Understanding the Ins and Outs of American Eel Migration in the Bronx River, a Fragmented Tributary of the Hudson Estuary

View of the 182nd Street dam on the Bronx River. Photo © WCS

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For more information, please contact:

Merry Camhi, PhD
Director, New York Seascape

Wildlife Conservation Society
New York Aquarium
Surf Ave at West 8th St
Brooklyn, NY 11224
631.581.9011
mcamhi@wcs.org

Catherine Grippo
Senior Development Officer, Foundation Relations

Wildlife Conservation Society
2300 Southern Boulevard
Bronx, NY 10460
718.220.6828
cgrippo@wcs.org

Executive Summary

Over the past three years, thanks to the generous support of the Hudson River Foundation, the Wildlife Conservation Society (WCS), in partnership with CUNY Queens College, has conducted extensive monitoring of the American eel in the Bronx River, the only freshwater river in New York City. Our objectives were to measure the seasonal presence, abundance, densities, and size distribution of eels in various life stages across the nine dams that bisect this 23-mile river, and to determine the impact that these barriers pose to the upstream and in-stream movements of resident eels.

Based on this study, we draw the following conclusions about American eels in the Bronx River, which are discussed below and will be expanded on for publication in professional journal articles:

- Prior to implementation of an eel pass in 2016, glass eels did not make it past the first dam, though some elvers did.
- Eels get larger with distance upstream, with the largest size increase between the second and third dams.
- Few eels great than 250 mm in total length are present past the second dam.
- Eel abundance stabilizes past the second dam.
- Biomass appears to be relatively consistent among sites; dams in the Bronx River appear partially limiting to upstream penetration.
- Eels appear to remain within their river segments and largely in place, indicating site specificity and small home ranges.
- It remains unclear whether upriver individuals are larger because of greater age correlated with the length (and likely corresponding time) of the journey or because of a relative lack of competition.
- Eel ladders on additional dams above the first dam would likely facilitate additional ingress.
- A limiting factor in the interpretation of our results is that it is not known how eel size and abundance vary in an undammed system.

Progress towards Goals

The target of this project is the American eel (*Anguilla rostrata*), a species that is considered depleted in U.S. waters (Atlantic States Marine Fisheries Commission, 2017) and is listed as globally Endangered under the IUCN Red List (Jacoby et al., 2017). It is a catadromous fish that is born in the ocean but spends most of its lifetime maturing in freshwater rivers and streams, including the Bronx River. Diadromous fishes, like eels, are fundamentally important to both marine and freshwater ecosystems: They serve as conveyors of energy and nutrients, as prey for many other species, and as indicators of ecosystem health. Increasing river connectivity, by removing barriers or providing passage to allow these fish to gain access to freshwater habitat needed for their growth and reproduction, is key to their restoration.

The Bronx River is the only freshwater river in New York City. It stretches 23 miles from its source at the Kensico Dam in Westchester to its mouth at the eastern end of Long Island Sound. Dammed since the 1600s and suffering centuries of pollution and other assaults in one of the most urbanized places in the world, the Bronx River is slowing being restored through the hard work of many community partners.

There are nine dams on the Bronx River, all four feet or more in height (Figure 1, Table 1). The largest (height of 14 feet), the 182nd Street dam, is the first dam and located three miles from the mouth of the river. The last dam, Haubold's Dam, sits just above river mile 18. Despite these dams, American eels of

various life stages including glass/elver, yellow, and silver eels are found in the Bronx River. The lower dams on the river represent a formidable barrier to young eels, and all dams may play a role in restricting in-stream movements of yellow and silver eels (although the latter are able to pass downstream over the dams when they permanently exit the river on their return to the Sargasso Sea to spawn).

To improve American eel access to its developmental habitat in the Bronx River requires, in part, a better understanding of the presence and timing of baby eels (glass and elvers) entering the river and the abundance, size distribution, and movements of juvenile and adult eels in various river segments, as well as the impact that dams and other barriers have on eel movements and productivity. These questions were the focus of this project, begun in 2014 and generously funded by the Hudson River Foundation from 2015 to 2017.

