THE EFFECTS OF DAMS ON DENSITIES AND SIZES OF AMERICAN EELS IN THE BRONX RIVER

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Most American eels (*Anguilla rostrata*) move up rivers to mature before migrating to their natal region of the Sargasso Sea to spawn and die. It is well known that dams impede, but don't always prevent the upriver movements of eels. The effects of a series of dams on the densities and size structure of eels in the highly urbanized Bronx River, a tributary to New York Harbor, was examined. Eels were sampled by electrofishing and trapping. It was hypothesized that the sequential impedence of upriver movements would result in fewer and larger eels progressing from the first to the third dam above tidewater. In the first round of electrofishing, the eel population density was found to decrease traveling upriver from 0.212 eels/m^2 at the 182nd Street Dam, to 0.0765 eels/m^2 at the Twin Dams, and to 0.040 eels/m^2 at the Snuff Mill Dam. While eel population density decreased from downstream sites to upstream sites, median eel length increased from 240 mm to 272 mm to 520 mm via electrofishing. With recent declines in American eel populations, the findings of this research may be useful in gaining support for the installation of eel ladders at dams in this watershed to increase the ability of eels to travel to reaches farther upriver.

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INTRODUCTION

American eel (*Anguilla rostrata*) are found in a variety of aquatic habitats along the Atlantic coastline from Brazil to Greenland (U.S. Fish and Wildlife Service 2011). This species also extends inland as far as 1,000 km in systems such as the Mississippi River. Eels occupy a variety of habitats, including streams, rivers, and lakes, as well as oceans, coastal bays, and estuaries. With an elongated form and benthic preferences, eels take shelter in such places as burrows, rock crevices, vegetation and sunken lumber. Eels are mostly nocturnal feeders, and during winter eels burrow in mud and remain inactive (U.S. Fish and Wildlife Service 2011).

The American eel has an unusual and complex life cycle (U.S. Fish and Wildlife Service 2011). As a catadromous species, American eels are born in salt water, migrate to and spend most of their lives in fresh water, and then return to salt water to reproduce. Their eggs are spawned in the Sargasso Sea near the middle of the North Atlantic. Little is known about the conditions in which this takes place, and this process has never been observed. After hatching, the leaf-shaped larvae are passively transported west to the North American coast by the Gulf Stream. Once the larvae have reached the coast, they become glass eels, which possess the typical eel shape and are transparent. Glass eels then start to move up estuaries and begin to behave as a benthic organism. When glass eels become more pigmented, they are termed elvers. Elvers are generally over 100 mm in length, with some pigmentation, and spend most of their time traveling upstream. As eels become larger and fully pigmented they begin to turn yellowish on their bellies; at this stage they are called yellow eels. The majority of growth, as well as sexual differentiation, take place during this stage. As yellow eels mature reproductively, they become silver eels. This maturation includes a metamorphosis that prepares the silver eel for its migration back to the Sargasso Sea to reproduce (U.S. Fish and Wildlife Service 2011).

Eels that do not migrate far upstream and remain in an estuarine environment complete their life cycle much more quickly. Eels that migrate farther upstream into fresh water tend to live longer and grow larger, increasing their potential reproductive output. An additional benefit of extensive upstream migration is greater dispersal within a watershed, which reduces intraspecific competition. Recent declines in the American eel population have largely been due to commercial fishing, specifically, the harvesting of glass eels and elvers, as well as degradation of habitat and migration corridors (U.S. Fish and Wildlife Service 2011).

The Bronx River is an ideal site for determining the effects of dams on eel populations because it is extensively dammed. Since the Bronx River is a fairly small system with many dams spread over a short distance, it is easy to sample in comparison to a larger system with a greater flow rate. In addition, it was known prior to sampling that each dam site within the Bronx River was passable by eels to some degree, so populations were expected to be found at every sampling site.

The objectives of this study were to estimate eel abundance and population density for each section (separated by the dams), as well as to assess the differences in size structure of the eel populations in each section. Determining the abundance, density, and differences in size structure of this population will help to better understand the overall effects of an array of small dams on inland penetration by American eels. In addition to helping support the construction of more eel passes, this data could aid in strengthening the conservation status of eels.

