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Fate of translocated American eel (*Anguilla rostrata*) in the lower Ottawa River and passage behavior at a multichannel barrier

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Abstract

American eel (*Anguilla rostrata*) is considered endangered under the IUCN's red list. Hydropower facilities are considered a significant threat to American eel, impacting both the outmigration of adults and upstream migration of juveniles. To overcome upstream passage issues, juvenile eels may be trapped and transported around barriers as a mitigation strategy, though few studies have evaluated the efficacy of this approach. To understand the fate of transported eels, we monitored posttranslocation movements in a 110-km reach of the Ottawa River bounded by two hydropower facilities: Carillon Hydroelectric Generating Station (lower barrier) and Chaudière Falls Hydroelectric Facility (upper barrier). Additionally, we assessed the approach behavior of eels that reached the upper barrier, a multichannel facility, to assess potential fishway locations. To assess these objectives, 40 juvenile eels (440–640 mm) were implanted with acoustic transmitters and were transported and released either just upstream (∼6 km) of the lower barrier or just downstream of the upper barrier (∼2 km), approximately, 60 and 166 km from the capture site, respectively. Over the three-month study period, 78% of tagged eels remained upstream of the lower barrier. Of the nine eels that returned downstream of the lower barrier, seven were from the downstream release site; however, the proportion of eels that returned downstream of the lower barrier did not differ significantly between release sites. One eel passed the upper barrier despite no existing fish-passage structures. At the upper barrier, most eels visited just one of the five channels, suggesting that more than one passage structure may be necessary to allow eels entering different channels to pass upstream of the barrier. Findings from this work will help inform passage efforts for American eel, particularly in the Ottawa River where eel populations have declined severely from their historic abundance.

KEYWORDS
carillon, chaudiere, downstream, elver, migration, upstream

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1 | INTRODUCTION

American eel (*Anguilla rostrata*) is a catadromous fish that is distinguished by its distinctive long, serpentine-like body (Scott & Crossman, 1973). The species is distributed throughout eastern North America, Greenland, Iceland, and northern South America. All American eel (regardless of continental origin) spawn in the Sargasso Sea (J. Schmidt, 1923; Scott & Crossman, 1973) and eventually choose to remain in brackish waters or migrate upstream to freshwater habitats (MacGregor et al., 2009). Eels moving into freshwater are challenged by the presence of hydropower dams that restrict their access to suitable habitat during multiple life stages. Large body size and length of adult freshwater eels make them highly susceptible to turbine mortality during outmigration (Haro, Castro-Santos, & Boubée, 2000; Larinier, 2001; McCleave, 2001), while juvenile eels are challenged to ascend upstream beyond barriers (McGrath, Bernier, Ault, Dutil, & Reid, 2003).

Historically, American eel exhibited the largest geographic range of any freshwater fish species in the Western hemisphere and eels were an important species for food, skins, and medicines of Indigenous peoples throughout its range (Algonquins of Ontario, 2014). The range and abundance have dramatically declined over the last 100 years through a combination of natural and anthropogenic factors (MacGregor et al., 2009; Ogden, 1970; Smith & Saunders, 1955). Access to freshwater habitat for American eels has been greatly reduced, likely as a result of large dams with no suitable fish passage facilities (Pratt et al., 2014). Unlike most fish species, some eels are able to pass upstream of large barriers even when fish passage structures are absent. Elvers are remarkable climbers (Watz, Nilsson, Degerman, Tamario, & Calles, 2019) and are known to climb vertical surfaces or use riparian habitats to circumnavigate barriers. However, eel passage is highly dependent on the slope, height, and construction material of the barrier (Tremblay, Cossette, Dutil, Verreault, & Dumont, 2016), and passage is unlikely or highly curtailed at large barriers that lack passage structures or approaches. Eel passage can be facilitated through both fishways (eel ladder) and trap-and-transport programs. Trap-and-transport is often used at locations where a fishway retrofit is challenging or not practical, to provide passage across multiple barriers, or as a temporary solution while permanent structures are under construction.

Trap-and-transport programs involve capturing fish downstream of a barrier and releasing them upstream to improve habitat access and are widely used around the globe for a variety of species including eels (Kock, Ferguson, Keefer, & Schreck, 2020). For instance, implementation of a trap-and-transport program greatly increased the number of short-finned eel (*Anguilla australis*) and New Zealand longfin eel (*Anguilla dieffenbachii)* elvers upstream of two dams on the Waikato River, New Zealand (Jellyman & Arai, 2016). Trap-and-transport of American eel has also been used at a large scale within the St. Lawrence River system, Canada, where 3.9 million eels were transported beyond dams and released in the upper watershed from 2006–2010 (Threader, Blimke, & Groman, 2010). The success of trap-and-transport can vary across barriers and species, in part because trap-and-transport can be stressful and have sublethal consequences for individual fish (Kock et al., 2020). Posttransport consequences can include increased disease susceptibility, injury, downstream fallback, and mortality (Colvin, Peterson, Sharpe, Kent, & Schreck, 2018; Kock et al., 2020; Naughton et al., 2018), compromising the effectiveness of trap-and-transport programs. In a trap-and-transport context, fall back is typically assigned to fish expected to continue upstream migration after release above a barrier that instead move back downstream of said barrier (Frechette, Goerig, & Bergeron, 2020; Kock et al., 2020). A means to minimize fallback associated with trap-and-transport is to increase the distance of release sites from downstream barriers (Kock, Ekstrom, Liedtke, Serl, & Kohn, 2016; Naughton et al., 2018), though the effectiveness of this strategy for American eel has received limited attention.