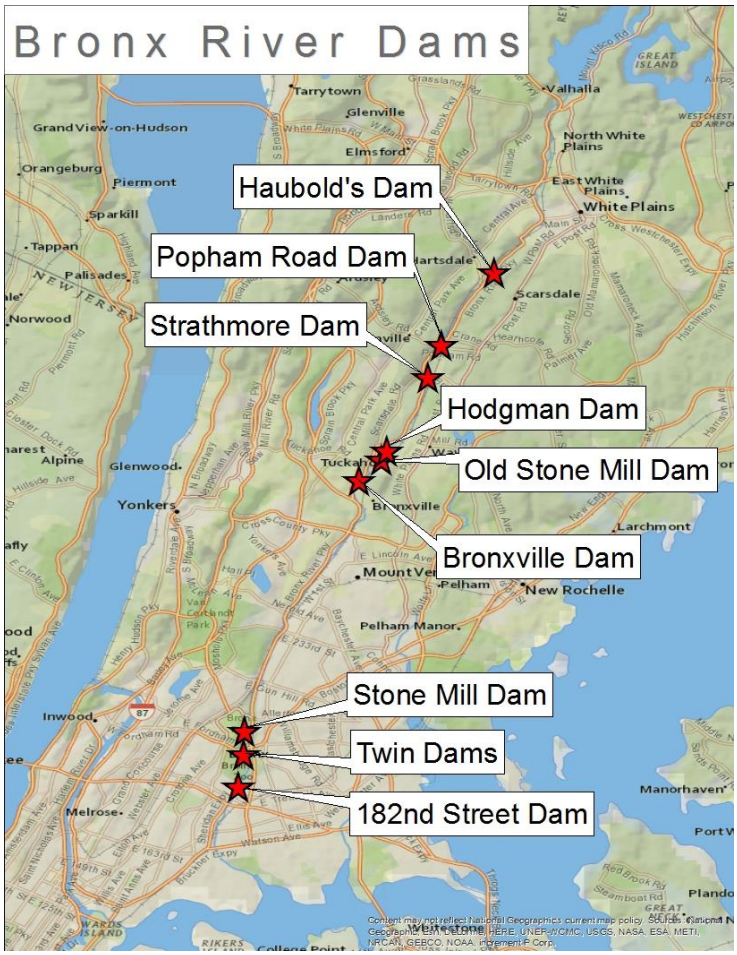

Figure 1. Map of nine dams along the Bronx River.

Table 1. Dams on the Bronx River including their distance from mouth of the river and their height.

Dam #	Dam Name	River Mile	Dam Height (ft.)
1	182nd Street Dam	3	14
2	Twin Dams	3.9	10
3	Stone Mill Dam	4.5	7
4	Bronxville Dam	11	5
5	Old Stone Mill Dam	11.8	4
6	Hodgman Dam	12	4
7	Strathmore Dam	14.6	4
8	Popham Road Dam	15.8	10
9	Haubold's Dam	18.4	6

Throughout the project we used two distinct survey techniques to assess the American eel population and impacts of dams on their movements and distribution in the Bronx River:

- **Eel mops:** Also known as "medusas," hand-constructed eel mops (Figure 2) were used to assess the timing and abundance of young eels (glass and elvers) entering the rivers (Silberschneider et al., 2001; Sullivan et al., 2009), and the potential impact that the dams posed to their upstream passage. Eel mops provide shelter to young eels as they seek day-time cover. A set of three eel

mops was placed near the base of the first six dams in 2015 and 2016, and only below the first two dams (182nd Street and Twin dams) in 2017. Mops were checked twice weekly from April to August each season.