It was hypothesized that sections farther upstream would host smaller populations but contain larger eels, while the sections farther downstream would consist of larger populations but contain smaller eels. The rationale behind this hypothesis is that each dam acts as a physical barrier that prevents eels from traveling upstream, so fewer eels will be able to reach each upstream section. Since fewer eels will inhabit the site farther upstream there will be less competition for food, so these eels will be able to thrive. In addition, it can be assumed that the eels found farther upstream are larger because they are older and have spent more time traveling upstream than those eels found downstream.

Sampling Locations:

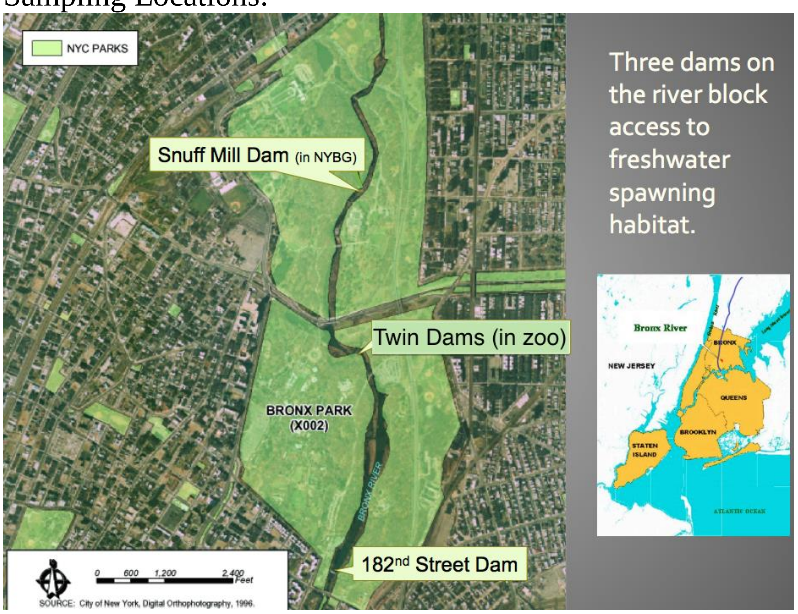

Figure 1. Aerial view of sampling locations (City of New York, 1996)

182nd Street Dam:

METHODS

The 182nd Street Dam is located just outside of the southwest corner of the Bronx Zoo property. This is among the most urban areas that the river runs through, and is also the closest of the sites sampled to the mouth of the Bronx River. There are no dams or obstructions between this sampling site and the mouth of the Bronx River. The stream channel at this site is primarily composed of riffles that are approximately 0.5 min depth as well as low-gradient sections that are approximately 1 m in depth. The banks are fairly littered and there is some heavy wood, as well as garbage debris including things such as rusted bicycles, street signs, and other bulk items in the river.

Figure 2. Ground view of the 182nd Street Dam.

Twin Dams:

The Twin Dams site is located on the Bronx Zoo property and consists of two dams that are adjacent to each other, separated by land acting as a natural barrier. Underneath the larger dam is a small area of very shallow water, followed by a deep pool between the two dams, followed by a 30-m section that is narrow and approximately one meter deep.

Figure 3. View of the larger dam at the Twin Dams site

Snuff Mill Dam:

The Snuff Mill Dam is located in the New York Botanical Gardens. The river is narrow at this site and flows more rapidly than it does at the other sites. Directly below the dam is a deep plunge pool followed by a large bedrock outcrop, with the depth varying from 0.15 m to 2.0 m. After the section immediately below the dam, there is a 40 m stretch that is approximately 1.0 m in depth, followed by a narrow section of rapidly flowing riffles. Below this section, there is great variation in river characteristics (depth, substrate type, gradient, etc.).

