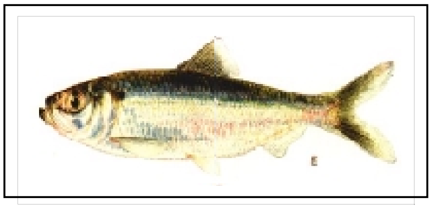

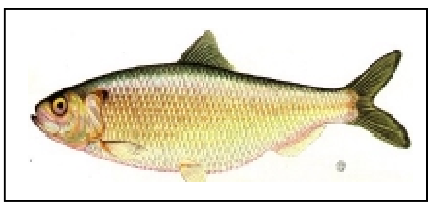

Phase 1 Final Report

Fish Passage Needs and Feasibility Assessment

March, 2004

City of New York
Parks and Recreation
Natural Resources Group

Phase 1 Final Report:

Fish Passage Needs and Feasibility Assessment

March, 2004

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the WCS-NOAA Regional Partnership Grant

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EXECUTIVE SUMMARY

In the Spring of 2003, the New York City Department of Parks and Recreation's Natural Resources Group (NRG) and Lehman College began work with support from the Wildlife Conservation Society (WCS) and the National Oceanic and Atmospheric Administration (NOAA) Regional Partnership Grant to study the feasibility of restoring diadromous fish to the Bronx River. Phase 1 of the study, which aimed to identify and evaluate the relative importance of factors that could limit diadromous fishes' access, spawning, and survival in the river, are reported here. The approach was to investigate historical fisheries and river conditions, assess existing fish conditions, and evaluate existing environmental factors. Alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), together known as river herring, were the focus of the study.

The historic review indicated that dams on the river had effectively cut off diadromous fish migration since the 1600s. The industries associated with the dams, including mills and bleacheries, probably resulted in high mortality or at least severely impacted much of the aquatic life found in the river. Today, however, anadromous species, such as striped bass and river herring are found at the mouth of the river, indicating suitable water quality. The water quality data collected also indicate that water temperature and suspended sediment concentrations are within an acceptable range for anadromous fish in freshwater and tidal reaches. Dissolved oxygen (DO) concentrations typically meet the requirements for anadromous fish, although occasionally values were below recommended thresholds during the summer or after storm events due to high combined sewer overflow. Low DO levels have not been reported to cause mortality in the system in recent years, and low levels would typically occur after adults have left, and while juveniles are leaving the river. In addition, the low values appear to be localized and transient, occurring in portions of the river with sufficient DO nearby that could serve as refugia.

Physical channel characteristics in the river indicate that even relatively steep reaches between dams are passable, and that suitable spawning and rearing habitat is available for both blueback herring and alewife. Based on information collected to date, we conclude that river herring could survive, reproduce, provide recruitment of a river population, and help increase faunal diversity in the river. Further, their reintroduction would fit well with the broader conservation and restoration goals for the river. To pursue their reintroduction, several steps are recommended and should be implemented in parallel. These include: working with the dam owners and other stakeholders to develop acceptable passage alternatives at the dams; implementing a fish stocking program to "jump start" river herring establishment in the river; and continuing to enhance habitat through local and watershed-wide water restoration measures.

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APPENDICES

Phase I Final Report: Fish Passage Needs and Feasibility Assessment

INTRODUCTION AND OBJECTIVES

The Bronx River in New York City is a quintessential urban river. It has been subjected to centuries of straightening, damming, armoring, industrial and domestic effluent and watershed development. Despite the ensuing ecological impacts, the river has come into focus recently as a historic and environmental resource, as many urban rivers have across the country. Over the past decade, efforts to reduce point and non-point source pollution, to protect remaining natural areas, to restore natural functions to degraded sites, and to expand community access and educational opportunities along the river have increased dramatically. Today several watershed-wide inter-organizational and -governmental efforts are underway to define restoration priorities, provide design and management recommendations, and articulate specific objectives and targets within the general ecological goals of conserving and establishing diverse native plant and animal communities in an urban watershed context.

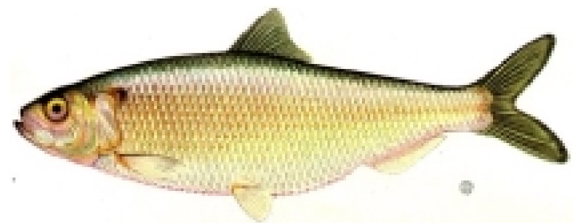
Since 2000, much of the funding for estuarine and diadromous fish habitat restoration, land acquisition and river access, and community-based environmental education has come from the National Oceanic and Atmospheric Administration (NOAA). NOAA, which has an emphasis on marine systems, expressed interest in developing a better understanding of the potential for the Bronx River to support diadromous fish – those fish that either migrate upstream to spawn in freshwater and return to the ocean for their adult lives (anadromous) or vice versa (catadromous). Anadromous fish, such as Atlantic salmon *(Salmo salar)*, American shad *(Alosa sapidissima)*, and river herring (alewife ***(Alosa pseudoharengus)*** and blueback herring ***(Alosa aestivalis)***) and catadromous fish such as the American eel *(Anguilla rostrata)* have an important place in the ecology and cultural history of Northeast rivers. These were key species in the fishing industry at one time and remain an important energy source throughout the food chain in the river systems where they flourish. Further, their populations vary in response to a range of environmental factors and processes, and thus their presence is one indication of ecological health. Today, populations of anadromous fish are drastically reduced from historic levels and continue to decline in many locations in the Northeast. The effort being made to reverse this trend focuses, in part, on protecting and expanding habitat for these species throughout their potential range.

In 2002, the New York City Department of Parks & Recreation's Natural Resources Group (NRG) and Lehman College received a Wildlife Conservation Society/NOAA Regional Partnership Grant to study the feasibility of restoring anadromous fish to the Bronx River. The study, which began in the winter of 2002, was divided into two Phases. The first phase aimed to examine the potential for anadromous fish to access, spawn, and survive in the river, and the second phase would develop passage design alternatives. In Phase I, NRG's objectives were as follows:

- Determine which anadromous fish species should be targeted for restoration.
- Identify and evaluate the potential factors that explain the absence of anadromous fish in the river including historic and existing fish presence, water quality, food supply, habitat quality and quantity, and blockages.
- Determine whether environmental conditions upstream of blockages are suitable for anadromous fish spawning and survival.
- Determine whether fish passage construction at dams is feasible, from a technical perspective.
- Make recommendations for fish habitat improvements in the river.

This report summarizes findings to date for Phase I of the study, discusses the potential ecological functions and interactions of anadromous fish, were they to return to the river today, and makes recommendations for further study and action.

Alewife (*Alosa pseudoharengus*)[1]



Blueback Herring (*Alosa aestivalis*)[2]

TARGET SPECIES AND LIFE HISTORIES

The Bronx River is one of the smaller of the major tributaries draining into the East River and Long Island Sound. Larger rivers, such as the Hudson and Connecticut, historically supported Atlantic salmon (*Salmo salar*) or American shad (*Alosa sapidissima*). Alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), two closely related species that are collectively known as river herring, typically occupy rivers the size of the Bronx River and smaller streams, thus they are the focus of this study.

Alewives begin their migrations from the ocean up freshwater rivers in the Northeast between mid-April and mid-May, depending on water temperatures, with blueback following several weeks later. Alewife and blueback tend to partition habitat; alewife typically spawn in ponds or slower-flowing sections of river, while blueback often occupy deep sections of faster flowing river reaches over hard substrate (Mullen *et al*. 1986, Loesch 1987). The eggs of both species are initially adhesive and then drift in the water column until they hatch in two to three days. Adults return to the ocean within days of spawning, while the larvae and early juveniles remain in freshwater. Seaward migration for juveniles is typically triggered by heavy rainfall and drops in temperature from late summer through fall. Juveniles and adults are typically found in coastal waters with varying depth. Adults typically reach spawning maturity in three to four years (Loesch 1987, Murdy *et al*. 1997) at which point they return to their natal rivers to spawn.

APPROACH

To identify and evaluate the potential factors that explain the absence of anadromous fish in the river, we sought historical river and fisheries information, gathered data on fish currently in the river system, and investigated environmental variables that impact river herring and their riverine habitat at various life stages. The critical environmental variables examined here included water quality (temperature, dissolved oxygen, suspended sediment, salinity and contaminants), flow conditions (return frequency, velocity and depth), and physical habitat conditions (substrate and channel bed morphology). Conceptual passage alternatives were also examined. The investigation focused on the lower two-thirds (13 miles) of the river, where flow and channel conditions were thought to be most favorable for anadromous fish re-establishment (Map 1).

[1] http://www.nmfs.noaa.gov/habitat/habitatprotection/anadromousfish_descriptions.htm
[2] http://www.dec.state.ny.us/website/dfwmr/fish/fishspecs/bluebackherring.gif

Historic Conditions

The historical extent and types of dams along the lower Bronx River were investigated to assess the past impacts upon the channel, water quality, and fish communities. Historic documents were sought at the Bronx Zoo Library, the City Municipal Archives, Westchester County Archives, the New York City Parks & Recreation Library, the Bronx Historical Society, New York State Department of Environmental Conservation (NYSDEC) Dam Safety records, and the Huntington Free Library- Library of the American Indians.

Present Extent of Fish

The present extent of fish was evaluated from data collected by Schmidt and Samaritan (1984), HydroQual, Inc. (2002), and Lehman College in 2002 and 2003 (Appendix A). From June 2002 until September 2003, Lehman College sampled by boat at the mouth of the river, and in tidal reaches to help identify which species are present in the river and approach the dams. Multiple freshwater stations were sampled upstream and downstream of the dams beginning in June 2002 (Appendix A). Sampling for fish prey items was conducted at all sites.

In the estuary, fish were caught using a 12-foot wide Shrimp Trawl with #9 (1 and 1/2 inch) stretch mesh body and #15 (1 and 1/4 inch) stretch mesh cod end bag, 3/8 inch by 100-foot length tow lines (to provide a 3:1 line out to depth ratio) and 12x24 inch doors run off the stern deck of the "Privateer", towed at an average speed of 2.0 knots between the mouth and Lafayette Avenue. Tows were run both up-river and down-river, when run down-river trawls were pulled at a velocity faster than the current velocity. Plankton and pelagic invertebrates were taken using a half-meter plankton net towed for 10 minutes at 2 knots, usually on the run from Lafayette towards the mouth. Cruise dates for 2002 were: June 10, 12, 24, and 26, July 8, 10, 12, 22 and 24, August 9 and 21, and September 4 and 25. For 2003, they were: February 13, 20 and 27, March 13, 20 and 27, April 3 and 10, May 28, June 11, 25 and 27, July 11, 25, 28 and 30. Shore sampling of fish and invertebrates involved the use of a 4x4 foot push seine, with 1/4 inch stretched nylon mesh, on the dates and locations specified in Appendix B and Appendix C. The net was set just offshore and fish were scared into it by people stomping in from the shore or the net was pushed through the near-shore vegetation and bank overhangs. In the lower estuary, a 4x10 foot seine was used. Here, the depth was four feet and a standard semicircular path to the shore was followed. Minnow traps were also used for near-shore sampling. These were placed randomly within the specified locations. Plankton were sampled from the shore using a small 10 cm square hand operated plankton net on the dates and times shown in Appendix C. Fish observations also provided indirect evidence of water quality conditions (Map 2).

