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Walleye (Sander vitreus) Stock Assessment (2006-2007) in the Buffalo River, NY, USA

Patrick J. Herbert

The College at Brockport, hoboherbs77@yahoo.com

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Walleye (*Sander vitreus*) Stock Assessment (2006-2007) in the Buffalo River, NY, USA

A Thesis Presented to the
Graduate Faculty of the Department of Biological Sciences,
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Partial Fulfillment of the Degree of Master of Science

by
Patrick J. Herbert
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THESIS DEFENSE

Patrick J. Herbert

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Abstract

Walleye stock assessment

The presence of a naturally occurring spawning stock of walleye *(Sander vitreus)* in the Buffalo River has gone undetected. This study sought to determine the extent of use of the Buffalo River by adult and juvenile walleye in 2006 and 2007 in order to assess the New York Department of Environmental Conservation's stocking efforts. Walleye were first stocked in 2004 and stocking continued in 2005 and 2006. A total of 29 walleye, mostly juveniles, were caught during the two year study period. None of the walleye were believed to be using the river to spawn. The source of these walleye is not known but genetic analysis is pending. The Buffalo River and tributaries have limited habitat potentially suitable to support walleye spawning. No physicochemical conditions were observed that would preclude some successful walleye spawning in the Buffalo River watershed, but habitat conditions are not suitable for larval survival during movements to Lake Erie. Mean zooplankton density during the walleye larval period ranged from 41.0- 86.4 individuals/L in 2006 and 2007, with rotifers being the dominant taxon in both years: 78% and 86%. Mean density of zooplankton at the river confluence with Lake Erie ranged from 21.8-25.1 individuals/L in 2006 and 2007. Rotifers were the dominant taxon in 2007 (73%) and cyclopoid copepods (40%) and rotifers (25%) were the dominant taxa in 2006. While abundance of zooplankton was adequate for walleye fry feeding, the predominance of small-bodied zooplankton was suboptimal. No ichthoplankton, including larval walleye, were caught during the study period despite intensive sampling.

Fish community comparison: 2006 vs. 1981-1982

The Buffalo River, once a large industrial port for the City of Buffalo, has gone through great environmental stresses over the years. Through the development of environmental regulations and decline of industry in the City of Buffalo, the condition of the river has improved. The objective of this aspect of my thesis was to replicate a survey conducted in 1981-1982 (Makarewicz et al. 1982), using electro-fishing and gill netting, to determine the extent of change in the fish community. The fish communities of the Buffalo River exhibited similarities and differences between the surveys. Simpson's diversity was high (0.89) in 1981-1982 and in 2006 (0.91) but community similarity was only 48.3%. In 2006, 51 species from 14 families were caught. In 1981, 32 species from 10 families were caught. Twenty three species of fish captured in 2006 were not captured in 1981-1982. Four species caught in 1981-1982 were not caught in 2006. Centrarchidae (41.4%), Cyprinidae (20.7%), and Clupeidae (15.5%) were the most commonly captured families in 2006. Cyprinidae (36.8%), Catostomidae (18.0%), and Centrarchidae (17.4%) were the most prevalent families in 1981. Changes in the relative abundance of major families and the addition of many new species both indicate a change from a moderately pollution-tolerant to a less pollution-tolerant fish community during the 25 years between studies.

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Introduction

The open water, rocky shoals of Lake Erie support spawning stocks of the walleye (*Sander vitreus*). The use of these unprotected shoals by adult walleye has been an important factor leading to high variability in their recruitment success in the eastern basin of Lake Erie since the 1960s (Einhouse 1994). Exact causes of this variability are not well understood but may be due in part to excessive walleye mortality during early life stages, especially egg survival through the first winter (Mion et al. 1998). Stochastic events are common in the basin and often cause extreme fluctuations in environmental conditions at these open water spawning sites. Walleye eggs are dislodged by increased wave action from severe winds, causing substantial mortality (Roseman et al. 2001) Thermal shock from extreme water temperature changes during spawning and incubation periods is also thought to cause high egg mortality (Busch et al. 1975; Koonce and Shuter 1977). Development of walleye embryos is delayed when water temperatures increase slowly, leading to recruitment variability (Figure 1) due to longer exposure of severe weather events, siltation, abrasion and predation (Einhouse 1994).

Developing spawning stocks that use different limnological habitats, such as stream beds and lotic shoals or shores, may decrease the amount of recruitment variability in Lake Erie walleye stocks (Regier et al. 1969). This idea led to the development of a stocking program by the New York Department of Environmental Conservation (NYDEC). The program is designed to create or enhance the walleye spawning activity in selected New York steams. Walleye spawning activity in streams is very limited in Lake Erie's eastern basin (Einhouse 1994), especially when compared to the stream-spawning populations in the western basin (Jude 1992). Historically river spawning was common amongst the Great Lakes walleye populations, but pollution, sedimentation, and damming destroyed or damaged many tributary systems (Schneider 1977; Schneider and Leach 1979; Feilder 2002).

Common characteristics of these walleye spawning streams were used by the NYDEC to identify candidate streams for walleye introduction in New York State (Einhouse 1994). However, it is still unclear why some rivers support better walleye recruitment than others.

By flowing into a warm, turbid, nutrient- rich embayment or estuary, the Buffalo River (Figure 2) was thought to share some of the habitat characteristics of the productive walleye spawning rivers such as the Maumee, Saginaw, Sandusky, and Thames Rivers (Haas and Thompson 1997). Therefore, the Buffalo River was chosen by the NYDEC in 2003 as part of a plan to establish self-sustaining riverine populations of spawning walleye along the NYS shore of Lake Erie. This relatively large lotic system flows from the east into the eastern basin of Lake Erie just south of the Lake's outlet into the Niagara River (Figure 3).

Historically, the Buffalo River has been severely degraded by industrial and urbanized development (Sauer 1979; Rossi 1995; Buffalo Niagara Riverkeeper 2005; Irvine et al. 1990.) Poor water quality, contaminated sediment, and physical alteration led to the designation of the Buffalo River as an Area of Concern (AOC; see Figure 3) in the mid-1980s (NYDEC 1989). The AOC extends 9.4 river kilometers up the

Buffalo River from the mouth and includes the greatly compromised riparian corridor. The Buffalo River watershed is 1139.6 km² and contains 38 combined sewer outfalls and 45 inactive hazardous waste sites (Buffalo Niagara Riverkeeper 2005). Annual maintenance dredging and bulkheading is performed by the U.S Army Corps of Engineers to accommodate safe and convenient movement by Great Lakes cargo vessels (NYDEC 1989). This activity has been ongoing since the 1800s, causing negative impacts to fish and wildlife habitat (NYDEC 1989). Increasing the depth and width of the river channel greatly increased the residence time of pollutants and sewage that pass through the system (Kozuchowski et al. 1993). Signs of biological recovery in the river have been observed and documented (Diggins and Snyder 2003) but historical degradation persists, impeding further recovery of the system.

Walleye stocking in the Buffalo River commenced in 2004 and continued through 2006 with annual fry and fingerling stocking planned for a 5-7 year period (Table 1). Walleye for stocking were reared at the NYDEC Chautauqua Hatchery using brood stock from Cattaraugus Creek. Cattaraugus Creek is stocked with fry and fingerling walleye annually and is perhaps the only true riverine stock along the Lake Erie shore in New York (NYDEC 2006). Cattaraugus Creek brood stock provides the most comparable genetics to what was once assumed to reside in the Buffalo River. Genetic analysis revealed that spawning walleye from Lake Erie's tributaries and offshore reefs are genetically divergent, suggesting spawning site philopatry (Stepien and Faber 1998); tagging data reported by Todd and Haas (1993) further suggest adult walleye return to their natal grounds to spawn.

Although the success of establishing a fish species through stocking has a history of unpredictability (i.e., ineffective or detrimental consequences) (Ellison and Franzin 1992), it is a universal management tool for restoring populations. Low intensity, annual electrofishing surveys of potential walleye spawning sites were conducted by NYDEC in the Buffalo River but no juvenile or adult walleye, from stocked or natural origin, were found (NYDEC 2006). However, stocked walleye were not expected to return until 2007-08, based on known sexual maturity rates (male walleye generally mature at 2-4 years of age and >280 mm TL; females mature at 3-6 years of age and >360 mm TL; McMahon et al. 1984). Accordingly, it was determined that sampling for walleye and knowledge of habitat requirements for developing young were insufficient to draw valid conclusions about the status of the NYDEC stocking plan for the Buffalo River.

Walleye Restoration Studies

The lack of information described above raised several important questions as to the fate of the walleye released into the Buffalo River. First, are adequate zooplankton populations available at critical times and locations (i.e., river mouth) to support the growth and development of larval walleye? Secondly, do physical habitat conditions in the river (spawning substrate, dissolved oxygen, temperature, secchi transparency, velocity, pH) fall within the ranges presented in the national Habitat Suitability Index (HSI) for walleye (McMahon et al. 1984) and thesis work by Christopher Lowie (1998), which was later published (Lowie et al. 2001)? Finally, what is the extent of walleye presence in the river and is the presence the result of stocking efforts? In order to know if walleye restoration in the Buffalo River is likely to succeed or fail, there was a critical need to evaluate existing habitat conditions and the results of NYDEC's stocking efforts to date.

Fish Community Studies

In addition to assessing the zooplankton, habitat parameters and the presence of walleye, I also examined the composition and diversity of the overall fish community in the Buffalo River. This work was designed to determine if changes in the fish community have occurred in the 25 years since the river was first examined in 1981 (Makarewicz et al. 1982). With the decline of industry in the City of Buffalo, increased awareness of water pollution/quality and public safety, and increased regulatory and monitoring efforts by the state and federal agencies, for example the Environmental Benefit Permit System (EBPS) and the State Pollution Discharge Elimination System (SPDES) (Buffalo Niagara Riverkeeper 2005), the water quality of the river has improved and therefore the fish community should have followed suit, but to what extent? A historical perspective may assist in educating and even modifying the attitudes and actions of the human population that interacts with the river and its fishery. In order to develop a greater understanding of the Buffalo River fish community and to supplement my walleye research, monthly fish surveys were conducted in the lower sections of the river to replicate the survey conducted by

Makarewicz et al. 1982. In doing so, I tested the null hypothesis that the Buffalo River fish community of 2006 is not different from the community present in 1981.

Study Area

The geographic range of the project primarily focused on the lower 9.4 km section of the Buffalo River designated as the Area of Concern (AOC; Figure 2). This stretch of river ranges from the Buffalo River and Cazenovia Creek confluence to the mouth of the Buffalo River at Lake Erie. During the April-May period when walleye are likely to be spawning, sampling focused on suitable spawning habitats, as determined though preliminary surveys in the lower sections of Buffalo, Cayuga, and Cazenovia Creeks. The most upstream sites for sampling in Buffalo (Reach 16), Cayuga (Reach 20) and Cazenovia Creeks (Reach 9) were at their first impassible barriers (Figure 4).

Methods

Physicochemical Data

At all sampling locations dissolved oxygen (DO) and water temperature were measured. At sites located within the AOC, pH and secchi transparency also were measured. Water quality data was taken while sampling for biota. DO (mg/L) and temperature (C^{o}) were measured with a YSI meter at mid channel. DO was calibrated using the air saturation method as recommended by the manufacturer. At locations with depths >3 m, measurements were taken at 3 m; at locations <3 m deep, measurements were taken at one-half the water depth. A LaMotte Tracer Pocketester was used to measure pH and was calibrated before each use with a pH buffer of 4, following the manufacturer's recommendation.

Water transparency was measured only during day trips with a 200-mm diameter secchi disc. Depths at deep sites were determined using the boat-mounted Garmin GPS fish finder and at shallow sites with a meter stick at mid-stream. Percentages of primary and secondary substrate types were estimated visually at potential spawning sites: 9, 10, 12-20 (Figure 4). Substrate was classified as sand/silt (<2 mm), gravel (2-150 mm), cobble (151-256 mm), or boulder (>256 mm) (Lowie et al. 2001). Stream velocity was measured at potential spawning sites with a Pigmy Gurly meter at ~60% of the stream depth at mid-channel.

Zooplankton

Zooplankton samples were collected vertically, twice weekly, with a 63-µm Wisconsin net (130 mm diameter) from two weeks before (April 29, 2006 and March 11,2007) until two weeks after (June 10, 2006 and June 2, 2007) predicted walleye fry emergence. Fry emergence was predicted by monitoring water temperatures and predicting the peak spawning period (Wolfert 1981, McMahon et al.1984). Zooplankton samples were collected at sites 1-10 (Figure 5a), starting at the Buffalo River mouth and ending approximately 0.5 km upstream of the stocking location. Three vertical tows, taken at 25%, 50%, 75% of the stream width, were composited and preserved in 4% formalin for 24 h then transferred to 70% ethanol. Zooplankton were enumerated and classified into Rotifera, Cladocera, Calanoida, Calanoid nauplii, Cyclopoida, Cyclopoid nauplii, Oligochaeta, Chironomidae, and *Dreissena* veliger. Assuming filtration efficiency of 100%, zooplankton densities were calculated as the number of organisms/L using the formula provided by Wetzel and Likens (1991):

$$\frac{C \times V'}{V'' \times V'''}$$, where

C = number of organisms counted

V' = volume of the concentrated sample (L)

V'' = volume counted (L)

V''' = volume of water through which net was towed (L) = $\pi * r^2 * d$

r= radius of net opening

d = depth

Ichthyoplankton

Ichthyoplankton were collected with a Miller high speed sampler equipped with a flow meter to determine the volume of water filtered. The sampler was towed for 5 min behind a 4.5-m aluminum boat at various speeds (3-6 km/h), as determined by a Garmin hand held GPS unit. Three samples were obtained from the five sites (1, 5, 7, 8, and 9; Figure 5b), at 25%, 50%, 75% of the stream width. Composite sampling was chosen to sample both the littoral and pelagic portions of the river. These five sites were chosen to concentrate sampling effort in the upper portion of the river where fish stocking had occurred. By varying the sampler's speed, depressor weight and distance behind the boat, sampling depths varied from 0-4 m. Collection of icthyoplankton occurred primarily at night because newly hatched walleye are photonegative (Bulkowski and Meade 1983), but several day trips were made as well. Ichthyoplankton were preserved in 4% formalin for 24 h then transferred to 70% ethanol, enumerated, and identified to the lowest possible taxonomic level (Auer 1982). Weekly ichthyoplankton sampling began in late May 2006 after fry stocking and ended in mid July 2006 after fingerling stocking. No larval stocking and sampling took place in 2007 because of the NYDEC's emergency regulations put in place to control viral hemorrhagic septicemia (VHS).

Walleye

Adult Sampling—. During the non-spawning period (June 2006-March 2007, excluding the winter months of November, December, January, and February when river access was limited due to ice conditions), boat electrofishing and gillnets were used to sample for adult and juvenile walleye. Sampling occurred monthly at sites 1-8 (Figure 5c) using SUNY Brockport's electrofishing boat at twilight for 15 min. A circular pattern was used to fish both river banks and mid-channel habitat. At sites where depths were greater than 2 m (Figure 5c), gillnets were set perpendicularly to the river bank (depending on the proximity to large vessel activities) and retrieved after 24 hours of soak time. Each gillnet had six, 8-m panels of gradually increasing mesh sizes ranging from 2.5 to 10.2 cm bar measure. The depths at which the nets were set are presented in Table 2.

During the walleye spring spawning season of 2006 (April-May), sampling occurred upstream of the AOC to the first fish barrier (Figure 4), primarily at sites with suitable gravel and swift currents, two very important factors which influence the suitability of river spawning (McMahon et al. 1984), but also at some haphazardly selected sites. Depending on accessibility, either boat or backpack electrofishing was used with run times of 15 min. At various times during the spring, a portable spotlight was used at night at several tributary sites (Figure 6) to observe if adult walleye were present in the streams. Standing from a bridge or bank, I scanned the stream for several minutes looking for the reflection from walleyes' eyes.

Captured fish were identified to species, counted, and measured (fork length) to the nearest mm. When 30 individuals of one species were caught at a single site location, measurements were discontinued and only fish counts were recorded. All walleye were weighed, and scale and tissue samples (anterior dorsal fin) were collected for age determination and genetic analysis, respectively. Fin tissue was dried, placed in scale envelopes and sent to DEC Region 9 Fisheries Manager Don Einhouse. Scales samples were collected from behind the pectoral fins, dried and stored in scale envelopes. Walleye ages were determined by magnifying the scales on a projection microscope and counting the number of annuli.

Predatory Impact on Fingerlings—. On the day after walleye fingerlings were released at the stocking location, known walleye predators (walleye, yellow perch, rock bass, largemouth bass and smallmouth bass; McDonnell and Cornwell 2002) were collected for stomach analysis during a 15-min boat electrofishing survey at Site

7 (Figure 5c). Carnivorous fish >100 mm long (total length) were frozen, returned to the lab, and stomach contents were identified qualitatively under a dissecting microscope.

Fish Community

The Buffalo River fish community was examined by replicating protocols described in Makarewicz et al. (1982). Fish surveys were conducted at the same six locations (Sites 1-6, Figure 5c) in 2006 and 1981 (Appendix 1). Two sites were added in 2006, one at the walleye stocking location (Site 7) and the other in Cazenovia Creek (Site 8; Figure 5c), to assess the presence of walleye upstream from the stocking site. Fish were collected by boat electroshocking and gillnets using the methods and during the months described above for adult walleye. Electrofishing differed in the important respects between 1981 and 2006. 1) Different electrofishing units were used and the unit in 2006 was far more efficient than the one used in 1981, which likely produced greater catch rates. 2) The standard unit of effort in 2006 was calculated as the number of fish caught during 15 min of power-on electrofishing, whereas in 1981 it was the number fish caught along 65 m of shoreline. 3) Electrofishing was done at night in 2006 and during daylight in 1981. Night electrofishing has been shown to produce more species, larger individuals, and higher abundance than electrofishing during the day (Johnson and Nielsen 1989). Assuming that fish in both years were caught in relation to their abundance, the general trends in species composition and relative abundance should not be biased. Hence, the communities were compared by percent, not absolute, abundance.