Figure 2. New eel mop as it was being deployed (right) and Jake Labelle collecting young eels from an eel mop in the Bronx River (left). Photos © Merry Camhi/WCS

- **Electrofishing tag-and-recapture surveys:** These labor-intensive surveys, requiring teams of 6-10 people, were conducted using a Halltech backpack shocker and a two- or three-pass depletion approach (Carle and Strub, 1978) at each site (Figure 3). All captured eels were measured and recorded, and those greater than 250 mm were implanted with a Passive Integrated Transponder (PIT) tag, which enabled us to identify individual eels and subsequent recaptures. All eels were released at the site of their capture. The benefit of PIT tags is that they do not require a battery and so can be read throughout the eel's lifetime. This will enable us to return to the river periodically in subsequent years to reassess the size, distribution, and survivorship of previously tagged animals. We conducted 66 electrofishing surveys between 2014 and 2017 (Table 2). We initially conducted electrofishing surveys below all dams, but when no eels were caught at the eighth and ninth dams, future surveys were constrained to the first seven.

Figure 3. Electrofishing survey in the Bronx River (left; © Jake LaBelle/WCS) and measuring and checking eel for PIT tag (right; Julie Larsen Maher © WCS).

Table 2. Summary of eel mop and electrofishing sampling by year.

Measure	2014	2015	2016	2017	Total
Eel mops deployed	9	18	18	6	42
Eel mops sites	3	6	6	2	n/a*
Eels captured in mops	n/a	515	121	351	987
Electrofishing surveys	6	26	19	15	66
Eels captured during electrofishing	180	379	255	219	1033
Eels tagged (> 250 mm) and released	31	152	46	93	322
Eel size range (mm) (electrofishing)	n/a	112-897	102-790	58-756	58-877

*Eel mop sites are not cumulative since mops were placed in a similar location each year.

The following sections, organized by our original objectives, provide a brief explanation of our findings to date. These results will be expanded on for inclusion in a manuscript for journal publication.

Objective 1. Assess extent of upstream penetration and the permeability of barriers to instream movements of all eel life stages

We used eel mop arrays along the lower stretches of river to assess the ability of glass eels and elvers entering the Bronx River to pass various dams. Electrofishing and tagging of yellow and silver eels (i.e., eels longer than 250 mm) were used to assess the distribution of eels of various sizes across river segments, as well as the movement of recaptured (tagged) eels across dam barriers.

Our research had two main conclusions regarding the permeability of barriers to upriver movements of American eels in the Bronx River: (1) Some eels do make it past the first six dams, but (2) there is a pronounced falloff in eel numbers from dam to dam, particularly after the first two dams (Figure 4).

The first dam at 182nd Street is three miles from the mouth of the Bronx River with no barriers to impede passage along the way. All electrofishing surveys at this site yielded large numbers of eels, mainly of smaller sizes. Both electrofishing and eel mops produced eels as small as the elver stage. Eel mops also captured low numbers of glass eels. Glass eels may be scarce at this site given the lengthy distance between it and marine waters, which would provide time for transformation of glass eels to the pigmented stage. Moderate numbers of young eels were found below the second dam (Twin Dams) on the grounds of the Bronx Zoo, however no glass eels or elvers were found above this dam.

Considerable effort was also applied using semi-quantitative eel mops in the reach below the 182nd Street dam and in the Bronx Zoo waters below the Twin Dams (Table 3). This gear showed for young-of-the-year eels, both glass eels and elvers were found below the 182nd Street dam, but only elvers were found above it.

The density of eels dropped steeply after the first two dams (Figure 4). Yellow eels of varying sizes were found within every river segment to the base of the seventh dam (Strathmore). No eels were encountered during our surveys at the eighth and ninth dams. This suggests that about 8.5 miles of potential developmental habitat, or one-third the length of the Bronx River, remains inaccessible to American eels.

Table 3. Eels of various life stages caught in eel mops below the first two dams 2015-2017.