Environmental Parameters

Water quality information was collected to help determine whether riverine conditions could support the various river herring life history stages. Known ranges of temperature, dissolved oxygen (DO), and total suspended solids indicate habitat suitability, while values outside the suggested range for river herring can cause physiological stress and mortality. Water quality was evaluated directly from field data collected during this study including:

- Routine sampling of temperature, DO, and salinity during biotic surveys by Lehman College in the Bronx River Estuary. (June - September, 2002) (Appendix A)
- Opportunistic grab samples after storm events and spectrophotometric analysis to determine total suspended solids by NRG. (June 2003) (Appendix D)

- Temperature and DO monitoring at six sites and a total of 23 samples between the 182nd Street Dam and the Snuff Mill Dam by NRG. (July 2003)

Water quality data collected by other agencies were also examined including:
- Toxicity and water quality data collected by HydroQual, Inc. for the NYCDEP's Use and Standards Attainment (USA) Project. (2000-2002) (HydroQual, Inc. 2002)
- Chemical data, including PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls), heavy metals, chlordanes, and dioxins in the water column at the New York Botanical Garden and the Bronx Zoo collected by the New York State Department of Environmental Conservation's Contamination Assessment and Reduction Project (CARP). (1998-1999) (NYSDEC 1999)
- Fecal coliform and other contaminants at six sites in Westchester County collected by the Westchester County Health Department. (April 2003) (Vassallo *et al*. 2003)
- Fecal coliform, suspended sediment, and petroleum hydrocarbon data in New York City and Westchester collected by the New York City Department of Environmental Protection (NYCDEP) Bureau of Wastewater Treatment Research. (NYCDEP 1999)
- DO, temperature, suspended sediment, and turbidity data published by Schmidt *et al*. (1981)
- DO and temperature data collected by volunteers of the Riverkeeper Program (Mankiewicz and Mankiewicz 1993, Gaia 2001, Bronx River Riverkeeper Program 1990,1991,2000)

Flow characteristics and channel geomorphology were examined to evaluate habitat suitability for river herring and to characterize passage obstacles. Channel width, depth, and reach length help determine how much habitat is available for what size fish. Velocity and channel slope affect fish passage and spawning. Substrate and in-stream structures influence flow velocity, high-flow refuge, spawning habitat, and egg survival and retention in the system. Flow range was assessed to evaluate flow conditions and relate them to fishway passage and potential operational periods for fishways.

Flow data were obtained from the U.S. Geological Survey (USGS) Bronxville gauge for the period 1944 to 1989. Return frequency analyses were performed for the entire peak flow data set and for a post-1968 data set for comparison of results. The flows were fit to a Log Pearson Type 3 distribution to develop return frequency flows. Additional flow information came from a water depth sensor installed by NRG at the Burke Ave Bridge in 2002, from discharge measurements by NRG and the USGS at the Burke Ave Bridge, and by the USGS in Bronxville beginning in May 2003. This depth sensor and discharge data were used to obtain a stage versus discharge measurement relationship that was used to predict discharge and velocity from the depth data. Velocity and water surface height information was also calculated for the mile upstream of the Snuff Mill Dam from a HEC-RAS (Hydrologic Engineering Center River Analysis System) water surface profile model. At specific reaches where flow data were not available, average cross-sectional velocities were calculated from the channel slope and flow area using Manning's equation:

$$V = [\ (A/P)^{2/3} \times S^{1/2}\ ] / n$$

A = cross-sectional area
P = wetted perimeter
S = water surface slope
n = roughness coefficient (assume 0.04 for cobble-beds)

Physical channel information was obtained through field inspections and surveying, and from aerial photographs in existing reports. Channel slope, reach length, and dam height were measured from channel longitudinal profiles published in Federal Emergency Management Agency

(FEMA) flood insurance studies (Appendix E). Representative channel cross-sections and longitudinal profiles were surveyed at West Farms and downstream of the Snuff Mill Dam (Appendix F) Channel geometry and flow modeling data for the mile upstream of the Snuff Mill Dam were taken from a water surface profile model (HEC-RAS) prepared by Interfluve, Inc. Channel width and area were measured from 1996 scaled digital orthophotos of NYC. Dominant substrate grain size was estimated both visually and by pebble count methods (Wolman 1954, Harrelson *et al*. 1994), and categorized into dominant or sub-dominant size classes (silt, sand, gravel, cobble, or boulder) in most reaches.

RESULTS & DISCUSSION

Historical dams and river conditions

Prior to European settlement (ca. 1600s) natural obstructions due to beaver activity or fallen trees were probably frequent along the Bronx River, as in most Northeastern forested river systems. These blockages may have barred fish from passing at times, but were dynamic features in the river. No documentation of bedrock falls (i.e. hydraulic jumps or controls) that might have historically precluded diadromous fish passage has been found.

Human-made dams were prevalent on the river after European settlement (Table 1) – as many as four were located between the 182nd Street Dam and the Snuff Mill Dam at one time (Bronx Valley Sewer Commission 1896). The mill and textile bleaching industries associated with the numerous dams along the river severely impaired water quality, probably killing much of the aquatic life and deterring fish from migrating upstream. Anadromous fish species have likely been prevented from naturally reaching the freshwater reaches in the Bronx River for several hundred years.

Table 1. Summary of Dam History for the lower Bronx River

Approx. Time	Location	Notes/Reference
Prior to 1600s	Freshwater reaches	Beaver dams (Frankel 1979)
1639	182nd Street	Dam built at 182nd Street (Bolton 1948)
Early 1840s	New York Botanical Garden	Snuff Mill Dam built (Hermalyn 1982)
Early 1840s	Bronx Zoo	Bronx Zoo Dam built (Hermalyn 1982)
Late 1880s	177th Street	Drew Gardens Dam built (Comfort 1906)
Late 1880s	Bronx Park	Many dams removed (Comfort 1906)
1896	Between 182nd St. and Kazimiroff Blvd.	Four dams listed (Bronx Valley Sewer Commission 1896)
1896	Westchester	Seven dams listed (Bronx Valley Sewer Commission 1896)
1910	182nd Street	Dam repair and addition of "cascade" (NYZS 1910)

Historic and present fish communities

No historical evidence of the presence of an anadromous fish run in the Bronx River prior to the construction of the first dams in the 1600s was found. Since pre-colonial documents are relatively scarce, and a pre-colonial fish run may not have been recognized as significant commercial value, one should not conclude this lack of information as evidence that river herring never occupied the river. The historic data is inconclusive with respect to the presence of river herring, but given that river herring are currently or have historically been found in nearby river systems, such as the Hutchinson, the Mianus, and the Croton, we can deduce that the Bronx River also supported these fish.

A survey of fish at 16 stations along the entire freshwater length of the Bronx River in 1982 showed an assemblage typical of an urban stream (Schmidt and Samaritan 1984). Several species found in other Westchester streams were not found in the Bronx River. The study found relatively pollution tolerant species had the widest distribution: the mummichog (*Fundulus heteroclitus*), American eel (*Anguilla rostrata*), and tessellated darter (*Etheostoma olmstedi*).

Much more recently, freshwater sampling by Lehman College at four stations in the lower portion of the river and one in Westchester indicated much of the same, pollutant-tolerant fish assemblage (Table 2). The most widely distributed freshwater species found were the mummichog, four-spine stickleback (*Apeltes quadracus*), and tesselated darter (*Etheostoma olmstedi*). Compared to 1984, three additional species were caught, and eight species were not found in 2003. Most of those found only in 1984, however, had been rare and only two had been common: goldfish (a non-native species) and the red breast sunfish. Lehman College also found that the tidal portion of the Bronx River supports catadromous (breeding in the ocean and maturing in freshwater) eel– a population that was also found throughout the Bronx River in the 1980s (Schmidt and Samaritan 1984).

Table 2. Distribution and number of fish sampled on the Bronx River 2002, 2003 by Lehman College (also see Map 2, Appendix A).

		Number of fish sampled by river station #							
Genus Species	Common Name	1*	2*	3	4	5	6	7	8
Alosa aestivalis	Blueback herring	1	0	0	0	0	0	0	0
Alosa mediocris	Hickory shad	1	0	0	0	0	0	0	0
Anchoa mitchelli	Bay anchovy	291	0	0	0	0	0	0	0
Anguilla rostrata	American eel	0	0	17	1	0	0	0	0
Apeltes quadracus	Fourspine stickleback	0	1	1	52	10	26	6	0
Brevoortia tyrannus	Atlantic menhaden	12	215	0	0	0	0	0	0
Catostomus commersoni	White sucker	0	0	1	0	0	42	0	24
Dorosoma cepedianum	Gizzard shad	2	0	0	0	0	0	0	0
Etheostoma olmstedi	Tesselated darter	0	0	12	3	16	2	18	46
Etheostoma sp.	Unknown darter	0	0	0	0	0	2	0	6
Fundulus heteroclitus	Mummichog	2	54	16	1	0	7	22	1
Gobiosoma bosci	Naked goby	0	8	0	0	0	0	0	0
Lepomis macrochirus	Bluegill sunfish	0	0	0	0	0	3	0	1
Menidia menidia	Atlantic silverside	4	37	0	0	0	0	0	0
Micropterus dolomieui	Smallmouth bass	0	0	0	0	1	0	0	0
Morone saxatilis	Striped bass	49	4	0	0	0	0	0	0
Myxocephalus scorpius	Shorthorn sculpin	2	1	0	0	0	0	0	0
Notemigonus crysoleucas	Golden shiner	0	0	0	0	0	0	0	4
Notropis cornutus	Common shiner	0	0	0	0	0	0	0	1
Peprilus triacanthus	Butterfish	3	0	0	0	0	0	0	0
Pseudopleuronectes americanus	Winter flounder	16	0	0	0	0	0	0	0
Rhinichthys atratulus	Blacknose dace	0	0	1	0	2	5	10	53
Urophycis regia	Spotted hake	11	0	0	0	0	0	0	0

* These stations are in the estuary and were not sampled by Schmidt (1984).

Key to Table 2

Sampling Station #	Station Name (See Map 2)	
1	Soundview	} estuary: trawl between these points
2	Lafayette Avenue	
3	Drew Gardens	} tidal channel
4	Tremont Ave	
5	River Park	← First dam
6	Bronx Zoo (Downstream of dam)	
7	Snuff Mill bridge area	
8	Yonkers	

The recent fish sampling in the estuary by Lehman College and HydroQual (2002) also found river herring in the estuarine sections of the Bronx River, suggesting that river herring may already make some use of the Bronx River. Blueback herring were found at the mouth (Table 2 and 3) and herring eggs and larvae (not identified to species) were found at the mouth of the river and approximately 1.5 miles upstream (Table 3). Several other estuarine species also migrate into the Bronx River, including blue crab (*Callinectes sapidus*) as far north as the 182nd Street Dam, and striped bass (*Morone saxatilis*), which were regularly sampled in the tidal reaches, and have been reported within several hundred feet below the 182nd Street Dam. In total, Lehman College collected twenty-two fish species in the Bronx River estuary (Appendix A). In 2003, anadromous fish species migrations into the Bronx River estuary were later than expected. The delay in migrating fish was observed throughout the western end of Long Island Sound and the East River. This may have been due to a combination of an unusually cold spring resulting in cooler water temperatures in the estuary, and the extensive dredging in the East River, near the mouth of the Bronx River. Subtidal dredging in the East River, to lay a high pressure gas-line to Hunts Point, has been ongoing in the winter months since 2002.