Data Analysis

Zooplankton densities in 2006 and 2007 at sampling sites in the Buffalo River were compared with a paired t-test; the null hypothesis tested was that the mean differences between paired observations is zero ($\alpha = 0.05$). Utilizing Microsoft Excel, a linear regression was calculated for the plot of log weight vs. log length of captured walleye. Predators' stomachs were analyzed by calculating the perrcentages of stomachs which contained walleye. Percent similarity of the 2006 and 1981 fish communities was computed following Brower and Zar (1984). A Sign test used to determine if there was a significant difference in fish communities (1981 vs. 2006) whose percent abundances were greater than 1 %. A two-tailed t-test evaluated the null hypothesis that the Simpson's diversity of the 2006 and 1981 fish communities was not different (Brower and Zar 1984). Water quality parameters were compared using descriptive statistics: mean, standard error, and minimum and maximum values.

Results

Physicochemical Data

From April-October 2006, the average water temperature at sites 1-8 in the Buffalo River was 18.3 ± 0.9 °C (Table 3, Figure 7). The minimum (11.3 °C) and maximum (26.3 °C) temperatures were observed on October 7 and July 15.

The average dissolved oxygen (DO) concentration at sites 1-8 in the Buffalo River was 7.5 ± 0.3 mg/L (Table 3). The minimum DO of 4.3 mg/L was observed on August 19 in the Buffalo Ship Canal (Site 6, Figures 4 & 5c). The highest average DO, 10.9 mg/L, was measured on April 30.

Secchi depths throughout the study period ranged from 0.1-2.1 m (Table 3, Figure 8). On average the secchi depth was 0.82 ± 0.1 m.

pH measurements taken in May and June ranged from 7.5-8.3 with an average of 7.9 ± 0.05 (Table 3, Figure 9).

Potential Spawning Tributaries—. During the spring spawning period in 2007, water temperatures in Buffalo, Cayuga, and Cazenovia Creeks averaged 9.9 ± 0.5 °C (Table 4). On March 26, water temperature averaged 7.4 °C, steadily warmed to an average of 11.2 °C by April 26, and fell to 9.7 °C by April 29 (Table 4). Lake Erie's water temperature on March 26, 2007 was 0 °C and remained at 0 °C through April 14. By April 29, Lake Erie's water temperature reached 1.7 °C (NOAA 2009).

The three streams were well oxygenated, with an average DO concentration of 10.9 ±0.3 mg/L (Table 4) in the spring of 2007. Average DO concentrations ranged from 12.7 mg/L on March 26 to 9.9 mg/L on April 14 (Table 4).

Stream velocities for the three creeks were fairly consistent, with no major rain events. Average stream velocity was 61.0 ± 8.0 cm/sec and ranged from 27.4-79.2 cm/sec (Table 4).

Zooplankton

<u>River—</u>. Zooplankton densities varied greatly from April to June (Tables 5 & 6), as indicated by large mean standard errors. In 2006 and 2007, total zooplankton densities (individuals/L) at the ten Buffalo River sites (Figure 5a) averaged 41/L and 86/L, respectively; the null hypothesis that the mean differences between paired observations is zero was accepted (P = 0.331). During both years the zooplankton community in the river was dominated by rotifers: 31.9 ± 25.4/L in 2006 and 74.4 ± 62.9/L in 2007. In both years, the second most abundant zooplankter was cyclopoid copepods and their nauplii. Cladoceran densities were 2.2 ± 1.0/L in 2006 and 0.4 ± 0.3/L in 2007.

<u>River Mouth—</u>. In 2006 and 2007, mean zooplankton densities from April to June at the two sites at the mouth of the Buffalo River (Z1 and Z2; Figure 5a) were 4.3 ± 2.4/L and 5.2 ± 4.2/L (individuals/L), respectively; the null hypothesis that the mean differences between paired observations is zero was accepted (P = 0.848; Table 5). In both 2006 and 2007, rotifer densities were high, but they were the dominant taxon only in 2007. The dominant taxa at the river mouth were cyclopoid copepods (8.8 ± 7.6/L) and their nauplii (4.3 ± 0.6/L) in 2006 and rotifers (18.4 ± 16.0/L) in 2007 (Table 5). Cladocerans were moderately abundant in 2006 (2.2 ± 2.2/L] but not

in 2007 (0.4 ± 0.4/L. Conversely, calanoid copepods were more abundant in 2007 (2.3 ± 2.2/L) than in 2006 (0.9 ± 0.9/L (Table 5).

Ichthyoplankton

From April 29 through June 23, 2006 32 5-min tows for larval fish were completed at an average speed of 4.3 knots. A linear regression provided by the manufacturer (Appendix 2) was used to determine the volume of water filtered during each tow by the Miller Sampler. An estimated 121.6 m^3 of water was filtered at an average volume of 3.8 m^3 per tow. This effort caught no larval fish. However larval fish, believed to be bluegill and largemouth bass, were observed in the river. The only fishes caught during the larval sampling were sixteen adult emerald shiners on the 8-9 May 2006 (Table 7).

Walleye

2006 Adult Survey—. During the 2006 sampling period, 29 walleye were captured at all AOC survey locations in the Buffalo River (Table 8). Twenty six were caught in the AOC, except site 5 (Figure 10), but none were caught upstream of the stocking location (site 7) or in adjacent Cazenovia Creek. The most productive location was site 2 which produced 13 walleye. One, 1-year old fish was caught near the stocking location on June 14. June (N=9) and July (N=6) were the most productive sampling months (Table 8). During the presumed 2006 post-spawning period, three walleye were caught from May 26-29. Of the three caught, only one (age-3) was old enough to be near maturity (ages 4-5). After examining the plumpness of the body and the size and rigidity of the genital papilla, it could not be determined if this fish had spawned or not.

At the stocking location on June 10, three walleye fingerlings were found (Table 8), which almost certainly were from the previous day's stocking. They were caught during a predator survey; based on their conditions they likely were regurgitated from one or more of the captured predators. These three walleye fingerlings were not included further in the analysis unless stated otherwise.

The dominant age group of captured walleye was age-1 (N=15, Figure 11). Ten of the remaining eleven were ages 2 or 3;only one walleye was older than 4 years. Based on reported ages of maturity (McMahon et al. 1984), only five of the 26 walleye had the potential to be sexually mature. The age-4+ walleye caught in the Ship Canal (site 6) on October 9 was definitely old enough to be sexually mature.

The relationship of walleye log weight to log length was strong ($r^2 = 0.991$, Figure 12). Due to the limitations of the scales used, no weights were obtained for the largest and smallest walleye captured.

Clipped fins from all walleye were given to the NYDEC for genetic analysis but the results are not yet available. After completion of the genetic analysis it should be possible determine if captured walleye were of stocked origin.

2007 Adult Spawning Survey—. From March 30 to April 20, night-time spotlighting in sections of Cazenovia Creek (site 9), Buffalo Creek (sites 15 and 16), Buffalo River (Harlem Road DEC Fishing Access Point), and Cayuga Creek (sites 17, 19, 20) (Figure 6) produced no observations of adult walleye. Prior to spotlighting, backpack electrofishing surveys conducted in Cazenovia (site 9), Buffalo (sites 15 & 16), and Cayuga Creeks (sites 17 & 20) on the 27th and 29th of March also produced no walleye. Once the Buffalo River was accessible by boat, gillnet and electrofishing surveys at reaches 1 through 8 also caught no adult walleye from April 20-21. Beginning on April 26th, and repeated on the 29th, boat electrofishing surveys in the Buffalo River (sites 10 & 12) and Cazenovia Creek (site 9) also caught no walleye. Despite observing spawning temperatures (9.3-11.5 °C), substrate (gravel/cobble), and current (0.37-2.97 m/s) in Cazenovia, Buffalo, and Cayuga Creeks that appeared suitable for walleye spawning, as described by McMahon et al. (1984) and Lowie et al. (2001), no walleye were caught or observed in the spring of 2007.

Predatory Fish Stomach Contents—. Yellow perch, rock bass, largemouth bass, and smallmouth bass are significant predators of stocked walleye in other systems (McDonnell and Cornwell 2002). All four species are abundant in the Buffalo River (Table 9). A total of 32 largemouth bass, seven smallmouth bass, one rock bass, and one yellow perch were caught during the predatory fish survey near the stocking location. The stomachs of 12 largemouth bass, and six smallmouth bass contained 14 walleye fingerings and three unknown species (Table 10). Of the stomachs analyzed, 22% contained walleye fingerlings. Seven walleye fingerlings were found in the stomach of a 353 mm largemouth bass. It is also noteworthy that when the fish were in the live well, three fingerling walleye were regurgitated, making the total stocked walleye fingerlings consumed 17. Other predators captured included walleye, northern pike, and muskellunge.

In 2007 no fish were allowed to be transported from one water body to another in New York State. Since stocked walleye were raised from the NYDEC's Chautauqua Hatchery, no potentially infected brood stock walleye from Cattaraugus Creek were allowed into the hatchery facility. Thus, no walleye were stocked in the Buffalo River and no predator survey was conducted in 2007.

Fish Community: April- October, 2006 vs. 1981

In 2006, 4,269 fish representing 51 species from 14 families were caught; in 1981, 1,049 fish and 32 species from 10 families were caught (Table 9). Twenty-three species of fish captured in 2006 were not captured in 1981; conversely, four species caught in 1981 were not caught in 2006 (Table 9). The four families caught in 2006 but not in 1981 were Petromyzontidae, Lepisosteidae, Atherinopsidae, and Gobiidae (an invasive family not present in Lake Erie in 1981). The difference in total catch was due to electrofishing methodology (see Methods).

Based on percentages of all species caught, the 1981 and 2006 communities were only 48.3% similar (Table 11). However, there was no significant difference ($P > 0.5$, Sign test) between years among the 18 species >1 % abundance in one or both years (redhorse suckers, *Moxostoma* spp., were combined). In sum, despite much greater species richness in 2006, the new species were not abundant enough to distinguish the communities statistically.

Simpson's diversity was 0.910 in 2006 and 0.890 in 1981 (Table 11). These values were statistically different, but a difference of 0.02 has no ecological meaning.

In 2006, Centrarchidae (41.4%), Cyprinidae (20.7%), and Clupeidae (15.4%) were the most abundant families caught (Table 9, Figure 13). Due to the extreme abundance of emerald shiners in the system, this species was not fully counted and is not included in the analysis. If emerald shiners had been fully counted, Cyprinidae likely would have been the most numerous family in 2006. Percidae (7.7%) and Catostomidae (7.6%) were moderately abundant in 2006. In 1981, Cyprinidae was the most prevalent family (36.8%); Catostomidae (18.0%) and Centrarchidae (17.4%) were the next most abundant families (Table 12, Figure 14). Percidae (8.8%), Ictaluridae (8.8%), and Clupeidae (6.5%) also were frequently caught.

The species most commonly caught in 2006 (Figure 15) were gizzard shad (15.3%), largemouth bass (15.1%) and pumpkinseed (14.2%). In 1981, common carp (20.5%), white sucker (16.9 %) and pumpkinseed (11.3%) were the most frequently caught (Figure 16).

Discussion

Are biological conditions in the Buffalo River adequate to support larval and fingerling walleye?

Food supplies—. The critical period for walleye year-class success is the time between the fry and fingerling stages when post-larvae must switch from endogenous (maternal yolk sac) to exogenous (zooplankton) food supplies (Bulkley et al. 1976;

Roseman 1997). When post-larval walleye were given a choice between large- and small-bodied zooplankton, they ate organisms considerably larger than the average size found in samples from their habitat (Haas and Thomas 1997). In New York and Iowa, young walleye in May and June preferred cladocerans and copepods and rarely fed on moderately abundant rotifers and copepod nauplii (Houde 1967; Bulkley et al. 1976). However, Hohn (1966) observed planktonic diatoms to be the first food of pelagic walleye fry in western Lake Erie and Smith and Moyle (1945) observed rotifers to be the most important early food of fry in rearing ponds.

Despite considerable information on post-larval walleye feeding preferences in lakes and ponds, little information is available on their feeding preferences in rivers. Walleye spawn in rivers that are shallow with swift currents; such systems do not typically support large zooplankton populations and walleye fry are quickly transported to a lake after they hatch. The Buffalo River is unique in that it is has a long history of environmental degradation which was compounded by the deepening and widening of the river, increasing residence time for drifting walleye fry.

Haas and Thomas (1997) examined five Great Lakes tributaries (Maumee, Thames, Saginaw, Clinton, and Huron) that share characteristics with the Buffalo River. Based primarily on zooplankton densities, three of the rivers were considered to be potentially productive walleye rivers (Maumee, Thames, Saginaw) and two were considered to have potentially poor conditions (Clinton, Huron). Overall zooplankton densities in the Buffalo River and Harbor (21.8-86.4/L; Table 5) place it in the productive walleye river category (Appendix 3). The three potentially productive walleye rivers had zooplankton densities of 12.2, 6.9, and 4.9/L, respectively, while the potentially unproductive rivers had less dense zooplankton populations (1.5-1.7 organisms/L). Despite higher total zooplankton densities than the productive walleye rivers, I found no walleye fry in the Buffalo River.

Singer et al. (1994) reported that the zooplankton community of the lower Buffalo River on May 29, 1992 was different from a Lake Erie control site but was as diverse as near shore habitats in Lake Erie. Singer et al. (1994) also reported high abundance of Copepoda (range: 25.0/L to 35.6/L) but low abundances of large bodied zooplankton (Appendix 4). In both Singer et al.'s and my studies, total zooplankton densities appeared to be sufficient to support the growth and development of larval walleye but food quality was poor because small-bodied rotifers were the dominant taxon in the Buffalo River (Table 5, Appendix 4). Houde (1967) showed that rotifers in Oneida Lake were rarely consumed by walleye fry.

In late April and early-mid May of 2006 and 2007, densities of large bodied zooplankton were low but those of rotifers were high (Table 5). Cyclopoid nauplii were fairly abundant in the Buffalo River in 2006 (Table 5) but Bulkley et al. (1976) found very few nauplii in the stomachs of walleye fry in Clear Lake, Iowa; despite high abundance, fry ate fewer, larger zooplankton. Roseman (1997) examined the diets of age-0 walleye from Western Lake Erie in 1994 and 1995 and found that calanoid copepods and large bodied zooplankton accounted for nearly 60% of the dry-weight biomass. He found no diatoms or other phytoplankton in age-0 walleye diets, but observed small cladocerans, rotifers and nauplii in walleye stomachs (usually less that 20% of the dry-weight biomass). Prey electivity data (Roseman 1997) strongly suggested that pelagic age-0 walleye in Western Lake Erie in May and June consumed large bodied zooplankton in greater proportion than their presence in the zooplankton community. The information presented above indicates that zooplankton densities in the Buffalo River are high enough to support larval walleye, but the low density of large zooplankton, such as cladocerans, may hinder the growth and development of larval walleye.

Fingerling walleye also have been stocked in the Buffalo River (Table 1). Except for regurgitated stomach contents of predators, I found no evidence of them immediately after stocking in 2006. However, the small numbers of age-0 and 1 walleye I captured may suggest the survival of some fingerlings (or fry—this cannot be determined from my study) after earlier stockings. Fingerling walleye consume small fishes, and there is good evidence for abundant larval and small fishes in the lower Buffalo River. I observed large numbers of adult emerald shiner and gizzard shad spawning in the river. The U.S Fish and Wildlife Service (Kozuchowski et al. 1993) captured large numbers (N = 9,378) of larval fish in the river in May and June, particularly gizzard shad (35-75%) and sunfishes (4-20%) (Appendix 5). Although I did not catch any larval fish in 2006, I did observe schools of juvenile largemouth bass and bluegill along the banks of the Buffalo River by early June 2006, showing that these species use the river for spawning and are also potentially available as food for walleye fingerlings.

In 2006 age-0 emerald shiner abundance increased to near record levels in Lake Erie (Great Lakes Fishery Commission 2006). In the eastern basin of Lake Erie, emerald shiner (70%) and gizzard shad (16%) are the dominant forage fish for walleye (Great Lakes Fishery Commission 2006), consistent with my observations of their availability in the Buffalo River in 2006. It appears that excellent forage fish populations are available for fingerling walleye in the lower Buffalo River and nearby Lake Erie.

Predators—. Successful establishment of a walleye spawning population in the Buffalo River by stocking also depends on fry or fingerlings surviving a post-stocking predator gauntlet in the river. Yellow perch, rock bass, largemouth bass, and smallmouth bass are important predators of stocked walleye (McDonnell and Cornwell 2002); all are abundant in the Buffalo River and were caught near the walleye stocking site (Table 9, Figure 15). I found 14 walleye fingerlings in the stomachs of the 18 largemouth and smallmouth bass sampled, (22% had consumed walleye). Since largemouth and smallmouth bass made up 17% of the fish community in 2006, the potential impact of post-stocking predation on walleye fingerlings is great. One of the major factors limiting the success of other walleye stocking programs, especially with walleye fry, has been predation pressure (Brooking et al. 2001; McDonnell and Cornwell 2002). One strategy to reduce predation on fingerlings walleye has been to stock at night. A study conducted at Oneida Lake, NY reported a 30% reduction in walleye predation after stocking at night, especially by largemouth bass, smallmouth bass and yellow perch (McDonnell and Cornwell 2002).

Are habitat conditions in the Buffalo River consistent with the HSI model for walleye?

Dissolved oxygen—. Walleye typically inhabit water bodies with dissolved oxygen concentrations >3-5 mg/L (McMahon et al. 1984; Lowie et al. 2001), with optimal concentrations for fry >5mg/L (McMahon et al. 1984) During the potential spawning period from March through May, DO at the eight AOC sites in the Buffalo River ranged from 4.3-10.9 mg/L (average: 7.5 ± 0.03 mg/L) (Table 3). DO levels below the NYS guideline (minimum daily average shall not be less than 5.0 mg/L and at no time below 4.0 mg/L) within the dredged portion (AOC; sites 1-6) of the study area have not been reported during these months (Irvine et al. (2005). The one time measurement of 4.3 mg/L is not ideal for fry but is survivable. Also to be considered are the diel fluctuations in DO concentrations, as DO concentrations may dip below the optimal range, especially before sunrise. I measured DO during the day and night and did not find any evidence to suggest DO concentrations in the Buffalo River are not suitable for adult and juvenile walleye.

