Generalizing Trends in Upstream American Eel Movements at Four East Coast Hydropower Projects

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Abstract

Dams impede the upstream migration of juvenile American Eel *Anguilla rostrata*, limiting their access to freshwater habitat and potentially contributing to population declines across their range. The implementation of fishways at large hydropower dams help restore access to upstream habitat and represents a long-term dataset of American Eel captures. We analyzed the relationships between eel captures and select environmental variables (river discharge, water temperature, and lunar illumination) at four hydropower projects on east coast rivers with a comparable decade of data and sampling techniques: Roanoke Rapids Dam on the Roanoke River in North Carolina, Conowingo Dam on the Susquehanna River in Maryland, Holyoke Dam on the Connecticut River in Massachusetts, and the Moses-Saunders Dam on St. Lawrence River in New York and Canada. The number of eels captured varied among projects, from year to year, and seasonally. American Eel are opportunistic in their upstream movements, with peak movement events associated with high flows, increased water temperature, and low lunar illumination. Our results suggest that systems altered by hydropower dams offer unique challenges to American Eel migrants and that a multitude of factors play a role in the timing of upstream movements.

Keywords: American Eel; fish passage; migrations

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Introduction

Hydroelectric dams alter the natural hydrology of river systems and physically impede the upstream and downstream movements of migratory fishes, including the American Eel *Anguilla rostrata*. Dams limit access to freshwater habitat needed in later life stages (Facey and Van den Avyle 1987; ASMFC 2000) and contribute to a decline in American Eel populations throughout their range (Haro et al. 2000). Implementing upstream passage at hydroelectric dams is a key step to restoring access to important American Eel habitat (Greene et al. 2009), which is accomplished partially through the conditioning of licenses for eelways at hydropower projects by the Federal Energy Regulatory Commission (FERC). Data collected during passage operations helps resource managers understand upstream migration patterns in American Eel.

American Eel are a catadromous species with a complex life cycle and are present in estuaries and freshwater waterbodies along the Atlantic Coast of North America. American Eel have a wide range and occur from the southern tip of Greenland to northeastern South America. Within that range, American Eel occupy habitats in the ocean, estuaries, rivers, streams, lakes, and ponds at various stages in their lifecycle (Helfman et al. 1987; Jessop 2010). The species is panmictic, and adult American Eel migrate out of freshwater habitats to spawn as a single population in the Sargasso Sea in the North Atlantic subtropical gyre (Facey and Van den Avyle 1987; Côté et al. 2013; Shepard 2015). Eggs hatch into a planktonic larval stage (leptocephalus) and are dispersed along the North American Coast by drifting with ocean currents.

As the larvae approach the continental shelf, they metamorphose into glass eels (Kleckner and McCleave 1982; Kleckner and McCleave 1985) and begin migrating into estuaries during winter and spring months. Early metamorphosis is associated with recruitment to lower latitudes, while eels with a later metamorphosis tend to travel further before reaching continental waters (Miller et al. 2009). The glass eel stage lasts only a few months, and a second metamorphosis into the elver stage occurs in brackish waters of coastal estuaries. Elvers continue migrating into upstream freshwater habitats and are the life stage primarily impacted by dams and other impediments. American Eel upstream movements occur in high-density pulses but also vary significantly in their timing and numbers (Overton and Rulifson 2009; Welsh and Liller 2013; Welsh et al. 2015). Such migration events are associated with darkness and high river flow and potentially are initiated by a water temperature threshold (Martin 1995; Jessop 2003; Schmidt et al. 2009; Sullivan et al. 2009). Anguillid eels are both crepuscular and nocturnal with the timing of upstream movements associated with lower levels of ambient light and lunar illumination (Schmidt et al. 2009). Numerous other factors contribute to the variability in upstream eel movements; even the personality of individual eels influences the use of fishways to move upstream (Mensinger et al. 2021).

Providing passage for American Eel at dams blocking upstream passage, particularly at large hydroelectric facilities, partially restores access to historical habitat. One way passage is accomplished is through fishway conditions included in the hydropower licenses issued by FERC. Here, we sought to review the last decade of eel passage operations at four FERC-licensed hydropower projects along the east coast of North America, and we identify environmental cues that initiate American Eel upstream movements at dam passage facilities. We identified four FERC-licensed hydropower dams that have had fishways in place and passed American Eel upstream for more than a decade. From south to north, these dams are Roanoke Rapids Dam on the Roanoke River in North Carolina, Conowingo Dam on the Susquehanna River in Maryland, Holyoke Dam on the Connecticut River in Massachusetts, and the Moses-Saunders Dam on the St. Lawrence River between New York and Canada. We compared capture data to variations in river discharge, water temperature, and lunar illumination at the four hydropower projects over the last 10 y. We also examined variations from year to year, seasonally, and among locations. Our work identified peak periods for juvenile eel migration in systems with altered hydrology, which may help resource managers refine operations to improve fish passage efficacy at hydropower facilities.

