetized in a solution of tricaine methanesulfonate (approximately 50 mg/L), measured to the nearest 0.5 cm, and marked. Eight readily recognizable marking locations were used during 1994. A mark was placed at one of the eight locations. Different mark-location combinations were used to identify the fish in each of the eleven release groups. The ink colors used to mark smolts for the mark-recovery portion of the study were unique to that portion of the study to avoid any possibility of confusion with stream-reared smolts from the population estimate study at the time of recapture at Holyoke. Following marking, fish were observed until they had recovered from the anaesthetic and were swimming normally. Initially, fish were held for 24-48 h following marking prior to transport to the release location. However, it was decided that handling stress could be reduced by transferring recovered fish directly into the transport tank. Fish were marked and released on the same date beginning with the May 16, 1994 release.

Fish were transported from Cronin to the release site at Turners Falls Canal in two 100-gal, oxygenated, transport tanks mounted on a pick-up truck. Estimated transport time to the release site was 20-30 min. At the release site, water temperatures in the transport tank and in Turners Falls Canal were compared. The water temperature difference was not greater than 2°C on any occasion, thus it was not necessary to acclimate test fish to river water temperature during the study.

Smolts were transferred to the holding pen at the release site. Fish were held in the pen for at least 1 h to allow them to acclimate to their surroundings. After the 1-h period, the door at the downstream end of the pen was opened and smolts were allowed to voluntarily exit the pen for a period of 2 h. After this time, the pen door was closed and any fish remaining in the pen were removed and enumerated. Live fish remaining in the pen were released downstream from Cabot Station.

Twelve smolts were radiotagged at Cronin for release with each group of 200 fish used in the mark-recapture study. Radiotagging was accomplished following a protocol similar to that followed for Panjet marking. Fish were collected from the raceway at Cronin and anaesthetized in a solution of tricaine methanesulfonate (approximately 50 mg/L) and tagged. Tags were lightly lubricated using a water-soluble, non-toxic jelly and gently inserted through the fish's mouth and esophagus into the stomach. Following tagging, fish were observed until they had recovered from the anaesthetic and were swimming normally. Fish were held at Cronin for 24-48 h prior to transport to the release location.

Radiotag operation was checked following tagging, prior to transport, and prior to release. These checks helped identify possible tag malfunctions prior to releasing the fish.

Radiotagged smolts were placed in the transport tank with marked smolts immediately prior to transport to the release site. At the release site the radiotagged smolts were transferred to the holding pen with the marked smolts following the procedures described previously.

Passage Monitoring

Monitoring of smolt passage was conducted for 24 h following each release during the primary series of releases (May 9-21) to allow recovery of marked smolts. In addition, monitoring for radiotagged smolts was conducted after the 24-h period had elapsed until additional passage events were unlikely.

Following each release, the log sluice sampler was operated and monitored for 24 h. All smolts collected were examined for marks and the type of smolt (stream-reared or hatchery) and the marks present, if any, were recorded. The time of collection was noted as the 1-h period during which collection occurred. Water temperature and canal elevation were recorded at the beginning of each hour.

The bypass efficiency of the log sluice was determined for each release by dividing the number of marked smolts recovered at the log sluice sampler by the total number assigned to either the sluice or turbine passage route.

Data were retrieved from the receivers using a lap-top computer and stored on the lap-top's hard drive and on diskettes. Data retreival typically occurred twice during each 24-h sampling period. An initial data download was conducted 4-5 h after fish were released. At the end of a 24-h sampling period, the Turners Falls Canal from Cabot Station to the canal gatehouse was surveyed with a portable radio telemetry receiver and the presence and location of radiotagged smolts remaining in the canal was determined. Following the survey, receivers were downloaded and the receiver was programmed for the next release.