To further our understanding of the fate of eels after trap-and-transport, we tagged transported American eel with acoustic telemetry transmitters. The Ottawa River is an ideal study site, given the cultural importance of American eel (or pimisi in the language of the Algonquin people) to the Algonquin people that inhabit this area. This area has also experienced a severe decline in the American eel population (MacGregor et al., 2009) and at the time of this study, did not have any upstream or downstream passage structures at any hydro facilities. The first objective for this study was to compare the behavior and fate of transported juvenile eels released at two distances upstream of a barrier, including their retention upstream of the barrier and direction of movement. The second objective for this study was to evaluate the approach behavior and upstream passage success of eels at a multichannel barrier containing turbine flumes, ring dam falls, and semi-permeable walls. Findings from this study will help inform optimal release locations for transported American eel to maximize their access to historic habitat and will provide insight into their behavior at upstream migration obstacles.

2 | METHODS

2.1 | Study area

The Ottawa River is a large river located in Eastern Canada and serves as the provincial border between Ontario and Quebec for the majority of its 1,271 km length. It originates in the Laurentian mountains in Quebec, flowing southeast throughout the Ottawa valley into the St. Lawrence River at Montreal, QC (over 200 km inland of the St. Lawrence Estuary). Barriers within the St. Lawrence watershed prevent free passage into an estimated 12,140 km^2 of potential American eel habitat, with 3,700 km^2 of potential habitat in the Ottawa River alone (Tremblay et al., 2016; Verreault, Dumont, & Mailhot, 2004). Our study was conducted in a 110-km reach of the lower Ottawa River constrained by two physical barriers: Carillon Hydroelectric Generating Station (lower barrier) and Chaudière Falls Hydroelectric Facility (upper barrier). The study reach focused on the Lac Dollard-des-Ormeaux reach and spanned from 5 km downstream of the lower barrier near Riguad, QC (45.56775°N, 74.38423°W) to 1 km upstream of the upper barrier near downtown Ottawa, ON (45.42089°N, 75.72137°W) (Figure 1). The lower barrier is a large, single channel, run of the river hydroelectric generating station that contains 14 hydro turbines and is the first barrier that fish encounter when migrating upstream in the Ottawa River. The dam has a head of 18 m and an installed capacity of 752 MW. Although no formal fish passage structures exist at the site, Parks Canada operates a lock system from mid-May to mid-October for recreational boating use. Given that juvenile eels are still detected upstream of the lower barrier, this lock system is assumed to be the primary means by which they bypass the barrier, though the extent to which they do is unknown. Further, several organizations transport a few hundred eels upstream of this barrier annually (Comité scientifique sur l'anguille d'Amérique, 2019). The upper barrier is a run-of-the-river, multichannel facility that historically was a large waterfall with various small islands until development for industrial use in the mid-19th century. This area now consists of four high-flow tailrace channels and a large ring dam (spillway) with a head of 15 m. At the time of this study, no fish passage structure existed, but an eel ladder was installed in 2017. Nonetheless, eel populations exist upstream of the barrier, demonstrating that some passage occurs. The exact mechanism of this passage is unclear, though eels are known to be capable of climbing spillways and other vertical structures at barriers.

2.2 | Eel acoustic telemetry

American eel was obtained by dipnet as migrating juveniles from a trap at the top of the eel ladder at Hydro-Quebec's Beauharnois Generating Station (45.313889° N, 73.908889° W) and were translocated into the Ottawa River as part of an ongoing trap-and-transport program. Trapped eels were held up to 5 days to obtain a sufficient number for the study and were then transferred (~1 hr) in an aerated Bonar insulated fishing tank to the release sites on the Ottawa River on July 15, 2015. Eels >420 mm were anesthetized using tricaine methanesulfonate (MS-222; ~90 mg/L) mixed with river water. Eels were measured for total length and weight and were marked with a passive integrated transponder (PIT) tag (≤4 mm diameter, ~20 mm total length, ~0.1 g in water) injected into the dorsal musculature above the anus (as per all eels included in the ongoing trap-and-transport program). An acoustic transmitter (V7-4x, 69 kHz, 7 mm diameter, 22.5 mm total length, 1.0 g in water, 136 dB output power, battery life 173 days; VEMCO Division of AMIRIX Systems; Halifax, Nova Scotia) was surgically implanted that randomly emitted an acoustic signal every 50–130 s. A small incision (~2 cm) was made approximately 5 cm in front of the anus using a scalpel, and the acoustic transmitter was inserted into the peritoneal cavity. The incision was stitched closed with two sutures (size 5, monocryl). Eels were recovered for 30–60 min following surgery in a 200 L cattle tank with