Methods

Study locations

Roanoke Rapids Dam (FERC number 2009) is the most downstream dam on the Roanoke River, which drains approximately 25,300 km^2 from the Blue Ridge Mountains in Virginia to the coastal plain in North Carolina into Albemarle Sound. The dam is located 221 river kilometers (rkm) upstream from the river mouth and is the first in a series of hydropower projects that alters the river hydrology. Dominion energy operates the 95-megawatt (MW) project built in 1955. The FERC issued a new license in 2004 with a condition for passage of American Eel. Passage operations began in 2009. Eels ascend eelway structures that discharge into holding tanks before Dominion personnel transport them above the dam for release. Passage operations occur from March 1 to November 30 of each year, and personnel check traps every Monday, Wednesday, and Friday. Dominion staff manually count eels, except during peak passage events when they use a biomass estimation method.

Conowingo Dam (FERC number 405) is the most downstream dam on the Susquehanna River, located just 16 rkm upstream from the Chesapeake Bay. The Susquehanna River Basin is the largest on the Atlantic Coast, draining approximately 70,000 km^2 across New York, Pennsylvania, and Maryland. Exelon Generation owns and operates the 573-MW project built in 1928. The previous FERC license for operation of the dam expired in 2014, and the project operated on a yearly license until 2021 when FERC issued the new license. In 2005, the U.S. Fish and Wildlife Service began collecting American Eel below the dam. The collection process was modified in 2008. In 2015, FERC issued Exelon Generation a new license for operations of the Muddy Run Pumped Storage Project (FERC number 2355), located upstream of Conowingo Dam. A condition of the license was the installation and operation of a permanent eelway at Conowingo Dam. Upstream passage at the dam occurs through a trap and transport operation. Eels ascended a single eel ladder located on the western shore directly below the dam where they become trapped in holding tanks. Staff then transport them to locations upstream of the dam where they are released. Passage operations continue from May to September each year. Staff check for eels on an irregular basis and daily during peak migration events. Personnel count eels individually, but during peak events, numbers were volumetrically estimated based on a 200-mL subsample.

Holyoke Dam (FERC number 2004) is the most downstream dam on the Connecticut River at rkm 138. The Connecticut River Basin drains over 29,000 km^2 from the Canadian border through Vermont, New Hampshire, Massachusetts, and Connecticut. The City of Holyoke Gas