Site	Glass Eels	Elvers	Yellow Eels	Total
182nd Street	300	422	186	908
Twin Dams	0	24	43	67

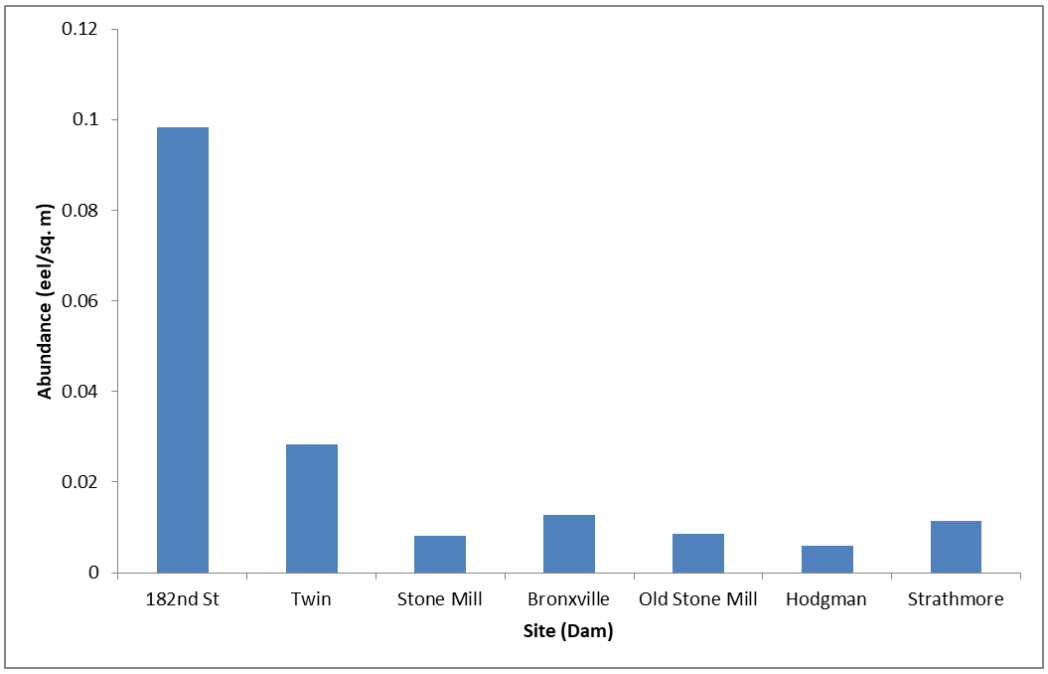

Figure 4. Eel abundance expressed as density (individuals/m^2) at the first seven dams on the Bronx River, 2015-2017.

Objective 2. Improve and extend upriver, inter-barrier estimates of eel size distribution, abundance, and density as a pre-eel pass baseline for possible post-barrier comparison

Our electrofishing surveys as well as our eel mop arrays helped assess the presence and distribution of eels of different sizes (life stage) in various river segments (Table 4). Eels caught in mops were not measured because they were not sedated. Eels caught during electrofishing surveys were measured to the nearest mm on a fish board.

Although eel numbers declined substantially along the series of dams, their mean lengths increased across the first three dams (Figure 5). There was no significant difference in average eel length among the third through the sixth dams. Measured eel lengths were converted to estimated weights using a standard empirically derived length-weight equation from FishBase. These values were then used to estimate eel biomass on a unit area basis at seven dam sites and two sites on between-dam reaches (NYGB and Shoelace sites) (Figure 6). Biomass appeared more evenly distributed than mean length across these sites, inasmuch as it was the product of countervailing trends in an upriver direction (i.e., decreasing abundance and increasing individual size). However, one outlier was found among these sites, Strathmore Dam, which showed about double the biomass of the other sites.

Table 4. Length of eels from electrofishing surveys below each dam, 2014-2017.

Dam #	Dam Name	Eel Length (mm)	Mean Length (mm)
1	182nd Street Dam	58-560	224
2	Twin Dams	107-655	300
3	Stone Mill Dam	172-716	469
4	Bronxville Dam	196-761	537
5	Old Stone Mill Dam	185-876	558
6	Hodgman Dam	221-747	597
7	Strathmore Dam	164-877	682
8	Popham Road Dam	n/a*	n/a*
9	Haubold's Dam	n/a*	n/a*

*No eels were caught at these sites.