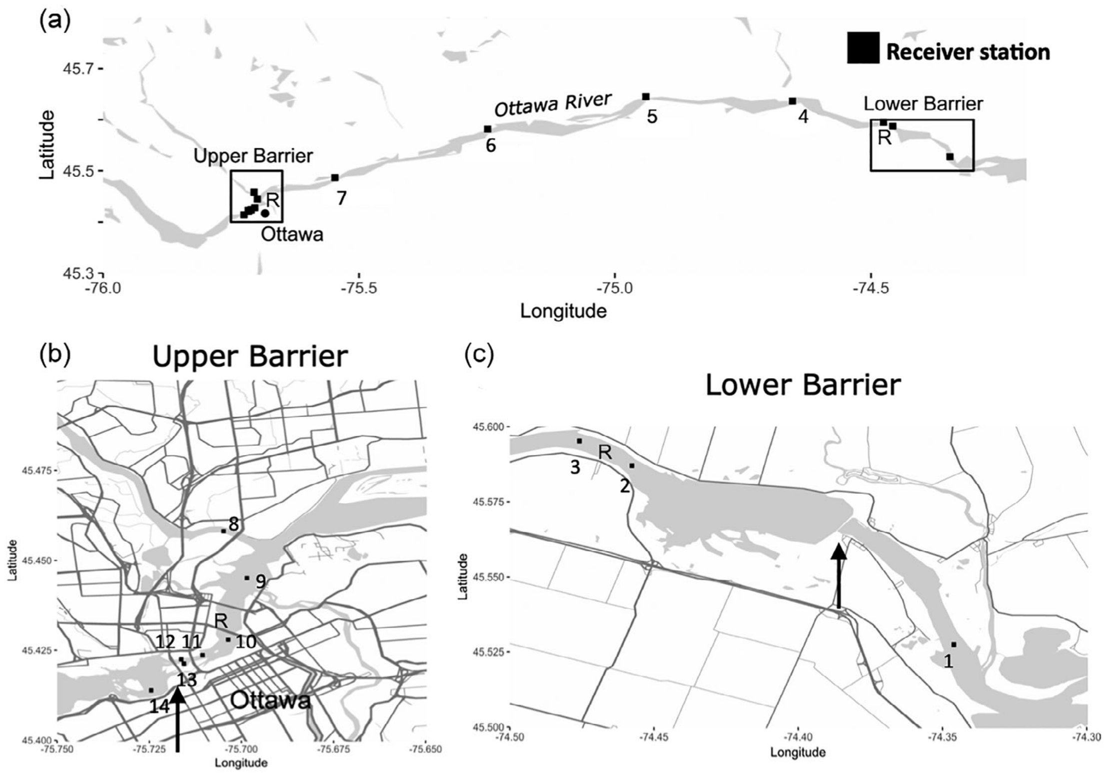

FIGURE 1 Study site in the lower Ottawa River depicting the location of receiver stations (black squares) and release sites (R). (a) shows the Lac Dollard-des-Ormeaux reach consisting of a lower and upper barrier. (b) shows the upper barrier (black arrow), with receiver stations upstream (#14), immediately downstream (#12, 13), and in a series of three stations further downstream (#9–11). A single receiver station is shown at the mouth of the Gatineau River (#8), the largest tributary in this reach. (c) shows the lower barrier (black arrow), with two receiver stations upstream (#2, 3), and one downstream of the barrier (#1)

circulating river water. Twenty eels were first tagged and released at a downstream site located 6.1 km upstream of the lower barrier and 3 hr later another 20 eels were tagged and released at an upstream site. Suitable locations (i.e., low flow areas) to release eels were small and infrequent at the upstream site, so 10 eels each were released in eddies located 1.1 and 1.8 km downstream of the upper barrier to reduce crowding (111.5 and 112.2 km upstream of the lower barrier, respectively; henceforth pooled). Released eels had a mean length of 498 mm (range: 440–640 mm) and a mean weight of 180 g (range: 113–384 g). There was no significant difference in the length ($t = -0.81$, $df = 37.99$, p-value $= .42$) or weight ($t = -0.84$, $df = 37.56$, p-value $= .41$) of eels between release locations.

An acoustic array consisting of 30 VR2W omnidirectional acoustic receivers (69 kHz) distributed among 14 receiver stations was deployed over 120 km of the Ottawa River (Figure 1). Receiver stations generally consisted of two receivers arranged in a pair perpendicular to the riverbank (to ensure detection across the entire width of the river channel). Only receiver stations 8 (one receiver) and 13 (5 receivers) were not arranged as paired receivers. Acoustic receivers were deployed (June 11– July 13, 2015) prior to tagging, with the exception of station 14 (upstream of the upper barrier), which was deployed on August 28, 2015. Receiver stations were retrieved between October 5 and 22, 2015. One receiver from station 1 (the downstream most station) was never recovered, thus only partial detection coverage was possible. Receiver stations 1 and 14 were placed downstream of the lower barrier and upstream of the upper barrier, respectively, to monitor eels that moved outside of the study reach. Further downstream ($\sim$50 km), additional telemetry arrays in Quebec around Montreal Island and the Beauharnois Dam were available to detect additional downstream movement below the lower barrier. Receiver station 14 provided only partial detection coverage upstream of the upper barrier due to a limited number of receivers. Additional receiver stations (10–12) and receivers 13.1–13.5 (collectively station 13) were deployed downstream of the upper barrier to detect small-scale movements at the base of this barrier (Figure 5). Receiver 13.1 was deployed at the outflow of a municipal water pumping station. Receivers 13.2, 13.3, and 13.5 were deployed in the tailraces of separate hydro-generating facilities of the upper barrier. Receiver 13.4 was deployed downstream of a ring dam, which acts as the primary spillway for the upper barrier. Detection probability was defined as the proportion of all known eel movements beyond a receiver that were detected (92%; $n = 64$).

