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ARTICLE

Effects of Seasonal Drawdowns on Fish Assemblages in Sections of an Impounded River–Canal System in Upstate New York

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Abstract
The Mohawk River and New York State Barge Canal run together as a series of permanent and temporary impoundments for most of the distance between Rome and Albany, New York. The downstream or lower section is composed of two permanent impoundments, the middle section of a series of temporary (seasonal) impoundments, and the upper section of a series of permanent impoundments. In the middle section, movable dams are lifted from the water during winter and the wetted surface area decreases by 36–56%. We used boat electrofishing during spring 2014 and 2015 to compare the relative abundance of fish populations and the composition of fish assemblages between the permanently and seasonally impounded sections of the Barge Canal and to infer the effects of the two flow management practices. A total of 3,264 individuals from 38 species were captured, and total catch per unit effort (CPUE) ranged from 46.0 to 134.7 fish/h at sites in the seasonally impounded section, compared with 140.0–342.0 fish/h in the permanent lower section and 89.0–282.0 fish/h in the permanent upper section. The amount of drawdown explained 55% of the variation in total CPUE and was a highly significant predictor variable. Mean total CPUE in the seasonally impounded section was significantly lower (by about 50%) than that in either permanently impounded section, and the assemblage composition differed significantly between sections. The relative abundance of many lentic species was markedly lower in the seasonally impounded section, while the relative abundance of several native cyprinids and the percentage of individuals belonging to species that are native to the watershed was greater in this section. Overall, these findings suggest that winter dam removal in impounded rivers may reduce the abundance of fish but may also create more natural riverine conditions that favor some native species.

Riverine ecosystems in developed regions are threatened by many anthropogenic stressors. Of these, damming and the resulting hydrologic modification arguably constitute the single greatest disturbance (Bunn and Arthington 2002; Dynesius and Nilsson 1994; Limburg and Waldman 2009). In North America, the era of constructing large (>15-m-high) dams for flood control, hydropower, and navigation dates back to the New Deal in the 1930s, but the rate of dam development exploded in the 1960s to meet increasing demands for hydropower (Pringle et al. 2000; Haxton and Findlay 2009). In the United States, more than 85% (by area) of inland waterways are artificially controlled (NRC 1992; Poff et al. 1997), and the hydrologic regime of most large rivers has been extensively altered (Benke 1990). The effects of these habitat alterations on fish assemblages include the proliferation of nonnative lentic species and the extirpation of migratory and riverine species that depend on specific lotic habitats (Bunn and Arthington 2002; Poff et al. 1997; Pringle et al. 2000; Haxton and Findlay 2009; Limburg and Waldman 2009).

Although the ecological impacts of permanently impounding large rivers have received ample attention in the literature,

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the effects of temporarily (seasonally) impounding rivers have not been thoroughly documented. Water levels in impoundments are often drawn down in the winter to maximize power generation and to minimize spring flooding (Karchesky and Bennett 2004; Haxton and Findlay 2009). These drawdowns can cause a contraction in the area and volume of habitat available to fish and may adversely affect the quality of off-channel overwintering habitats for some species (Karchesky and Bennett 2004; Haxton and Findlay 2009). For example, Raibley et al. (1997) observed a large winterkill of warmwater fishes in the Illinois River that resulted because declining water levels stranded fish in a backwater. Similarly, Largemouth Bass *Micropterus salmoides* experienced unusually high winter mortality when low water levels prevented access to suitable winter habitat on the upper Mississippi River (Pitlo 1992). Long-term changes to fish assemblages from repeated winter drawdowns may also occur, although such effects have seldom been documented. In one of the few studies to investigate the chronic effects of drawdowns, Haxton and Findlay (2009) noted that populations of littoral benthivores such as Pumpkinseed *Lepomis gibbosus* and Brown Bullhead *Ameiurus nebulosus* were adversely affected by annual winter drawdowns in the Ottawa River. These results were largely attributed to reductions in prey, but the availability of winter refuge to warmwater fishes in riverine environments is also critical. Comparable, but unknown effects may occur in parts of the Mohawk River that were incorporated into the New York State Canal System in 1918 and that experience substantial drawdowns each winter. Historically shallow and free flowing, the river exists today as a series of small impoundments in which water levels are controlled by a series of dams (McBride 1994, 2009). Determining the effects of these alterations on the historical fish assemblage would require precanal baseline data and is beyond the scope of this investigation. Instead, we assessed fish assemblages in temporary (seasonally drawn down) and permanent impoundments of this system during 2014–2015 to determine the current status of these assemblages and to infer the effects of the different flow management practices on the relative abundance of fish populations and the composition of fish assemblages. We also compiled information on the physical characteristics of each impoundment and explored the relationships between these data and the relative abundance of fish to identify confounding factors that might complicate an assessment of drawdown effects.