RESULTS

A total of 2,216 hatchery-reared Atlantic salmon smolts was marked and released in the Cabot Station power canal (Table 2). Of these, 1,425 (64.3%) passed downstream through the log sluice; the remainder were assumed to have passed through the turbines, although predation between release and recapture was not assessed. Of 1004 smolts released while the sluice light was on, 756 (75.3%) passed downstream by way of the sluice. With the sluice light off, 565 (55%) of 1028 marked, released smolts passed through the sluice. In addition, 158 hatchery-reared smolts were radiotagged and released (Table 3), 142 of which were detected or captured at either the spillway, the tailrace, or the sluice. A total of 86 (61.0% of the smolts detected or captured) of the radiotagged smolts passed downstream by way of the log sluice. With the sluice light on, nearly 70% of the radiotagged smolts passed through the sluice. Virtually all the radiotagged smolts passed downstream; use of the mobile antenna and receiver did not indicate that smolts remained in the power canal.

Releases of both marked and radiotagged smolts conducted when the sluice gate was fully open resulted in a higher proportion passing through the sluice (Tables 1 and 2). About 87% of the marked smolts and 75% of the radiotagged smolts detected passing through the Cabot Station area with the sluice light on and the sluice gate fully open passed downstream by way of the sluice; about 73% of the marked smolts and 71% of the radiotagged smolts smolts released with the light off and sluice gate fully open passed via the sluice.

Effect of the Sluice Light

Since the light condition was usually changed nightly during the course of the study, only recoveries during the 24 h following each release were included in the following analyses of the effect of lighting on downstream passage. The results of the 9 May release were excluded from analyses because the light over the walkway at the sluice entrance failed during that release. The results of the May 24-27 releases of radiotagged smolts were excluded from analyses because no marked fish were released with the radiotagged fish, and because the sluice light was left on for all three of these releases.

Table 2. Summary of the number of marked, hatchery-reared salmon smolts released in the Cabot Station power canal and recovered in the sluice sampler, with percent bypassed and light status, Turners Falls Project, May 9-21,1994.

Release date	Sluice light status	No. smolts released	No. smolts recovered within 24 h	Total no. smolts recovered	Percent of released smolts passing through sluice
9 May[1]	Off	184	31	49	26.6%
10 May[1]	On	188	116	124	66.0%
11 May[1]	Off	206	28	30	14.6%
12 May[1]	On	207	164	166	80.2%
13 May[1]	Off	201	108	113	56.2%
16 May[1]	On	199	125	126	63.3%
17 May[1]	Off	204	125	157	77.0%
18 May[2]	On	205	178	180	87.8%
19 May[2]	Off	206	132	133	64.6%
20 May[2]	On	205	173	175	85.4%
21 May[2]	Off	211	172	172	81.5%
Total		2216	1352	1425	64.3%

[1]Releases conducted with sluice gate 30 to 40% open.
[2]Releases conducted with sluice gate 100% open.

Table 3. Number of radiotagged hatchery-reared Atlantic salmon smolts released in the Cabot Station power canal and detected passing downstream through the log sluice, turbines and wasteway, May 9-27, 1994.

		No. of smolts					Percent
Release date	Sluice light	Released	Detected	Through sluice	Over wasteway	Through turbines	
9 May[1]	Off	12	11	3	0	8	27.3%
10 May[1]	On	12	11	8	0	3	72.7%
11 May[1]	Off	10	9	3	0	6	33.3%
12 May[1]	On	12	11	7	0	4	63.6%
13 May[1]	Off	12	10	6	0	4	60.0%
16 May[1]	On	11	11	6	0	5	54.5%
17 May[1]	Off	12	12	5	0	7	41.7%
18 May[2]	On	12	11	8	0	3	72.7%
19 May[2]	Off	6	6	4	0	2	66.7%
20 May[2]	On	10	9	7	0	2	77.8%
21 May[2]	Off	12	8	6	0	2	75.0%
24 May[3]	On	10	9	6	1	2	75.0%
25 May[3]	On	10	9	6	0	3	66.7%
27 May[3]	On	17	15	11	0	4	73.3%
Total		158	142	86	1	55	61.0%

[1]Release occurred with sluice gate open 30 to 40%.

[2]Release occurred with sluice gate open 100%.
[3]Release occurred with sluice sampler not in place.