2.3 | Fate of translocated eels

Translocated eels were classified as either retained or having returned back downstream of the lower barrier based on their final detection location in 2015. Eels detected downstream of the lower barrier, either at station 1 or at another acoustic telemetry array downstream (i.e., Montreal Island or the Beauharnois Dam arrays) were classified as having returned back downstream, otherwise eels were classified as retained. Eels that returned downstream of the lower barrier were further classified as "fall backs" if they fell back within $\sim$24 hr (Reischel & Bjornn, 2003). Eel behavior was further categorized into three different behavioral categories (resident, upstream, and downstream) with sub-categories (unidirectional or bidirectional) within each (See Figure 2). We define these categories as follows:

1. *Resident*—an individual that was not detected >14 km from the release site. This distance approximately represents the spacing between release sites and the next mainstem station (i.e., stations 4 and 7).
2. *Upstream*.
   a. *Unidirectional*—an individual that displayed a unidirectional >14 km movement upstream from its release site or was detected upstream of the upper barrier.
   b. *Bidirectional*—an individual that moved >14 km upstream but then returned downstream.
3. *Downstream*
   a. *Unidirectional*—an individual that displayed a unidirectional >14 km movement downstream from its release site or was detected downstream of the lower barrier.
   b. *Bidirectional*—an individual that moved downstream >14 km but then returned upstream.

2.4 | Channel selection at a multichannel barrier

Eel channel selection was monitored as eels approached the multichannel barrier at Chaudière Falls. We quantified the number of visits to each of the five main channels at the Chaudière Falls complex: *pump station channel*, the outflow from the City of Ottawa's municipal drinking water pumping station; *generators 1–3*, the outflow from hydroelectric generators, and; *spillway*, outflow from water that spills over a ring dam as well as outflow from two hydroelectric generators that also use the same outflow channel. Channel-selection metrics were summarized as follows: *first choice*, defined as the first channel an eel was detected in; *total days present*, defined as the sum of days that at least one eel was detected in a channel; and *total eels*, defined as the number of unique individuals detected at least once in a channel. We also counted the number of channels each eel visited and channel visit durations. Channel visit duration was calculated as the elapsed time between consecutive detections in a channel.

2.5 | Data analysis

The fate of each eel (retained or having returned downstream of the lower barrier) by release location (upstream or downstream) was tabulated into a 2 × 2 contingency table (Table 1). A Chi-squared test was performed on the eel fate contingency table with $\alpha = .05$. A power analysis was performed for this test using the pwr.chisq.test function from the pwr package (Champley, 2015). Chi-squared tests were also performed on all three channel-selection summary metrics (first

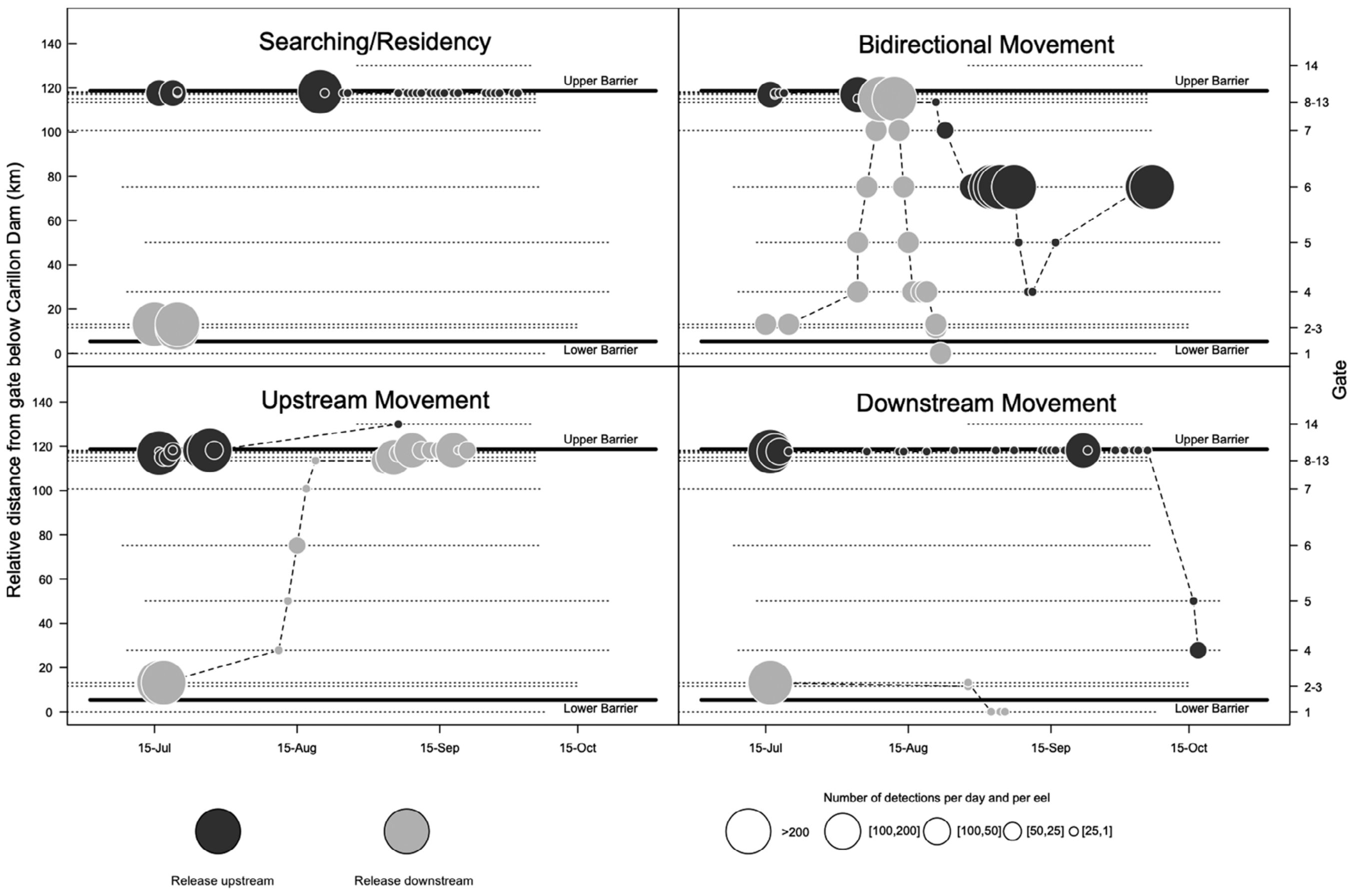

FIGURE 2 Examples of eight translocated eel movements in 2015, tracked by an acoustic telemetry array in the Ottawa River. Solid horizontal lines represent passage barriers. Dotted horizontal lines represent acoustic receiver deployment periods. Station 14 is shown ~11 km upstream of the actual position for easier interpretation of the figure