METHODS

Study area.—The Mohawk River is approximately 257 km long (McBride 1994) and flows south from its headwaters near Boonville to Rome, New York, where it turns and flows eastward, joining the Hudson River just north of Albany. The completion of the Erie Canal (a land cut that ran through the Mohawk River valley) in 1825 created a water linkage between the Great Lakes and Hudson River drainages and enabled the movement of migratory and resident species into the Mohawk River watershed (Mills et al. 1996; Carlson and Daniels 2004; Pimentel 2005). Due to its limited capacity, the Erie Canal was replaced by the New York State Barge Canal in 1918, a canalized river system which transformed most of the east–west portion of the Mohawk River into a series of permanent and seasonal impoundments (McBride 1994, 2009). The focus of this study is the 181.6-km section of the Barge Canal between Waterford (at Lock 6) and Rome (upstream of Lock 20), where the canal, crossing the drainage divide with the Oswego River basin, joins the Mohawk River (Figure 1). The 35.2-km section between Locks 6 and 8 is permanently impounded, the 75.6-km section between Locks 8 and 16 is seasonally impounded, and the 70.8-km section between Lock 16 and Rome is permanently impounded (hereafter referred to as the permanent lower, seasonal, and permanent upper sections, respectively). In the seasonal section, movable dams composed of steel uprights and horizontal plates are lifted after the navigation season (approximately May through early November). When this occurs, water levels drop 1.5–5.8 m and the river becomes free flowing from mid-November to April (McBride 1987, 1994, 2009). The surface area of these impoundments is reduced 36–56% when the dams are lifted, and large areas of the littoral zone are dewatered (McBride 1987). In contrast, water levels generally decrease by less than 1 m in the permanent lower section (McBride 1994) and by 0–2.5 m in the permanent upper section (J. Savoie, New York State Canal Corporation, personal communication) during the nonnavigation season. Although parts of the permanent upper section experience a small to moderate winter drawdown, the habitat remains fairly lentic and little habitat is dewatered.

The physical characteristics of the impoundments vary across a downstream–upstream gradient from larger, wider impoundments in the permanent lower section to smaller, narrower impoundments in the permanent upper section (see Supplementary Table S.1 in the online version of this article). A navigation channel with a minimum depth of 4.3 m is maintained throughout each impoundment, and the percent of the total habitat comprised by the shipping channel increases moving upstream (Table S.1). In some parts of the permanent upper section the Barge Canal and Mohawk River are separate parallel channels, and dam use on the separated sections of the Mohawk River largely controls water levels on adjacent parts of the Barge Canal. Given all of these characteristics, the impoundments in the permanent lower and permanent upper sections are relatively different, their chief similarity being the limited degree of drawdown. The permanent upper section, therefore, serves as a control to separate the confounding effects of differing impoundment characteristics (and natural differences based on watershed position) from those of drawdown.

The Barge Canal supports a diverse fish assemblage that is used extensively by recreational anglers. Historical estimates of fishing pressure between Locks 6 and 16 reached 155 h/ha over a 6-month period in 1982, which caused the study area to rank as one of the most heavily fished waters in New York