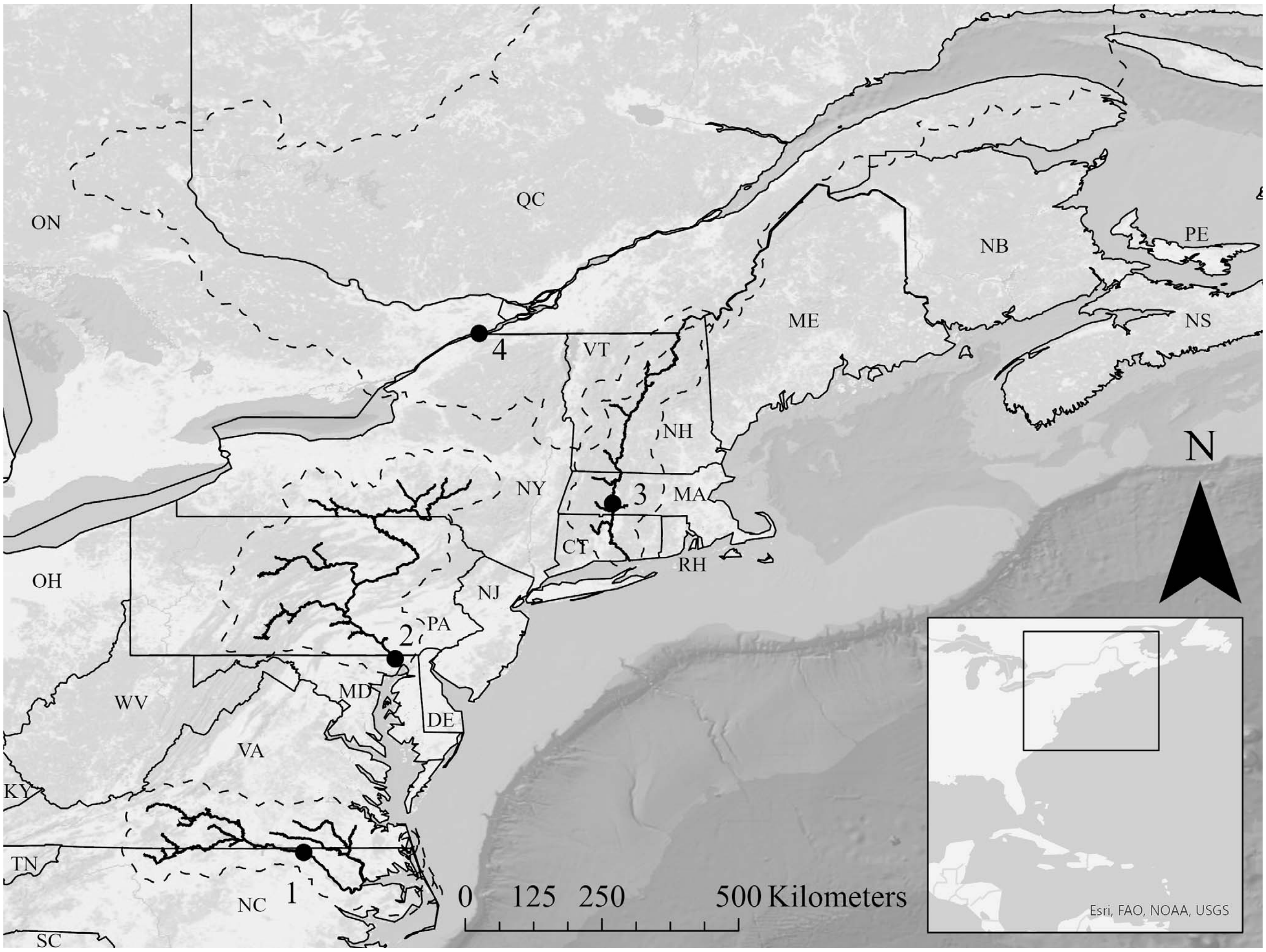

Figure 1. Map indicating locations of the four hydropower projects where we analyzed upstream American Eel *Anguilla rostrata* movements from 2010 to 2019 and the river systems they impound. The circular symbol and number identify each hydropower project, from south to north: Roanoke Rapids Dam on the Roanoke River, North Carolina (1), Conowingo Dam on the Susquehanna River, Maryland (2), Holyoke Dam on the Connecticut River, Massachusetts (3), and Moses-Saunders Dam on the St. Lawrence River, New York and Canada (4). Thin black line represent state/territory boundaries. Thick black lines represent each river and major tributaries. Dashed lines represent the extent of each river basin. For the St. Lawrence River, we excluded the Great Salt Lakes basin.

and Electric Department operates the 43.8-MW project built in 1900. The FERC issued the current license in 1999. Since 2005, a trap and release operation passes eels upstream using three portable traps and one permanent eel ladder at various points along the base of the dam. The eel passage season is from May to November. Staff check traps on a semiregular basis and count eels individually.

The Moses-Saunders Dam (FERC number 2000) impounds the St. Lawrence River at rkm 804 on the border between New York and Canada. The St. Lawrence River drains the Great Lakes–St. Lawrence River Basin, the largest watershed in the world, with an area of 1,344,200 km^2. Using the dam built in 1958, the New York Power Authority operates a 912-MW generating station on the U.S. side of the border, and Ontario Power Generation operates a 1,045-MW facility on the Canadian shoreline. Eel passage at the dam is accomplished with two eel ladders, one on either shore of the project. The ladders allow American Eel to ascend past the dam and deposit them directly back into the river approximately 300 m upstream. Ontario Ministry of Natural Resources and Ontario Power Generation have operated the eelway on the Ontario side of the dam since 1974. FERC issued a new license for New York Power Authority's facilities in 2003, with a condition for eel passage that began in 2006. The eel passage season is from June 16 to October. The licensee enumerates eels using a photoelectric counter that automatically tallies eels moving through the passage facilities.

Data collection

We collated American Eel capture data at four hydropower dams along the east coast of North America (Figure 1; Table 1; Data S1, *Supplemental Material*). Capture data at each dam are available through the public record or directly from project operators. At Roanoke Rapids Dam, Conowingo Dam, and Holyoke

Table 1. Summary of the four hydropower projects (Roanoke Rapids Dam, North Carolina; Conowingo Dam, Maryland; Holyoke Dam, Massachusetts; Moses-Saunders Dam, New York and Canada) where we sourced American Eel *Anguilla rostrata* captures and environmental data from 2010 to 2019. The waterbody and basin area columns provide context for each project sampled. Project location indicates the distance in kilometers upstream from the mouth of the drainage the project is located. The duration of the eel passage season and average ± SE daily discharge and water temperatures during the passage season from 2010 to 2019 are also given.

Hydropower project	Waterbody	Basin area (km^2)	Project location (rkm)	Passage season	Average daily discharge (cfs)	Average water temperature (°C)
Roanoke Rapids	Roanoke River	25,300	221	March–December	7,886 ± 812	20.8 ± 0.2
Conowingo	Susquehanna River	70,000	16	May–September	32,742 ± 4,668	26.1 ± 0.8
Holyoke	Connecticut River	29,000	138	May–November	11,325 ± 1,138	20.0 ± 0.4
Moses-Saunders	St. Lawrence River	1,344,200	804	June–October	281,775 ± 12,037	19.9 ± 0.2

cfs = cubic feet per second; rkm = river kilometer.

Dam, we obtained eel capture data from 2010 to 2019. At Moses-Saunders Dam, we sourced eel capture data from both sides of the dam, but complete records were only available from 2012 to 2019.