TABLE 1 Contingency table for the fate of eels released at upstream and downstream sites

Release site	Returned downstream of the lower barrier	Retained
Upstream	2	18
Downstream	7	13

choice, total days present and number of eels) using the chisq.test function from the stats package (R Core Team, 2020) followed by a pairwise post hoc test using the chisq.post.hoc function from the fifer package (Fife, 2015). *p*-values for channel-selection summary metrics were then adjusted using a Bonferroni correction.

To test whether eel channel selection was influenced by channel discharge, we developed three logistic regression candidate models using either discharge, channel, or channel and discharge as predictor variables for daily presence or absence of each eel within each channel. Discharge is defined as the proportion of mean daily discharge flowing through each channel. Channel is the unique channel ID. Only eels detected at the upper barrier on any given day were included in the analysis. The addition of a random effect to account for repeated measures of individual eels did not improve model fit and this parameter was not included in the analysis. Model selection was based on lowest bias-corrected Akaike Information Criterion (AIC_c; Burnham & Anderson, 2002). If no clear best model with a weight of the bias-corrected AIC_c (ωAIC_c) >0.9 was found, model averaging would be performed for models with $\Delta AIC_c < 2$ (Burnham & Anderson, 2002). All analysis and figures were conducted using R Statistical Software (R Core Team, 2020).

3 | RESULTS

3.1 | Fate of translocated eels

In total, 31 of the 40 (77.5%) translocated eels were retained upstream of the lower barrier. Nine (22.5%) eels exited the system, one of which was classified as a "fall back" as it returned downstream of the lower barrier within ~24 hr of release. Seven of the eels that returned downstream of the lower barrier were from the downstream release site (Table 1). Nonetheless, the probability of returning downstream of the lower barrier did not differ significantly between release locations ($X^2 = 2.29$, *df* = 1, *p*-value = .13). Power analysis revealed the probability of detecting a significant effect of release location ($\alpha = .05$) with 40 samples to be 0.35 at our effect size of 0.25. Our sample size had sufficient power (0.89) to detect a significant stronger effect (0.5). For the current estimated effect size of 0.25, 157 samples would be needed to detect a significant effect with a power of 0.89.

Of the eels that returned downstream of the lower barrier, five were detected on acoustic receivers operated by Hydro-Quebec near Montreal in 2015. One additional eel was detected in 2016 in the telemetry array at the Beauharnois Generating Station, but it was not clear whether this individual returned downstream of the lower barrier in 2015 or 2016.

The majority of eels (55%) released upstream displayed resident behavior while only 10% of the eels released at the downstream site displayed resident behavior (Table 2; Figure 2). Further, 70% of eels from the downstream release site made an upstream movement, though 8 of 14 turned back downstream (Table 2, Figure 2). One individual released at the upstream site moved upstream of the upper barrier (see the upstream movement panel in Figure 2); however, upstream movement was mostly restricted for this release group by the upper barrier. Downstream movement was evident from both release sites. Eight eels from the upstream site moved downstream and of these, three returned (Table 2; Figure 2). Of the seven eels from the downstream release site that returned downstream of the lower barrier, four showed unidirectional downstream movement (Table 2). Eels were of similar size that returned downstream of the lower barrier (509 mm) and that were retained (501 mm). Size was also comparable among eels that displayed resident behavior (511 mm), unidirectional upstream (485 mm) and downstream movement (488 mm), and bidirectional movement (508 mm).

3.2 | Channel selection at a multichannel barrier

A total of 21 (53%) eels released at both sites were detected at one of the five channels downstream of the upper barrier. First choice was not evenly distributed among channels (Figure 3; $X^2 = 16.86$, $df = 4$, p-value $= .002$), with significantly more eels detected at the pump station channel over Generator Channel 3 (Figure 3). The number of days with eels detected differed among channels (Figure 3; $X^2 = 55.07$, $df = 4$, p-value $<.001$), with the highest number of days at the spillway channel (32 days), followed by the pump station and Generator Channel 2 (both 16 days), Generator Channel 1 (6 days), and Generator Channel 3 (2 days). The number of unique eels differed significantly among channels (Figure 3; $X^2 = 13.52$, $df = 4$, p-value $= .009$) and was highest at the pump station channel (12 eels), followed by the spillway (11 eels), then Generator Channel 1 (5 eels) and Generator Channel 2 (4 eels). Only one eel was detected in Generator Channel 3. The majority of eels (57%) only visited one channel, while a third visited two channels. No eels visited all five channels, but one eel visited four and another visited three channels. Visits to each channel varied greatly in duration (<1 min to 13 days). Median channel visit durations were similar and relatively short at the pump station (0.07 hr), Generator Channel 1 (0.69 hr), and Generator Channel 2 (2.24 hr) compared to the spillway (75.22 hr). Approximately half of all eels that visited channels at the upper barrier (52%; $n = 21$) undertook relatively long channel visits (24–794 hr). This behavior was most common for eels visiting the spillway (73%; $n = 11$).