Temperature—. Einhouse (1994) indicated that water temperatures from 6.7-8.9 °C are important at walleye spawning sites, although walleye have been observed spawning at much lower temperatures in western New York (Lowie et al. 2001). Einhouse (1994) is in agreement with McMahon et al. (1984), who stated that optimal temperatures are 6-9 °C for fertilization and 9-15 °C for incubation. During the anticipated walleye spawning period in the spring of 2007 (March-May), water temperatures from Buffalo Creek, Cayuga Creek, Cazenovia Creek ranged from 7.4-

11.2 °C (average: 9.9 ± 1.4 °C), slightly higher than the optimal range suggested by McMahon et al. 1984. Optimal temperatures were recorded during late March but rose above the literature-based optimal range through April (Table 4). However, Lowie et al. (2001) observed walleye spawning in a tributary of Chautauqua Lake at temperatures near 4 °C on approximately the same dates in 1996 (April 3-22) and 1997 (April 3-19); they suggested that photoperiod rather than temperature maybe the primary cue for the timing of walleye spawning in western New York streams.

Early in life walleye fry require temperatures similar to spawning walleye (8-15 °C). However, the rate of warming in the spring is also an important factor. According to McMahon et al. (1984), steady warming rates of 0.28°C/day are positively correlated with fry production. Spring warming rates in the tributaries of the Buffalo River averaged 0.11 °C/day. Spring warming rates are quite unpredictable and variable from year to year, and this variability is thought to play an important role in walleye recruitment variability (Busch et al. 1975, Einhouse 1994, Madenjian et al. 1996). Many years of data on spring warming rates in the tributaries would be needed to determine variability in the Buffalo River system. Once fry begin to feed independently, optimal temperatures for growth are near 22 °C; such temperatures were never recorded in the Buffalo River and Lake Erie during fry development season (Tables 3 and 4; Figure 7)

Turbidity—. The Buffalo River watershed includes the southern half of the City of Buffalo, the second largest city in New York State, along with the heavily urbanized suburbs of central Erie County. To the south, the watershed is more rural;

there are approximately 904 farms and 55,700 acres of pastureland (USDA 2005). These types of land uses cause significant turbidity from storm water runoff and stream bank erosion (Buffalo Niagara Riverkeeper 2005). During rain events turbidity can reach 1,000 nephelometric turbidity units (NTU), enough to smother fish eggs (Buffalo Niagara Riverkeeper 2005); during dry periods turbidity can be relatively low (<20 NTU) (Buffalo Niagara Riverkeeper 2005). A sechii disc was not used in the Buffalo River tributaries during my spring sampling in 2007 because of their shallow depths. Based on visual estimates, the water clarity was 1-2 m, well above levels that impair walleye feeding ability (McMahon et al. 1984).

High turbidity in the Buffalo River has been suspected of contributing to impairments to fish and wildlife populations (Buffalo Niagara Riverkeeper 2005). Turbid conditions in the river are more likely to impact the feeding success of fry and fingerling walleye than adults. High turbidity in a river system have been shown to reduce reactive distances and foraging efficiency, to cause mechanical damage to gill tissues, and to obstruct interstitial spaces in gravel which reduces water flow and oxygen availability to eggs and fry, ultimately causing them to suffocate (Czesny et al. 2001, as cited by Sharma 2003).

pH—. The optimum pH range for walleye, according to the HSI developed by McMahon et al. (1984), is 6-9. The average pH in the river during the study period, 7.9 ± 0.2), was quite constant and always within the range specified in the HSI.

Substrate—. One of the key requirements for walleye spawning is a substrate of clean gravel or rubble (2.5-5 cm). Spawning success is greatly reduced when eggs are deposited over sand, mud, detritus or bedrock (McMahon et al. 1984). Lowie et al. (2001) only observed spawning walleye over gravel in Dewittville Creek (a tributary of Chautauqua Lake), further suggesting that walleye primarily select spawning habitat based on preferred substrate. In the Buffalo River and tributaries, clean gravel substrate is limited and soil erosion and sedimentation are continuous. The primary substrate of the lower Buffalo River is a gray-black gyttja (Makarewicz et al. 1982). Above the Ogden Street Bridge and below the Thruway Bridge (Figure 4), the sediment is mostly sand and clay with a small proportion of rubble and gravel. Substrate in the tributaries is primarily shale bedrock (e.g., site 20, Figure 4). However, in limited areas with swift current, such as site 16, gravel and rubble mixed with sand are present; these are suitable but not ideal spawning substrates for walleye.

Stream Velocity—. According to McMahon et al. (1984), optimal stream velocity for walleye spawning is 0.6-0.9 m/s and must be sufficient to transport fry downstream within 3-5 days. Instream velocities vary greatly as a result of numerous factors, including measurement locations, habitat types, precipitation, and stream width. From March-May 2007, water velocities averaged 0.61 ± 0.08 m/s and ranged from 0.27- 0.82 m/s. In Dewittville Creek, Lowie et al. (2001) observed spawning walleye at stream velocities of 0 .21-1.05 m/s. In sum, suitable velocities are available for walleye spawning in the Buffalo River and its tributaries.

Physicochemical summary—. Except for a general lack of suitable spawning substrate, it appears that physicochemical conditions in the Buffalo River and its tributaries during the likely walleye spawning and fry migration season are generally in accord with the walleye HSI (McMahon et al. 1984) or observations in another western NYS stream (Lowie et al. 2001). However, physicochemical conditions can vary considerably among years, a major reason why iteroparity is nearly universal among native Great Lakes fishes.

Habitat suitability for walleye fry—. Productive walleye streams cannot be defined only by food supplies (which appear to be adequate for walleye fry and fingerlings in the Buffalo River), by ever-present predators, or by habitat conditions suitable for spawning adults. Habitat suitability for fry and fingerlings in the Buffalo River before they reach Lake Erie is critically important.

Although cover (bank, emergent and submergent vegetation, and wood) was not measured in my study, walleye prefer extensive littoral areas in riverine systems (McMahon et al. 1984). The Buffalo River is a highly altered system with minimal littoral areas due to past channelization and current dredging. Few walleye fry and fingerlings were caught after stocking during my study, perhaps suggesting that the river is not suitable as habitat for fry or fingerlings.

The highest walleye embryo production in streams has been observed on clean gravel and rubble; production is greatly reduced on sand (McMahon et al. 1984). In the lower portion of the Buffalo River, clean gravel and rubble is non-existent; this substrate is rare in upper reaches where sand becomes more abundant. There are limited areas of clean gravel available for a restricted number of spawning walleye, but if numbers of walleye grow intra-specific competition for suitable sites would increase and or walleye would spawn over poor substrates.

Also required in all life stages of walleye is adequate cover (i.e., boulders, logs, brush piles, and submerged vegetation), which is deemed to be ideal at 35-55% (McMahon et al. 1984). Such habitat features are important in all sections of a river because they provide shade, concealment, and orientation (Ontario Ministry of Natural Resources 1997). Past channelization and habitat alteration in the lower Buffalo River have virtually eliminated natural stream processes which would promote the development of natural cover. There is a need to quantify suitable cover in the Buffalo River and its tributaries and to consider restoration efforts.

Are walleye caught in the Buffalo River a result of stocking efforts?

During monthly electrofishing and gillnet surveys from June-October in 2006, 26 walleye were captured; none were caught or observed during night-time electrofishing and spotlight surveys in tributaries during April-May 2007. Only one captured walleye was old enough to be of spawning age but it showed no obvious signs of maturity. My results were consistent with previous studies by the NYDEC and USFWS. Since 2003 the NYDEC has conducted annual electrofishing surveys at broad spatial and temporal scales which have yet to detect spawning-phase walleye (NYDEC 2006). In 1993, Buffalo State College and the USFWS caught many largemouth and smallmouth bass but no walleye after setting hoop nets at the mouth of the Buffalo River (Singer et al. 1994). Makarewicz et al. (1982) captured one walleye during a study that set gills nets and electrofished at 14 sites in the Buffalo River and Inner Harbor each month from March-December. Walleye captures began to increase slightly in 1991 when USFWS reported catching a “few” walleye (Table 13). In 1992 and 1993, the USFWS caught four and eight walleye, respectively (Kozuchowski et al. 1993, 1994). The eight walleye caught from May-July in 1992 were at six river sites and one site in Cazenovia Creek; I caught 21 walleye from May-June 2006 at the same number of river sampling locations.

The small increase in walleye captures over time is interesting in that walleye stocking began 2004. However, Lake Erie walleye populations fluctuate greatly from year to year so the increase could also be a result of good walleye year classes from Lake Erie spilling over into the river. The NYDEC Lake Erie gillnet assessment in 2007 indicated that the overall abundance of walleye was below the long term average, yet the age composition was composed of mostly age 1 (2006), age 2 (2005), and age 4 (2003) walleye (NYDEC 2008). The assessment also indicated that yearling walleye catch rates in 2007 ranked the 2006 year class as above average and the sixth largest in this 27-year time series (NYDEC 2008). It is also interesting that in 1992 three yolk-sac larval walleye were caught at the mouth of the Buffalo River on the 18th of May (Kozuchowski et al.1993) but none were caught up stream. Walleye may have spawned in the river and their larvae were drifting toward the lake or they may have come from the lake by wind driven currents.

Successful populations of river-spawning walleye are genetically adapted to spawn in rivers (Strange and Stepien 2007; Stepien and Faber 1998); this is why the NYDEC stocked the Buffalo River with walleye from Cattaraugus Creek. To determine the origin of the walleye I caught requires genetic analysis. Of the 29 walleye captured in 2006, it is very likely that the three fingerlings were stocked but the origins of the remaining 26 are undetermined. Tissue samples were given to the NYDEC and sent for genetic analysis but no results are available.

Without genetic analysis there can be no certainty about the origin of the walleye captured in the Buffalo River but there is a correlation between their ages and the beginning of the stocking program in 2004. All but one (96.1%) of the captured walleye was between the ages of 0-3. The strongest year classes observed were age-1 (N=15) and age-0 (N=6); both year classes could have been stocked fish. Although there is no evidence of a spawning population, finding a few young walleye in the Buffalo River may indicate that the stocking program is contributing to the slightly increasing captures of walleye in the Buffalo River.

The majority of the western and central walleye populations in Lake Erie mature sexually by age-4 (Madenjian et al. 1996), although Henderson and Nepszy (1994) argue that most females do not spawn until age-5. If this is the situation for walleye stocked in the Buffalo River, adults were not expected to return to spawn until 2008 or 2009, similar to what happened after walleye stocking in Cattaraugus Creek. The stocking of walleye in Cattaraugus Creek began in 1994 but spawning stock was not abundant until 1998 (Appendix 6) (NYDEC 2006). These observations suggest that the DEC's stocking efforts in Cattaraugus Creek may be working but genetic studies revealed no statistically significant evidence that the walleye spawning in Cattaraugus Creek are mostly of stocked origin (Krausse 2002; Wilson 2003; as cited by NYDEC 2006). No walleye were captured by the NYDEC in the

Buffalo River in 2008 and 2009, suggesting that stocking may not be working as it has in Cattaraugus Creek.

Based on previous river stocking programs where walleye fry were used, fry stocking in the Buffalo River may not be the best option. Genetic analysis and comparisons among fry and fingerling stockings have showed that fry contribute little to walleye populations in Iowa rivers (Iowa Department of Natural Resources 2001). However, the drawback in the stocking of fingerlings is that they require more hatchery time and resources which may not be available now but might be an issue that could be addressed in the future.

Has the fish community changed from 1981 to 2006?

Since the biological survey conducted by Makarewicz et al. (1982) there has been much effort to restore the ecological health of the Buffalo River (Buffalo Niagara Riverkeeper 2005). My adult fish surveys were designed to duplicate those of Makarewicz et al. to examine if and how the fish community may have changed after 25 years of remediation efforts in the river. Fish species richness was substantially higher and pollution tolerance was somewhat lower in 2006 than in 1981-82, suggesting that Buffalo River fish community is becoming healthier.

<u>Methodology Issues—</u>. In 2006, 3,851 fish were caught and in 1981 423 fish were caught by electrofishing. This dramatic difference is attributed to three factors: 1) different electrofishing systems (homemade in 1981-82; professionally

manufactured in 2006), 2) differences in fishing effort (distance along shore in 1981-82; 15 min of power on in 2006), and 3) time of day (day in 1981, night in 2006).

The same gillnets were used in 1981-82 and 2006. In 2006, 418 fish were caught; in 1981, 626 were caught. Nets were set at the same locations with the same soak times in both studies. The similarity of total gillnet catches in the two studies further indicates that the dramatic difference in electrofishing catches described above was due to differences in equipment and effort.

Species Caught—. The Buffalo River fish community is a combination of warmwater residents and cool- and coldwater migrants from Lake Erie (Kozuchowski et al.1994; this study). I collected 51 species; 44 were native and seven were introduced /invasive). Makarewicz et al. (1982) reported 32 species (28 native and four introduced/ invasive). NYDEC (1993) (as cited in Kozuchowski et al.1994) reported 24 species in 1984, Adrian and Merckel (as cited in Kozuchowski et al.1994) reported 29 species in 1988, and the USFWS reported 33 and 35 species (larvae and adults) in 1992 and 1993, respectively (Kozuchowski et al. 1994). In all studies, no state or federally listed species were caught.

Between 1982 and 2007 18 additional fish species were reported. Species caught in 2006-07 that were not reported in from 1981-82 were brook silverside, bigmouth buffalo, golden redhorse, greater redhorse, silver redhorse, smallmouth buffalo, spotted sucker, green sunfish, white crappie, alewife, fathead minnow, mimic shiner, rudd, spotfin shiner, striped shiner, channel catfish, longnose gar, johnny darter, logperch, sea lamprey, brown trout, and round goby (Table 9). Of the species listed above, bigmouth and smallmouth buffalo and spotted sucker are the most notable. Both buffalo species inhabit areas of the Lake Erie basin but have not been previously documented in the Buffalo River. The spotted sucker is interesting because until recently very few have been documented in the region. The few specimens that have been documented were from tributaries of Lake Ontario (personal communication, D. M. Carlson, NYDEC, Watertown, NY). The spotted sucker is found in eastern and central North America from the lower Great Lakes east to Pennsylvania (Fisheries and Oceans Canada 2009) but has not been reported in eastern Lake Erie. Due to the rarity of the species there is some concern about misidentification, but the specimen was identified by fellow graduate student Ross Abbett and me using two dichotomous keys. The round goby, from Eurasia, first appeared in the Great Lakes system in 1990 and quickly spread.

Despite the increase in species richness over time, four species caught in 1981-82 were not caught in 2006-2007 (warmouth, trout-perch, Chinook salmon, and coho salmon). Studies following Makarewicz et al. (1982) also found species that were not observed during my 2006-07 study. Adrian and Merckel (unpublished, as cited by Kozuchowski et al.1993) found larval bowfin in 1988. In 1992-93, the USFWS collected burbot, rainbow smelt, river chub, and black bullhead (Kozuchowski et al.1993; Kozuchowski et al.1994). These differing results reflect temporal and spatial variability in fish distributions and sampling.

Qualitative changes—. Understanding improvements in the quality of the Buffalo River fish community depends on the types of fishes present and their relative abundance and pollution tolerance. Fish communities are good indicators of long term water quality and habitat conditions. The fish assemblage in 1981-82 (Figure 16) was composed primarily of species moderately tolerant or tolerant to pollution (Meixler 2006). In 1981-82, common carp (20.5%) and white sucker (16.9%), both pollution- and disturbance-tolerant, were the most common species caught (Figure 16). By 2006-07, the percentages of these tolerant species in fish catches dropped by factors of six and three, respectively (Figure 15). Similarly, the percentage of brown bullhead, another tolerant species, fell from 8.8% to 1.5% (Figure 16, Table 9). These reductions in pollution tolerant species, known for their high tumor and deformity rates in the Buffalo River (Diggins and Snyder 2003), are important signs of a healthier system.

Conversely, in 1981-82 largemouth bass were only 0.4 % of the fish caught; their percentage increased to 15.1% in 2006-07 (Figure 15), the second most abundant species. Largemouth bass are considered to be moderately pollution tolerant but they also provide an important recreational fishery in the Buffalo River. Increasing recreational opportunities in the river is one of the objectives highlighted in the Buffalo River Remedial Action Plan (Buffalo Niagara Riverkeeper 2005). Although their percentages were not much higher in 2006-07 than in 1981-82, another important recreational species more prevalent in the Buffalo River now is the steelhead which begin to migrate into the river in the fall and some remain until spring months. Increases in steelhead are attributed to stocking by the NYDEC.

Conclusions

The economic importance of walleye in the Lake Erie fishery is substantial, providing a significant source of revenue to the states and provinces adjacent to Lake Erie (Great Lakes Fishery Commission 2005). This study helped NYDEC fishery managers better understand the potential the Buffalo River for walleye production.

Through 2009 it does not appear that walleye stocking in the Buffalo River has produced a spawning run, as previous stocking may have done in Cattaraugus Creek. The primary reasons for this appear to be lack of suitable spawning habitat for adults and lack of protective habitat for stocked fry and fingerlings, both in the Buffalo River and its tributaries. It appears that substantial habitat restoration or enhancement will be required to re-establish walleye in the Buffalo River system.

Habitat restoration or enhancement to improve spawning success would include management activities such as ceasing channelization and dredging upstream from the commercial area of Buffalo Harbor, engineering natural stream designs (meanders, plunge pools, riffles, and shoreline protection) and creating artificial spawning areas in tributaries, and using best management practices in the watershed and riparian zones to minimize erosion and reduce sediment loads. Habitat restoration in the lower river will be required to provide for the survival of stocked fry and fingerlings (preferred due to better survival probabilities), including adding bank cover, aquatic vegetation and woody debris, plus creating shallows, for hiding.

My study adds to a substantial, 25-year data set indicating that the long-term health of the fish community in the lower Buffalo River is improving, both in terms of species richness and pollution tolerance (i.e., more, and relatively higher abundance of, less tolerant species). It also provides a solid data set for managers and other stakeholders to evaluate further changes in the Buffalo River and to make decisions regarding its future uses.