Table 3. Fish findings in the Bronx River estuary (HydroQual, Inc. 2002)

		Number of fish sampled by river station No.*		
Genus Species	Common Name	1 (fish)	1 (eggs & larvae)	2 (eggs & larvae)
Alosa aestivalis	Blueback herring	223	0	0
Alosa sp.	Herring	0	244	244
Anchoa mitchelli	Bay anchovy	76	14	184
***Brevoortia smithi*	Yellowfin menhaden	2	0	0
Brevoortia tyrannus	Atlantic menhaden	20	0	202
Clupea harengus	Atlantic herring	6	0	0
Cynoscion regalis	Weakfish	544	6	0
Enchelyopus cimbrius	Fourbeard rockling	0	3758	8
Family Gobiidae	True gobies	0	2	150
Hyspoblennius hentzi	Feather blenny	0		12
Morone saxatilis	Striped bass	35	0	0
Paralichthyus dentatus	Summer flounder	3	0	0
Pomatomus saltatrix	Bluefish	14	0	0
Prepilus triachanthus	Butterfish	22	0	0
Prionotus evolans	Striped searobin	1	0	0
***Prionotus scitulus*	Leopard searobin	1	0	0
Prionotus sp.	North American searobin	1	0	2
Pseudopleuronectes americanus	Winter flounder	7	64	0
Scophthalmus aquosus	Windowpane flounder	0	146	20
Stenotomus chrysops	Scup	2	0	2
Syngnathus fuscus	Northern pipefish	0	0	2
Tautoga onitis	Tautog	0	240	566
Tautogolabrus adspersus	Cunner	6	1470	438

* See Appendix G: River station 1 = BRNXF01 (fish) and BRNXI02 (eggs and larvae) at mouth; station 2 = BRNXI01 1.5 miles upstream of the mouth.

** Suspect fish misidentification. *Brevoortia smithi*'s range extends from Florida to North Carolina and *Prionotus scitulus*'s range extends from Florida to Virginia.

Plankton sampling conducted by Lehman College in 2002 and 2003 (Appendix C) showed that abundant food is available in the water column at the mouth of the river to support the predominantly planktivorous juvenile herring as well as migrating adults. A suggested minimum of 100 zooplankton per liter as a suitability index for juveniles (Pardue 1983) is exceeded by an order of magnitude. Adult herring also feed on insects, insect eggs, and plankton, although typically not on benthic organisms (Bozeman and Van der Avyle 1989). Freshwater benthic samples from 2001 and 2002 include diptera, on which juvenile herring feed, and caddisflies and amphipods, on which adult river herring prey (Bozeman and Van der Avyle 1989, NRG 2003)

Environmental Parameters

Water quality

Dissolved oxygen

Dissolved oxygen (DO) concentrations under 5 mg/L are considered stressful to adult fish (Stier and Crance 1985) and concentrations under 3 mg/L are considered stressful to juveniles (Loesch 1987). More recent studies have shown lethal effects in saltwater at DO concentrations under 2.3 mg/L in the lab and as low as 2 mg/L in the field (U.S. EPA 2000). Throughout the Bronx River, DO concentrations can dip significantly below 5 mg/L and occasionally below 3 mg/L. Low DO events typically occur from mid-July to August when water temperature exceeds 20^{o}C. (Figure 1). However, DO levels do not drop to stressful levels during every high temperature event. Furthermore, in an atypically wet and cool spring and summer, as seen in 2003, this pattern changes. Drops in DO levels were found in the estuary during the months of May and June when repeated storm events caused high combined sewer overflow (CSO) discharges (Joe Rachlin, pers. comm.). In contrast, typical drops in DO were not observed during the mild summer temperatures of 2003 (minimum sampled DO was 5.8 mg/L). The typical dips in summer dissolved oxygen concentrations do not pose a threat to spawners that will leave before the summer when DO may become a problem, but could be a threat to juveniles of both alewife and blueback. Since low DO may be local (at CSO's and in shallow impoundments) and transient in nature, these low DO pockets could potentially be avoided by the juveniles. Fecal coliform levels are not directly linked to fish survival, but can negatively affect dissolved oxygen concentrations. Fecal coliform levels are extremely variable and have been recorded from 2 MPN/100ml to an anomalously high level of 308,500 MPN/100ml (NYCDEP 1999, Vassallo and Harrison 2003) with a mean of 612 MPN/100ml in the sampling done in 2000 (Hydroqual 2002).

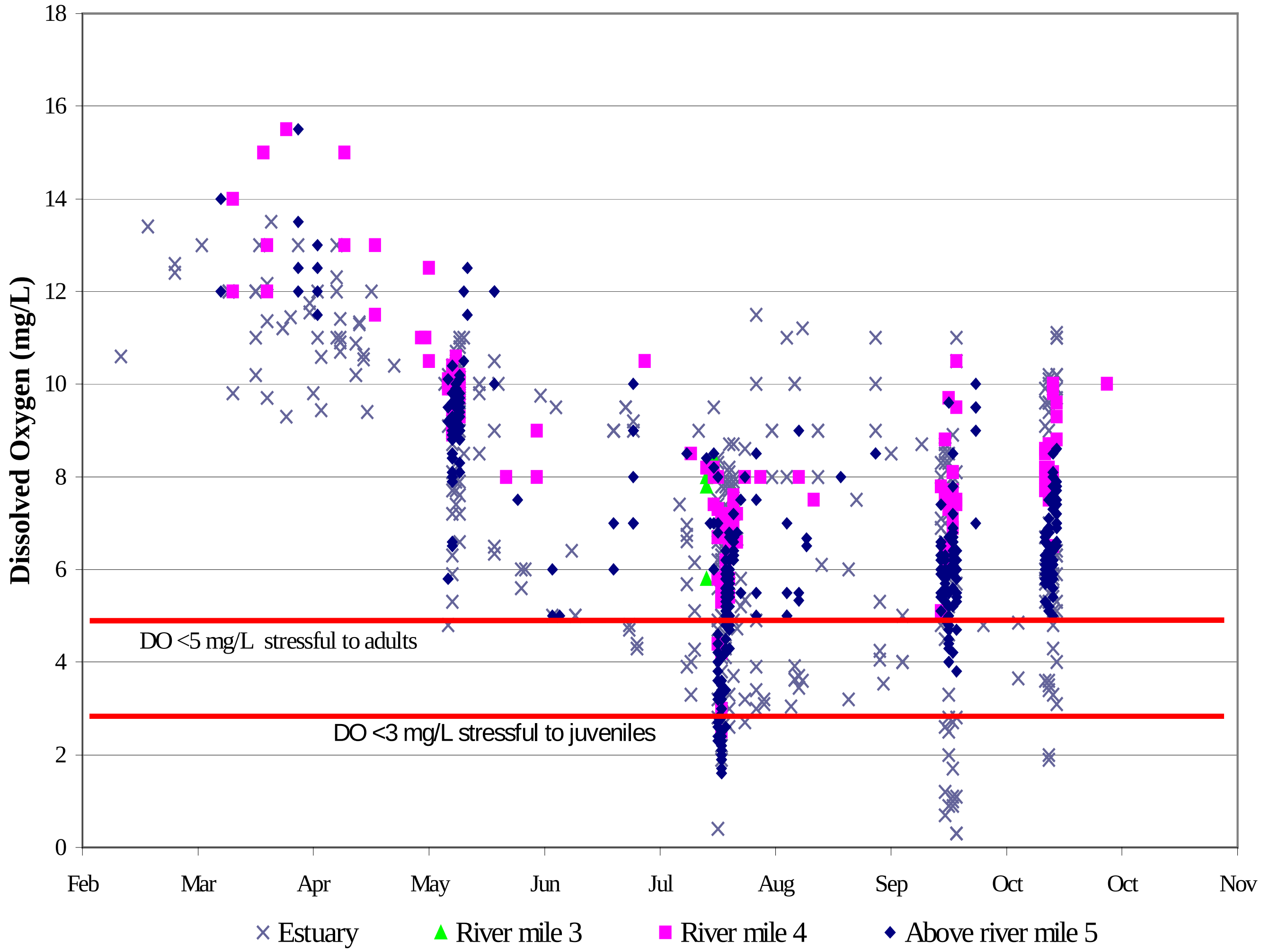


Figure 1. Bronx River Dissolved Oxygen Data. Data compiled from 2002-2003 NRG/Lehman data, 2000-2002 HydroQual study (HydroQual 2002), 1988-1989 LMS study (Lawler 1991), 2000 & 1990-1993 Bronx River Restoration volunteer monitoring (Mankiewicz and Mankiewicz1993, Bronx River Riverkeeper Program 1990,1991,2000), and 2001 Gaia study (Gaia 2001). See Stier 1985 for adult and Loesch 1987 for juvenile river herring habitat suitability values. When depth data was available, we used the DO measurements taken at one foot below the water's surface.

Temperature

Alewife and blueback can spawn at a maximum temperature of 27°C (optimal is 15-20°C for alewife and 20-24°C for blueback) (Pardue 1983). Juvenile alewife and blueback can survive at maximum temperatures of 30°C (optimal is 15-20°C) and 35°C (optimal is 20-30°C), respectively (Loesch 1969, Edsall 1970, Pardue 1983). Bronx River water temperatures have been recorded between 27°C and 30°C but only during the summer when spawning does not occur[3] (Figure 2). Therefore, though sometimes stressful, water temperature does not seem to be limiting for fish spawning or survival.

[3] Of 23 samples collected the summer of 2003, the maximum recorded water temperature was 24.5°C and the average was 21.7°C.

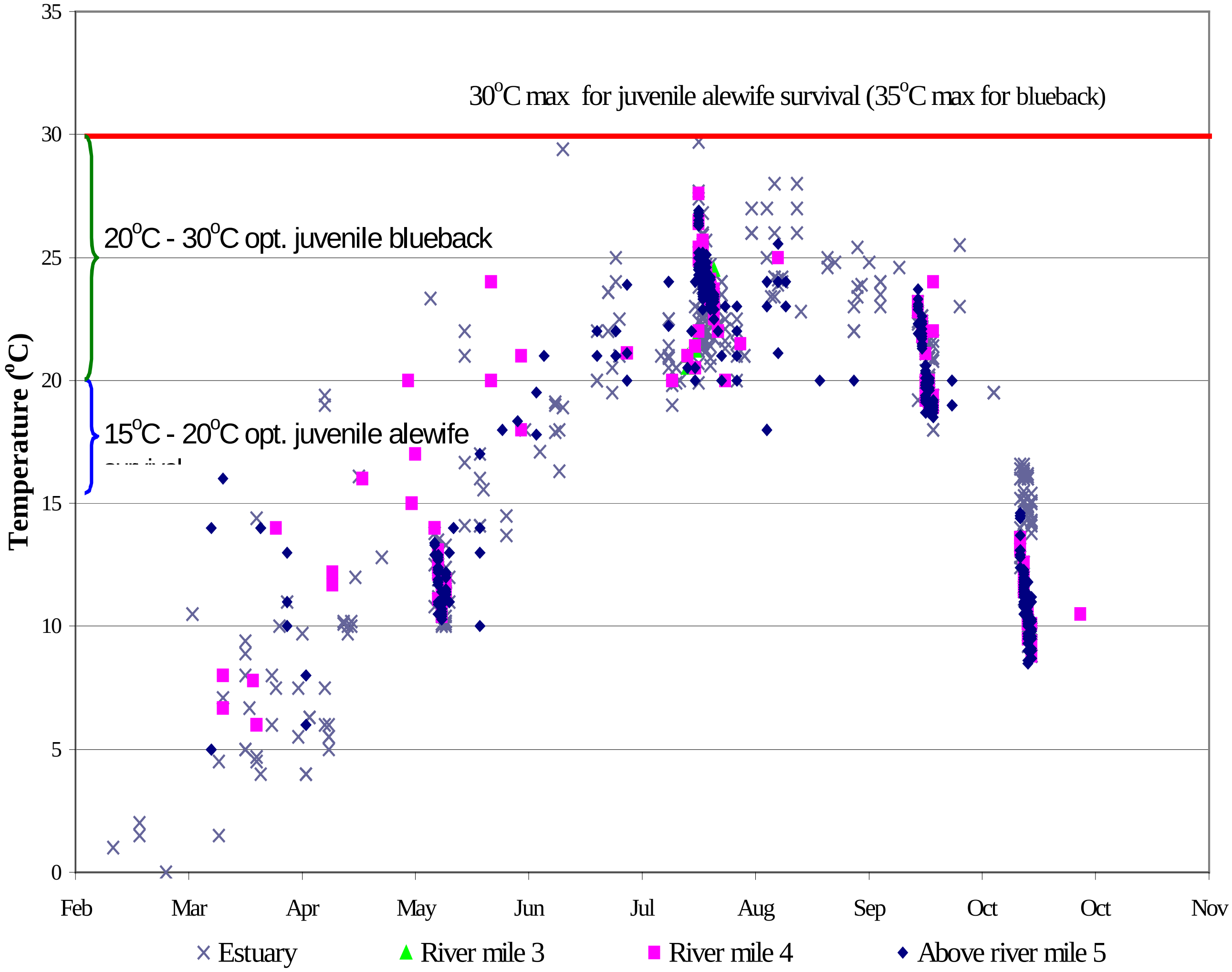


Figure 2. Bronx River Temperature Data. Data compiled from 2002-2003 NRG/Lehman data, 2000-2002 HydroQual study (HydroQual 2002), 1988-1989 LMS study (Lawler 1991), 2000, 1990-1993 Bronx River Restoration volunteer monitoring (Mankiewicz and Mankiewicz 1993, Bronx River Riverkeeper Program 1990,1991,2000), and 2001 Gaia study (Gaia 2001). See Pardue 1983 for habitat