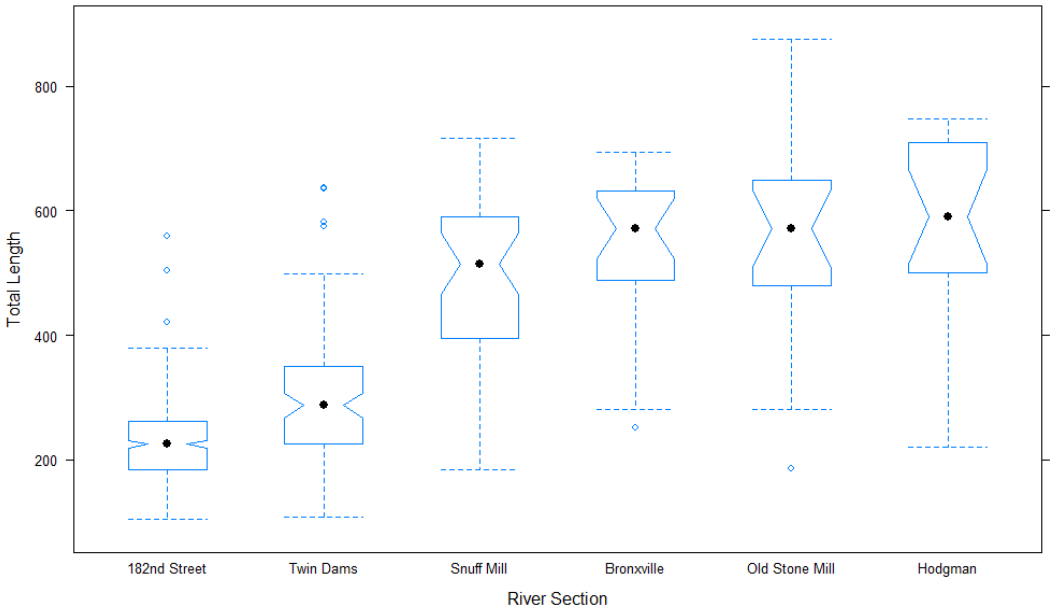

Figure 5. Mean length (mm), standard deviation, and range of eel lengths captured at the first six dams, 2015-2017.

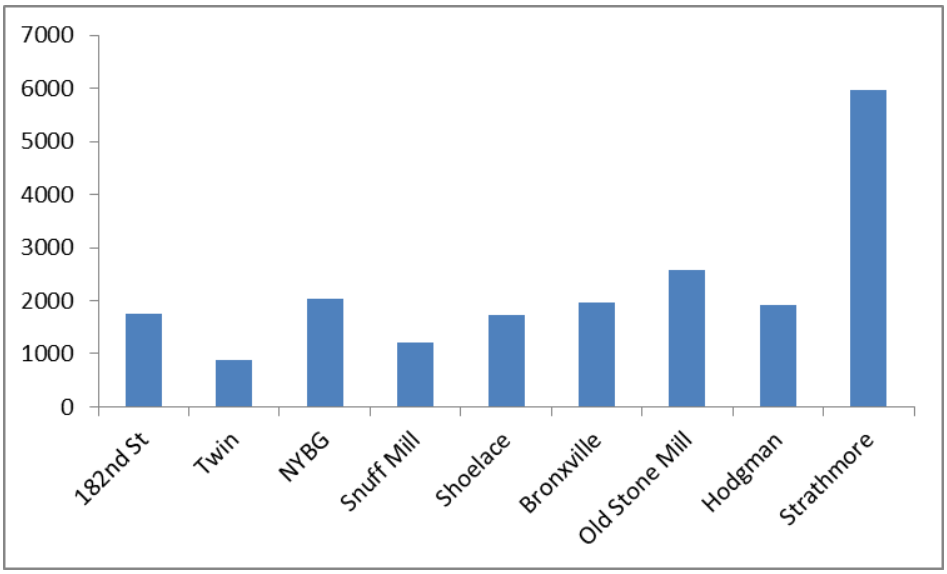

Figure 6. Area-corrected biomass estimates (density g/m^2) at seven dam sites and two between-dam reaches (NYBG and Shoelace Park).