Recommendations

1. Before engaging in a major fry or fingerling stocking effort in the Buffalo River, it is important to estimate their survival in two ways.
    a. Cage studies at the release site: How long do fry and fingerlings survive when predators are excluded but zooplankton and fish larvae are not? If the walleye do not survive for at least a few days (the time needed to reach Lake Erie), then inadequate food supplies probably will prevent their successful stocking in the Buffalo River.
    b. Predator impacts: If stocked fish do survive for a few days is cages, how long do they survive after release into the river? Such releases should be done at night followed by immediate and intense sampling for fry, fingerlings and predators. If released walleye are not found for at least a few days, then lack of cover and predator pressure probably will prevent successful stocking of walleye in the Buffalo River. The remaining alternative would be to stock huge numbers of walleye to attempt to overwhelm the functional responses of predators.

2. The Buffalo River Remedial Action Plan (Buffalo Niagara Riverkeeper 2005) addresses the need to protect, conserve, enhance, and restore the aquatic and terrestrial ecosystems associated with the Buffalo River. My study showed that aquatic ecosystem health is improving, as evidenced by greater species richness and lower proportions of pollution-tolerant species over time, but re-establishing walleye almost certainly will require habitat restoration (i.e., bank cover, shallow areas along shore with aquatic vegetation, in-stream wood, etc.) in the lower river to establish adequate cover so that fry and fingerlings have a chance to survive the passage to Lake Erie.
3. The lower Buffalo River and selected sections of its tributaries should be sampled periodically, starting in the spring of 2010, to determine (by genetic analysis if any are caught) if any adults from the 2004-2006 stockings are returning to the river.

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Table 1. NYDEC walleye stocking summary, Buffalo River, NY. Stocking was suspended after 2006 due to NYDEC fish disease policy.

Buffalo River Walleye Stocking Program*

Year	**Fry**	**Fingerling**	**Fingerling Mean Length**
2004 **	105,000	28,200	1.34
2005	61,000	24,900	1.23
2006***	253,000	22,900	1.05

*- All walleye from Cattaraugus Creek Egg Source

**- Surplus of 11,000 fry into Catt. Cr.

***- surplus of 14,000 fry into Catt Cr.

Table 2. Approximate river depths where gillnets were deployed in 1982 biological survey (Makarewicz et al. 1982) and 2006 fish community survey (*added netting sites in 2006).

1981 Buffalo River Biological Survey

Station #	**Depth (m)**
9	[7-8]
10	[7-8]
11	[7-8]
12	[7-8]
13	[2-3]
14	[7-8]

Makarewicz et al. (1982)

2006 Buffalo River Fish Survey

Station #	**Site Name 2006**	**Depth (m)**
9	Reach 1	[6-7]
10	Reach 6	[5.5-7]
11	Reach 2	[6-8]
12	Reach 3	[6-8]
13	Reach 4	[4-7]
14	Reach 6	[4.5-5.5]
	Reach 7*	[1-2]
	Reach 8*	[1-2]

Table 3. Water quality data for the Buffalo River, NY, April-October 2006.

	DO (mg/L)	Temperature (C°)	pH	Secchi (m)
Minimum	4.3	11.3	7.5	0.17
Maximum	10.9	26.3	8.3	1.75
Average	7.5 (±0.3)	18.3 (±0.9)	7.9 (±0.05)	0.82 (±0.9)

Table 4. Water quality data for Buffalo, Cayuga and Cazenovia Creeks, spring 2007.

Date	Temperature (C°)	DO (mg/L)	Stream Velocity (cm/s)
26-Mar-07	7.4	12.7	48.77
27-Mar-07	8.7	10.6	42.67
29-Mar-07	10.6	11.2	33.53
7-Apr-07	11	10.2	79.25
14-Apr-07	10.7	9.9	27.43
26-Apr-07	11.2	10.6	82.3
29-Apr-07	9.7	11	48.77
Average	9.9 (±.5)	10.9 (±.3)	61.0 (±8.0)

Table 5. Comparison of mean (SE) zooplankton densities (individuals/L) during the 2006 and 2007 sampling seasons in the Buffalo River, NY (Z1 through Z10) and at its confluence with Lake Erie (Z1 and Z2).

Taxon	**River06**	**River07**	**Mouth06**	**Mouth07**
Rotifera	31.9 (25.4)	74.4 (62.9)	5.5 (1.7)	18.4 (16.0)
Cladocera	2.2 (1.0)	0.35 (0.3)	2.2 (1.6)	0.4 (0.4)
Calanoida copepods	0.7 (0.5)	1.7 (1.7)	0.9 (0.9)	2.3 (2.2)
Cyclopoida copepods	3.4 (32.2)	4.2 (3.8)	8.8 (7.6)	2.2 (1.8)
Cyclopoida nauplii	2.8 (1.0)	5.7 (3.6)	4.3 (0.6)	1.8 (0.7)
Calanoida nauplii	0.04 (0.03)	0.04 (0.04)	0.05 (0.03)	0.00
Mean total zooplankton	41.0	86.4	21.8	25.1
P (paired t-test)		0.331		0.848

Table 6. Mean zooplankton densities (individuals/L) at the combined Buffalo River, NY sampling sites (Z1 through Z10), spring 2006 and 2007.

	2006				**2007**			
Taxa	**April-29-2006**	**May-17-2006**	**June-10-2006**	**2006 Density**	**May-11-2007**	**May-23-2007**	**June-2-2007**	**2007 Density**
Rotifera	3.9	9.2	82.7	**31.9**	3.5	19.8	199.9	**74.4**
Cladocera	0.8	1.8	4.08	**2.22**	0.07	0	1	**0.4**
Calanoida copepods	0.02	1.6	0.5	**0.7**	0	0.06	4.9	**1.7**
Cyclopoida copepods	0.4	2.05	7.7	**3.4**	0.07	0.7	11.9	**4.2**
Cyclopoida nauplii	1.9	1.8	4.8	**2.8**	1	3.2	12.7	**5.7**
Calanoida nauplii	0.07	0.05	0	**0.04**	0.1	0	0	**0.04**
All Zooplankton	1	2.4	34.3	**9.106**	1.3	6.6	56.7	**21.6**

Table 7. Larval fish catches in the Buffalo River, NY, spring 2006.

Date	**Fish Species**	**#**	**Site # (Figure #)**	**Time of Day**
4/29/2006	None	-	-	Day
4/30/2006	None	-	-	Night
5/1/2006	None	-	-	Day
5/7/2007	None	-	-	Day
5/8/2007	Adult Emerald Shiner (*Notropis atherinoides)*	15	1,5,8	Night
5/9/2007	Adult Emerald Shiner (*Notropis atherinoides)*	1	5	Night
5/10/2007	None	-	-	Day

Table 8. Summary of methods and biological data for juvenile and adult walleye collected in the Buffalo River in 2006-2007.

Buffalo River Walleye

#	Date	Gear	Site	Length (mm)	Weight (g)	Age
1	26-May-06	ES	1	243	140	1
2	28-May-06	GN	1	466	980	3
3	29-May-06	GN	4	241	119	1
4	10-Jun-06	ES	7	31	X	0
5	10-Jun-06	ES	7	32	X	0
6	10-Jun-06	ES	7	33	x	0
7	14-Jun-06	ES	7	300	256	1
8	15-Jun-06	ES	3	257	137	1
9	15-Jun-06	ES	2	264	158	1
10	15-Jun-06	ES	2	237	105	1
11	15-Jun-06	ES	2	446	789	3
12	16-Jun-06	GN	2	461	1076	3
13	16-Jun-06	GN	2	440	836	3
14	16-Jun-06	GN	2	485	1181	2
15	16-Jun-06	ES	1	392	517	1
16	13-Jul-06	ES	2	291	180	1
17	14-Jul-06	GN	2	275	170	1
18	14-Jul-06	GN	2	382	511	2
19	15-Jul-06	GN	4	284	168	1
20	15-Jul-06	GN	4	293	231	1
21	15-Jul-06	GN	4	267	146	1
22	17-Aug-06	ES	6	321	248	1
23	17-Aug-06	ES	6	135	16	0
24	17-Aug-06	ES	2	141	22	0
25	17-Aug-06	ES	2	422	686	2
26	17-Aug-06	ES	2	147	25	0
27	24-Sep-06	GN	2	341	341	1
28	25-Sep-06	GN	4	367	413	1
29	9-Oct-06	GN	6	757	x	>4

ES= Electroshocking GN= Gillnet x= no weight taken

Table 9. List of fish species and their relative abundances in 2006 and 1981 (Makarewicz et al. 1982) in the Buffalo River, NY, April-October.

			Community 2006-2007		**Community 1981-1982**		
Family	**Common Name**	**Latin Name**	**Abundance**	**% Abundance**	**Abundance**	**% Abundance**	**Status**
Atherinopsidae	**brook silverside**	*Labidesthes sicculus*	29	0.68	0	0	N
Catostomidae	**bigmouth buffalo**	*Ictiobus cyprinellus*	1	0.02	0	0	N
	golden redhorse	*Moxostoma erythrurum*	58	1.36	0	0	N
	greater redhorse	*Moxostoma valenciennesi*	1	0.02	0	0	N
	northern hog sucker	*Hypenteium nigricans*	16	0.37	2	0.19	N
	Quillback	*Cariodes cyprinus*	9	0.21	0	0	N
	shorthead redhorse	*Moxostoma macrolepidotum*	16	0.37	10	0.95	N
	silver redhorse	*Moxostoma anisurum*	3	0.07	0	0	N
	smallmouth buffalo	*Ictiobus bubalus*	3	0.07	0	0	N
	spotted sucker	*Minytrema melanops*	3	0.07	0	0	N
	white sucker	*Catostomus commersoni*	215	5.04	177	16.87	N
Centrarchidae	**black crappie**	*Pomoxis nigromaculatus*	6	0.14	4	0.38	N
	Bluegill	*Lepomis macrochirus*	230	5.39	2	0.19	N
	green sunfish	*Lepomis humilus*	1	0.02	0	0	N
	largemouth bass	*Micropterus salmoides*	643	15.06	5	0.48	N
	pumpkinseed	*Lepomis gibbosus*	606	14.2	119	11.34	N
	rock bass	*Ambloplites rupestris*	184	4.31	29	2.76	N
	smallmouth bass	*Micropterus dolomieui*	81	1.9	22	2.1	N
	warmouth	*Lepomis gulosus*	0	0	2	0.19	N
	white crappie	*Pomoxis annularis*	18	0.42	0	0	N

Table 9 cont.

Clupediae	**alewife**	*Alosa pseudoharengus*	2	0.05	0	0	I
	gizzard shad	*Dorosoma cepedianum*	655	15.34	68	6.48	N
Cyprinidae	**bluntnose minnow**	*Pimephales notatus*	211	4.94	2	0.19	N
	common carp	*Cyprinus carpio*	175	4.1	215	20.5	I
	common shiner	*Notropis cornutus*	29	0.68	3	0.29	N
	emerald shiner	*Notropis atherinoides*	*	*	35	3.34	N
	fathead minnow	*Pimephales promelas*	19	0.45	0	0	N
	golden shiner	*Notemigonus crysoleucas*	53	1.24	42	4	N
	goldfish	*Carassius auratus*	10	0.23	49	4.67	I
	mimic shiner	*Notropis volucellus*	2	0.05	0	0	N
	rudd	*Scardinius erythrophthalmus*	4	0.09	0	0	I
	spotfin shiner	*Cyprinella spiloptera*	2	0.05	0	0	N
	spottail shiner	*Notropis hudsonius*	362	8.48	40	3.81	N
	striped shiner	*Luxilus chrysocephalus*	16	0.37	0	0	N
Esocidae	**muskellunge**	*Esox masquinongy*	P	P	2	0.19	N
	northern pike	*Esox lucius*	9	0.21	1	0.1	N
Gobiidae	**round goby**	*Neogobius melanostomus*	31	0.73	0	0	I
Ictaluridae	**brown bullhead**	*Ictalurus nebulosus*	60	1.41	92	8.77	N
	channel catfish	*Ictalurus punctatus*	21	0.49	0	0	N
	stonecat	*Noturus flavus*	P	P	4	0.38	N
Lepisosteidae	**longnose gar**	*Lepisosteus osseus*	2	0.05	0	0	N
Moronidae	**white bass**	*Morone chrysops*	5	0.12	2	0.19	N
	white perch	*Morone americana*	94	2.2	8	0.76	N

Table 9 cont.

Percidae	**johnny darter**	*Etheostoma nigrum*	4	0.09	0	0	N
	logperch	*Percina caprodes*	43	1.01	0	0	N
	walleye	*Sander vitreus*	25	0.59	3	0.29	N
	yellow perch	*Perca flavescens*	256	6	89	8.48	N
Percopsidae	**trout perch**	*Percopsis omiscomaycus*	0	0	2	0.19	N
Petromyzontidae	**sea lamprey**	*Petromyzon marinus*	1	0.02	0	0	I
Salmonidae	**brown trout**	*Salmo trutta*	1	0.02	0	0	I
	Chinook salmon	*Oncorhynchus tshawytscha*	0	0	1	0.1	I
	coho salmon	*Oncorhynchus kisutch*	0	0	1	0.1	I
	lake trout	*Salvelinus namaycush*	1	0.02	1	0.1	N
	rainbow trout	*Oncorhynchus mykiss*	29	0.68	3	0.29	N
Sciaenidae	**freshwater drum**	*Aplodinotus grunniens*	24	0.56	14	1.33	N
		Total	**4269**			**1049**	
		Species Richness	**51**			**32**	

*= Emerald Shiners not included in 2006-2007 tabulation, due to extreme abundance

I= introduced or non native   N= Native

Spotted sucker identification pending confirmation with state rare fish specialist.

Table 10. Stomach contents of predatory fish caught on June 9, 2006 at the Buffalo River, NY stocking location one day after the release of fingerling walleye.

Predator	**Species**	**Stomach**	**Length (mm)**
1	Lmb	NA	376
2	Smb	fish sp.	412
3	**Lmb**	**7- walleye**	**353**
4	Lmb	fish sp.	342
5	Lmb	NA	338
6	Smb	NA	298
7	**Lmb**	**5- walleye**	**286**
8	Smb	NA	195
9	Lmb	NA	315
10	Lmb	NA	257
11	Lmb	fish sp.	210
12	Smb	NA	156
13	**Lmb**	**1 walleye**	**207**
14	**Smb**	**1 walleye**	**150**
15	Smb	NA	142
16	Lmb	Annelida	206
17	Lmb	Crayfish	198
18	Lmb	NA	193

Smb= smallmouth bass
Lmb= largemouth bass
NA= Empty stomach

Table 11. Ecological metrics for fish community comparisons in the Buffalo River, NY, in 2006 and 1981, April-October.

	Electroshocking		**Gillnet**		**1981**	**2006**
	1981	**2006**	**1981**	**2006**	**Community**	**Community**
Sum Total	423	3851	626	418	1049	4269
Simpson's (Ds)	0.882	0.9	0.819	0.871	0.890	0.910
Simpson's t-calc	3.87		4.76		4.304	
Richness	23	47	20	27	32	51
Percent Similarity	55.8		58.1		48.3	

Table 12. Percentages of fish families present in the Buffalo River, NY in 1981 and 2006.

Family Percentages (Ranked in Descending Order)

	2006	**1981**	
Centrarchidae	41.4	36.8	Cyprinidae
Cyprinidae	20.7	18	Catostomidae
Clupediae	15.4	17.4	Centrarchidae
Percidae	7.7	8.8	Percidae
Catostomidae	7.6	8.8	Ictaluridae
Moronidae	2.3	6.5	Clupediae
Ictaluridae	1.9	1.3	Sciaenidae
Gobiidae	0.7	1	Moronidae
Salmonidae	0.7	0.6	Salmonidae
Atherinopsidae	0.7	0.2	Percopsidae
Sciaenidae	0.6	0.1	Esocidae
Esocidae	0.2	0	Atherinopsidae
Lepisosteidae	0.05	0	Gobiidae
Petromyzontidae	0.02	0	Lepisosteidae
Percopsidae	0	0	Petromyzontidae

Table 13. Comparisons among studies of walleye capture in the Buffalo River.

1981-82 (April-October)	1991 (May, July, October)	1992(May-July)	1993 (May-July)	2006-2007(April-October)
Makarewicz et al.1982	NYDEC 1993	USFWS 1992	USFWS 1993	This Survey
		Kozuchowski et al.1993	Kozuchowski et al.1994	
1	“Few”	4	8	29
Gillnets and electrofishing	Electrofishing and seining	Plankton net and electrofishing	Electrofishing	Gillnets and electrofishing

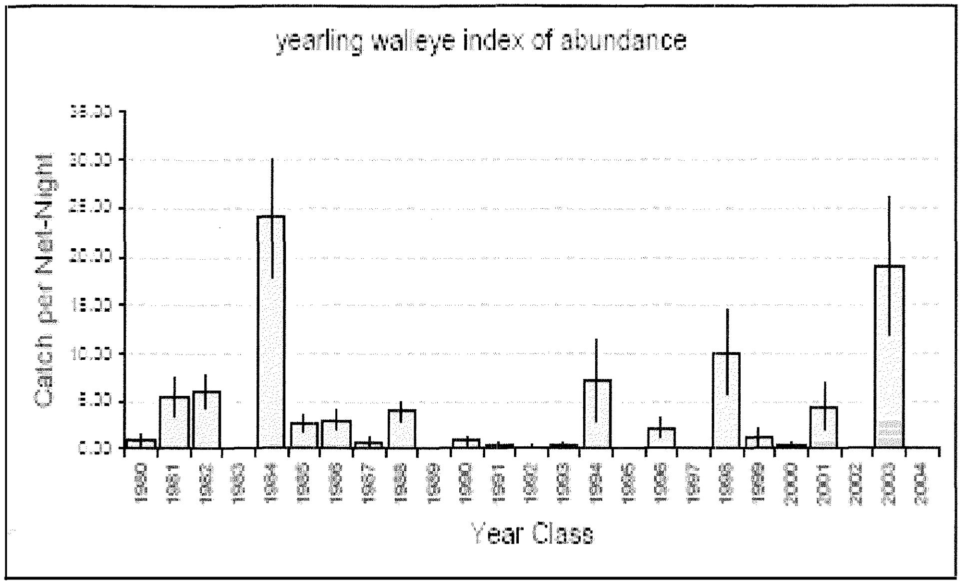


Figure 1. Relative abundance of age-1 walleye collected from the New York waters of Lake Erie, September-October 1981-2005 (NYDEC 2005).