Suspended Sediment

American shad, the least tolerant of the Alosids, have a threshold for suspended sediment of 100ppm (Stier and Crance.1985). The maximum total suspended solid concentration measured during 2003 summer storm events between the 182nd Street Dam and the Snuff Mill Dam was 27ppm. The highest suspended sediment load found throughout the river in 1981 was 38.5mg/L, also within the suitable range (Schmidt *et al*. 1981). In 1999, New York City Department of Environmental Protection (DEP) found most suspended sediment values under 10mg/L. There were several samples taken in Westchester that were over 100mg/L; these high values were probably the result of proximity to CSOs (Jennifer King, pers. comm.). Though pulses are common in urban watersheds, suspended sediment values in the Bronx River apparently do not usually exceed threshold levels, and we assume that during short periods of high suspended sediment load fish will be able to find refuge.

Salinity

Salinity can be a limiting variable for the fitness of river herring larvae and young juveniles, before the fall migration. Optimal salinity values are below 5 ppt but the young fish can tolerate values up to 12 ppt (Pardue 1983). The highest salinity value measured in the freshwater portion of the river was 1.5 ppt 5.5 miles upstream of the mouth in July (Rachlin 2003, Lawler 1991). The zone of tidal influence on the Bronx River extends up to 179th Street, leaving an approximately 500 foot freshwater section downstream of the 182nd Street Dam. Salinity values within the range suitable for young fish extend past the West Farms section where average values were measured at 0.33 ppt and the maximum measured was 5.2 ppt (Lawler 1991). Downstream, between Bruckner Boulevard and the Cross Bronx Expressway, values can reach as high as 25.7 ppt (Lawler 1991), precluding successful rearing. Since we have not found anadromous fish spawning below the first dam, we have assumed that another variable, not salinity, must be limiting in this section. Less than optimal channel characteristics and habitat quantity downstream of the 182nd Street dam might contribute to the absence of spawning herring there; also see Plane-bed reach section on page 16.

Contaminants

Contaminants in the water column, such as heavy metals and PAHs, have been linked to tumors and lesions in fish in various studies (for example, Baumann *et al*. 1996, Fong *et al*. 1993). The applicability of these findings to anadromous fish that stay in the river system for only a few months, however, has yet to be evaluated. A study measuring hazardous chemical concentrations in fish tissues found much lower levels in anadromous than resident fish (U.S. EPA 2002 (August)). These results suggest freshwater contaminant criteria limits for anadromous fish must be higher than limits for resident aquatic life, probably due to shorter residence time in the system. The average concentrations of heavy metals (cadmium, lead, and mercury) in Bronx River water samples (NYSDEC 1999) are about an order of magnitude below the concentrations to which an entire aquatic community can be exposed indefinitely without resulting in an unacceptable affect (U.S. EPA 2002). PAH and PCB concentrations for which we have data (NYSDEC 1999) are also below aquatic life criteria limits except the PAHs benzo(a)pyrene and pyrene which exceed criteria (Ministry of Environment, Lands and Parks 1993, U.S. EPA 2002).

All criteria linking sediment contamination to aquatic life toxicity are consensus-based and their reliability has been questioned. (e.g. Lee and Jones-Lee 2003). Also, the sediment data we have obtained may not be representative of the river as a whole since it is from the remediation site of an abandoned gas manufacturing plant located in the estuarine portion of the river (GEI Consultants, Inc. 2002). Nonetheless, according to an NYSDEC-determined threshold, some samples of the following substances exceeded a value above which a majority of benthic species would be adversely affected: Cu, Fe, Pb, Hg, Ni, Ag, and Zn. Additional substances exceeding NYSDEC criteria above which some sensitive benthic species would be adversely affected were Sb, As, Cd, Cr, and Mn (GEI Consultants, Inc. 2002). According to Long and Morgan's ERM criteria some samples of the following exceeded the concentration above which toxic effects are probable: Pb, Hg, Ni, Zn; none of the PAH's exceeded criteria (Long and Morgan 1991). According to MacDonald's Consensus-Based PEC criteria some samples of the following exceeded concentrations above which harmful effects are likely to be observed: Cd, Cu, Pb, Hg, Ni, Zn; none of the PAH's exceeded criteria (MacDonald *et al.* 2000). Since these values are unlikely to be representative of the river as a whole their validity for this study is minimal. We would recommend taking more representative sediment samples in the future.

Toxicity tests on organisms have classified the Bronx River as "not toxic" (GLEC 2000) and the fish and invertebrate community present in the river supports this claim. The continuation of river herring runs in the historically highly polluted Hudson system also suggests that anadromous fish would tolerate the current level of water quality contamination in the Bronx River.

Benthic and fish indicators

Benthic macro-invertebrate sampling in the Bronx River, primarily in Westchester, indicates moderately impacted water quality conditions, despite suitable water quality conditions for trout and the presence of pollution intolerant species in some reaches (Olson 1997, NYSDEC 1998). Brown trout has been stocked in the upper Bronx River as recently as 2002 (NYSDEC 2002), however the program was stopped in part due to suspicions (no specific data was considered) of poor water quality (Melissa Cohen, pers. comm.). Brown trout is considered in some urban areas as a pollution intolerant species, however, while river herring are not (NJSDEP 2000). Schmidt and Samaritan (1984) suggest that the high sediment load and disturbed channel, which is evident today in upstream depositional reaches, contributed to the disturbance-tolerant benthic invertebrate population.

The presence of adult herring and herring eggs and larvae in the tidal sections of the Bronx River indicates that the existing water quality can support these anadromous fish, despite seasonally sub-optimal dissolved oxygen (DO) and temperature values (NYSDEC 1998). Most of the fish seen frequently in the river are relatively pollution-tolerant - not surprisingly, given the centuries of pollution of the river and the degree of urbanization of the watershed. As point sources of pollution continue to be eliminated, however, Bronx River water quality is continually improving. Even in 1981, water quality data collected in Westchester indicated temperature, DO, and suspended sediment levels predominantly within appropriate ranges for anadromous fish, with the exception of low DO levels at a raw sewage effluent around 234th Street in the Bronx (Schmidt *et al*. 1981). Today, DO levels continue to present a concern at CSO's and in shallow impoundments. These problems are the focus of municipal, state, and interagency efforts to improve water quality[4].

Flow

To evaluate passage opportunities and constraints, we looked at the average discharge during April and May, the time herring typically migrate upstream in adjacent river systems. Discharge has historically averaged about 60 cubic feet per second (cfs) in Bronxville (river mile 10.5) during April and May (Figure 3a). At the Burke Avenue Bridge in Bronx Forest Park (river mile 5.5), the average was about 80 cfs based on an increase in drainage area from 26.5 to 34.5 square miles (Figure 3a, Map 2). Flow velocity was obtained by determining the relationship between USGS cross-section velocity measurements and discharge (Figure 4, 5a, 5b). We used this relationship to calculate historic average velocities during April and May.

Flow is generally too fast for spawning at the Bronxville site (Figure 3b), assuming optimal flow velocity is < 1 ft/sec (Pardue 1983). These flow velocities do not pose a problem for migration, but could readily flush eggs and larvae downstream. Where high flow velocities are associated with steeper channels slopes and cobble and boulder substrate, however, backwater associated with scour or plunge pools may produce conditions suitable for spawning, as discussed below (Steve Gephard, pers. comm.). At the Burke Ave site, and in similar reaches, flow would typically also be faster than ideal for spawning. As the single year of data at the Burke Ave Bridge shows (see 2003 data Figure 3b), however, velocities can be less than 1 ft/s between storm events. These average spring flow conditions pose no obstacle for migration, but would tend to flush eggs and larvae downstream if no obstacles are present in the channel to trap them.

[4] These efforts include the Westchester Bronx River Watershed Advisory Committee (WAC 7), the NYCDEP's Use Standards Attainment Study, and the Attorney General's efforts to halt illegal discharges to the river.

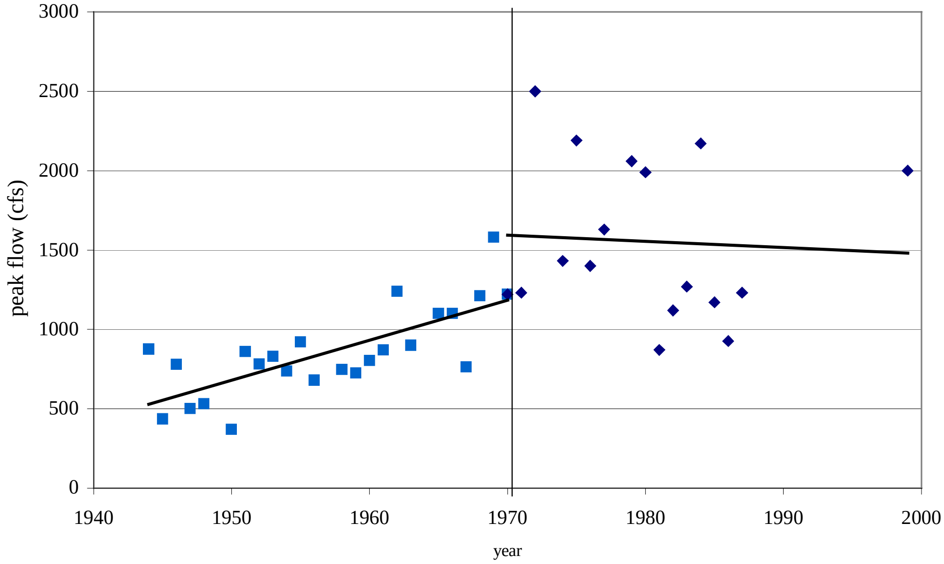


Figure 6. Peak Discharges on the Bronx River at Bronville

Flood flow magnitude has increased over time: the effect of storms on an urbanized landscape is to make floods larger (Table 4, Figure 6), but shorter in duration. Thus, flow conditions during storm events, are more likely to flush eggs and larvae downstream than in pre-development periods.

Table 4. Return Frequency Flows

Recurrence Intervals (years)	2	5	10	50	100
Flows (cfs) (1944 - 1989 + 1999 data set)	1,022	1,481	2,201	2,510	2,824
Flows (cfs) (1969 - 1989 + 1999 data set)	1,436	1,870	2,455	2,679	2,893

Available average daily flow and the associated velocity data provide a general perspective of the conditions that fish will experience at these locations in the river. More quantitative sampling is needed at potential spawning sites within specific reaches to estimate the potential total area of spawning habitat. Some local velocity conditions by reach type are described below.