We surveyed eels below and above the first barrier at 182nd Street for one year prior to installation of the eel pass in 2015 with a set of eel mops (three mops each) placed below both this dam and the Twin Dams (second dam). During the second and third years of monitoring, an eel pass was operated by the New York City Parks Natural Resources Group (NYC Parks) at the 182nd Street dam.

Unfortunately, we observed little change in the numbers of young eels caught in the eel mops at the base of the Twin Dams, despite a large number of eels using the pass. There are several possible explanations for this. The first may be due to predation: Young eels that use the pass are collected in a bin near the top of the dam that must be emptied manually into the river above the dam. Largemouth bass have been observed congregating at the release point for these eels, perhaps having learned that they can receive a free meal. Second, it is nearly a mile between the first and second dam. It is possible that the relatively few eels that ascend the pass do not make it to the second dam, either due to settling or predation. Third, it is also possible that the young eels that made it over the pass failed to encounter the mops at the 2nd dam, which only cover a very small area below the Twin Dams. A pass that scales the dam completely may lead to increased numbers of small eels at the base of the second dam because these eels would scale the pass under the cover of darkness, which could reduce loss to daytime predators.

Objective 3. Assess inter-barrier river segment distribution of eel size, abundance, and density
We were curious whether eels congregated below dams because these barriers interfered with their upstream movements. We conducted electrofishing surveys at random sites away from the dams to compare to our surveys at the dam sites.

From electrofishing conducted in 2017, it appeared that inter-barrier river segments had eels in similar sizes and densities as dam sites (Table 5). However, the largest eels were often captured in the plunge pools directly below dam flows, which may indicate that such locations are superior habitat. This is not to say that large eels were *not* caught in the between-dam sections, but the largest specimens caught were directly below dams on the upper reaches of the river.

Table 5. Mean number and length of eels per pass caught at dam sites (left) and between-dam sites (right) during electrofishing 2015-2017.

Dam #	Dam Site	# Eels/Pass	Mean Length (mm)
1	182nd Street	21	219
2	Twin Dams*	5.6	308
3	Stone Mill	1.6	451
4	Bronxville	1.5	537
5	Old Stone Mill	1.3	558
6	Hodgman	1.2	597
7	Strathmore	1.5	682

Dam Sites	# Eels/Pass	Mean Length (mm)
Below 182nd	25	220
Between 2nd & 3rd (NYBG)	3.6	456
Between 3rd & 4th (Shoelace)	1.1	493
Between 4th & 5th	0.5	594

*Survey done in the plunge pool below the Twin Dams resulted 6.6 eels/pass with a mean size of 333 mm.

Objective 4. Assess movements of tagged eels among inter-barrier river segments
There was virtually no movement of eels across barriers. Only one eel of the 322 eels tagged during the three field seasons was found to have moved across a dam: A 750-mm specimen tagged at the fifth dam on June 17, 2015, was recaptured six weeks later at the sixth dam. This suggests that the barriers may pose a formidable barrier to the movement of eels up and down stream, but that smaller dams may be scalable under some river conditions. It is also possible, however, that once settled, eels have fairly

restrictive home ranges within the river. There was remarkably little movement of tagged eels from site to site, even within the same river segment (although the area we sampled for each survey was small). All recaptured eels except the individual mentioned above were caught at the site at which they were tagged.

Objective 5. Initiate study to estimate silver eel egress and associated environmental factors
Because we ultimately found it infeasible to install a PIT tag detector across the river, which would have recorded every tagged eel that passed across the array, we were not able to directly track egress of silver eels. More intensive sampling at the end of the field season (October and November) would be needed to encounter silvers during egress, which is thought to occur after heavy storms. Given the flashy nature of the Bronx River, surveys right after storms are dangerous and were avoided. However, we did encounter six eels during the October 2015 survey that were in the silvering process (Figure 7). Five were relatively small individuals (291-346 mm) caught below the first dam, but one eel caught below the fifth dam was the second largest eel caught throughout the entire project (876 mm). This demonstrates that the eels of the Bronx River reach reproductive maturity in its urban waters and likely contribute to the Atlantic population.