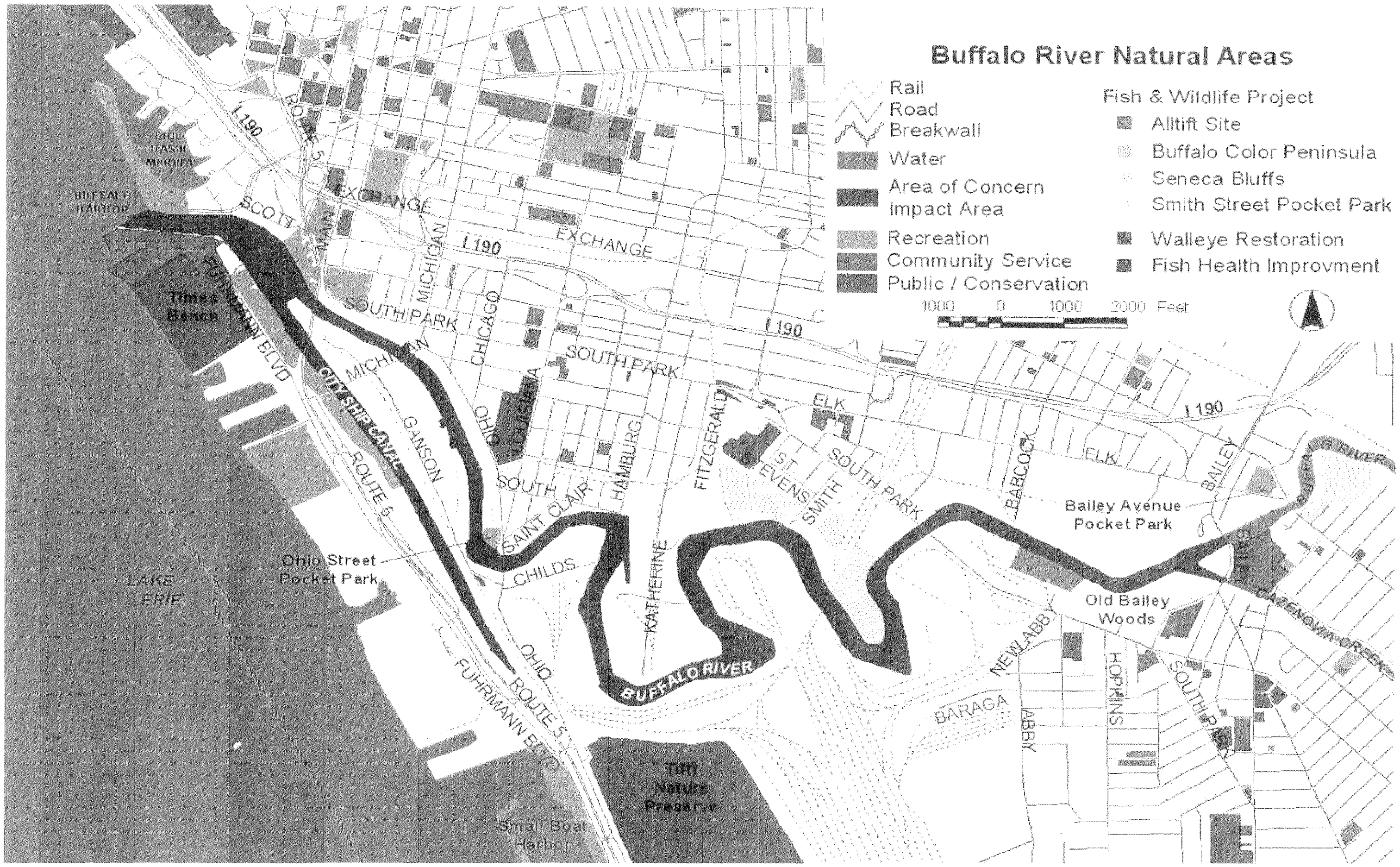


Figure 2. The Buffalo and Niagara River Basin (Buffalo Niagara Riverkeeper 2005).

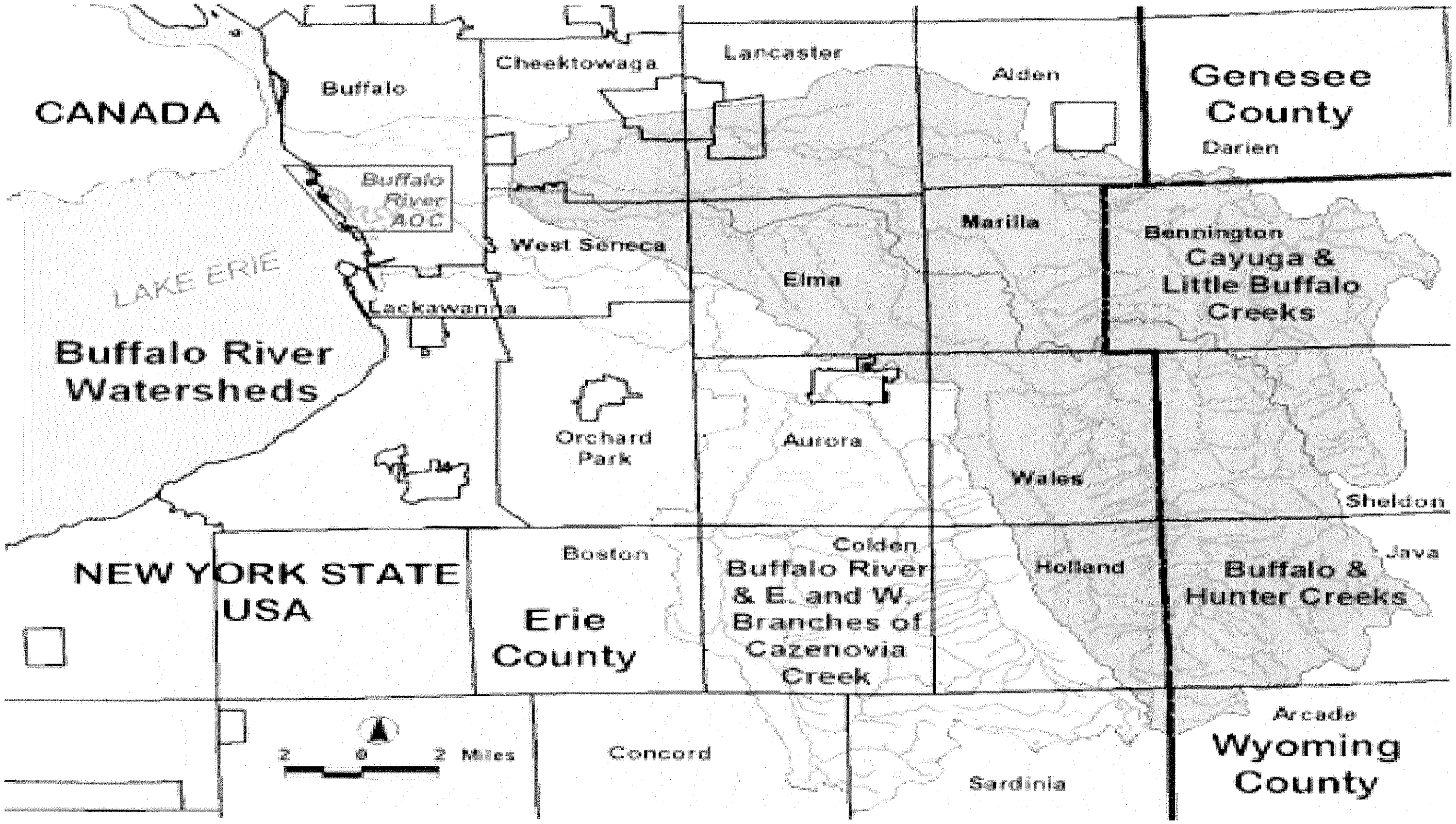


Figure 3. Buffalo River Area of Concern (AOC) (Buffalo Niagara Riverkeeper 2005).

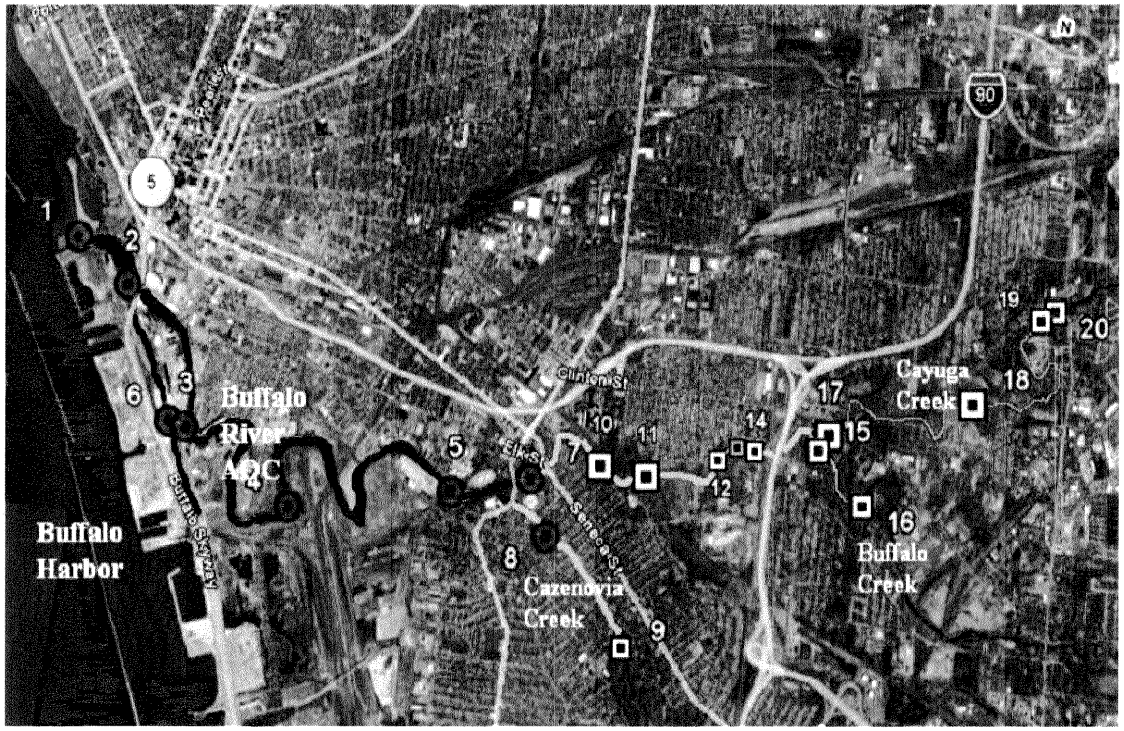


Figure 4. Buffalo River, Cazenovia Creek, Buffalo Creek, and Cayuga Creek fish sampling locations, 2006. Farthest upstream sampling locations: Reach 9: 42°50'59.18"N, 78°48'31.65"W; Reach 16: 42°51'51.97"N, 78°46'46.13"W; Reach 20: 42°52'59.02"N, 78°45'24.26"W.

● = Sites 1-6 (also sampled by Makarewicz et al. 1982); sites 7-8 (additional fish community sampling sites) in 2006.

▣ = 2007 adult walleye sampling sites

5a. Buffalo River zooplankton sampling locations, 2006.

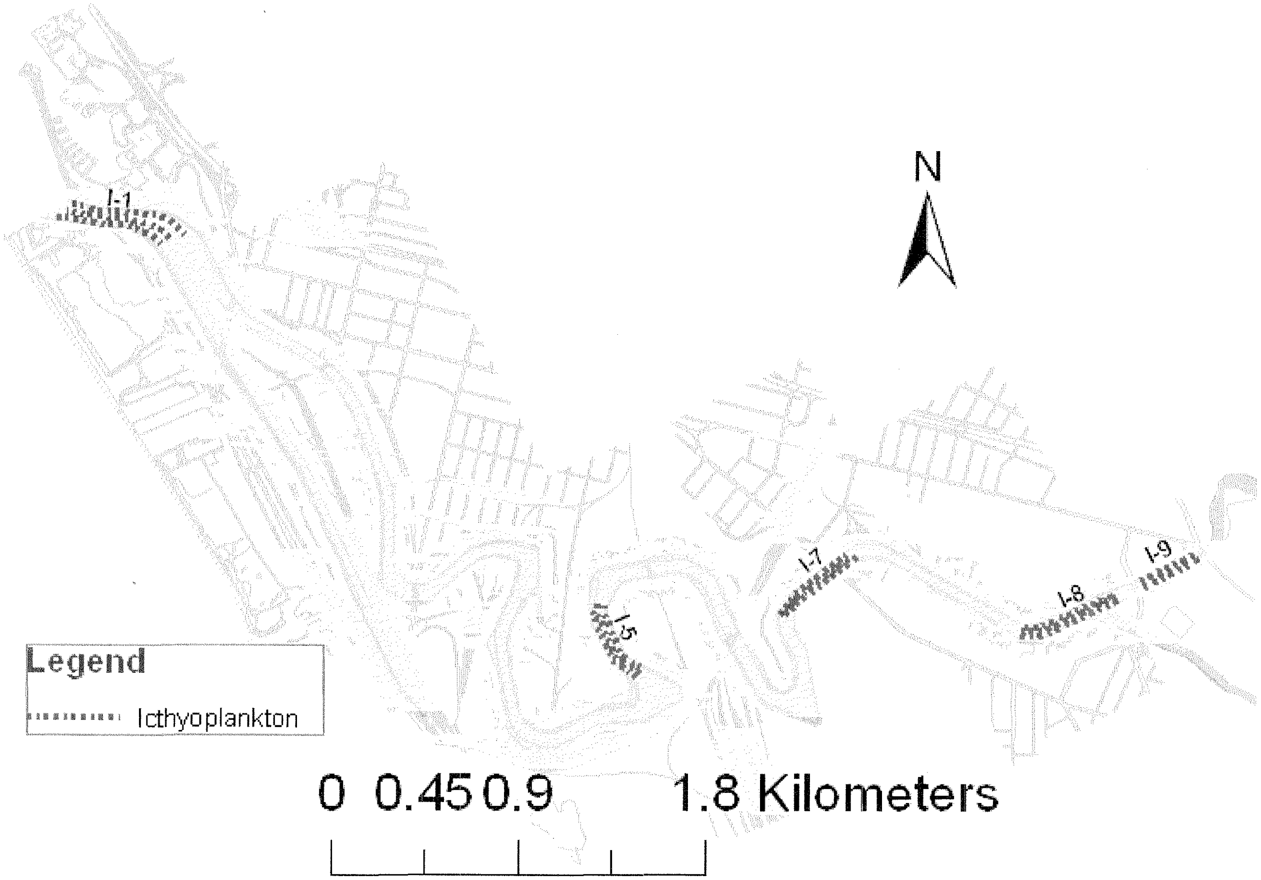


Figure 5b. Buffalo River ichthyoplankton sampling locations, 2006.

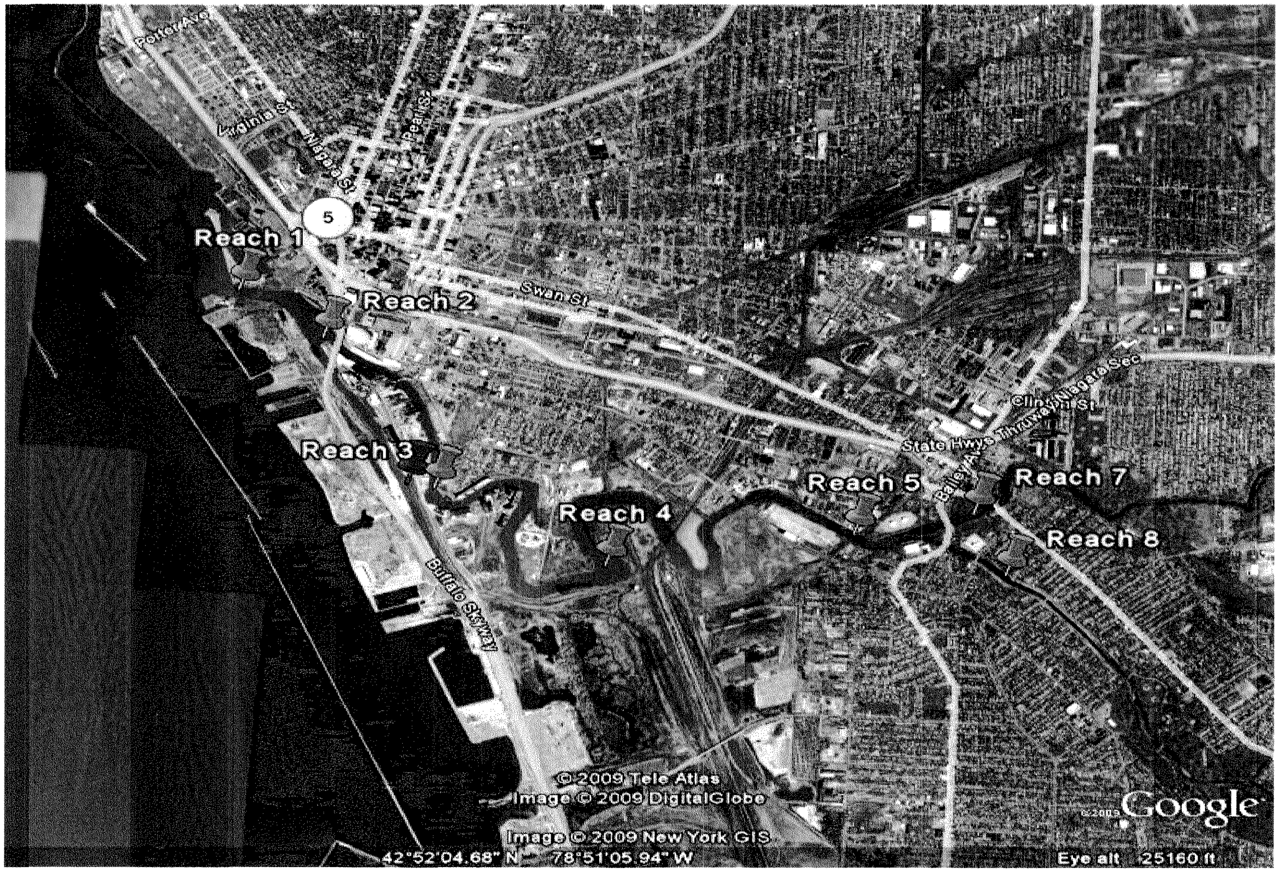


Figure 5c. Buffalo River fish sampling locations, 2006. Sites 1-6 were also sampled by Makarewicz et al. (1982).