Channel geomorphology

Channel habitat must meet at least four different life-stage needs (adult, eggs, larvae, juvenile) for fish, allowing upstream and downstream passage, providing appropriate spawning substrate and depth, providing foraging and rearing habitat, and providing cover and refuge from predators and high flows. The three dominant channel types in the freshwater reaches of the Bronx River (Map 3) are discussed below in terms of these habitat requirements. Each type is distinguished largely based on slope, substrate type (after Montgomery and Buffington 1993), as well as channel cross-sectional geometry (after Rosgen 1996, see Appendix H). The first channel type is the impoundment, a pond-like area of slow-moving water backed up behind a dam. The second is the dune-ripple channel type (C or F channel after Rosgen 1996), characterized by very low slopes (less than 0.1%) and a predominantly sandy substrate. The third is the plane-bed (B or F channel after Rosgen 1996), the steepest reach type (slopes 0.5 % or greater), with cobble and boulder substrate and fast-flow. In Westchester, there are also channel reaches with slopes greater than the dune-ripple reaches, but less steep than plane-bed channels. These riffle-pool reaches have not yet been mapped, and are probably not as extensive as the other channel types. Channel straightening, bank armoring, dumping of riprap and rubble in the channel, disturbed hydrology, and installation of dams complicates the application of traditional channel classification systems to the Bronx River. The total channel area occupied by the plane-bed reach type is six acres, by the dune-ripple reach type is 17 acres, and by the impoundment reach type is 31 acres.

Impounded reaches

The largest impoundment, upstream of the 182nd Street Dam, is approximately 12 acres (0.8 miles long, and 100 ft wide, Table 5). The middle-third of the impoundment is a depositional, sand-bedded reach less than one foot deep. In the downstream one-third of the channel, depths range from two to six feet, and the substrate is fine and unconsolidated. The upstream one-third of the impoundment is similarly deep, and transitions into a gravel- and cobble-bed, ideal for blueback herring spawning, towards the base of the Bronx Zoo Dam (Steve Gephard, pers. comm.). The impoundment upstream of the Bronx Zoo Dam is approximately three acres, with depths ranging from two to five feet and similarly fine and unconsolidated substrate. The Snuff Mill Dam retains an area of less than two acres and no wider than the average free-flowing channel width. About seven miles upstream, the two largest impoundments on the Bronx River in Westchester are less than 14 acres total, with maximum depths of less than two feet, and fine, unconsolidated sediment.

Typically, slow-flowing, deep, pond-like impoundments with vegetated banks or aquatic vegetation provide spawning and rearing habitat preferred by alewife, and can provide refuge from bird predation and high flows for both species of river herring. The lowest two impoundments in the Bronx River offer these habitat characteristics. The upstream impoundments, particularly in Westchester, are probably too shallow to provide optimal spawning and rearing habitat. The very fine material deposited in the impoundments is also not ideal substrate for spawning, although the criteria for suitable substrate was not precise in the literature (Pardue 1983, Loesch and Lund 1977). Most of the impoundments, however, provide high-flow refuge along their shores, particularly where vegetation or other roughness features are found.

Dune-ripple reaches (Rosgen C5 and F5 channel types)

The freshwater reaches, particularly in the northern Bronx and southern Westchester, are dominated by the dune-ripple reach type, characterized by low slopes, a wide width to depth ratio, and a mostly sand and small gravel-bedded channel. These reaches fluctuate between having some floodplain (C5-type, only slightly entrenched) and being highly confined or entrenched with little or no floodplain (F5, see Appendix H). Relatively short (50-200 feet-long) cobble- and boulder-bedded sections are also found within these dune-ripple reaches, particularly around bridges or where riprap has been deposited. Low summer base flow in these reaches, reduce depths to much less than 1 foot, making even canoe navigation difficult at times. Calculated velocities from April to May (during upstream fish migration) are typically around one foot per second (Figures 5a,b and 3a, b). Flows are significantly faster at channel constrictions near bridge crossings, for example near the Bronxville gage station.

The dune-ripple reaches have the potential to provide forage and rearing habitat for both alewife and blueback. Flows are not fast enough to present a barrier to upstream migration, and herring could easily pass through or reside in them most of the season. Measured and modeled flow velocities during the spring, however, frequently exceed Pardue's (1983) suggested range for spawning of less than one foot per second (e.g. Figure 3b, 7, Appendix I). The flow modeled at the Bronx River Forest, for example (Figure 7) show that for flows of greater than 200 cfs average channel cross-section velocity is greater than 1 ft/sec. Point velocity measurements taken at various locations across the channel in the dune-ripple reach type in the Bronx and lower Westchester at approximately 350 cfs show that there was relatively little channel habitat area with velocities of less than one foot per second. Pools provide cover and high flow refuge in these reaches, although pools are relatively scarce due to the historic straightening and clearing of the channel.

Plane-bed reaches (Rosgen B3 and F3 channel types)

The relatively steep, cobble-bedded plane-bed reaches are located in confined valley segments in the Bronx River. The first plane-bed reach (Drew Gardens to River Park, see Table 5) is at the upper limit of tidal influence and the second, very short, section is downstream of the Bronx Zoo Dam. The third reach, in the ravine in the Botanical Garden at river mile 4.5 (Figures 8 and 9), is more confined and entrenched than downstream (F3 type). Other plane-bed reaches are found where the river valley becomes very narrow in Bronxville and Tuckahoe. Some sections of channel where the river has been confined by bridges or floodplain development were too short to map as separate reaches. Low flow depths in plane-bed reaches range from one to two feet in the furthest downstream reach, to less than six inches in the upstream reaches. Pools in the lower plane-bed reaches are 1.5-3 feet deeper than the average water depth (Figures 8a and 9a).

Plane-bed reaches provide suitable spawning habitat for blueback herring, particularly where obstructions create plunge pools or backwater (Steve Shepard and Dave Bryson, per. comm.). High flow velocities in the plane-bed reaches during high flow events, however, can potentially present an upstream migration challenge for river herring, or contain too little refuge for spawning. In the West Farms reach (river mile 2.7), the calculated average cross-section velocities were greater than two feet per second for a length of more than 1000 feet during typical low spring flows (ca. 25-50 cubic feet per second (cfs)). At flows of ca. 200 cfs, predicted velocities are often over four feet per second (Table 6). High and low flow velocities are similar in the Botanical Garden ravine for a length of ca. 1000 feet (Table 7). Burst speed data for river herring shows them achieving sprinting speeds of over 12 ft/sec (Castro-Santos 2002). Fish maintain their burst speeds for only relatively short periods of time, however, and require resting sites between bursts. The cobble and boulder substrate in these reaches and the occasional pools maintained by these roughness features, may provide adequate resting sites. Castro-Santos (2002) also found that blueback herring had an average swimming speed the equivalent of about 3.7 ft/sec for a variety of flows. This speed would be sufficient for migrating through these reaches most of the time based on available flow data for April- May[5]. In 2003, flows greater than 200 cfs were observed less than 15% of the time during April to May. This suggests that river herring should be able to migrate up through these faster reaches during most of the spring season. From field observations, several fisheries experts also concurred that the plane-bed reaches looked passable (Dave Bryson, Karin Limburg, Steve Shepard, Steve Gephard, John Waldman, pers. comm.).

[5] During the upstream migration season, flows have historically been less than 80 cfs over 50% of the time (Figure 3a). We assume that average velocities would be around 3 ft/sec at 80 cfs (see Figure 6a).

Table 6. Velocities calculated using Manning's equation at the plane-bed reach between river mile 2 and 3 (Appendix F)

Distance downstream of 182nd Street Dam (ft)	XS #	Low flow* Velocity (f/s)	High flow** Velocity (f/s)
200	1	4	6
1086	2	3	5
1184	2a	2	4
1367	*2b*	-	-
1377	2c	3	6
1439	2d	3	7
1463	3	4	5
1497	4	-	6

*Low flow = ca. 25-50 cfs (from March and July survey days)
**High flow = ca. 200 cfs (estimated)

Table 7. Velocities calculated using Manning's equation at the plane-bed reach at river mile 4.5 (Appendix F)

Distance downstream of Snuff Mill Dam (ft)	XS #	Low flow Velocity (f/s)	High flow Velocity (f/s)
60	1	3	4
150	2	1	4
200	3	4	5
350	4	3	4

*Low flow = ca. 25-50 cfs (from March and July survey days)
**High flow = ca. 200 cfs (estimated)

In sum, the Bronx River appears to have no apparent hydrologic or natural channel barriers for the upstream migration, spawning, and rearing of alewife and blueback herring. The amount of optimal spawning habitat for alewife and blueback is relatively small, however, compared to river systems such as the Mohawk or Connecticut draining into the Hudson River estuary and the Long Island Sound. Unpredictable storm events determine whether both species can readily migrate through the steeper, faster flowing (plane-bed) reaches of river in the spring, or whether they are detained. Flow velocities throughout the dune-ripple reaches suggest further investigation into the potential need to increase high-flow refuge, such as boulder vanes, large woody debris (LWD), or tree root masses that obstruct flow and create backwaters. If in-stream habitat improvements are determined critical, restoration will precede stocking in that section.

CONCLUSIONS

Our study of current conditions on the Bronx River indicates that no single critical environmental variable, such as water quality, flow, depth, or habitat availability, either downstream or upstream of the dams, would preclude river herring from surviving in or being successfully re-introduced to the Bronx River. Water quality parameters, dissolved oxygen (DO), temperature, and suspended sediment, are generally within the range suitable for adult spawners, eggs, and juveniles.

Although low DO levels have been observed in some summers in freshwater and tidal sections of the river, this is primarily a concern for juveniles, since adults are more likely to have migrated out of the system prior to typical low-DO periods. Contaminants data for the Bronx River in the water column and sediments does not indicate that deleterious effects on anadromous fish should be expected.

Flow and habitat conditions appear to be adequate for upstream migration and suitable for river herring spawning and rearing; both pond-like and faster flowing cobble-bedded reaches are available. Depending on seasonal flow conditions, however, suitable habitat can significantly decrease. Extreme low flows in the summer can reduce available rearing habitat, particularly in upstream reaches, and increase risk of predation. During the spring, storm events can temporarily limit upstream passage at steeper channel reaches due to high flow velocities. The latter conditions can be mitigated to some degree by adding in-stream structures such as boulder vanes or anchored large woody debris that provide resting habitat and cover. High spring flows might also contribute to the premature flushing of eggs out of the system, and may make it more difficult to monitor for larvae and juveniles. The downstream impounds can provide slower-flow refuge during these periods, however sedimentation in the river is also reducing potential habitat in impoundments over time. Further identification and quantification of high and low flow refuge and suitable spawning habitat, is needed to determine target quantities and distributions of in-stream structures, as well as appropriate protection and monitoring at expected spawning grounds.

Finally, the aquatic life in the Bronx River Estuary indicates that anadromous fish could survive in the river, and that river herring, do venture into the river mouth. Though the fish assemblages observed in the river, in both the brackish and freshwater sections, are not particularly sensitive to pollution, they share most of the same water quality requirements as river herring. The analysis of prey items in both the water column (zooplankton) and channel bed (macro-invertebrate larvae and eggs) also suggests that sufficient food is available for anadromous fish.