We also compiled river discharge, water temperature, and lunar illumination data from each hydropower dam (Data S2, *Supplemental Material*). We obtained discharge data from U.S. Geological Survey gauges at each project (Roanoke Rapids Dam number 02080500, Conowingo Dam number 01578310, Holyoke Dam number 01172010, and Moses-Saunders Dam number 04264331). We also obtained water temperature data from U.S. Geological Survey gauges for Roanoke Rapids Dam (Halifax, North Carolina, number 0208062765) and Conowingo Dam (Darlington, Maryland, number 01579550). At Conowingo Dam, water temperature data were only available from 2014 onward, and the records for 2014, 2015, and 2019 were incomplete. At Holyoke Dam, the licensee collects water temperature data near the eel ramp during the passage season. At Moses-Saunders Dam, water temperature data were available from the City of Cornwall, approximately 6 rkm below the dam. We estimated lunar illumination at each dam using the National Aeronautics and Space Administration's HORIZONS tool (https://ssd.jpl.nasa.gov/horizons.cgi#results) and used a nearby city as the observer location (Raleigh, North Carolina; Baltimore, Maryland; Springfield, Massachusetts; and Watertown, New York).

Statistical analysis

To examine the relationship between environmental covariates and eel captures, we used a generalized linear model to compare the timing of upstream eel movements to variations in river discharge, water temperature, and lunar illumination at each of the four hydropower projects. Before analysis, we removed instances when eel capture data were recorded but one or more of the environmental covariates was missing. We then standardized eel captures and environmental covariates at each project by implementing a *z*-score transformation. Finally, we corrected those transformations by adding the lowest transformed score to all scores for each covariates at each project. This resulted in a standardized dataset without any negative records that would work with our chosen analysis methods.

We fit capture rates (eels per day) to three candidate regression models using generalized linear models with a negative binomial distribution and a log link function (Table 2). We generated multiple models to determine which terms yielded the best fit and to evaluate collinearity among model terms. All models included terms for the project as a factor and for year as a covariate. In the first candidate model, we included additional terms for each of the three environmental variables as covariates. In the second candidate model, we dropped average water temperature and included terms for day of the year and day of the year^2 as covariates. We included these terms to determine any seasonal trends in passage and to account for potential collinearity between day of the year and water temperature, which increases then decreases throughout the year. In the third candidate model, we included terms for day of the year and all three environmental variables as covariates. In all three candidate models, we included

Table 2. The three candidate models generated to analyze American Eel *Anguilla rostrata* captures and environmental variables at four hydropower projects (Roanoke Rapids Dam, North Carolina; Conowingo Dam, Maryland; Holyoke Dam, Massachusetts; Moses-Saunders Dam, New York and Canada) from 2010 to 2019. The model terms, AIC, and pseudo-R^2 (McFadden's) of each model are given. We included project and year in all models. In the first model, we included all three environmental factors: river discharge, water temperature, and lunar illumination. In the second model, we dropped water temperature and instead included terms for day of year and day of year^2. In the third model, we included terms for day of year and for all three environmental factors.

Model terms	AIC	Pseudo-R^2
Project + year + discharge + temperature + illumination	5,544.8	0.15
Project + year + day of year + day of year^2 + discharge + illumination	5,510.8	0.16
Project + year + day of year + discharge + temperature + illumination	5,477.7	0.17

AIC = Akaike Information Criterion.