Figure 6. Spring 2007 walleye spotlight survey locations: Buffalo River, Cazenovia Creek, Buffalo Creek, and Cayuga Creek.

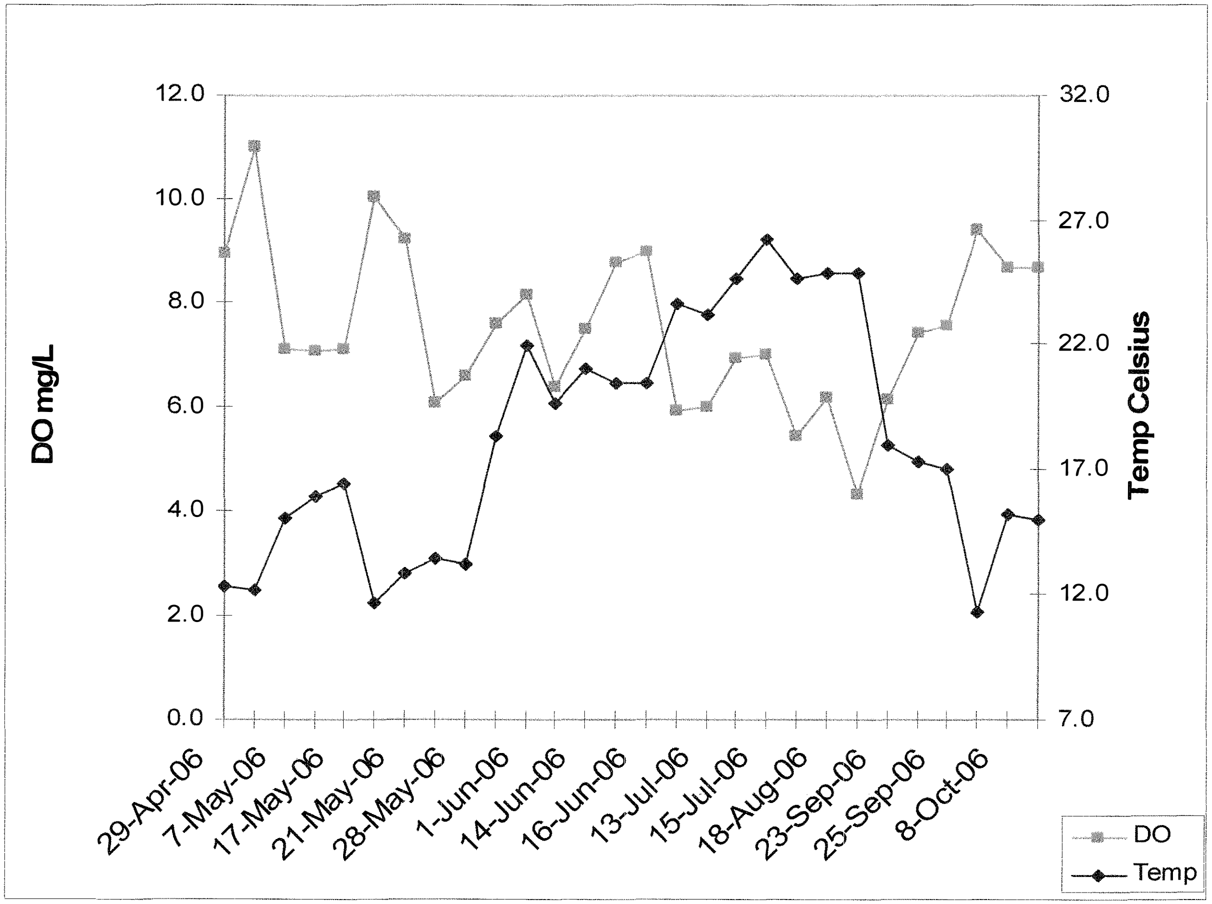


Figure 7. Average water temperature (°C) and dissolved oxygen (mg/L) in the Buffalo River (Sites 1-8), April-October 2006.

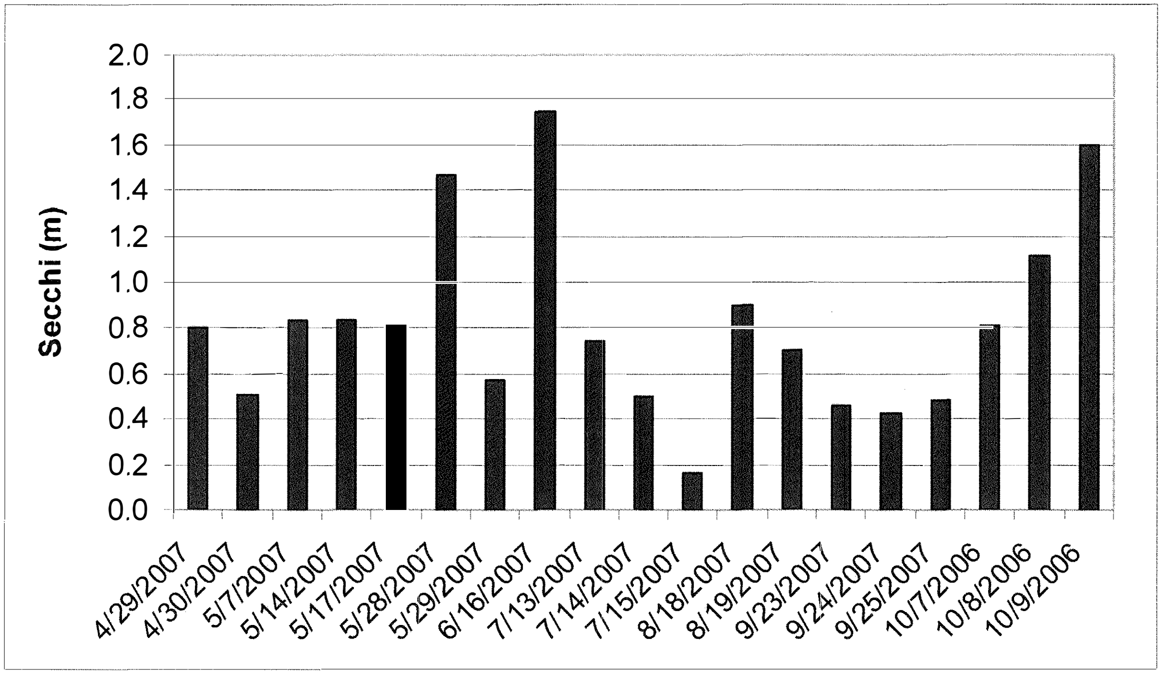


Figure 8. Average secchi depth (m) in the Buffalo River (Sites 1-8), May-October 2006.

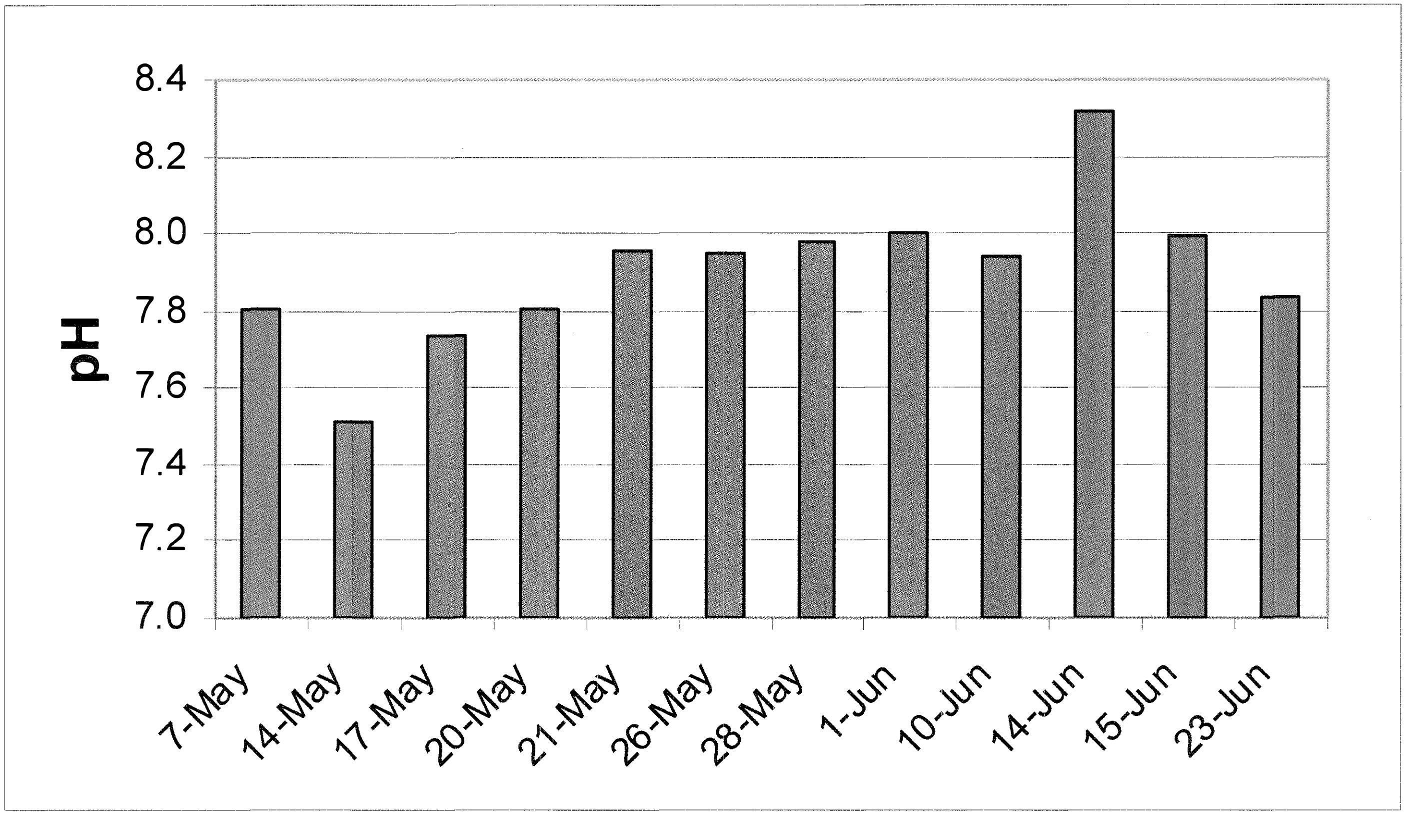


Figure 9. Average pH in the Buffalo River (Sites 1-8), May-June 2006.

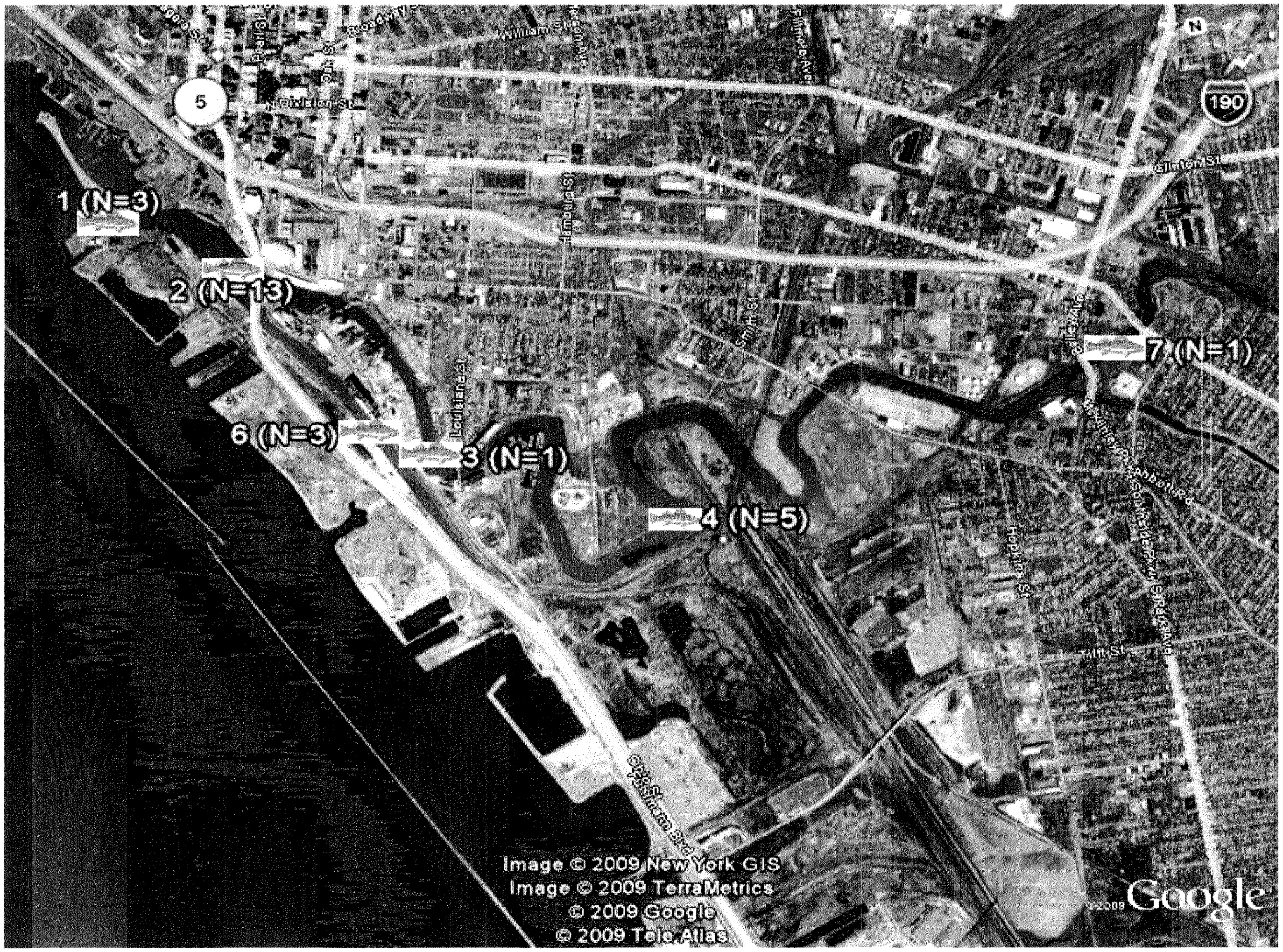


Figure 10. Sites in the Buffalo River in 2006-2007 where walleye were caught. None were caught upstream of site 7.

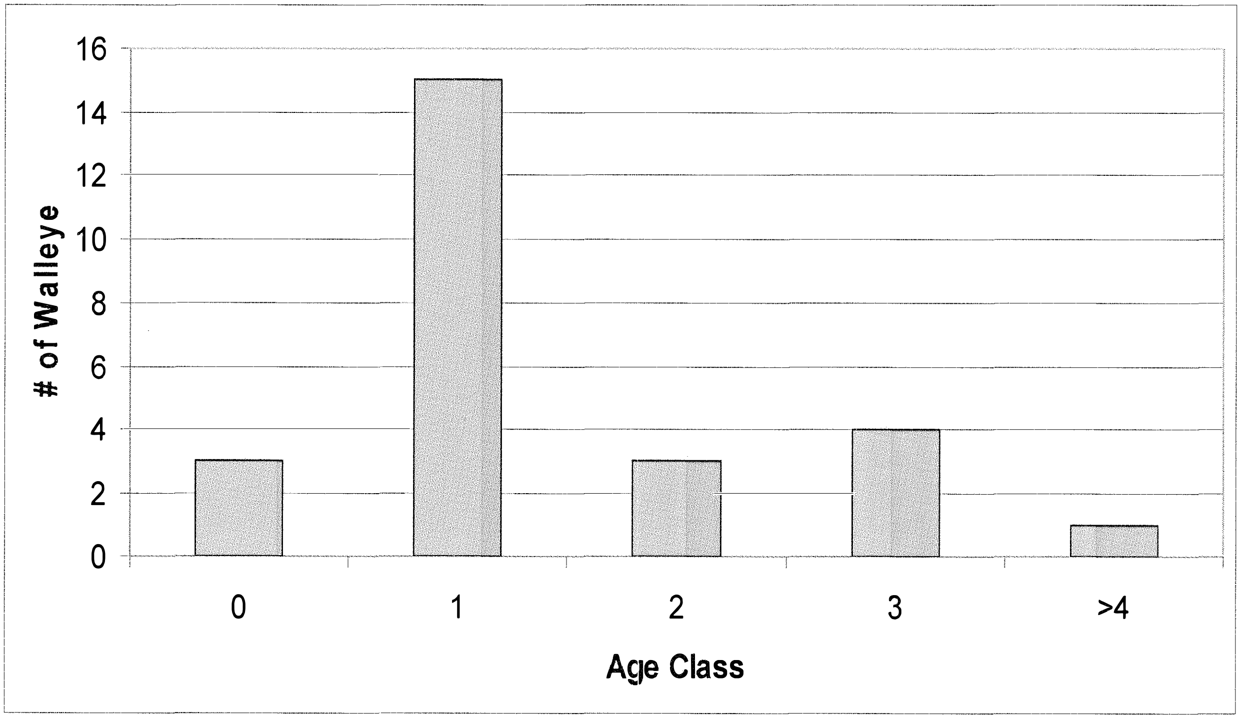


Figure 11. Age distribution of walleye caught in the Buffalo River, 2006-2007 (excluding fingerlings).