RECOMMENDATIONS

Conservation and restoration targets, and ecological model development and planning

River herring populations could survive in the Bronx River as we assume they did in pre-colonial times. But what other ecosystem features of the Bronx River should we expect to be able to restore? Given the extent to which the watershed hydrology, soils, and biotic interactions have been irreversibly altered by development, and physical and chemical disturbance, it is not possible to return the highly-urbanized Bronx River, to pre-urbanization conditions. (Even the contributing area to the watershed has changed - Kensico Dam diverts flow from about one-sixth of the original watershed). It has been possible, however, to return the river and adjacent landscape to a state of greater biological diversity and ecological functioning than its most degraded condition in the past century. We believe that even further improvements are possible, particularly considering the restoration projects that have been implemented on the Bronx River since 2000. It is possible to restore in-stream structural habitat features to a condition more closely resembling a time before the straightening and clearing of the river (NRG 2002). At the watershed-level, the impact of an urban hydrologic regime can also be mitigated in the watershed by limiting additional impervious surfaces, increasing areas for storm water retention, and controlling erosion. We believe that the restoration of anadromous fish is one appropriate conservation and restoration target, and we are working together with multiple organizations and government agencies along the river to define a range of key ecological attributes, specific conservation targets, and related performance standards. Some steps being taken towards these ends are described here.

Several watershed-wide restoration planning and management projects have been initiated recently that should help identify conservation protection goals and prioritize projects. The U.S. Army Corps of Engineers has initiated a multi-million dollar study, together with the NYC Department of Environmental Protection and Westchester County, to develop a Watershed Restoration Plan for the Bronx River. Westchester County has also established a Watershed Advisory Committee and is developing a Stormwater Management Plan for the Bronx River. They have received funding together with the Bronx River Alliance to extend this Plan through the Bronx.

The Bronx River Alliance, through its Ecology Team and funding from NOAA, is also beginning to develop a restoration plan. This plan will articulate ecological, conservation, and management goals for the river and watershed and is intended to provide the scientific rational for making management recommendations, identifying project priorities, and evaluating progress towards achieving stated goals. As this plan is an integrated effort intended for a variety of users, it is hoped that the Wildlife Conservation Society and the New York Botanical Garden will add their expertise to this process. Several on-going monitoring efforts on the river, such as the Environmental Protection Agency (EPA)-funded Urban Riparian Restoration Evaluation Project, should also help inform the plan. Through this project baseline data was collected on benthic invertebrates, hydrology, and vegetation characteristics at "restoration" and control plots. Finally, some continued monitoring to characterize the expected river herring-habitat associations and to quantify critical variables such as high and low flow refuge this spring should help us better identify and quantify physical attributes critical for river herring success. Ideally, this could be used to help develop an ecological model for river herring, as described by Parrish *et al*. (2003).

Ecological considerations

The investigation above focused on the potential interactions of river herring with the physical river environment. Since river herring could, in theory, survive in the river, the impact their potential presence would have on ecological processes in the river will be considered before implementation occurs. Potential ecological interactions include competition for food between young river herring and resident fish species and increased nutrient input to the system (adult spawning fish do not generally eat). We found little evidence for the potential of interspecies competition as juvenile river herring are predominantly planktivorous (Mullen *et al*. 1986) and so utilize a different food source from most adult fish in the river. Furthermore, present data indicates that plankton levels are sufficiently high to sustain all young of the year fish (the predominant riverine planktivores) in the system. Though some papers have attributed a decrease in zooplankton abundance to river herring (see Loesch 1987), a review of papers addressing interspecies competition found no conclusive evidence for a corresponding decrease in the abundance of other fish species (Loesch 1987). Durbin *et al*. (1979) found that decomposing post-spawning alewives stimulate microbial activity and increase production and respiration in leaf litter deposited on stream and lake bottoms. This accelerated breakdown of leaf litter may reduce the sedimentation rate of lakes (Durbin 1979). However, the potential addition of nutrients from river herring in the Bronx River would probably be insignificant compared to current nutrient inputs from CSO's and other diffuse sources in the watershed. A primary ecological advantage of river herring in the Bronx River would be their presence as an important prey item. Predators of river herring already present in the Bronx River system include striped bass, American eel, brown trout, sunfish, bass, shiners, snapping turtles, herons and osprey (Loesch 1987, Lehman 2003). River herring would redistribute nutrients in the river, connecting river reaches by their extensive migration and would increase the abundance and health of predatory populations throughout.

Phase II Passage alternative development

Our investigation of the historic and existing conditions in the Bronx River suggest that there are no environmental factors preventing the use of the Bronx River by river herring, except the lack of passage. Our preliminary evaluation of the dams also indicates that a variety of passage construction alternatives are feasible from a technical perspective, and that establishing passage could benefit several species already occupying the river, including the American eel. Currently there are no known ecological disadvantages to establishing passage but this will be further investigated and confirmed before passage is established. Potential ecological advantages to establishing passage include the introduction of river herring as a prey item in the food chain and the re-connection of river reaches, which would expand available aquatic habitat for all species. Species which may use the fish passage way include small-mouth bass and white sucker (Steve Shepard, pers. comm.). Undesirable species such as European carp can be excluded from passageways (Maine DMR 2002). From an educational perspective, the establishment of passage can give community groups a clear signal of the potential for life in the river, as well as the chance to participate in activities related to the life history of the river herring, such as monitoring at fish passage ways during the migratory season. For these reasons, we recommend proceeding with Phase II of the Fish Passage Feasibility Study.

In Phase II, the objective is to develop passage design alternatives that are acceptable to the landowners and managers of the dams in the Bronx. To do this, we will seek input from the Bronx Zoo/Wildlife Conservation Society, the New York Botanical Garden, and other project stakeholders (e.g. NOAA, U.S. Fish and Wildlife Service, NYSDEC) in determining the scope of work for an engineer and design consultant, and throughout the design development process. The development of passage design alternatives will focus on historical, cultural, management, operational, aesthetic, educational, and safety considerations, as well as technical issues. Below is a summary of the characteristics of dams of particular interest for fish passage on the Bronx River (and tributaries) and a general description of fish passage construction types.

<u>Dam characteristics</u>

182nd Street Dam

The dam at 182nd Street is approximately 2.9 miles upstream of the mouth and marks the southern border of the Bronx Zoo and the northern border of River Park. It is a masonry dam approximately 14 -ft high and 90-ft wide (120-ft wide including the western abutment). In the mid-1800s, the dam appeared in photos having a smooth front face, and there was little visible evidence of rock outcrop to indicate that the dam was originally located on a natural falls. In the early 1900s there were reports of extensive seepage through the dam. In 1910, restoration work on the dam included raising its height and adding a rugged natural-looking face.

The NYSDEC's Dam Safety Division conducted a routine inspection of the 182nd Street Dam in June 2003. Despite leakage reported around the dam, repair was not warranted given that it is not rated as a high hazard dam (a classification based in part on the downstream land use). However, the NYSDEC has indicated that any construction at the dam would require an upgrading of the dam (Alon Dominitz, pers. comm.).

Bronx Zoo Dam

The Bronx Zoo Dam, which consists of two dams on either side of an island, just upstream of the eastern entrance to the Zoo off the Bronx River Parkway and the old Boston Road, is approximately 3.7 miles upstream of the mouth. The dams are 10-ft high, extending nearly 60 ft from either side of the island in the river. Both dams are masonry and may have been built on natural falls. The natural rock outcrop across the channel to the West of the island is evident in photos from the 1800s. The masonry dam to the East of the island appears to have been built to mimic the rugged look of a natural falls (as at the 182nd Street Dam).

Snuff Mill Dam

The Snuff Mill Dam in the New York Botanical Garden is approximately 4.3 miles upstream of the mouth and has an approximately 7-ft head (water surface elevation difference), a 3-ft plunge pool at its base (see Figure 9), and a 50-ft width. It is located in a bedrock-lined ravine in the steepest section of the river in the Bronx. The dam is listed on the National Registry of Historic Landmarks but is below the height threshold and holds too little water to be included in the state Dam Safety Division's list of dams to be inspected (Alon Dominitz, pers. comm.).

Westchester Dams

The three dams furthest downstream in Westchester (in Bronxville and Tuckahoe), are within areas of the river that we expect would be suitable for river herring. Each is approximately 4 ft high. The dam in the middle (ca. river mile 12.0) is concrete and in a section of river where the banks are concrete walls. The other dams (river miles 11.3 and 12.3, respectively) are constructed of rock and impound Bronxville Lake and Crestwood Lake (Hodgeman Dam) further upstream. About river mile 14.4 and 15.0 in Eastchester and Scarsdale, two concrete dams are respectively 7- and 9-ft tall. To the West, on the Sprain Brook, over a mile upstream of its confluence with the Bronx River, there are eleven 2-ft high masonry dams and a 12-ft concrete spillway leading to the Grassy Sprain Reservoir.

<u>Types of fish passage</u>

There are three general approaches to achieving passage for anadromous fish species at dams: structural fishways, natural by-pass channels, or dam removal. Dam removal is not an option on the Bronx River in the Bronx, however, due to the historic status of the dams, and the integration of these features into the cultural landscape and programs at the Bronx Zoo and New York Botanical Garden. The Snuff Mill dam, in particular, is listed on the National Registry of Historic Landmarks. See Appendix J for more information.

Structural fishways, or fish ladders, allow fish to cross dam structures without removing dams. Fish ladders provide a gradual ascent (typically a 1:5 or 1:6, 20% grade) over dams, often providing resting pools along the way. Ladders are designed to accommodate the flow requirements of the weakest swimming species among those being targeted for passage. Of the most common anadromous fish, salmon are the strongest swimmers followed by river herring and American shad. Herring, however, are unable to jump over obstructions and require a moderately sloped fishway or ladder (for example, a steep-pass or Denil). A ladder and/or dam modification must be designed to create sufficient attraction velocities for fish – typically up to 10% of the natural river flow, not width (James MacBroom, pers. comm.). A simple steep-pass ladder requires a minimum flow of two to five cubic feet per second, with larger flow for greater widths (James MacBroom, pers. comm.). Although many pre-fabricated fish ladders are built without regard for aesthetics, their design principles also apply to fish passage structures installed at historic dams where aesthetics and preservation are very important. See Appendix K for examples.

A fluvial-geomorphically "natural" by-pass channel can be built around a dam. In the case of river herring, this type of channel would require adjacent land (preferably non-regulated uplands) to create a stream-like channel with less than 3% slope (on average) for upstream migration. Natural by-pass channels could require a higher discharge (e.g. 15 cfs minimum) than fish ladders since they do not have a regularly constructed, artificial geometry – this could be up to a 30% of the total river flow. If built correctly with the appropriate amount of flow, this type of channel can require little or no maintenance. It is also one of the most aesthetically pleasing passage alternatives.

Poor attraction flows, the presence of debris, and other physical factors may limit the success of a particular passage alternative. Urban streams are particularly vulnerable since they tend to have high debris loads, flashy flows, and low base flows. In an urban area, potential vandalism must also be considered when choosing the passage structure and location. Since correctly designed and maintained passage structures are generally used if fish are present, their success also depends on getting fish into the area, e.g. by stocking fish, and on the suitability of the habitat upstream and downstream. In general, fishways have had documented success in passing river herring while inappropriately designed, deteriorated, and un-maintained fish passage structures have been unsuccessful (please see Appendix L for a list and description of fish ladders passing river herring).

Stocking

Although blockages are the most direct reason why anadromous fish are not using the upstream reaches of the Bronx River, the fact that they have been blocked for centuries means that providing passage will not automatically serve to restore a fish run. This is because, though a few river herring have been found in the estuary, there are no fish populations genetically programmed to return and spawn in the river, and fish in the vicinity are not necessarily going to extend their spawning range into new waters (Richard St. Pierre, pers. comm.). Stocking adult fish in previously inaccessible habitat, however, can start the process of imprinting and jump-start a viable population that will home to a river and return for spawning (Belding 1920, Bigelow and Welsh 1925, Havey 1961, Thunberg 1971, Messieh 1977). Many fish restoration programs in the Northeast have long included fish stocking as an essential component of their management and restoration program. Please see Appendix M for examples and descriptions of stocking programs in the Northeast.