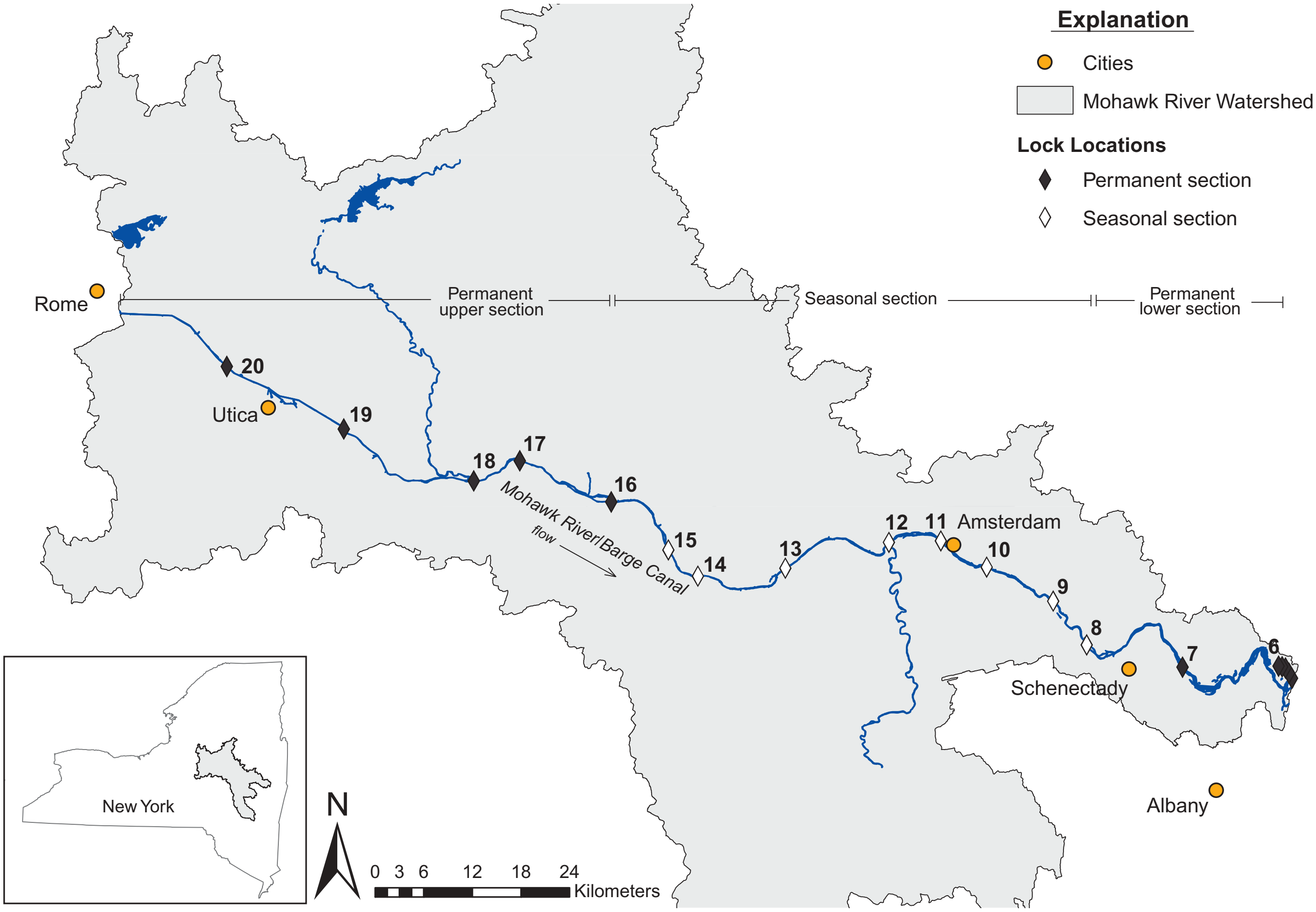

FIGURE 1. Map of the Mohawk River watershed showing the locations of the locks within the three sections of the Barge Canal, New York.

State (McBride 1983). Smallmouth Bass *Micropterus dolomieu* and Walleye *Sander vitreus* are the most popular game fishes among anglers (McBride 1983), but past biological surveys have documented at least 56 fish species within the immediate study area (McBride 1985, 1994, 2009) and as many as 71 fish species may inhabit the greater river–canal system (Carlson 2015). The study area receives annual spawning runs of anadromous Blueback Herring *Alosa aestivalis* during late spring, and their young of the year have been identified as a key component of the forage base for many piscivorous species (McBride 1985). Round Goby *Neogobius melanostomus* are invading the canal system from the Great Lakes drainage, although only one specimen has been captured in the study area to date (New York State Museum, catalog 71439, September 2014). Round Goby populations have had profound impacts on fish assemblages in the Great Lakes drainage and other areas (Corkum et al. 2004), although it is unlikely that they have substantially affected fish assemblages in the study area at this time.