Discharge differed among channels with the greatest median discharge occurring at the spillway followed by Generator Channel 3; Generator Channels 1 and 2, and the pump station (Figure 4). The spillway and Generator Channel 3 had much higher flow variation than other channels (Figure 4).

Model selection identified no clear top model (ωAICc >0.9) predicting daily presence/absence within each channel, thus model averaging was performed on the top two models, which differed only slightly (Table 3). The channel parameter appeared in both top models and was found to be the most important (relative importance = 1). This was followed by the discharge parameter, which appeared in only one of the candidate models with a lower relative importance of 0.48 (Table 3). Eels were more likely to select the spillway over all other channels except for the pump station channel. Discharge did not significantly affect channel selection (Table 4). The probability of channel selection based on model estimates shows the highest probability of selection to be the spillway (0.44), followed by the pump station (0.32), Generator Channel 2 (0.21), Generator Channel 1 (0.08), and Generator Channel 3 (0.03) (Figure 5).

4 | DISCUSSION

4.1 | Fate of translocated eels

We evaluated the effectiveness of trap-and-transport on eel retention upstream of a barrier with no purpose-built fish-passage structures available. Most eels were retained upstream of this barrier though a considerable proportion moved downstream of the barrier after

TABLE 2 Movement behavior classification by release site

		Upstream			Downstream		
Release site	Resident	Total	Uni	Bi	Total	Uni	Bi
Upstream	11	1	1	—	8	5	3
Downstream	2	14	6	8	4	4	—

Note: Upstream and downstream movements are split into uni (unidirectional), bi (bidirectional), and total (unidirectional and bidirectional combined).

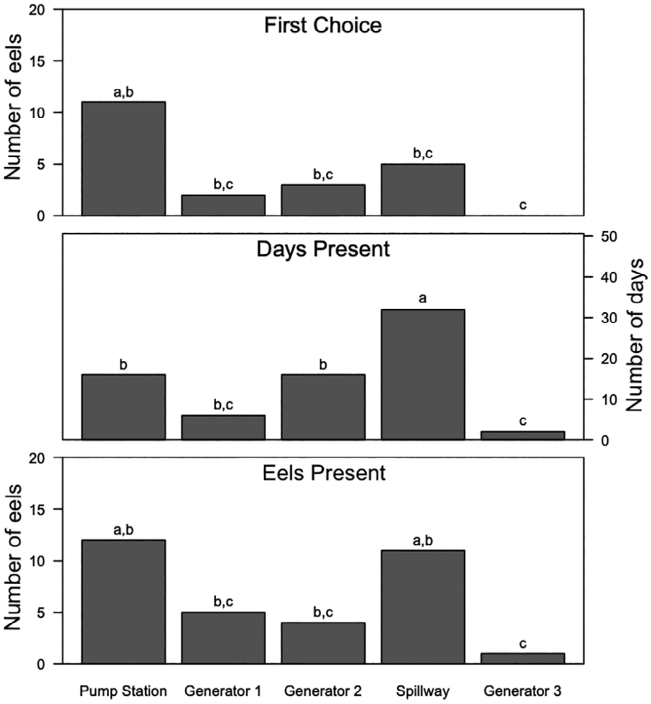

FIGURE 3 Channel-selection summary statistics for the number of eels selecting each channel as their first choice (first choice), total unique days with at least one eel present in each channel (days present), and total number of unique eels present in each channel (eels present). Superscript letters indicate which values were significantly different (Bonferroni adjusted p-values <0.05)

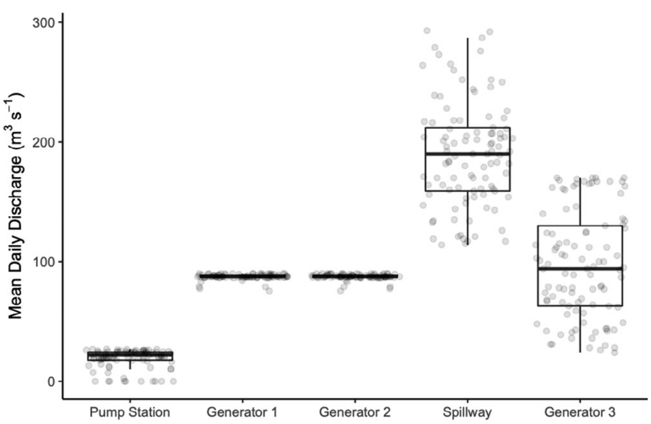

FIGURE 4 Boxplots showing approximate mean daily discharge (m^3s^{-1}) for each channel at the upper barrier during the study period. Center lines represent median values. Hinges correspond to first and third quantile (25th and 75th percentiles). Whiskers correspond to observations within 1.5 x interquantile range (distance between first and third quantile). Points represent raw mean daily discharge for each channel

transport (22.5%). The lower rate of eel retention in the downstream release group is consistent with findings from a trap-and-transport study on Pacific Salmon (Kock et al., 2016) and suggests that releasing eels further upstream of a barrier may decrease the likelihood of eels returning downstream of this barrier. However, results were not significant and may be spurious. Our sample size was modest (40 individuals), primarily due to the low abundance of eels in the study area and the cost of transmitters. If the effect size (0.25) observed in our study is determined to be large enough for concern, a new study with at least 162 samples should be conducted to fully address whether there is a significant impact of release site on retention. Future studies may also consider a closer release point (<6 km from the upstream barrier), which may result in a greater effect of release location on retention.