On the Bronx River, suitable stocking and spawning locations are available, and it is probable that river herring adults will breed, juveniles will survive, and, after three or more seasons, adult river herring will return to the river. Although upstream passage is not yet available, and may not be for many years, the life history of the river herring point to the logic of beginning a stocking program early. After migrating out to sea, river herring typically take 3 to 4 years to mature, but some may mature and return to spawn after as long as six years (Gibson and Myers 2003). A significant number of spawners, comprised of multiple age classes, may not return for five to seven years after stocking and, thus, multiple years of stocking may be necessary to re-establish a diverse population structure. If the stocking effort is highly successful and spawners do return to the foot of the furthest downstream dam before passage is available, trapping and trucking can be used to transport fish to upstream spawning sites.

State and federal agencies have been involved in trapping and transfer of adult river herring since the 1960's (ASMFC 1999 p. 40). These efforts frequently involve re-stocking above dams to imprint *Alosa* to return and re-colonize the rivers. Depending on the quality and size of habitat and the proximity of suitable source stocks, restoration can occur quickly at relatively small cost (e.g.

adult alewife introduction to a coastal pond), or it can take decades and cost tens of millions of dollars (e.g., large rivers with multiple main-stem dams) (ASMFC 1999 p. 52). Several rivers in New England are or were managed by stocking gravid adult river herring in inaccessible habitat with the hope of developing fish passage in the future. These include the Merrimack, Cocheco, and Lamprey rivers in New Hampshire, the Kennebec River in Maine, and the Neponset River in Massachusetts (Appendix M). Other programs have stocked river herring to boost pre-existing runs or to jump-start new runs after passage was established. Most of these efforts, but not all, have been successful. Since anadromous fish inhabit a wide range of environments, disparate, un-related stresses can effect populations and determine success or failure. Further, the degree of precision of homing in stocks occurring in tributaries of large estuaries has not been as well documented (ASMFC 1985).

Stocking also provides an opportunity of observing actual and potential threats to spawning success and survival, and gathering information on habitat improvements or the passage (upstream or downstream) modifications that might be necessary. As discussed above, we will, ideally, continue to refine our understanding of the appropriate range of ecological attributes for fish. Modeling and measurement, however, are limited in the answers they will provide – the only way to verify that spawning and stocking sites are adequate and that downstream passage is possible is through stocking. Over the time the river herring take to return and over the duration of the stocking, monitoring data can be used to refine our understanding of the acceptable conditions, and inform decisions about upstream habitat enhancement, downstream and upstream passage construction, and stocking and monitoring techniques. However, stocking will not proceed until there is agreement on conceptual passage alternatives for the dams.

Monitoring

As described in the attached fish re-introduction proposal (Appendix N), monitoring will be an integral part of the fish stocking program. Monitoring immediately after the stocking and in the weeks when juveniles should start feeding is critical in order to determine whether fish have survived transport, whether and where the fish have successfully spawned, and whether the juveniles are surviving. Monitoring downstream of dams is important to determine whether there was mortality over the dams as a result of injury or predation. Success will be evaluated at these various stages, including, finally, whether fish are returning to spawn after 3-7 years. With the help of experts, such as fisheries managers and conservation specialists at the Wildlife Conservation Society, we will continue to refine the proposed monitoring program, and, ideally, develop an accompanying ecological model to guide monitoring and educational programs.

Feasibility

There are many technical and physiological issues to be considered when stocking a fish sensitive to handling, such as river herring. Our fish stocking proposal, submitted to the Wildlife Conservation Society/NOAA Regional Partnerships Grant Committee, addresses many of these issues (Appendix N). We have identified the critical variables, and have much of the information we need to make an introduction as successful as possible. Nevertheless, we cannot immediately improve all environmental conditions, such as cover, high flow refuge, and downstream passage challenges, which might benefit the fish. If a fish stocking program is funded, fish will be stocked in areas where habitat improvements are not critical while the other sections continue to be improved. During the potential stocking program, we also intend to take advantage of assistance offered to us from fisheries ecologists and experts involved in stocking, trucking, and trapping programs throughout the Hudson River Basin and New England.

Community involvement

The fish stocking would be used as an educational opportunity with participation during the stocking and monitoring phases. Community groups such as the Sustainable South Bronx and Youth Ministries for Peace and Justice, as well as other members of the Bronx River Ecology Team have expressed support for the stocking proposal. Since the proposed stocking locations are in the Bronx Zoo in the first year (see Proposal, Appendix N), and upstream in Westchester in subsequent years, we would ask to collaborate with the Wildlife Conservation Society in facilitating access and conducting educational outreach and facilitating volunteer participation.

Habitat Enhancement

In a highly urbanized river system such as the Bronx River, inter-related and cumulative effects of landscape development and point and non-point source pollution make it difficult to correct any single factor that may adversely affect diadromous fish runs. There are several inter-related factors that contribute to stream habitat degradation. These include:

- high sediment loads that diminish the benthic invertebrate community diversity and fill in pools as well as cover gravel and cobble substrates.
- increased peak stormwater runoff that causes frequent bed disturbance and sediment transport
- channel clearing that removes cover and resting places
- removal of riparian vegetation that provides a canopy for in-stream thermal regulation and serves in bank stabilization
- exotic vegetation that reduces the biodiversity and function of riparian vegetation
- water quality degradation (CSOs, spills, non-point sources)

High sediment loads and accelerated runoff must be addressed at the watershed scale. Water quality improvements must be sought at both a watershed level and locally (point sources), and depend on effective regulations and enforcement. Although these types of problems are extremely difficult to resolve, multiple agencies and organizations are working together to evaluate these problems through recently initiated planning efforts and studies, as discussed above.

Lack of habitat structure can, to some degree, be mitigated for at the reach scale. Roughness features can be added to the channel, for example, to create refuge from high flows or create resting spots for fish during upstream migration, provided they do not create hydraulic barriers to migrating fish. Flow obstacles or cover structures such as boulder vanes, anchored large woody debris, or root wads, provide places for fish to hide from bird predation. Riparian vegetation can also be managed to help re-establish large mature trees that provide shade, establish bank cover, and, eventually, provide structure in the river in the form of large woody debris. Over-widened channels can be narrowed to increase summer base flow depth by adding structures and modifying the channel cross-section, where possible. Ultimately, the habitat for anadromous fish and other native aquatic species can only be significantly improved through a continued effort to identify and then to successfully reduce urban watershed impacts at the watershed and local scale. Further characterization, identification, and quantification of habitat types for anadromous fish and the species with which they interact is needed to more precisely determine conservation and restoration targets.

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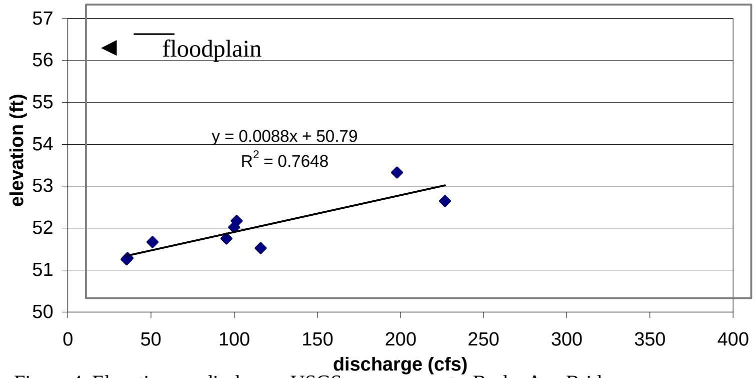

Figure 4. Elevation vs. discharge, USGS measurements, Burke Ave Bridge

Flood Flow Recurrence Intervals:
1.01-yr = 832 cfs
2-yr = 1780 cfs
5-yr RI = 2327 cfs

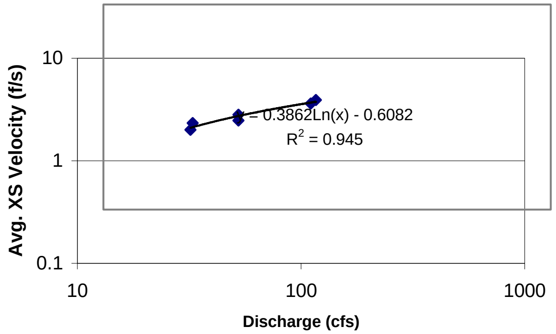

Figure 5a. Velocity vs. discharge, USGS measurements, Burke Ave

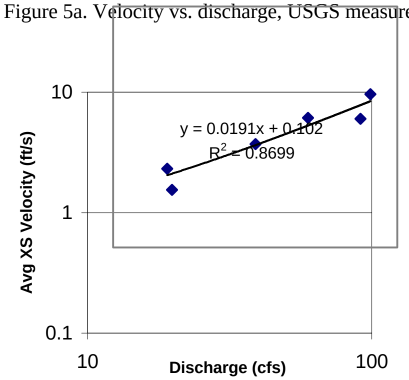

Figure 5b. Velocity vs. discharge, USGS measurements, Bronxville

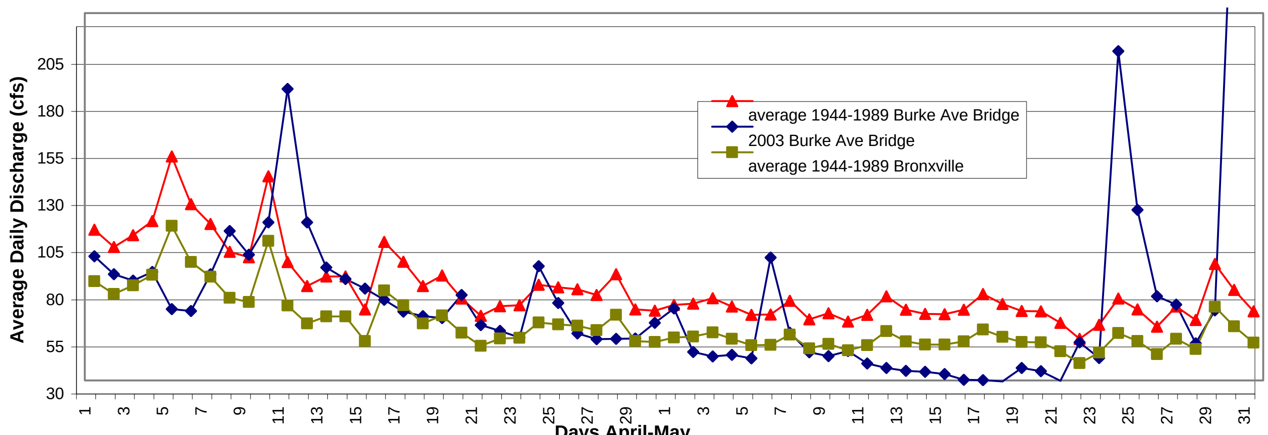

Figure 3a. Average Daily Discharge for April-May at Bronxville (from USGS gage) and Burke Ave Bridge (calculated).