Figure 4. View of the Snuff Mill Dam in the NYBG

Electrofishing:

A Halltech battery-powered electrofisher (model HT-2000) set to 150 Volts and 60 Hz was used as the primary sampling gear to collect eels. Block nets of sufficient length were deployed to section off the area of the river being sampled. At each site, an attempt was made to sample the area of the river closest to the dam (downstream of the dam). Block nets could not be placed equidistant from each other at each of the three sites due to differences in the structure of the river, which led to differences in the total area sampled at each site. A team of at least three people netted eels that were stunned by the electrofisher. Two passes were conducted at each site with one person operating the shocker and three or four netters walking in a serpentine pattern. Two samples were taken to allow for the calculation of a population estimate through two-pass depletion.

Trapping:

For trapping, approximately 30 baited eel traps were used. All traps were spaced 30 meters apart from each other at each site. At each trap location, depth and substrate type (silt, sand, gravel, pebble, cobble, boulder) were measured. The traps were baited with frozen menhaden (*Brevoortia tyrannus*) once per week and were checked for two consecutive days after being baited. All traps were kept in the same location throughout sampling. Some traps were sunk using rocks, others were also tied to trees.

The initial width of the eel trap entrances was 3.0 cm, which led to the capture of only small eels. Upon dropping the first two traps into the water with bait, very large eels were observed but seemed unable to enter the traps. After the first week of trapping, the trap entrances were widened to 3.8 cm.

Measuring/Tagging:

All captured eels were anesthetized with clove oil; eels were placed in a 5-gallon bucket half filled with water with 13 drops of clove oil for approximately five to ten minutes. Eel length was measured; if the eel was over 275 mm, a judgment based on girth was made as to whether the eel could be safely tagged. Eels were tagged with a needle (sanitized with alcohol wipes) and 12 mm passive integrated transponder (PIT) tags. If the eel was captured via electrofishing, it was released in the same section where it was captured. If the eel was captured via trapping, it was released at least two traps away from where it was caught in order to ensure population mixing.

Statistical Analysis:

Descriptive statistics were calculated for each site and sampling method used, including minimum eel size, first quartile, median, mean, third quartile, and maximum eel size. In order to compare the size structure of eels captured at different sites, three adjacent box plots were created to illustrate eel size patterns. Differences in size structure were inferred based on observed differences in the sample median.

To estimate population abundance at each site, two electrofishing passes were conducted. By using the number of eels captured from each separate round, an estimate of the eel population and a 95 percent confidence interval were calculated using a two-pass depletion approach (Lockwood et al. 2000).

RESULTS

Trapping took place during the weeks of 7/7, 7/21, 7/28, and 8/18 in 2014. Nine traps were set at the 182nd Street Dam, six traps were set at the Twin Dams (limited access on Zoo property as well as depth of river limited the number of traps that could be placed), and nine traps were set at the Snuff Mill Dam.

Two-pass electrofishing took place two times throughout sampling, once in July and once in August, and the same areas of each site were sectioned off both times. At the 182nd Street Dam the nets blocked an area that measured 640 m^2, at the Twin Dams the nets blocked off an area that measured 418 m^2, and at the Snuff Mill Dam the nets blocked off an area that measured 326 m^2. For both electrofishing events, the 182nd Street Dam site had the most captures and the Snuff Mill dam site had the fewest (Table 1 and Table 4). Capture data from the two pass electrofishing was used to calculate population estimates, of which the 182nd Street population was the largest and the Snuff Mill population was the smallest (Table 2 and Table 5). The population estimates and electrofishing sampling area sizes were used to calculate population densities for each site, with 182nd Street having the largest population density and Snuff Mill having the smallest population density (Table 3 and Table 6).

In addition, the size structure of eels from each of the three sites was compared for each electrofishing event. Few eels were captured at the site the farthest upstream with population estimates of 1 and 13 eels; however, the eels at this site were much larger in size with a median length of 520 mm. Many eels were captured at farthest downstream site with population estimates of 139 and 79 eels; however, the eels at this site were relatively small in size with a median length of 240 mm. Eels captured in the middle site fell between the other sites with population estimates of 27 and 14 eels and a median length of 272 mm. Data comparing the size structure of eels at each site was used to generate box plots (Figure 5 and Table 7).