Fish sampling.—Fish assemblages were sampled using daytime boat electrofishing of nearshore habitats during a 2-week period in late May and early June and generally followed the methods described in Miranda and Boxrucker (2009) and Moulton et al. (2002). All surveys used a 4.9-m (16-ft) Smith-Root electrofishing boat applying pulsed direct current at a frequency of 60 Hz. The study area was divided into 24 sites (reaches of river denoted by river kilometers), such that 8 sites were located in each of the three sections (permanent upper, seasonal, and permanent lower), thereby achieving a balanced study design with comparable effort between river sections (Table 1). Identification codes were generated for each site using the first 1–2 letters of the section name (PU, S, or PL) and the numbers of the lower and upper bounding locks (e.g., S8–9). Within each site, generally 2–3 subreaches (sections of shoreline) were sampled to account for the patchiness that is commonly present in fish distributions. Target shocking time at each subreach was 1,200 s but ranged from 900 to 1,800 s in an effort to collect a representative sample while minimizing fish stress during holding and processing (Miranda and Boxrucker 2009). All fish were identified to species and released, with the exception of some individuals that were kept for tissue analysis as part of the New York State Toxic Substances Monitoring Program.

TABLE 1. Site identification code, date sampled, range of river kilometers (measured from downstream to upstream starting at the confluence with the Hudson River), and estimates of total (all species) catch per unit effort (CPUE) and standard errors (SEs) for 24 sites sampled on the Barge Canal, 2014–2015, by river section.

Site ID	Date sampled	River kilometers	CPUE (fish/h)	SE (fish/h)
		Permanent lower section		
PL6-7a	May 27, 2014	3.5–7.9	304.0	8.0
PL6-7b	May 27, 2014	7.9–12.2	342.0	na
PL6-7c	May 26, 2015	12.2–16.6	152.6	2.0
PL6-7d	May 26, 2015	16.6–21.0	208.0	3.6
PL7-8a	May 28, 2014	21.0–25.4	217.3	8.9
PL7-8b	May 28, 2014	25.4–29.9	140.0	5.3
PL7-8c	May 27, 2015	29.9–34.3	262.5	68.3
PL7-8d	May 27, 2015	34.3–38.7	175.5	15.8
		Seasonal section		
S8-9	May 29, 2014	38.7–46.8	134.7	3.6
S9-10	May 29, 2014	46.8–56.4	128.0	11.5
S10-11	May 28, 2015	56.4–63.2	46.0	3.7
S11-12	May 28, 2015	63.2–70.0	101.0	15.7
S12-13	May 30, 2014	70.0–85.5	88.0	9.1
S13-14	May 29, 2015	85.5–98.1	79.0	2.7
S14-15	Jun 2, 2014	98.1–103.5	95.0	2.3
S15-16	Jun 2, 2014	103.5–114.3	67.0	5.2
		Permanent upper section		
PU16-17a	Jun 2, 2015	114.3–120.7	213.0	32.5
PU16-17b	Jun 2, 2015	120.7–127.1	132.0	0.6
PU17-18	Jun 2, 2015	127.1–133.9	89.0	3.0
PU18-19a	Jun 3, 2014	133.9–143.4	218.0	21.0
PU18-19b	Jun 3, 2014	143.4–153.0	154.8	3.7
PU19-20	Jun 3, 2015	153.0–169.5	93.0	6.4
PU20-21a	Jun 3, 2015	169.5–177.3	282.0	7.0
PU20-21b	Jun 4, 2014	177.3–185.1	240.0	16.0

Data analysis.—Ratio estimation was used across subreaches to calculate catch per unit effort (CPUE) and standard errors (Hansen et al. 2007) as fish per hour for each species and the entire assemblage for each site, impoundment, and river section. As a precursor to comparing fish assemblages among the three sections, simple linear regression was used to (1) determine whether there was a significant relationship between drawdown amount and total CPUE and (2) identify other physical impoundment characteristics affecting total CPUE that might confound an analysis of the effects of drawdowns. Analysis of variance (ANOVA) was then used to test for differences in mean CPUE for key species, groups, and the entire assemblage between the three sections, and Tukey's test was used to make pairwise comparisons when significant differences were identified. Additionally, the percentage of individuals that were native to the Mohawk River watershed was determined for each section using the species list in Carlson et al. (2016).