The illumination of the 400-watt mercury vapor light under the walkway and the overhead high-pressure sodium light above the walkway at the entrance to the sluice resulted in an additional 20% of the marked and released smolts passing downstream through the sluice (Table 4). The difference between passage under this lighting condition and under the ambient lighting condition (overhead high-pressure sodium lights over the walkway and at the opposite end of the forebay illuminated) was highly significant (Appendix A). These results were supported by the results of releases of radiotagged smolts as well (15% higher passage with the sluice light on; Table 4).

Analysis of the hourly catch of freely migrating, stream-reared smolts during the pairs of sluice light off and sluice light on 24-h sampling periods indicated that the diel distribution of passage was affected by prevailing light conditions. The 24-h pattern for the sluice-light-on day was significantly different from the pattern for the corresponding lights off day (Chi-squared test of goodness of fit; Appendix B) for each of the five pairs of sampling periods. During light-off sampling periods, the timing of peak passage was erratic (Figure 4), with substantial passage during daylight hours, except for the first light-off trial (May 11). During light-on sampling periods, passage was more concentrated between 2000 and 2100 hours, just after sunset (Figure 5).

Overall passage of marked hatchery-reared smolts, and of freely migrating hatchery- and stream-reared smolts during the 24-h sampling periods all reflected the effect of the sluice light (Figure 6). In all three cases, catch at the sampler peaked between 2000 and 2100 hours when the sluice light was on and passage was highly concentrated during that time. When the sluice light was off and both forebay lights were illuminated, this evening peak was much less prominent.

Passage without the Sluice Sampler in Place

Four groups of radiotagged salmon smolts were released from 24-27 May without the sluice sampler in place, with the sluice light and south forebay light on. The third group was excluded from the following results because of apparent problems with the radiotelemetry gear during this release. For all four releases, the antenna intended to monitor smolts passing through the sluice did not function effectively, necessitating reliance on indirect evidence to assign smolts to the sluice route.

If a smolt was last detected at the entrance to the sluice before detection downstream of the Cabot Station tailrace,

Table 4. Percent of marked or radiotagged hatchery-reared salmon smolts passed through the Cabot Station log sluice with and without sluice light deployed, May 10-21, 1994.

	Sluice light off[1]			Sluice light on	
Release date	Radiotagged smolts	Marked smolts	Release date	Radiotagged smolts	Marked smolts
11 May[2]	33.3%	13.6%	10 May[2]	72.7%	66.0%
13 May[2]	60.0%	53.7%	12 May[2]	63.6%	80.2%
17 May[2]	41.7%	61.3%	16 May[2]	54.5%	63.3%
19 May[3]	66.7%	64.1%	18 May[3]	72.7%	87.8%
21 May[3]	75.0%	81.5%	20 May[3]	77.8%	85.4%
Overall	53.3%	55.0%	Overall	67.9%	75.3%

[1]Excludes releases conducted on 9 May when overhead lights failed.
[2]Release occurred with sluice gate open 30 to 40%.
[3]Release occurred with sluice gate open 100%.

but was not detected in the sluice or the tailrace, it was assigned to the sluice. Examination of data from releases conducted with the sampler in place indicated that these criteria for assignment to the sluice were probably fairly reliable. Nonetheless, based on this examination, the number of smolts assigned to the sluice was adjusted downward to account for a 15% probability that the tailrace antenna would fail to detect a smolt passing through the turbines. Of the 33 smolts detected from the three releases, 23 (70%) passed downstream through the log sluice, one (3%) passed over the spillway, and the remainder (27%) passed through the turbines.

DISCUSSION

The overall rate of passage determined during this study with the sluice light operating (75% for hatchery-reared smolts marked and released) was the highest passage rate achieved for salmon smolts since development of downstream passage facilities for Cabot Station began. The subset of sluice-light-on releases that occurred with the sluice gate fully open demonstrated even greater passage (87%), although only two releases were conducted under this set of conditions.

Since the intake rack bar spacing could not be manipulated experimentally, the only way to assess the effectiveness of reducing the spacing is to compare the 1994 results, sluice light off, with previous studies. The uncertainty of the analysis of the 1992 results and the apparent low viability of the smolts released in the 1993 study (Harza 1994) make it difficult to compare passage results during those years to the present study. Results from 1991 are more comparable, although during that year the bulkhead creating the 11- by 4- ft opening at the entrance to the sluice had not yet been installed.