First Electrofishing Captures

Site	Captures
182nd Street Dam	82 individuals
Twin Dams	26 individuals
Snuff Mill Dam	8 individuals

Table 1. Total individuals captured during the first round of two-pass electrofishing.

First Electrofishing Population Estimates

Site	Population Estimate
182nd Street Dam	139 individuals (95% C.I. [49, 228])
Twin Dams	27 individuals (95% C.I. [24, 30)
Snuff Mill Dam	13 individuals (95% C.I. N/A)

Table 2. Population estimates with confidence intervals calculated from the first round of two-pass electrofishing.

First Electrofishing Population Densities

Site	Population Density
182nd Street	0.212 eels/m^2
Twin Dams	0.065 eels/m^2
Snuff Mill Dam	0.040 eels/m^2

Table 3. Population densities calculated from first round population estimates and sampling area sizes.

Second Electrofishing Captures

Site	Captures
182nd Street Dam	51 individuals
Twin Dam	14 individuals
Snuff Mill Dam	1 individuals

Table 4 Total individuals captured during the second round of two-pass electrofishing.

Second Electrofishing Population Estimates

Site	Population Estimate
182nd Street Dam	79 individuals (95% C.I. [27,130])
Twin Dams	14 individuals (95% C.I. [13,15])
Snuff Mill Dam	1 individual (95% C.I. N/A)

Table 5. Population estimates with confidence intervals calculated from the second round of two-pass electrofishing.

Second Electrofishing Population Densities

Site	Population Density
182nd Street	0.124 eels/m^2
Twin Dams	0.033 eels/m^2
Snuff Mill Dam	0.003 eels/m^2

Table 6. Population densities calculated from second round population estimates and sampling area sizes.