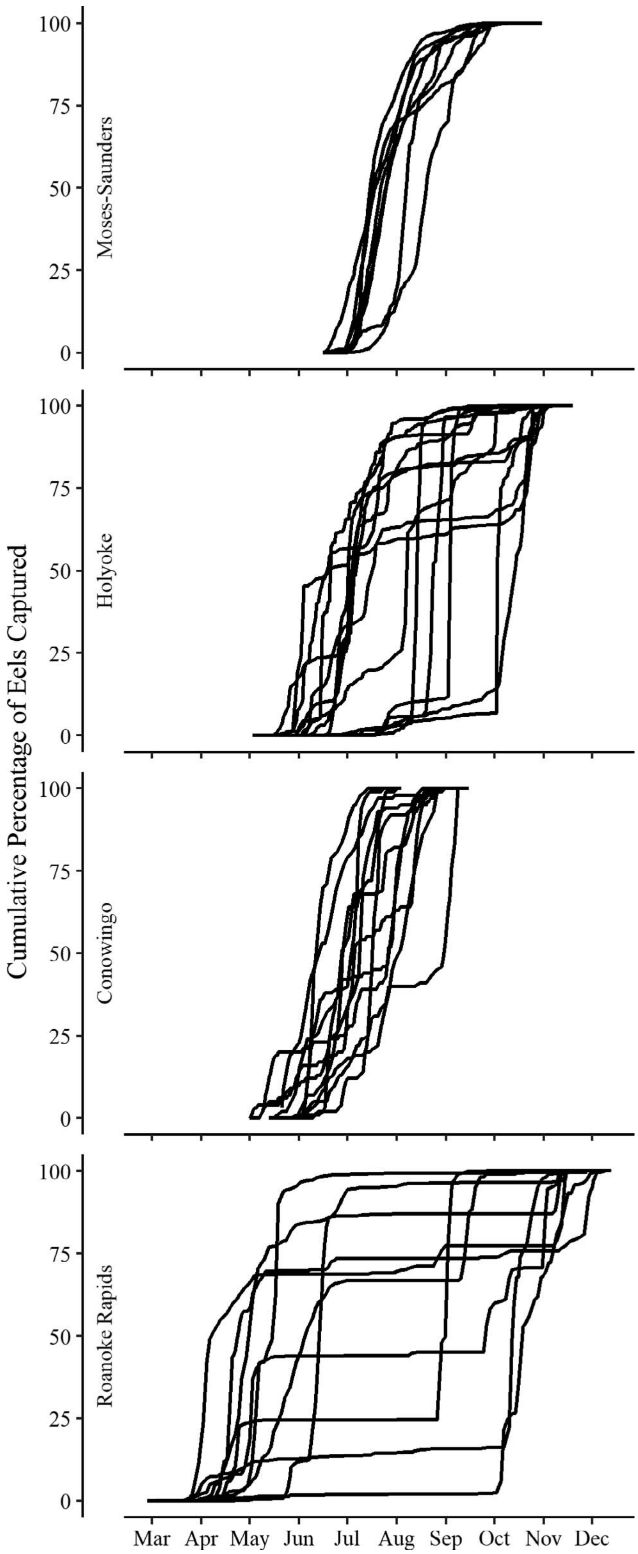

Figure 2. Cumulative percentage of American Eel *Anguilla rostrata* captured from 2010 to 2019 at the four hydropower projects from north to south: Moses-Saunders Dam (New York and Canada), Holyoke Dam (Massachusetts), Conowingo Dam (Maryland), and Roanoke Rapids Dam (North Carolina). Each line represents the cumulative percentage of eels captured over the course of an individual passage season.

project as a factor, but interpretation of these results is confounded by a variety of considerations. We conducted model selection using the Akaike Information Criterion (AIC). To determine the environmental covariates that significantly contributed to eel captures, we conducted hypothesis testing on the selected model with a likelihood ratio test fit by maximum likelihood.

Results

Passage overview

At Roanoke Rapids Dam, the facilities typically captured migrating eels during the first week of passage operations. Peak capture events occurred as early as mid-March and as late as November. Distinct spring and fall capture peaks occurred during several years (Figure 2). During the last 10 years (Figure S1, *Supplemental Material*), the facilities at Roanoke Rapids Dam captured 2,187,326 American Eels, with the majority in the first 4 y after passage operations began (2010 to 2013). By contrast, the facility trapped 263,614 eels within the last 5 y, representing approximately 12% of the 10-y total. Annual catch per unit effort (CPUE) ranged from 128 eels per day in 2014 to 2,930 in 2013, with an average ± standard error (SE) of 801 ± 293 eels trapped per day throughout the passage season.

At Conowingo Dam, the facilities typically captured migrating eels as soon as passage operations began for the season. Peak capture events were highly variable and occurred throughout the season (Figure 2). During the last 10 y (Figure S2, *Supplemental Material*), the facilities at Conowingo Dam trapped 1,051,961 American Eels. During the last 5 y, the facility trapped 377,558 eels, accounting for 36% of the 10-y total. Annual CPUE ranged from only 25 eels in 2016 to 2,342 in 2013, with an average ± SE of 974 ± 220 eels trapped per day.

During the first few weeks of passage operations at the Holyoke Dam, capture rates were typically low. Peak capture events were variable, occurring as early as mid-May and as late as early-October (Figure 2). During the last 10 y (Figure S3, *Supplemental Material*), the facilities at Holyoke Dam trapped 231,305 American Eels. During the last 5 y, the facility trapped 113,992 eels, representing 49% of the 10-y total. Annual CPUE ranged from 26 eels in 2010 to 303 in 2014, with an average ± SE of 138 ± 29 eels trapped per day.

At Moses-Saunders Dam, capture rates were typically low during the first few weeks of operations. Peak capture events reliably occurred in July, with the number of eels trapped trailing off by mid-September (Figure 2). During the last 10 y (Figure S4, *Supplemental Material*), the facilities at Moses-Saunders Dam trapped 288,333 American Eel. During the last 5 y, the facility trapped 73,004 eels, accounting for 25% of the 10-y total. Annual CPUE during the 10-y time series ranged from 7 eels in 2019 to 376 in 2011, with an average ± SE of 211 ± 40 eels trapped per day.