Figure 7. Silver eels caught during electrofishing in October 2015. Note the enlarged eye and silver color, marking them as silver eels. Photo © WCS

Objective 6. Develop recommendations for engineered eel passes at the first two dams
In 2013, we attempted to install a homemade eel pass on the 182nd Street dam of a design that has worked on dams on other systems. The vertical structure of the pass featured a mesh fishing net fit lengthwise within PVC tubing, through which a trickle of water flowed. Any eels making it through the pass would have been visible in a trap at the top end of it. However, no eels used this pass. One reason may have been that the dam has a highly irregular surface and is very wide, which would make it difficult for an eel to locate the pass entrance.

The failure of the homemade eel pass was a useful finding in that it provided impetus for acquiring funding for a far more costly commercial eel pass. Purchased and deployed by NYC Parks, this eel pass, installed in 2016, has proven successful in passing eels during its first two years of operation. During the testing phase in 2015, 143 small eels (a combination of elvers and small yellow eels) successfully used the pass over the course of two months. The pass delivers the young eels to a collection bin, rather than directly into the river above the dam. The bin was checked every 3-4 days and generally contained 5-10

eels over that period, although on one occasion 48 eels were collected during a 3-day span. Similar numbers of glass eels and elvers were passed during the 2016 and 2017 field seasons.

Our results show that eels do make it past the second dam, but that there is a substantial decline in their numbers. The second dam, on Bronx Zoo property, is actually two dams (the Twin Dams). The eastern side has a typical vertical face that could support an eel pass. The western side is more of an acutely angled bedrock fall that might be sculpted at low water to provide better passage for eels of various sizes and, possibly, river herring. NYC Parks is currently considering fish passage options at the Twin Dams. We anticipate that implementation of additional eel (and river herring ladders) on dams farther upriver will be considered sequentially.

Objective 7. Compare (literature based), where possible, eel access and productivity pre- and post-eel passage, to comparable river systems

Our eel density estimates ranged between approximately 1-10/100 m^2. Densities estimated elsewhere in the Hudson Estuary by Robert Schmidt and colleagues were as high as 131-169 /100 m^2, however, this was for age-0 eels below the first dam of a Hudson tributary, the Saw Kill (Schmidt, O'Reilly, & Miller, 2009). Upstream of the first dam on Hudson River tributaries, including the Saw Kill, eel densities were significantly lower (1.7-5.5/100 m^2) and in keeping with our estimates. Schmidt and colleagues noted that the upstream densities in the Saw Kill and other Hudson tributaries were lower than those found in other northeastern rivers with eel passages (8-22 eels/100 m^2), suggesting that this upstream habitat might be able to support higher densities of American eels.

Eel biomass per unit area at our Bronx River sites ranged between about 900-6,000 g/m^2. This is comparable to the estimates for streams and rivers elsewhere in the Hudson watershed. Though highly variable among systems, Schmidt, Machut, and colleagues had estimates of biomass downstream of the first barriers of 242.3 (Black Creek), 684.6 (Minisceongo Creek), 774.7 (Peekskill Hollow Brook), 1,782.9 (Saw Kill), and 2,363.1 (g/m^2) (Hannacroix Creek) (Machut et al., 2007). In the Bronx River, we found notably higher biomass at the seventh dam. Higher biomass far upriver was not the pattern for the six sub-watersheds in the Hudson tributaries study; five had lower biomasses farther up the river, with the exception of Black Creek. Together, our findings from the Bronx River and those from other Hudson Estuary tributaries indicates a general pattern of smaller but more numerous eels at lower dams within these watersheds and fewer but larger eels at higher dams. But also that there is enough variation in this pattern to indicate high site-specificity, likely most influenced by the dimensions and other physical characteristics of the dams themselves.