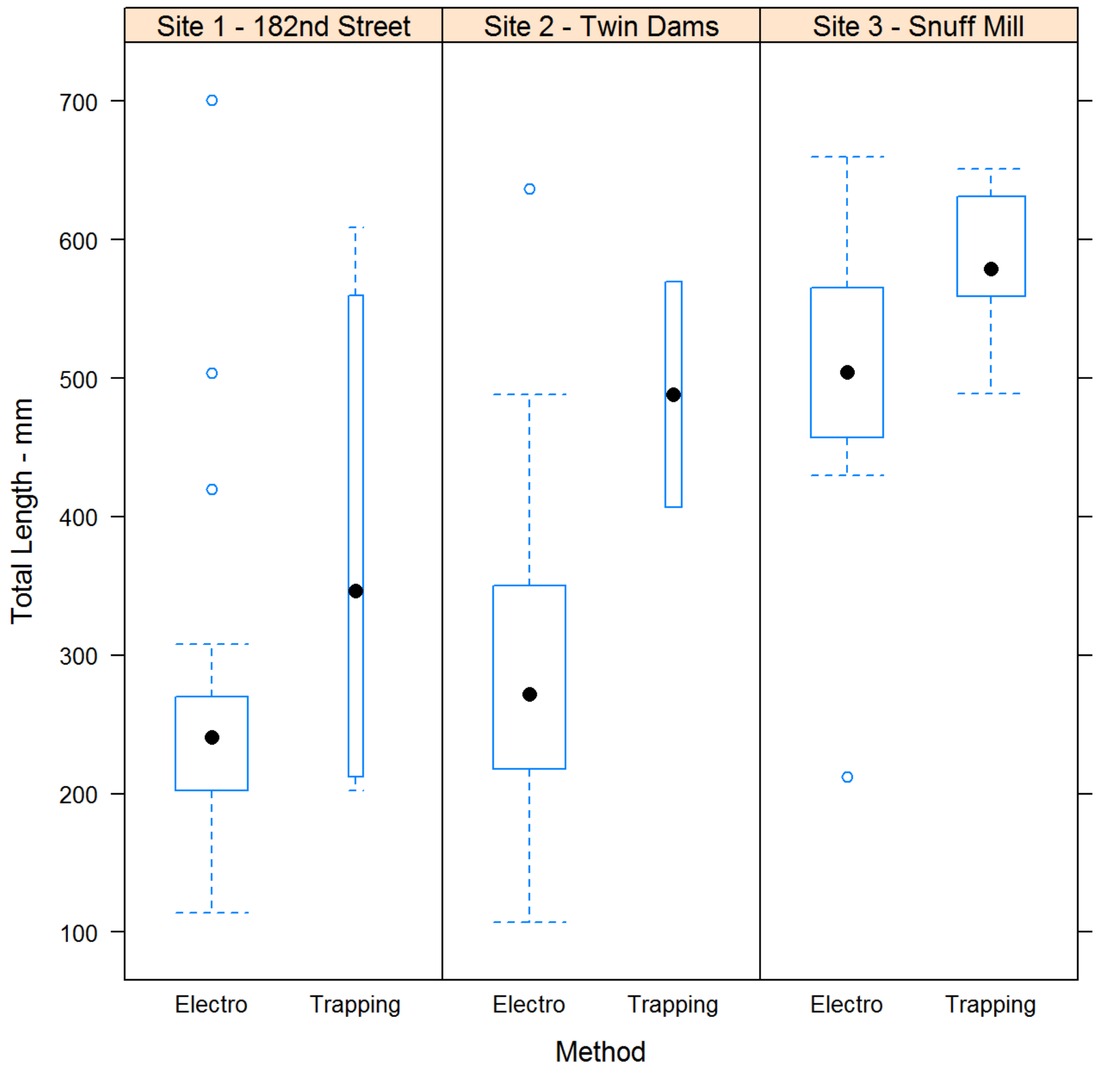

Figure 5. Box plots illustrating total length (mm) of American eel captured by trapping and electroshocking in the Bronx River, NY. Sample sites are ordered left to right from farthest downstream to farthest upstream. The dot represents sample median.

Sampling Type	Location	Min.	Q1	Median	Mean	Q3	Max.
Electrofishing	182nd Street	114	202	240	235.6	270	504
Trapping	182nd Street	202	238.8	346.5	379.3	513.5	609
Electrofishing	Twin Dams	107	220.8	272	292.3	350.2	637
Trapping	Twin Dams	407	447.8	488.5	488.5	529.2	570
Electrofishing	Snuff Mill	212	484	520	514.1	596	701
Trapping	Snuff Mill	489	559	579	585.6	631	651

Table 7. Size data (mm) of eels captured at each site via electrofishing and trapping.

DISCUSSION

As hypothesized, eel densities decreased along the upriver axis, and median eel lengths increased along the upriver axis. Eel populations along the upriver axis decreased from 0.212 to 0.650 to 0.040 eels/m^2 in the first round of electrofishing, and decreased from 0.124 to 0.033 to 0.003 eels/m^2 in the second round of electrofishing. While eel population density decreased from downstream sites to upstream sites, median eel length increased from 240 mm to 272 mm to 520 mm via electrofishing. Thus, the hypothesis could not be rejected. This means that with partial barriers in fresh waters, fewer eels are making it to upstream environments that would otherwise be more densely inhabited by this species. The life history of eels drives the species towards more upstream habitats; preventing eels from reaching these upstream habitats could result in reduced reproductive capacity of the species.

Bednarski et al. (2013) studied the effects of the removing two out of four dams on eel abundance in the Mill River system of Taunton, Massachusetts. Their study utilized mark-recapture analysis to calculate an estimate of total population size in preparation for these removals. Within Lake Sabbatia, the headwater impoundment of the Mill River system, eel population density was estimated between 0.75 and 2.21

eels/hectare compared to averages of approximately 215 eels/hectare at the most upstream site and 1680 eels/hectare at the most downstream site of the Bronx River. Eel population densities estimated at other locations include 182-232 eels/hectare in Fridaycap Creek, Georgia, 232-636 eels/hectare in Lake Champlain, Vermont, 875 eels/hectare in Sippewissett Marsh, Massachusetts, and 1-30 eels/hectare in the Hudson River, New York (Bednarski et al. 2013).