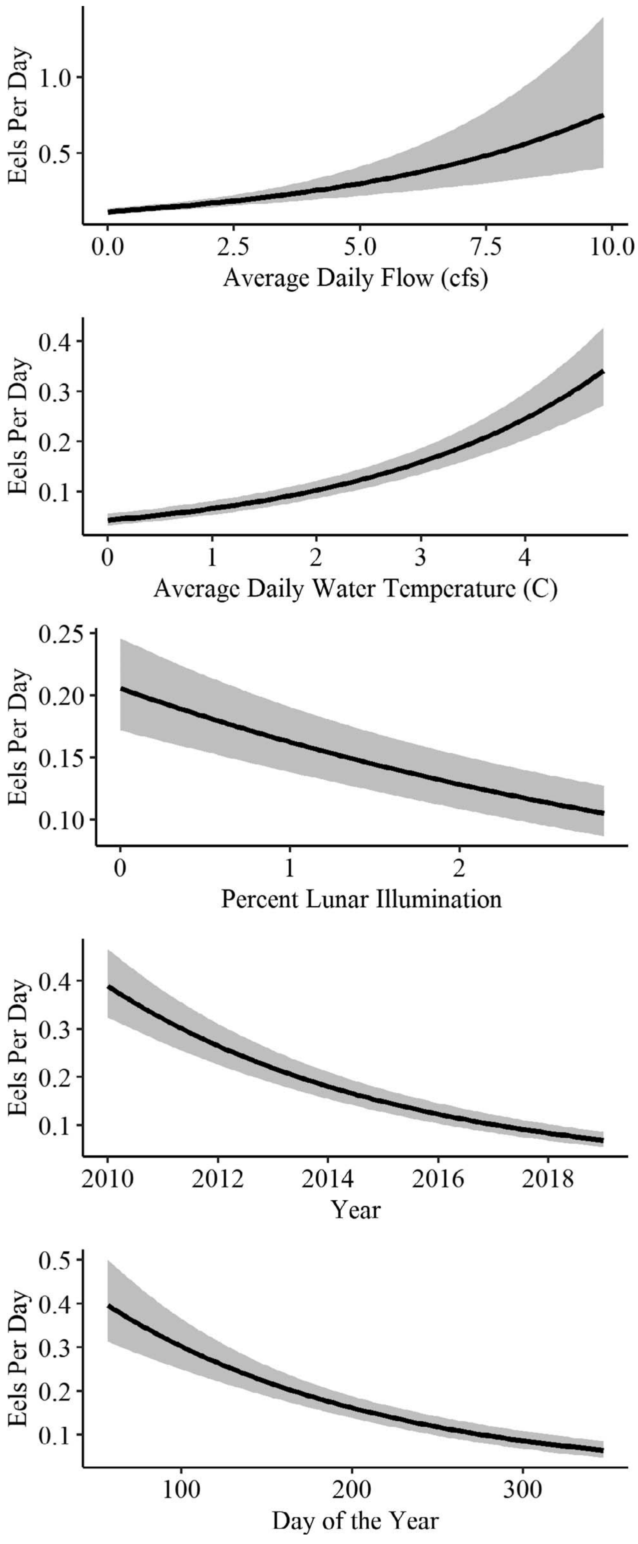

Figure 3. Predictive plots generated from the selected generalized linear model that fit *z*-score-transformed American Eel *Anguilla rostrata* capture rates to *z*-score-transformed environmental covariates for river discharge (average daily flow), water temperature, and lunar illumination at four hydropower projects (in North Carolina, Maryland, Massachusetts, and New York–Canada) from 2010 to 2019. The model also included terms for year and day of the year. The black line represents the modeled relative effect of each covariate, and the gray areas represent 95% confidence intervals. The axes for eels per day, average daily flows, average daily water temperature, and percent lunar illumination represent *z*-score transformations that we conducted before analysis.

Table 3. Summary of general linearized model analysis of American Eel *Anguilla rostrata* captures at all four hydropower projects (Roanoke Rapids Dam, North Carolina; Conowingo Dam, Maryland; Holyoke Dam, Massachusetts; Moses-Saunders Dam, New York and Canada) from 2010 to 2019, including the estimated regression coefficient, standard error, *z* score, and *P* value for each term of the model. We included project as a term in the model, but the analysis was confounded by the *z*-score correction and other project-specific factors; so results presented here are irrelevant to eel captures. Pseudo-R^2 (McFadden's) = 0.175.

Model term	Coefficient	SE	*z*	*P*
Intercept	383.61	29.42	13.04	< 0.001
River discharge	0.19	0.03	5.46	< 0.001
Water temperature	0.44	0.04	10.86	< 0.001
Lunar illumination	–0.24	0.03	–6.95	< 0.001
Year	–0.19	0.01	–13.07	< 0.001
Day of year	–0.01	0.00	– 8.28	< 0.001
Project: Conowingo	0.88	0.14	6.31	< 0.001
Project: Holyoke	0.22	0.10	2.14	< 0.001
Project: Moses-Saunders	1.12	0.11	10.59	0.03

SE = standard error.