Objective 8. Promote community and student engagement in Bronx River restoration and conduct outreach to share findings

All of our data means little without a vocal, dedicated constituency that is invested in the recovery of the Bronx River. We hoped to engage as many people as we could to share just how amazing an ecosystem the Bronx River is. We succeeded in enlisting over 100 volunteers to help with electrofishing and a similar number to monitor eel mops over the course of the study. Volunteers came from everywhere and anywhere, including but not limited to: WCS staff, WCS's Advanced Inquiry Program and Project TRUE, Rocking the Boat, Bronx River Alliance, NYC Parks Natural Resources Group, NY State Department of Environmental Conservation, US Environmental Protection Agency, CUNY Queens College, Fordham University, Stony Brook University, Manhattanville College, and even a few Bronx and Westchester residents who wanted to participate. The eel mops served as a lesson in data collection for Rocking the Boat students who took sole responsibility for monitoring a set of eel mops.

Our outreach was not limited to traditional audiences. On Tuesday, May 16, 2017, the New York Institute for Special Education brought a large group of 22 visually impaired 6th and 7th grade students, plus 11 chaperones, to check the eel mops at the 182nd Street dam. Students were led in small groups by the chaperones down to the river where a WCS staff member retrieved the eel mops. Each student took turns rinsing the mop and then were given the chance to hold the captured eels in their hands. It can be hard to read teenagers, but we got a great report from one of the teachers. When the Assistant Principal asked the students how the trip went, she was given really excited responses and shown multiple recordings and photos of the waterfall and the eels.

Our eel work was featured in at least a dozen educational talks, including professional development courses at the Bronx Zoo, lectures to students at Rocking the Boat, the Long Island Diadromous Fish Working Group, and the Long Island Sound Study, and of course, at the Hudson River Foundation itself. This project was also featured in three web series: a WCS webinar series that consisted of a recorded lecture about the American eel and then a live webcast from the river, viewed by classrooms from across the country (https://www.youtube.com/watch?v=ax1vww-CD04); Urban Waters (https://www.youtube.com/watch?v=xvTq2ynivZ4); and on the web series Urban Nature (http://interactive.wttw.com/urbannature/bronx-river-bounces-back#!/). Our work was also featured in a French documentary series on urban nature and on CUNY TV.

Further outreach will occur inasmuch as our findings are being prepared as a scientific journal article. We may also prepare a second article focusing on our statistical techniques. Moreover, our survey data are also being used to form the basis for calibrating results from an environmental DNA (eDNA) survey of many of these same sites (funded by the Hudson River Foundation for co-PIs Waldman and Alter). This will also result in at least one journal article.

Conclusion

American eels utilize the Bronx River as habitat for maturation. The first six dams on the river impede, but do not completely prohibit ingress. Abundances and biomass appear to be similar to other tributaries to the Hudson Estuary. Immigrating glass eels make it as far as the first barrier, but only elvers were found above it.

The pattern of abundance and biomass indicates that the Bronx River dams fall into three categories. One is the tall first barrier (182nd Street dam), where eels are numerous but young and small. Though passable prior to implementation of the eel pass in 2016, this dam was (and may still be) an impediment to upstream ingress. The second is the Twin Dams, below which eels are moderately numerous and moderately large. We believe an eel pass there would enhance upstream migration. The remaining dams upriver of the second barrier (Twin Dams) are lower in height and may be passable under some high-water conditions. Their below-dam pools support distinctly fewer but larger individuals than just below the first two barriers.

River reaches away from dams that were sampled showed eels in approximately similar numbers and sizes as sites immediately below their next upriver dam, suggesting that eels, except for the first barrier, do not aggregate immediately below dams. This may be linked to our observation that there was little evidence of movement among sampling reaches and only one instance of an eel moving between dam segments. Eels were also never seen moving volitionally in daylight, even in locations where many were caught during electrofishing. It may be that maturing and adult eels settle into lairs distributed somewhat evenly in accordance with densities as a means of controlling intraspecific competition.

Finally, we had suggested in our original proposal that this Bronx River study could serve as a model for eel research and restoration in other Hudson Estuary tributaries. We have recently proposed, with strong support from Westchester educators and river restoration organizations, to expand this research to Westchester's Sawmill and Hutchinson rivers in 2018, and are awaiting news on potential funding for this work. We thank the Hudson River Foundation not only for funding our Bronx River eel research but enabling us to leverage our expertise and equipment to the benefit of the American eels in other New York rivers.

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