Movement downstream of the lower barrier was higher than expected given that eels were captured as upstream migrating juveniles from the St. Lawrence River, and it was anticipated they would continue upstream migration or alternatively establish a relatively small home range after transport (summarized in Béguer-Pon et al., 2015). Bianchini, Sorensen, and Winn (1982), as cited in Oliveira (1997), hypothesized that eels establish short-term home ranges punctuated by long-range movements upstream, perhaps in response to environmental cues (Welsh & Liller, 2013). If some eels had established home ranges at the time of collection, it is possible that the source location of these eels affected their subsequent behavior. Telemetry research within the St. Lawrence River watershed suggested that eels have some site fidelity and may home back to collection sites after displacement (Béguer-Pon et al., 2015). Similar observations have also been made for European eel displaced from home locations (Rossi, Bianchini, Carrieri, & Franzoi, 1987; Tesch, 2003). In our study, eels were obtained from the Beauharnois Generating Station on the St. Lawrence River, upstream of the mouth of the Ottawa River, and may have sought to return to their home range or to continue upstream migration in the St. Lawrence River. Indeed, five of the nine eels that were translocated in our study moved at least as far downstream as their source location during the same season. The source location of these eels from a different river than that which they were released is reflective of the current trap-and-transport program on the Ottawa River but may not be reflective of all trap-and-transport programs that have been or will be established for eels elsewhere in their range. It may be hypothesized that eels collected and released within the same river would have greater retention to their release location than that observed in this study. It should also be noted that juvenile eels included in our study were much larger (and probably older) than eels typically considered to be undertaking active, uni-directional upstream migrations (Béguer-Pon et al., 2015; Oliveira, 1997). As such, trap-and-transport studies carried out with smaller, younger eels, closer to the marine environment, may yield higher retention rates above barriers, given these eels have a greater tendency to move upstream.

Movement downstream of the facility could also be a behavioral stress response to handling and tagging. Chinook salmon from the Kenai River were found to move downstream several kilometers after capture in gill nets and tagging with externally mounted transmitters (Bernard, Hasbrouck, & Fleischman, 1999). Behavioral responses to handling and tagging would be context and species-specific (Brownscombe et al., 2019), though eels are generally robust to tagging (Cottrill et al., 2006) and eels in our study showed no signs of

TABLE 3 Model-selection statistics from binomial generalized linear models predicting daily presence of eels at each channel

Model	*df*	LogLik	AICc	ΔAICc	ωAICc
Channel	**5**	**−183.107**	**376.4**	**0.00**	**0.52**
Discharge + channel	**6**	**−182.158**	**376.5**	**0.16**	**0.48**
Discharge	2	−213.709	431.4	55.09	0.00

Note: Columns include degrees of freedom (*df*), the log-likelihood of the models (LogLik), the bias-corrected Akaike Information Criterion (AICc); the difference in AICc between a given model and the top-ranked model (ΔAICc); and the relative weight of the bias-corrected AICc (ωAICc). Model averaging was applied to models in bold.

TABLE 4 Parameter coefficient estimates from model-averaged logistic regression models predicting daily presence of eels at each channel

Parameter	Estimate (*SE*)	Lower CI	Upper CI	z-score	*p*-value
Intercept (spillway)	−0.228 (0.401)	−1.014	0.558	0.568	.570
Pump Station	−0.743 (0.445)	−1.615	0.129	1.671	.095
Generator channel 1	−2.461 (0.513)	−3.466	−1.457	4.802	<.001
Generator channel 2	−1.346 (0.401)	−2.131	−0.561	3.360	<.001
Generator channel 3	−3.616 (0.768)	−5.125	−2.107	4.697	<.001
Discharge	0.022 (0.016)	−0.009	0.053	1.365	.172

Note: Discharge is the proportion of mean daily discharge among channels. SE is the unconstrained *SE* estimate from model averaging. CI represents 95% confidence intervals.