Modeling upstream movements

We selected the third candidate model for hypothesis testing. We found that all three environmental variables included in the model had a significant relationship with eels captured (Table 3; Figure 3). River discharge and water temperature were positively associated with captures, and lunar illumination was negatively associated. Additionally, upstream eel movements were highly variable from year to year, seasonally, and among projects. Year and day of the year were both negatively associated with eel captures. Finally, we found that eel captures varied significantly among projects, but these variations are likely an artifact of the corrections performed on the *z*-transformed data. Additionally, direct comparisons between projects are confounded by several other site-specific factors.

Discussion

We reviewed eel capture data from the last decade of passage operations at four FERC-licensed hydropower projects along the east coast. At all four of the analyzed projects, American Eel were highly opportunistic in their upstream movements. Those movements occurred in high-density pulses over short periods of time but were otherwise highly variable. We observed a decline in overall eel catches over the last decade. We also sought to identify environmental cues that initiate American Eel upstream movements and found that peak movement events were generally associated with higher water discharge coming from the dams, warmer water temperatures, and lower levels of moonlight. Finally, we found significant differences in eel catches among projects. Ultimately, interpretation of these results must consider site-specific factors that influence eel movements, such as how the project is operated, its location in the watershed, and length of the passage season.

At all four projects, upstream eel movements occurred in high-density pulses over short periods of time. This is typical for upstream migrations of American Eel (Overton and Rulifson 2009; Welsh and Liller 2013; Welsh et al. 2015). The timing and number of pulses each season varied among projects and may be dependent on latitude and a number of site-specific factors. Our analysis identified a negative association between eel captures and day of the year, indicating that more eels are moving earlier in the season. As ocean temperatures continue to rise, eel migrations may occur earlier in the year in the coming decades (Jessop 2021). At Roanoke Rapids and Holyoke dams, upstream pulses occurred both in the spring (April to May) and in the fall (October to November), while at Conowingo and Moses-Saunders, peak movements reliably occurred in June or July. The longest season was at Roanoke Rapids Dam, with 10 mo of passage operations. The shortest seasons were at Conowingo Dam and Moses-Saunders Dam, each with 5 mo of passage operations. However, the length of the passage season is directly tied to requirements of the FERC license for each project, and, therefore, our yearly dataset is truncated to exclude colder winter months.

Upstream eel movements varied greatly among the years that we analyzed. We found a negative association between eel catches and year, indicating a decline in overall abundance. Eel populations are in decline throughout their range (Haro et al. 2000), a trend made more worrying by the apparent stability of eel populations over the last 30,000 y (Feng et al., in press). At Roanoke Rapids Dam, the cumulative number of eels captured over the last 5 y was only 12% of the 10-y total. We also observed declines in abundance at Conowingo Dam and Moses-Saunders Dam, where less than 40% of the 10-y total occurred during the 5-y time series. Of the four facilities, only Holyoke Dam had approximately half of the 10-y total trapped within the last 5 y. The declines in eel captures that we observed are likely influenced by the unprecedented decline in overall eel abundance. However, in some instances, low eel captures can be explained by project operations. For example, at Conowingo Dam, passage operators noted extremely low discharge during 2016 (Reily and Minkkinen 2016), which corresponded to a record low passage year. Similarly, at Moses-Saunders Dam, passage operators noted in 2017 and 2019 that the dam spillway was in use, attracting eels to the spillway and away from the eel passage facilities (D. Stanley, Ontario Power Generation, personal communication). At Roanoke Rapids Dam, the drastic decline in abundance beginning in 2014 may be explained, in part, by an artificially high stock of eels below the dam moving in great numbers in the years after passage was implemented. Similar phenomena of high eel captures during the initial years of passage occurred at other barriers, including Chambly Dam on the Richelieu River, a tributary of the St. Lawrence River (Cairns et al. 2014).

Our analysis of environmental covariates and the relationship to the timing of upstream American Eel movements sought to identify potential triggers for American Eel upstream movements at dam passage facilities. We found that peak upstream movements were associated with high water discharge, warmer water temperatures, and lower levels of lunar illumination. This supports the findings of other studies, which showed similar associations (Schmidt et al. 2009; Welsh et al. 2015). High flow events may signal the presence of additional upstream habitat, and the increased turbidity and lower ambient light conditions associated with high discharge events likely encourage eels to move in large numbers. This study focused on upstream movements at fixed locations, and at that resolution, river discharge may be the most significant factor for triggering high-density upstream pulses among those factors that we considered. At a broader resolution, temperature is significant to the timing of the migration season, physiologically signaling to eels to move upstream as water temperatures warm. Finally, eels generally prefer to move during periods of nighttime darkness, but we should consider several factors beyond lunar illumination. It is also possible that our estimation of nighttime brightness did not reflect actual water light conditions. Our measure did not consider cloud cover or water turbidity, which would lower ambient light levels experienced by migrating eels. Our results also highlight how significantly eel migrations vary from one river basin to another and between modes of hydropower operation.