Overall passage during 1991 was 66%, based on the release of 87 radiotagged, hatchery-reared salmon smolts before the sluice sampler had been constructed. Overall passage of marked, hatchery-reared smolts in this study when only the forebay lights were on was 55% based on five releases (52 smolts). The two releases conducted in 1994 when the sampler was in operation and the sluice gate was fully open (forebay lights on) resulted in 71% sluice passage. Given the uncertainties and the different facilities that were in place, passage results in 1991 and the sluice-light-off results for 1994 appear to be similar, indicating that the reduced intake rack bar spacing probably did not influence passage.

The experimental lighting conditions, however, clearly affected passage. The sluice and south forebay light on, north forebay light off condition resulted in 20% better passage and a shift in the diel distribution of smolt captures in the sluice sampler.

Although the mechanism by which the lights affected passage is not known, it is possible that when the sluice light was off and the north forebay light was on, some smolts were attracted to the end of the intake opposite the sluice, and that smolts thus attracted were more vulnerable to passage through the turbines. An alternative explanation, however, is that forebay hydraulics and the attraction of the south forebay light caused most smolts to approach the intakes on the south side of the forebay, but that they did not pass readily through the sluice. The shadow cast by the walkway beneath the south forebay light when the sluice light was off may have retarded passage, as was hypothesized for juvenile clupeids (RMC 1994). This delay may have resulted in smolts accumulating in the forebay, eventually becoming entrained in the flow to the turbines. Both the analysis of the passage of marked, released, and recovered hatchery-reared smolts, and the contrast between the daily passage patterns of freely migrating stream-reared smolts during the light-off and light-on 24-h sampling periods support this interpretation.
With the sluice light on, on the other hand, the impediment caused by the walkway shadow may have been removed. The overhead, south forebay light may have attracted smolts to the area of the sluice mouth. Once in that area, the sluice light may have served to break up the shadow cast by the walkway, allowing smolts to pass quickly downstream.

CONCLUSIONS

- o The combination of the reduced intake rack bar spacing, and light deployment during this study resulted in an overall passage rate of 75% with the sluice light on and 55% with the sluice light off.

- o Passage rate appeared to be higher (87% with the sluice light on) when the sluice gate was fully open with the bulkhead in place than it was with the sluice gate open 30 to 40%.

- A statistically significant improvement of 20% in passage rate, from 55 to 75%, was realized by deploying the sluice light, and leaving the south forebay light on and the north forebay light off.

o The daily pattern of capture of freely-migrating smolts in the sluice sampler was influenced by the prevailing experimental lighting condition.

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Appendix A. Analysis of the effect of lighting condition on the downstream passage of marked and released salmon smolts through the Cabot Station log sluice, 10-21 May 1994.

Approximately 200 hatchery-reared Atlantic salmon smolts were marked and released daily in the Cabot Station power canal with two experimental lighting conditions alternating from one day to the next. The first condition (sluice light on) consisted of illuminating a 400-watt mercury vapor light under the walkway over the entrance to the log sluice (sluice light) and a sodium vapor light over the walkway. The second (sluice light off) consisted of leaving the sluice light off and illuminating the light over the walkway and a similar overhead light at the opposite end of the forebay. Of the 2,032 smolts marked during this experiment over 10 d days in May 1994, 1,028 were released under the sluice light off condition, 1,004 with the sluice light on. The number of marked smolts recovered at the sluice within 24 h of release was recorded hourly. The following table summarizes the release and recovery data used in this analysis.

Table A-1. Release and recovery data for marked, hatchery-reared salmon smolts released in the Cabot Station power canal and recovered in the Cabot Station log sluice, sluice light off and on, 10-21 May, 1994.