However, when comparing the data from these systems it must be taken into consideration that Lake Sabbatia, the other systems, and the Bronx River all differ in depth, flow rate, substrate composition, and overall structure. In addition, when comparing these population densities it is important to consider that the sampling method used in the Mill River, Sippewissett Marsh, and Fridaycap Creek systems consisted of trapping while the sampling method used to calculate population densities in the Bronx River consisted of electrofishing. Eel population density estimates in the Bronx River appear to be very high compared to other systems.

These high values may be attributed to the fact that sampling took place in areas directly following dams, the areas where eels tend to congregate. Dam removal in the Mill River system took place in 2012 and 2013, with more planned for the future, as well as the insertion of eel passes (Bednarski et al. 2013). With baseline data having been recorded, the effect of dam removal on eel abundance will be studied carefully in years to come. This research will serve a similar purpose, as baseline data for future studies. In a study conducted in headwater streams in Shenandoah National Park, Virginia, American eel demographics were estimated before and after the removal of a large dam located downstream (Hitt et al. 2012). Following the dam removal in 2004, eel abundances in headwater streams increased significantly. In addition, it was observed that eel abundances increased consistently from 2004 to 2010. Researchers also discovered that the minimum size of eels found in headwater streams had decreased following the dam removal. Significantly more eels measuring less than 300 mm in length were captured in headwater streams following the removal of dams, meaning that dams had previously been hindering smaller eels' ability to travel upstream to headwater streams (Hitt et al. 2012). This study showed that impediment of the river in the form of a dam is the primary factor effecting eel demographics, not predation, river structure, sediment type, or any other environmental factors.

In the Hudson River, researchers studied human impacts on eel populations in tributaries with a primary focus on dams (Machut et al. 2007). It was determined that eel population densities within tributaries are much greater than those found in the main river. Additionally, it was found that eel population densities in areas upstream of barriers were approximately a tenth of those in areas unimpeded by barriers, and the eels upstream of barriers had a smaller mass than those in unimpeded areas. Based on the size structure of eels captured in tributaries, it was hypothesized that tributaries are very important to the growth of immature American eels. Because of the important role American eels play in the balance of the food web and nutrient composition in rivers and tributaries, barrier removal as well as installation of eel ladders could help lessen the negative impacts of human interference in river systems and maintain biodiversity (Machut et al. 2007). Because tributaries tend to serve as "nurseries" for immature eels, and because eels play an important role in balancing food webs and nutrient compositions, providing eels with passage upstream of dams would likely help in the restoration of the Bronx River to a more natural condition.

With restorations taking place in other systems such as the Mill River and rivers in Shenandoah National Park, it is important to learn more about the success and impacts that these restorations are having on eel populations and the species overall. Protocols for dam removals and methods for constructing eel passes that have proven to be successful in other systems should be used as guidelines for future restorations in systems such as the Bronx River. The resulting eel population data from current restorations can also be used to determine which systems require the most immediate attention, so that the species as a whole can be recovered and its full range can be restored.

In future studies, using smaller tags would allow more eels to be tagged, generating a larger sample size for statistical analyses. In addition, more manpower would allow for more traps to be deployed at additional sites so that more data could be collected. Sampling the full river as opposed to just three small sections would provide a more comprehensive understanding of the eel population in the entire system. For example, while it is unclear whether or not eels tend to congregate in stretches of the river immediately below the dams, or inhabit full stretches between dams in equal densities, the former is more likely based on previous studies of eel populations in Hudson River tributaries (Machut et al. 2007). Electrofishing appears to be a much more efficient way to collect data than trapping because electrofishing takes away much of the chance involved in trapping; however, trapping is very useful in areas where electrofishing is not possible because of a lack of accessibility or water depth. In addition, trapping is easy to conduct with a minimum of two individuals whereas electrofishing requires a team of at least four.

Although a substantial effect of dams on eel demographics was not found, it was also noted that it is not apparent what the density and size distribution of eels would be in an undammed river of similar size. To better understand the effect of dams on eel population densities and sizes, these data collection methods must be repeated in a system similar to the Bronx River but without any barriers. The comparison of eel demographics in an unimpeded system and eel demographics in a heavily dammed river would reveal the extent at which dams inhibit the upriver movement of eels.

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