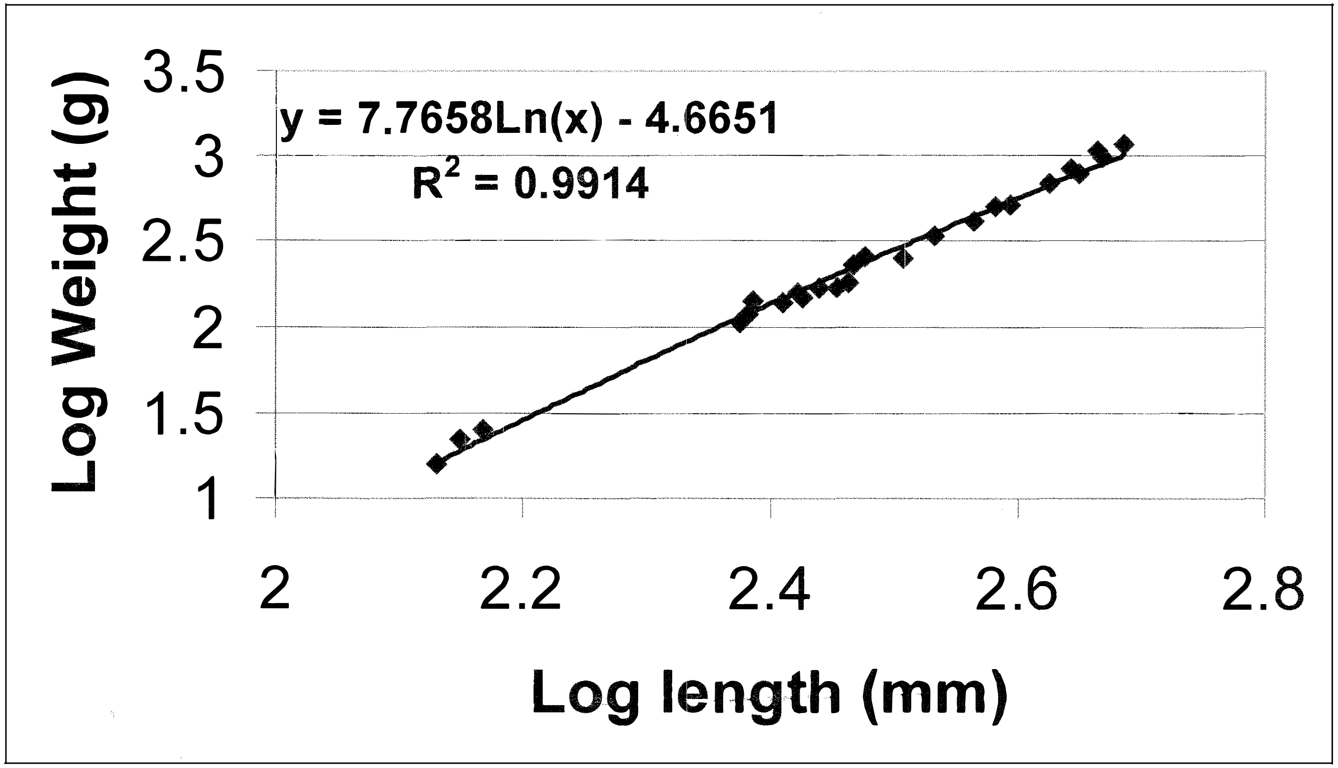


Figure 12. Plot of weight as a function of length for walleye caught in the Buffalo River, 2006-2007.

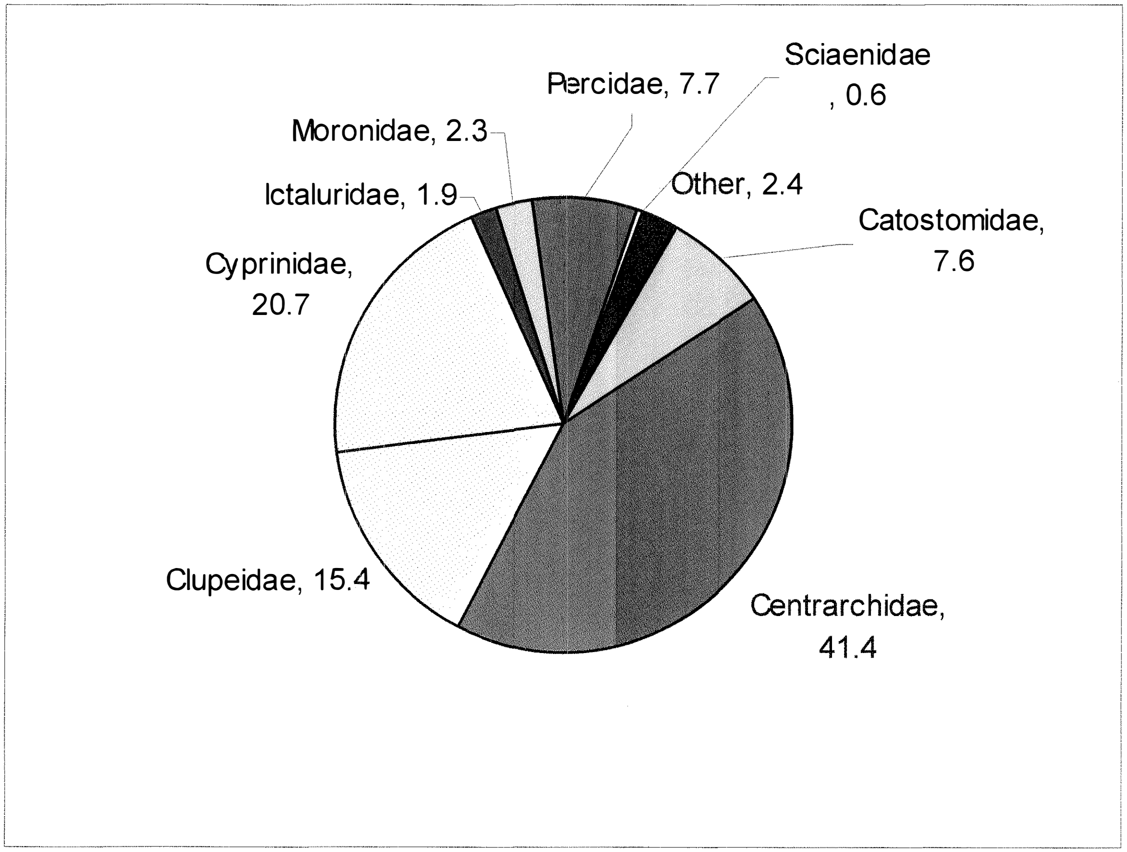


Figure 13. Percent abundance of the major fish families caught in the Buffalo River, NY, April-October 2006.

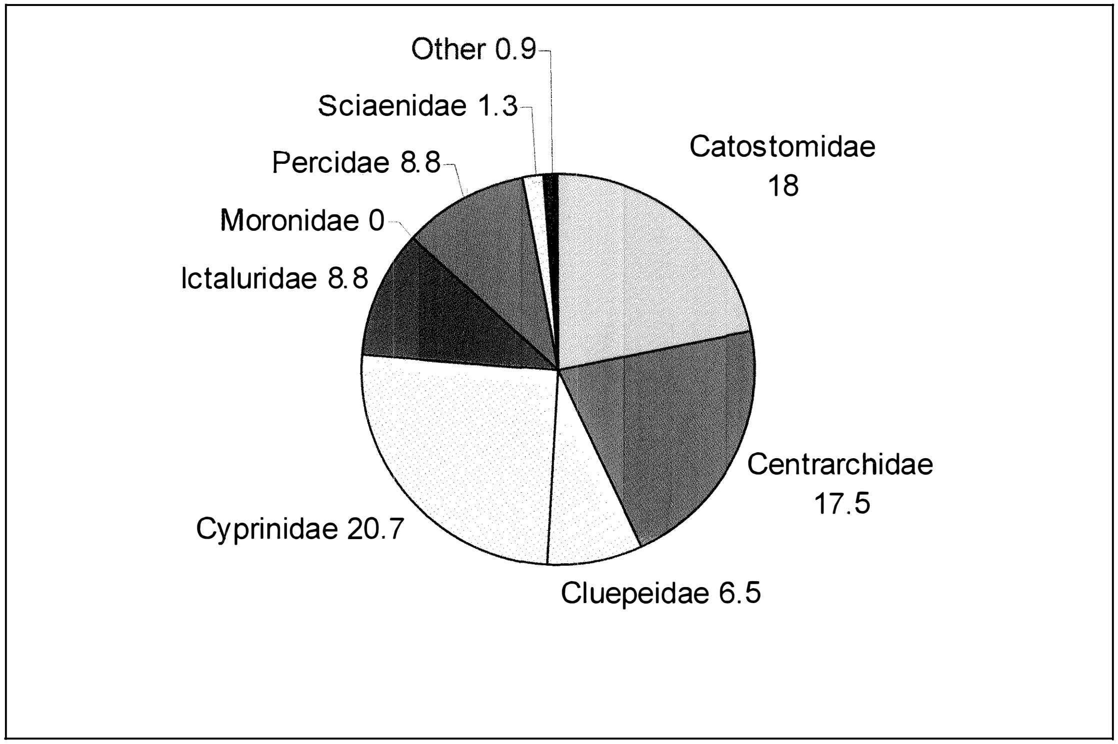


Figure 14. Percent abundance of the major fish families caught in the Buffalo River, NY, April-October 1981.

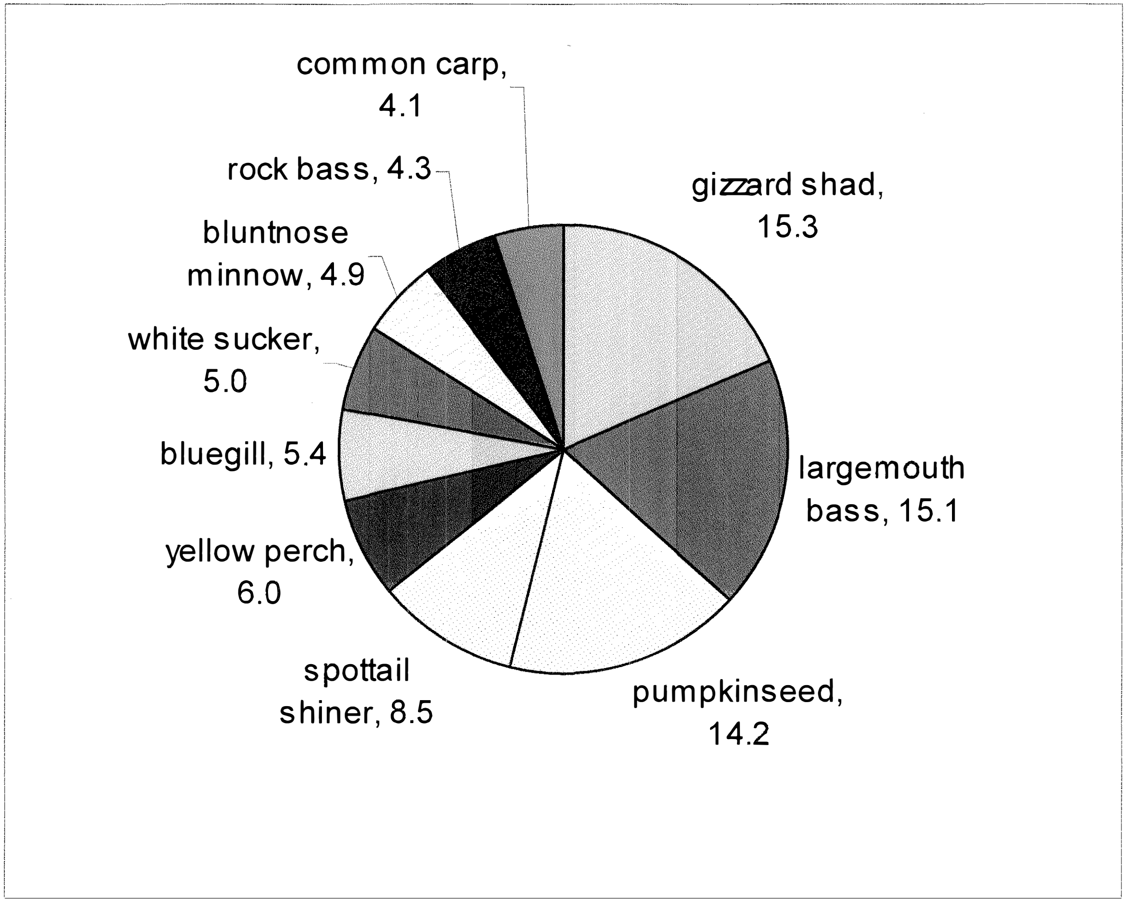


Figure 15. Percentages (>4%) of the most frequently caught fish species in the Buffalo River, NY, April-October 2006.

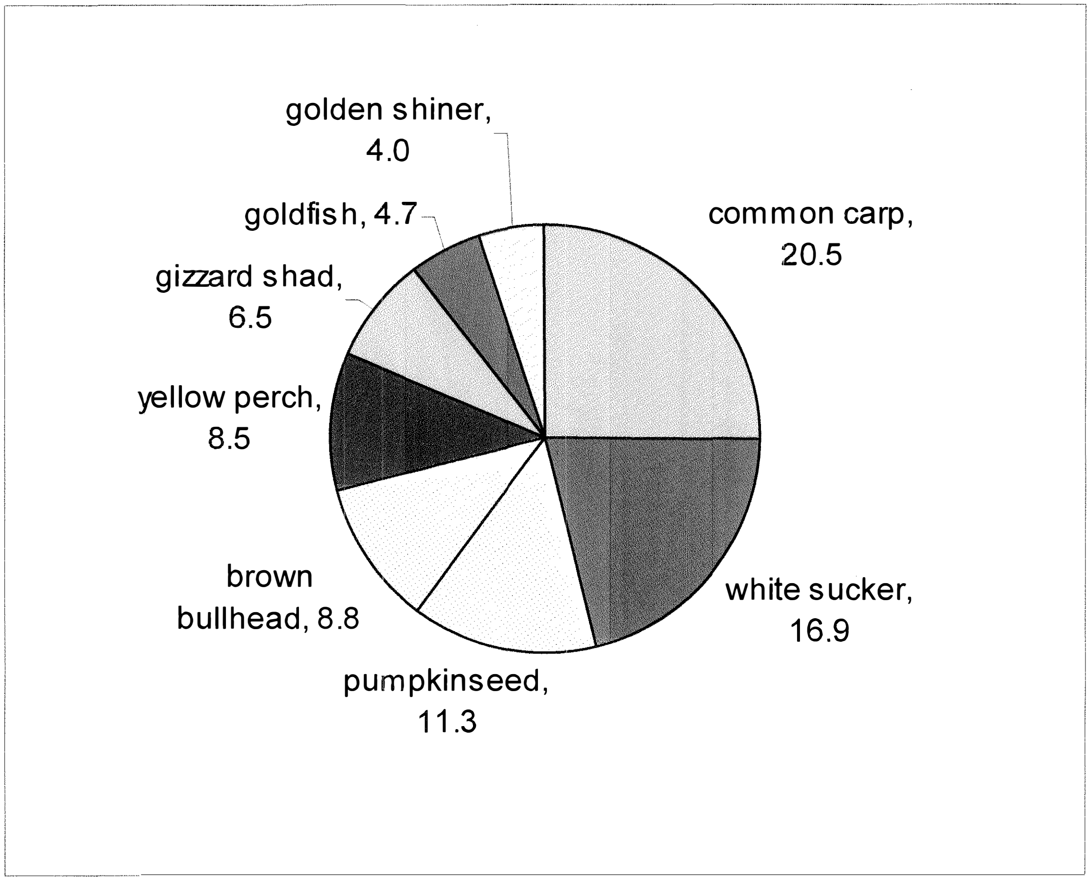


Figure 16. Percentages (>4%) of the most frequently encountered fish species in the Buffalo River, NY, April-October, 1981.

Appendix 1. 1981 biological survey map of the Buffalo River, NY (Makarewicz et al. 1982).

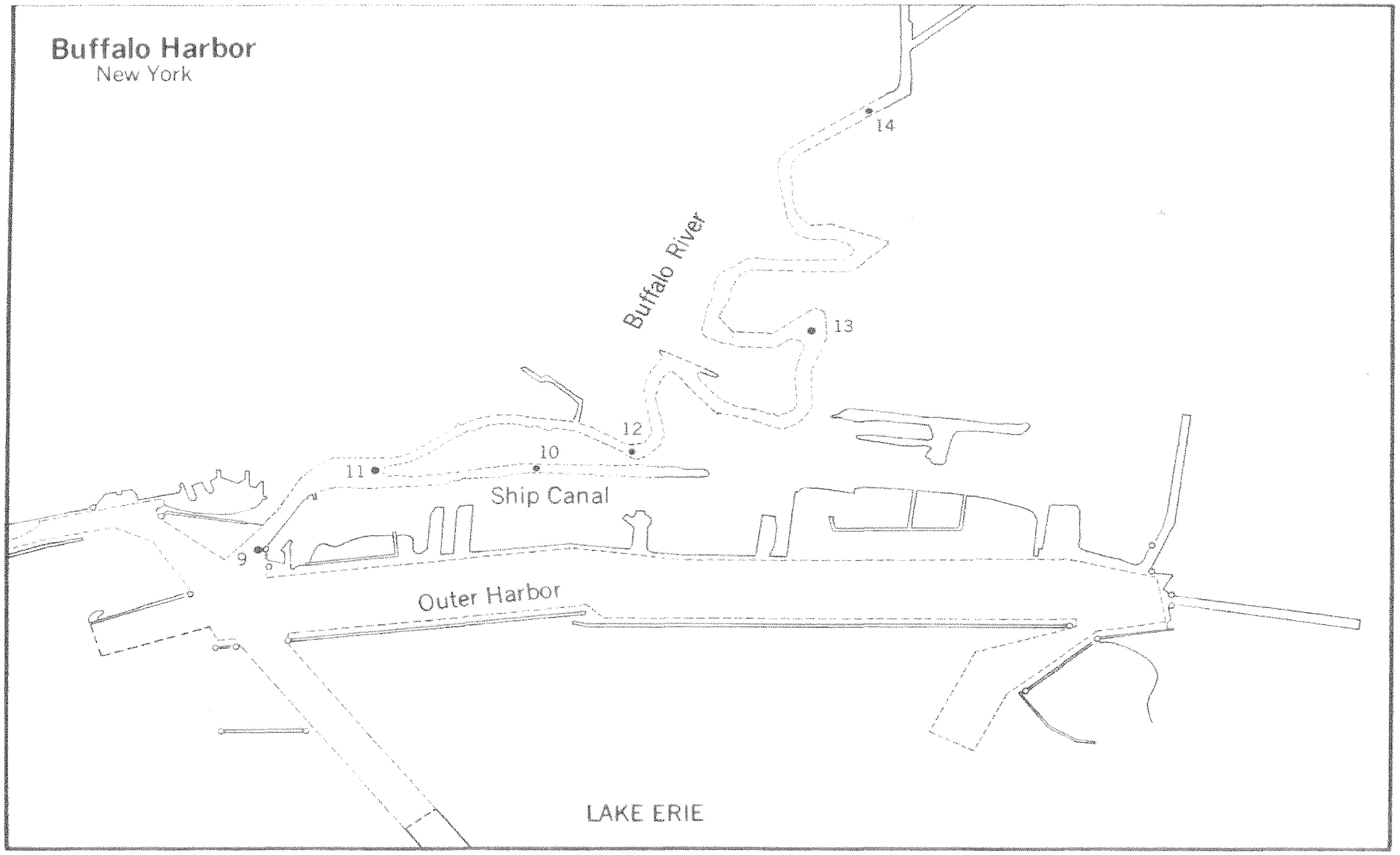


Fig. 1. Location of sampling sites (gill netting and ichthyoplankton) for fish on the Buffalo River and Outer Harbor of Buffalo. Electroshocking was done along shoreline of Stations 2, 3, 5, 6 and 9-14.