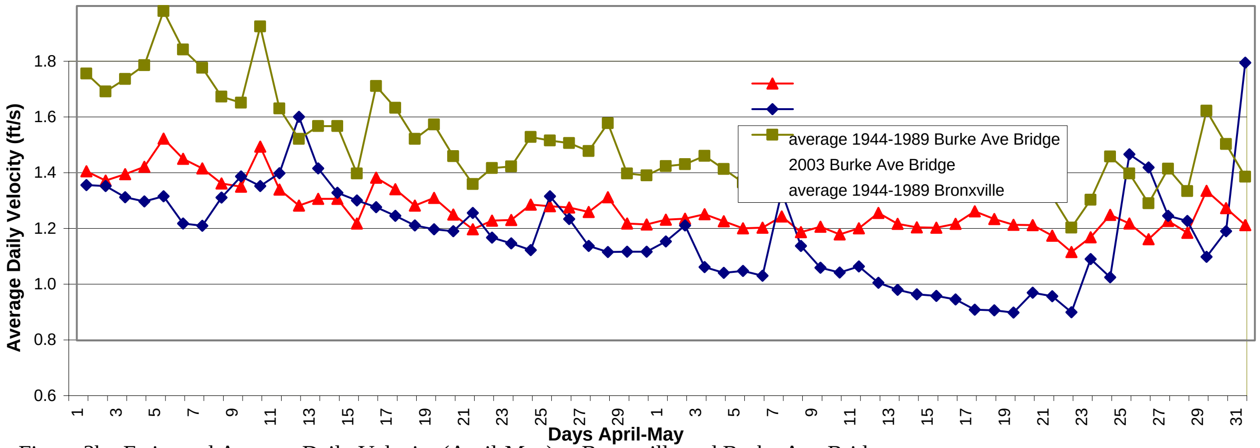

Figure 3b. Estimated Average Daily Velocity (April-May) at Bronxville and Burke Ave Bridge

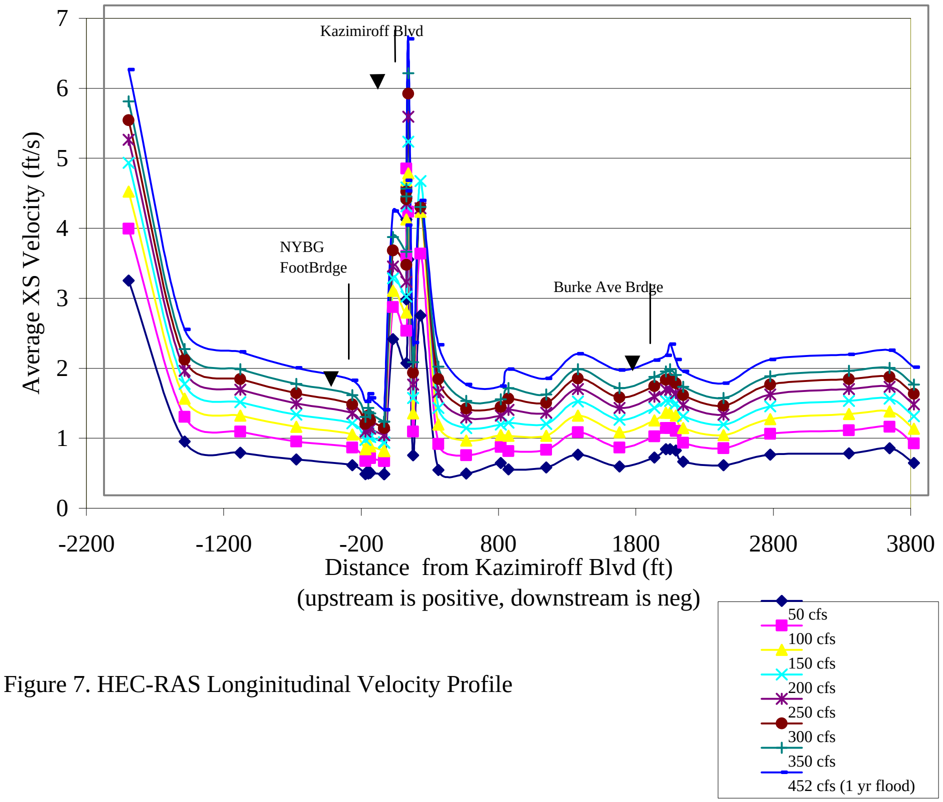

Figure 7. HEC-RAS Longinitudinal Velocity Profile

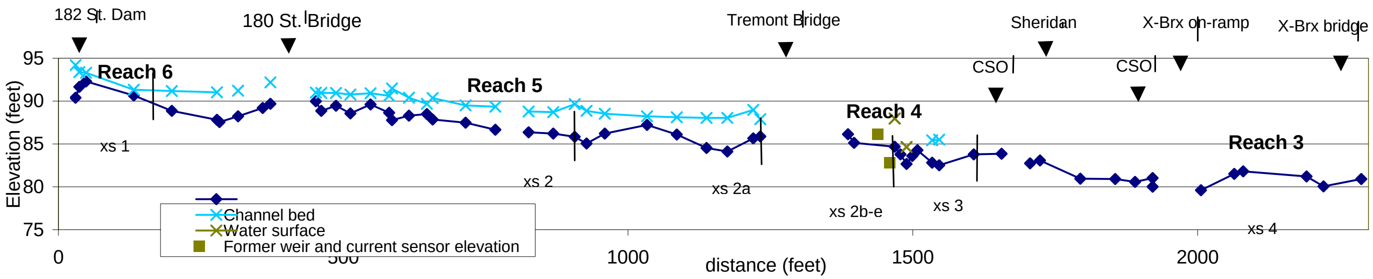

Figure 8a. Bronx River longitudinal profile between river mile 2-3 (at West Farms from River Park to downstream of Drew Gardens). Reach numbers relate to Table 4. Cross-sections plotted in Appendix G.

Figure 8b. Aerial photo of West Farms survey location

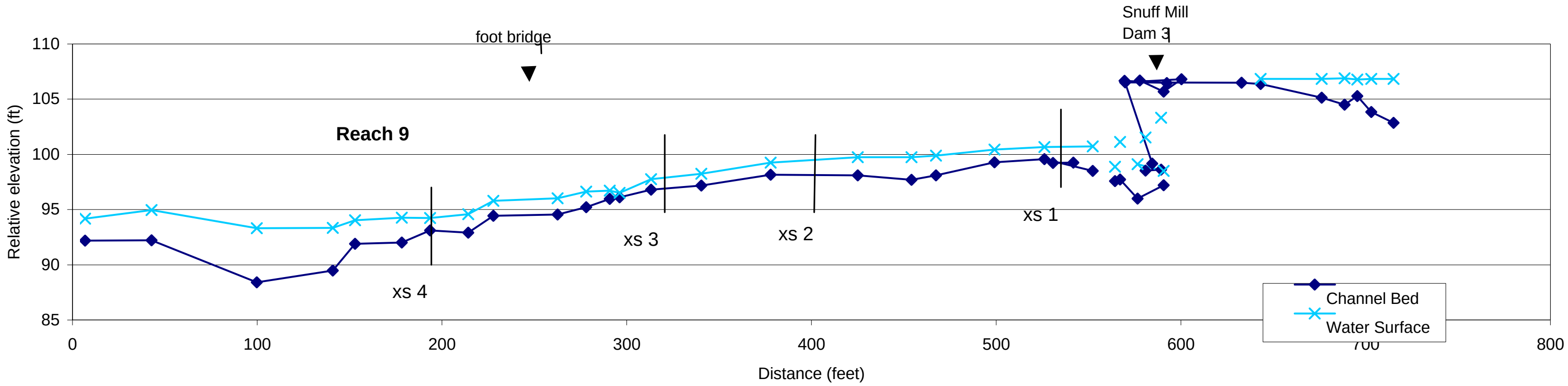

Figure 9a. Bronx River longitudinal profile at river mile 4.5 (ravine in New York Botanical Garden). Reach numbers refer to Table 4. Cross-sections plotted in Appendix G.

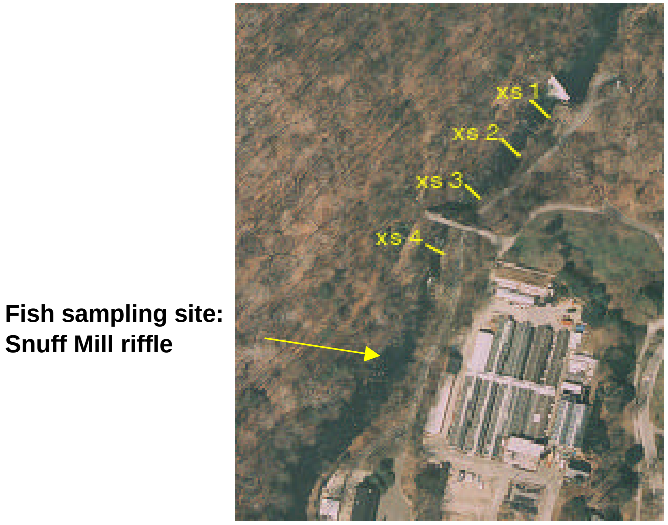

Figure 9b. Aerial photo of NY Botanical Garden survey location

Table 5. Channel reach characteristics

Reach #	Reach name	Distance from river mouth (river mile)	Reach length (mi)	Slope	Avg width[1] (ft)	Surface area[1] (acre)	Dominant substrate size class	Width to Depth Ratio[2]	Entrenchment Ratio[3]	Channel Type: Montgomery & Buffington[4]	Channel Type: Rosgen[5]	
1	DS of weir	0	2.0	0.0004		266.9	silt/sand			estuary		TIDAL
2	Weir to X-Bx	2.0	0.4	0.0013	64	3.1	silt/sand			estuary		
3	X-Bx to Drew Gardens	2.4	0.1	0.0050	58	0.9	cobble (sand)			plane-bed		
4	Drew Gardens	2.6	0.1	0.0067	56	0.6	cobble			plane-bed		
5	West Farms	2.6	0.2	0.01	36	0.7	cobble (sand/boulder)	20	1.4-2.2	plane-bed	B3c	
6	River Park	2.8	0.1	0.01	75	0.7	cobble (sand/boulder)	19	1.4-2.2	plane-bed	B3c	DAM
7	US Dam 1	2.9	0.8	3E-05	100	12.0	silt/sand (cobble)			impoundment		DAM
8	US of Dam 2	3.7	0.2	3E-05	99	3.4	silt/sand (cobble)			impoundment		
9	Ravine	3.9	0.4	0.01	53	2.4	cobble (boulder)	>>24	<1.4	plane-bed	B3 - F3	DAM
10	US of Dam 3	4.3	0.4	2E-04	51	1.8	silt/sand (boulder)			impoundment		FRESH
11	Bx Forest Pk to Shoelace Pk	4.8	0.9	0.001	49	5.9	sand (silt/gravel)	16	>2.2, <1.4	dune-ripple	C5 - F5	
12	Shoelace Pk to Pondfield Rd.	5.7	5.3	8E-04	50	10.2	sand (silt/gravel)	16	>2.2, <1.4	dune-ripple	C5 - F5	
13	Pondfield Rd to Bronxville Lk	11.0	0.4	0.008	45	2.2	cobble (sand/gravel)			plane-bed	B3 - F3	
14	Bronxville Lk	11.4	0.6	9E-04	150	6	silt			impoundment		DAM
15	Elm St to Concrete Dam	12.0	0.2	0.0020	45	0.9	cobble (sand/gravel)			plane-bed	B3 - F3	DAM
16	Concrete Dam to Crestwood Lk	12.2	0.3	0.0011	40	1.2	sand (silt/gravel)			dune-ripple		
17	Crestwood Lk	12.5	1.0	0.0008	200	8	silt			impoundment		DAM
18	Crestwood Lk to Harney Rd	13.5			50	0.0	sand (silt/gravel)			dune-ripple		

[1]measured from aerial photos and County of Westchester (1979) maps

[2] Channel width divided by average channel depth at the approx. 2-year flow.

[2] The width of the valley at approx. two times the maximum channel depth, divided by the channel width.

[2] Montgomery and Buffington (1993)

[3]Rosgen 1996 (see Table in Appendix I)