Upstream eel movements also differed significantly among the four projects analyzed; however, little can be reliably inferred from this result. Direct comparison of eel captures among projects is confounded by many factors. The hydropower projects in this study have differing positions in the watershed, plant configurations, operational regimes, and other unique habitat features that influence the upstream movements of American Eel. The projects that we examined differ considerably in size, drainage area, and location in the watershed. These factors certainly affect the upstream movements of eels and limit the ability to make direct comparisons between them. In discussing the length of the passage season, we noted that each project is required to operate the eel passage facilities based on a license condition, which results in our dataset not necessarily representing a full year of eel movements. Additionally, the location of the project in the watershed plays a role in structuring eel populations (Camhi et al. 2021) and would likely affect the timing of upstream migrations. Projects located closer to the mouth of the river or supply of new migrants (that is, estuary) may have a shorter passage season, with a single seasonal passage peak. At Conowingo Dam and Moses-Saunders Dam, the passage season was shorter and more condensed than at Roanoke Rapids Dam and Holyoke Dam, where the passage season was longer and had multiple seasonal peaks. This may be because the supply of migrating juveniles is delayed reaching projects further upriver, while projects near the estuary receive a single condensed supply of new migrants. Location in the watershed also influences the age and size of eels moving upstream (Camhi et al. 2021). Finally, because eel movements were associated with higher discharge from the dams, the specific project operations and plant configurations at the four projects in our study likely result in different migration trends.

Supplemental Material

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Data S1. Daily American Eel *Anguilla rostrata* captures from 2010 to 2019 at four hydropower projects: Roanoke Rapids Dam on the Roanoke River, Conowingo Dam on the Susquehanna River, Holyoke Dam on the Connecticut River, and Moses-Saunders Dam on the St. Lawrence River. The "Eels" column gives the number of eels captured on a given date. The "EelsPerDay" column gives the number of eels captured standardized by the number of days between checking the traps. The "Peak" column indicates whether or not the number of eels captured on any given day was ≥ 5% of the cumulative total for the season.

Available: https://doi.org/10.3996/JFWM-21-066.S1 (152 KB XLSX)

Data S2. Average daily river discharge, water temperature, and lunar illumination during the American Eel *Anguilla rostrata* passage season from 2010 to 2019 at four hydropower projects: Roanoke Rapids Dam on the Roanoke River, Conowingo Dam on the Susquehanna River, Holyoke Dam on the Connecticut River, and Moses-Saunders Dam on the St. Lawrence River. The "MeanDischarge" column gives the average water discharge in cubic feet per second (cfs) on a given date. The "MeanTemp" column gives the average daily water temperature (°C) on a given date. The "PercentIllumination" column indicates the calculated percent of the moon visible at each project location on a given date.

Available: https://doi.org/10.3996/JFWM-21-066.S2 (186 KB XLSX)

Figure S1. Summary of American Eel *Anguilla rostrata* captures and environmental variables from 2010 to 2019 at Roanoke Rapids Dam. The thick line represents the cumulative percentage of eels captured that season, with darkened segments representing single days when the number of eels captured was ≥ 5% of the cumulative total for the season. The solid black line represents average daily river discharge ×500 cubic feet per second (cfs). The dashed black line represents average daily water temperature. The gray dotted lines represent percent lunar illumination throughout the time series.

Available: https://doi.org/10.3996/JFWM-21-066.S3 (17,799 KB TIFF)

Figure S2. Summary of American Eel *Anguilla rostrata* captures and environmental variables from 2010 to 2019 at Conowingo Dam. The thick line represents the cumulative percentage of eels captured over the course of the season, with darkened segments representing single days when the number of eels captured was ≥ 5% of the cumulative total for the season. The solid black line represents average daily river discharge ×1,500 cubic feet per second (cfs). The dashed black line represents average daily water temperature. The gray dotted lines represent percent lunar illumination throughout the time series.

Available: https://doi.org/10.3996/JFWM-21-066.S4 (17,799 KB TIFF)

Figure S3. Summary of American Eel *Anguilla rostrata* captures and environmental variables from 2010 to 2019 at Holyoke Dam. The thick line represents the cumulative percentage of eels captured over the course of the season, with darkened segments representing single days when the number of eels captured was ≥ 5% of the cumulative total for the season. The solid black line represents average daily river discharge ×500 cubic feet per second (cfs). The dashed black line represents average daily water temperature. The gray dotted lines represent percent lunar illumination throughout the time series.

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Figure S4. Summary of American Eel *Anguilla rostrata* captures and environmental variables from 2012 to 2019 at Moses-Saunders Dam. The thick line represents the cumulative percentage of eels captured over the course of the season, with darkened segments representing single days when the number of eels captured was ≥ 5% of the cumulative total for the season. The solid black line represents average daily river discharge ×10,000 cubic feet per second (cfs). The dashed black line represents average daily water temperature. The gray dotted lines represent percent lunar illumination throughout the time series.

Available: https://doi.org/10.3996/JFWM-21-066.S6 (17,799 KB TIFF)

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