Appendix 2. Linear regression of the filtering capacity of Miller samplers, provided by the manufacturer, used to determine volume of water filtered.

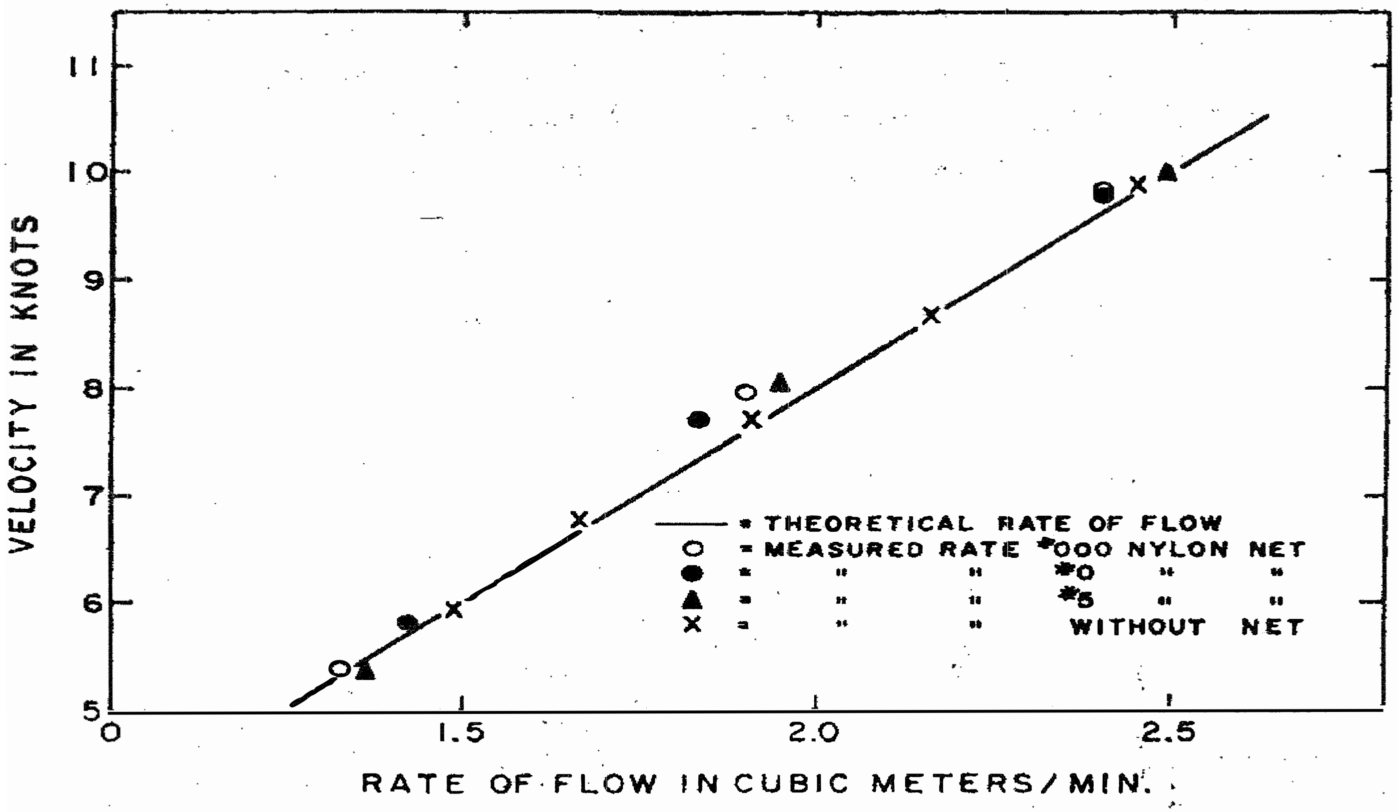


Fig. 2 — Filtering Capacity of Miller Samplers

Appendix 3. Zooplankton data for five Great Lakes tributaries (Haas and Thomas 1997).

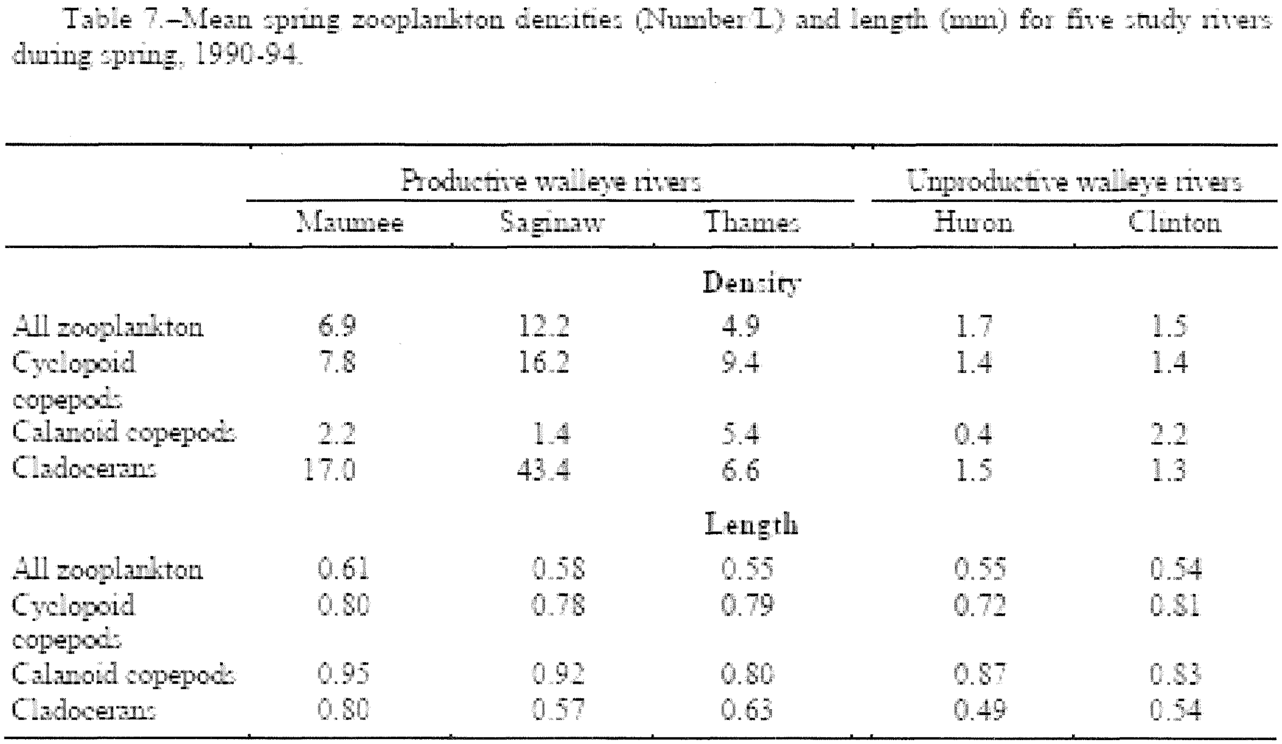


Table 7.–Mean spring zooplankton densities (Number/L) and length (mm) for five study rivers during spring, 1990-94.

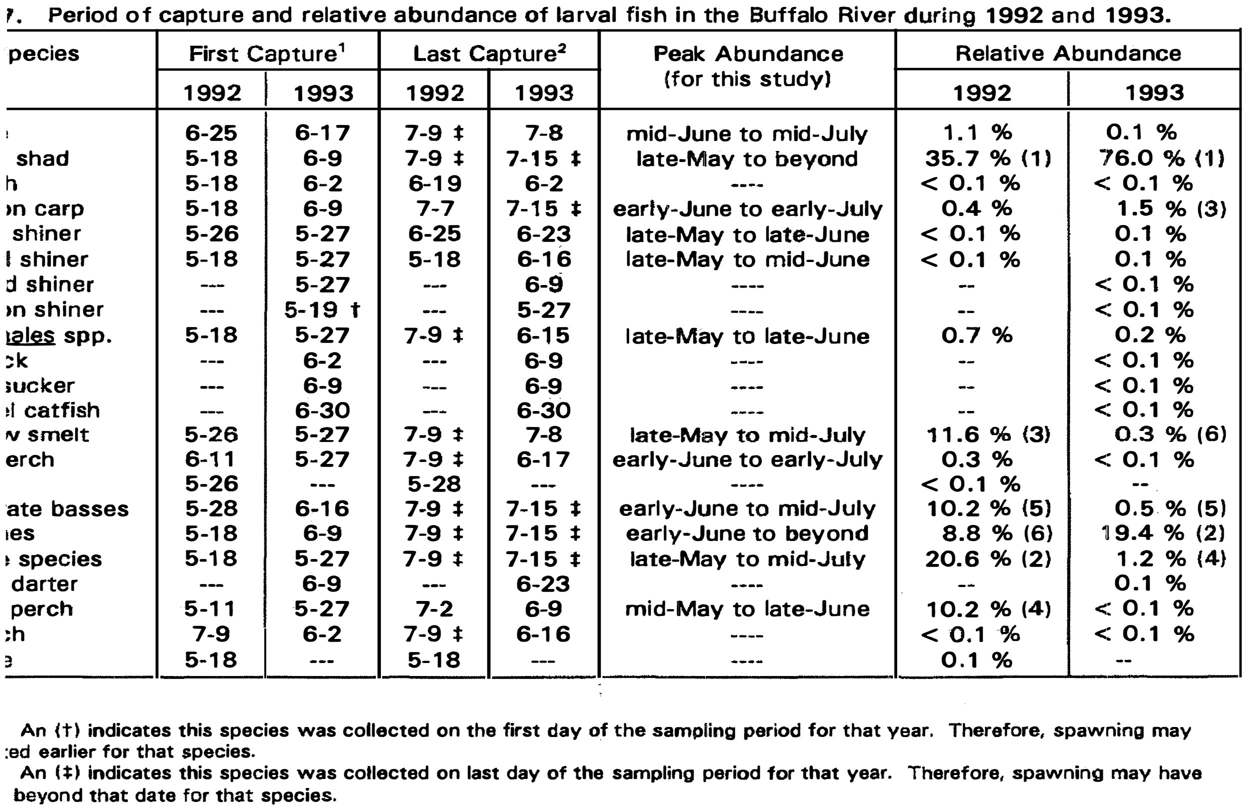
	Productive walleye rivers			Unproductive walleye rivers	
	Maumee	Saginaw	Thames	Huron	Clinton
			Density		
All zooplankton	6.9	12.2	4.9	1.7	1.5
Cyclopoid copepods	7.8	16.2	9.4	1.4	1.4
Calanoid copepods	2.2	1.4	5.4	0.4	2.2
Cladocerans	17.0	43.4	6.6	1.5	1.3
			Length		
All zooplankton	0.61	0.58	0.55	0.55	0.54
Cyclopoid copepods	0.80	0.78	0.79	0.72	0.81
Calanoid copepods	0.95	0.92	0.80	0.87	0.83
Cladocerans	0.80	0.57	0.63	0.49	0.54

Appendix 4. Zooplankton densities (individuals/L) in the Buffalo River. Taken from the U.S Fish and Wildlife 1993 Buffalo River Fish Assessment Summary for May 29, 1992 (Singer et al. 1994).

Zooplankton counts 5/29/92

	con	con	1s	1d	2s	2d	3s	3d	4s	4d
Copepoda	22.8	35.6	2.65	6.55	2.85	4.6	1.85	13.55	0.5	0.25
Daphniidae	0.4	0.5	0	0.05	0	0.55	0.1	0.45	0	0
Bosminidae	1	1.2	0	0.35	0.15	0.85	0.5	1.05	0.1	0.05
Chydoridae	0	0	0	0	0.1	0	3.3	0.1	0.2	0.15
Dreissenid	0.1	0.2	0.25	0.1	0.05	0.05	0	0.05	0	0
Other	0.2	0.1	0	0	0	0	0.05	0.05	0	0
Total	24.5	37.6	2.9	7.05	3.15	6.05	5.8	15.25	0.8	0.45

Appendix 5. Larval fish in the Buffalo River. Taken from the U.S. Fish and Wildlife Service 1993 Buffalo River Fish Assessment Summary (Kozuchowsi et al. 1994).



7. Period of capture and relative abundance of larval fish in the Buffalo River during 1992 and 1993.

pecies	First Capture[1]		Last Capture[2]		Peak Abundance (for this study)	Relative Abundance	
	1992	1993	1992	1993		1992	1993
	6-25	6-17	7-9 ‡	7-8	mid-June to mid-July	1.1 %	0.1 %
shad	5-18	6-9	7-9 ‡	7-15 ‡	late-May to beyond	35.7 % (1)	76.0 % (1)
h	5-18	6-2	6-19	6-2	----	< 0.1 %	< 0.1 %
n carp	5-18	6-9	7-7	7-15 ‡	early-June to early-July	0.4 %	1.5 % (3)
shiner	5-26	5-27	6-25	6-23	late-May to late-June	< 0.1 %	0.1 %
l shiner	5-18	5-27	5-18	6-16	late-May to mid-June	< 0.1 %	0.1 %
d shiner	---	5-27	---	6-9	----	--	< 0.1 %
n shiner	---	5-19 †	---	5-27	----	--	< 0.1 %
ales spp.	5-18	5-27	7-9 ‡	6-15	late-May to late-June	0.7 %	0.2 %
k	---	6-2	---	6-9	----	--	< 0.1 %
sucker	---	6-9	---	6-9	----	--	< 0.1 %
l catfish	---	6-30	---	6-30	----	--	< 0.1 %
v smelt	5-26	5-27	7-9 ‡	7-8	late-May to mid-July	11.6 % (3)	0.3 % (6)
erch	6-11	5-27	7-9 ‡	6-17	early-June to early-July	0.3 %	< 0.1 %
	5-26	---	5-28	---	----	< 0.1 %	--
ate basses	5-28	6-16	7-9 ‡	7-15 ‡	early-June to mid-July	10.2 % (5)	0.5 % (5)
es	5-18	6-9	7-9 ‡	7-15 ‡	early-June to beyond	8.8 % (6)	19.4 % (2)
species	5-18	5-27	7-9 ‡	7-15 ‡	late-May to mid-July	20.6 % (2)	1.2 % (4)
darter	---	6-9	---	6-23	----	--	0.1 %
perch	5-11	5-27	7-2	6-9	mid-May to late-June	10.2 % (4)	< 0.1 %
h	7-9	6-2	7-9 ‡	6-16	----	< 0.1 %	< 0.1 %
e	5-18	---	5-18	---	----	0.1 %	--

An (†) indicates this species was collected on the first day of the sampling period for that year. Therefore, spawning may ted earlier for that species.

An (‡) indicates this species was collected on last day of the sampling period for that year. Therefore, spawning may have beyond that date for that species.

Appendix 6. Walleye caught per electrofishing survey in the lower reaches of Cattaraugus Creek (NYDEC 2006).

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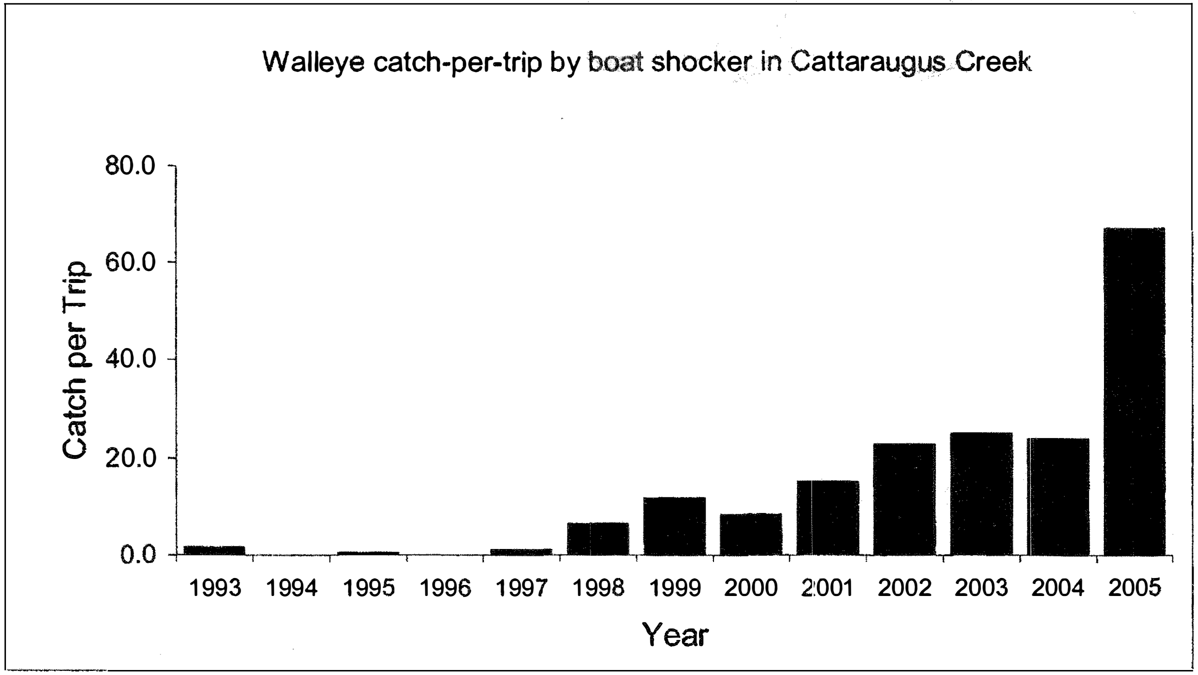

Figure O.1. Walleye catch per sampling trip by boat shocker in the lower reach of Cattaraugus Creek during March - April, 1993 to 2005.