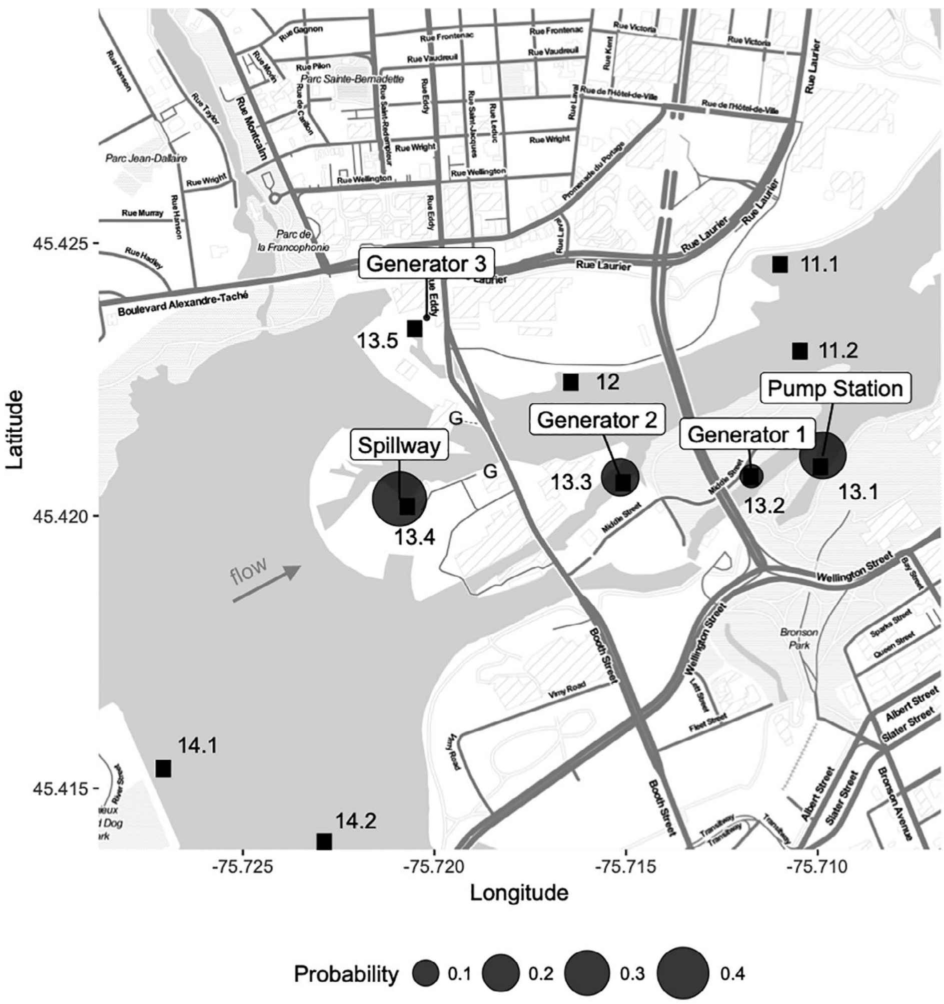

FIGURE 5 Acoustic receivers deployed at the upper barrier (black squares, station #) and the probability of daily presence in each channel by eels detected at the upper barrier (circles). Probabilities are based on backtransformed logistic regression parameter estimates (Table). Generators located within the spillway channel are shown (G). Note that the position of station 14.2 has been adjusted downstream of the actual position for easier interpretation of the figure

impairment after tagging. Nonetheless, one eel did return below the lower barrier ~24 hr after release (i.e., fallback). No other eels moved this quickly in either direction after release, making it likely that this fallback behavior was an adverse consequence of the trap-and-transport event rather than natural behavior. It may also be that eels were disoriented after trap-and-transport and resultingly returned downstream, an explanation that has been proposed for Atlantic Salmon (*Salmo salar*) falling back after transport (Hagelin, Calles, Greenberg, Nyqvist, & Bergman, 2016). Regardless of the biological mechanisms underlying this downstream movement, trap-and-transport could be damaging to the population if translocated eels are harmed through downstream passage back toward their point of capture (e.g., turbines; Algera et al., 2020), though this did not appear to be the case for eels in our study. Eels in our study were generally small (~50 cm) and injury risk in turbines appears to increase with size (Heisey et al., 2019).

4.2 | Upstream passage

The hydraulic environment downstream of Chaudière Falls is complex, which undoubtedly impacted the effectiveness of our acoustic telemetry array (Melnychuk, 2012). Although our study was not able to provide a comprehensive understanding of eel spatial use downstream of this barrier, we were able to characterize the general movement patterns and behaviors of eels in this area. Eels approaching the upper barrier were detected most frequently in the spillway and pump station channels compared to other channels. The underlying drivers of these preferences are not clear, though it does not appear that discharge drove channel selection as has been observed elsewhere (Welsh & Liller, 2013). Interestingly, eels tended to only be detected at one or two channels when approaching the barrier, rather than exploring all or most of the potential channels. If eels tend not to explore multiple potential passage routes, then a single ladder will be insufficient to pass all eels approaching a facility and will fail to meet the ideal goal of creating unrestricted passage at the barrier (Castro-Santos, Cotel, & Webb, 2009). The two channels visited most by eels at this barrier may be the most suitable candidate sites for future fish passage structures.

Despite no passage structures at this barrier, one eel was actually able to pass upstream. This eel was first detected on receiver 14.1 after passing the barrier, suggesting the eel potentially passed upstream via the spillway rather than channels closer to receiver 14.2. While this observation is remarkable, persistent observations of eels in the upper sections of the Ottawa River watershed, including recent observations of juveniles over 100 km upstream of the Chaudière dam complex and above the next upstream hydropower facility, provide clear evidence that some eels can move beyond barriers without passage structures. Given the low rate of passage at this barrier, it is clear that fish passage structures (e.g., eel ladders) are needed to allow a reasonable proportion of eels to access habitats beyond barriers (R. E. Schmidt, O'Reilly, & Miller, 2009).

5 | CONCLUSION

American eel populations are in severe decline throughout their distribution, particularly in the St. Lawrence River watershed where eels have been challenged by habitat fragmentation resulting from the proliferation of dams (MacGregor et al., 2009). American eel was once abundant throughout the Ottawa River watershed and played an important role in First Nation history and culture. First Nations of the Ottawa River watershed have for decades called for the restoration of American eel (or pimisi) to the Ottawa River and its tributaries. Our study has revealed that barriers without passage provisions restrict the upstream movement of almost all American eel, though observation of one eel navigating beyond the upper barrier indicates upstream passage is still possible. Our study also found that trap-and-transport can be used to increase the number of eels upstream of a barrier, but that a considerable proportion of transported eels will return back downstream of the barrier. Based on the movement patterns of our two release groups, it seems possible that increasing the distance of the release site from the barrier may help to increase retention. Eel behavior was variable in our study compared to the unidirectional upstream movement expected from younger juvenile eels. Researchers should be cognizant of this variability in migratory behavior when considering necessary sample sizes and eel sizes for studies on upstream passage at barriers. Despite a modest sample size, findings from our study highlight the need for passage opportunities for American eel at barriers, and that trap-and-transport is one such method that can be used.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Supporting data is available upon request.

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