	Sluice light off		Sluice light on		Combined tests	
	Number of smolts		Number of smolts		Number of smolts	
Release date	Re-leased	Re-covered	Re-leased	Re-covered	Re-leased	Re-covered
10 May	0	NA	188	116	188	116
11 May	206	28	0	NA	206	28
12 May	0	NA	207	164	207	164
15 May	201	108	0	NA	201	108
16 May	0	NA	199	125	199	125
17 May	204	125	0	NA	204	125
18 May	0	NA	205	178	205	178
19 May	206	132	0	NA	206	132
20 May	0	NA	205	173	205	173
21 May	211	172	0	NA	211	172
Total	1028	565	1004	756	2032	1321

	p_1 = 565/1028 =	p_2 = 756/1004 =	P = 1321/2032 =

The purpose of the experiment was to determine whether light conditions at the entrance to the Cabot Station log sluice affected the passage of salmon smolts through the sluice. Therefore, the null hypothesis was that there was no difference ($p_2 = p_1$) between the proportions of the released smolts recovered under the two sets of experimental light conditions (Sluice light off, north and south forebay lights on; Sluice light on, north forebay light off, south forebay light on).

The statistical significance of this difference was assessed using the z-statistic proposed by Fleiss (1981) for simple comparative clinical trials in which treatments are assigned to subjects at random. In this experiment (or trial) a treatment (sluice light on) was applied to a subsample of n_2 = 1004 smolts randomly selected from a sample of N = 2032, and no treatment (sluice light off) was applied to the remaining n_1 = 1028 smolts (Table A-1). It follows that the the difference between the proportions passed under the two conditions ($p_2 - p_1$) represents the improvement in bypass rate attributed to the treatment (sluice light on). The statistical significance of this improvement is tested by the z-statistic:

where Q = 1 - P = 0.350 and the sample sizes and proportions are taken from the Table A-1. For these data, z = 9.52, which is highly significant ($P<0.01$). Therefore, the null hypothesis of no light treatment effect must be rejected.

The difference between the two proportions ($d = p_2 - p_1 = 0.203$) represents the effectiveness of using the sluice light. The approximate standard error of d is:

For the above data d = 0.203 and s.e.(d) = 0.02074, so that an approximate 95% confidence interval for the effectiveness of the sluice light on condition is:

Upper bound = d + 1.96(s.e.(d)) = 0.24365
Lower bound = d - 1.96(s.e.(d)) = 0.16235.

Therefore it is reasonable to expect that, based on the release and recovery of hatchery-reared salmon smolts, 16 to 24% more of the smolts approaching Cabot Station would pass downstream through the log sluice with the sluice light and south forebay lights on than when the sluice light is off and both forebay lights are on.

Appendix B. Chi-squared goodness of fit test of the diel distribution of stream-reared salmon smolts captured in the Cabot Station log sluice sampler during five pairs of 24-h periods, sluice light off and on, 10-21 May 1994.

Analytical Method

The Cabot Station log sluice sampler was monitored for ten 24-h periods (starting at 1600 hours); the number of salmon smolts captured was recorded hourly. The experimental night lighting condition was alternated daily between the sluice light off, north and south forebay lights on condition and the sluice light on south forebay light on condition. Thus there were five pairs of days when the distribution of smolt passage under the two lighting conditions could be compared. The following pages present the results of Chi-squared tests of the goodness of fit (Snedecor and Cochran 1980) of the distributions of smolt captures on the two days within each pair. The null hypothesis was that there was no difference in the 24-h pattern of smolt captures between lighting conditions.

The proportion of smolts captured during each hour of a sluice-light off sampling period ('Light off; Proportion of daily total' column on the following tables) was calculated by dividing the number of smolts captured under the sluice light off condition during that hour ('Light off; No. of smolts captured' column) by the total number of smolts captured during that 24-h sampling period. Those proportions were then applied to the total number of smolts captured during the corresponding sluice-light-on sampling period to calculate the number of smolts expected to be captured during each hour if the distribution of catches were the same ('Expected no. smolts' column). If the hourly catch was zero for either the light-off or light-on hour, catches from adjacent hours were combined until neither the light-off value nor the light-on value was zero. These expected values were then compared to the observed hourly catches using the formula:

The results were highly significant ($p<<0.01$) for all five sampling period pairs.