The composition of fish assemblages was evaluated using multivariate techniques with PRIMER-E version 7 software (Clarke and Gorley 2015). Square-root transformed species CPUE data were used to form a resemblance matrix of Bray–Curtis similarities comparing all 24 sites. A nonmetric multidimensional scaling ordination and analysis of similarities (ANOSIM) were used to test the null hypothesis that species assemblages did not differ between the three sections (Clarke et al. 2014; Clarke and Gorley 2015). Although the ANOSIM test produces a *P*-value, the value of the *R*-statistic is considered more important for assessing differences between groups (Clarke and Gorley 2015). An *R*-value of >0.75 indicates well-separated groups, whereas an *R*-value of 0.50–0.75 indicates separate but abutting or slightly overlapping groups and an *R*-value of 0.25–0.50 indicates distinguishable but overlapping groups (K. R. Clarke, Plymouth Marine Laboratory, personal communication; Ramette 2007). When the ANOSIM test found significant differences among sections, the similarity percentages (SIMPER) technique was used to identify the species that contributed most strongly to the observed differences (Clarke and Gorley 2015). Blueback

Herring (662 adults and 1 juvenile) were excluded from all analyses because they are a migratory species that were sporadically encountered in large schools and their inclusion would bias an assessment of resident assemblages. The results for all statistical tests were considered significant at α = 0.05.

RESULTS

Electrofishing surveys collected a total of 3,264 individuals from 38 species; Smallmouth Bass was the only species captured at all 24 sites. Approximately 49% of the individuals captured were species native to the Mohawk River watershed. Total CPUE (all species) was 165.7 fish/h during the 2014 surveys and 150.1 fish/h during the 2015 surveys. Because the annual catch rates were similar, all data from both years were analyzed together.

Simple linear regressions between total CPUE (calculated for each impoundment) and physical impoundment characteristics indicated that the amount of drawdown was the primary driver of total CPUE (Table 2). Drawdown was a highly significant predictor variable (F = 15.6, P = 0.002) and explained 55% of the variation in total CPUE. Impoundment area approached significance (F = 3.8, P = 0.074) but only explained 23% of the variation in total CPUE, while elevation change at the lower bounding lock (approximate dam height), percent shipping channel, and river kilometer were not significant predictor variables and explained little of the variation in total CPUE.

Catch per Unit Effort by River Section

Total CPUE ranged from 46.0 to 134.7 fish/h at sites in the seasonal section, compared with 140.0–342.0 fish/h in the permanent lower section and 89.0–282.0 fish/h in the permanent upper section (Table 1; Figure 2). The differences in mean total CPUE between river sections were highly significant (ANOVA; F = 9.8, P = 0.001), and mean CPUE at the sites in the seasonal section (92.3 fish/h) was significantly lower (Tukey's test; P < 0.05) than at the sites in the permanently impounded lower section (225.2 fish/h) and permanently impounded upper section (177.7 fish/h; Table 3). Of the 38 species captured, only 5 had their greatest CPUE in the seasonal section (Table S.2). The remaining 33 species were captured at an equal or greater rate in one of the two permanently impounded sections and included lentic fishes like Pumpkinseed, Bluegill *Lepomis macrochirus*, Largemouth Bass, Rock Bass *Ambloplites rupestris*, and Yellow Perch *Perca flavescens* as well as a number of species that are well adapted to large riverine habitats, such as Smallmouth Bass and Walleyes. The low relative abundance of Yellow Perch and "other centrarchids" (members of the family Centrarchidae excluding Smallmouth Bass) at sites in the seasonal section is particularly noteworthy. The CPUE for many species (even within a particular river section) was highly variable, however, which reduced the power of the statistical comparisons. Despite this, mean CPUE for several species and groups differed significantly between river sections (Table 3).

TABLE 2. Results of simple linear regressions between five predictor variables and total catch per unit effort (CPUE) for each impoundment. Significant P-values are shown in bold italics.

Predictor variable	F-value	P-value	R^2
Drawdown amount (m)	15.6	***0.002***	0.5455
Impoundment area (km^2)	3.8	0.074	0.2256
Elevation change at lower bounding lock (m)	2.4	0.148	0.1543
Percent shipping channel	0.3	0.577	0.0246
River kilometer at lower bounding lock	0.0	0.960	0.0002

Assemblage Composition by River Section

Fish assemblages from sites in the seasonally impounded section grouped separately in the ordination, while sites from the two permanently impounded sections exhibited some overlap (Figure 3). A one-way ANOSIM test confirmed that fish assemblages differed significantly by river section (R = 0.463, P = 0.001). Pairwise comparisons showed that fish assemblages from the two permanently impounded sections differed more from the seasonal section than from one another. The relatively large R-values between the seasonal section and each of the permanently impounded sections indicate substantial differences in fish assemblages. In contrast, the small R-value comparing the two permanently impounded sections suggests that fish assemblages differed minimally between these sections (Figure 3). The SIMPER analysis indicated that Brown Bullhead, Rosyface Shiners *Notropis rubellus*, and Bluegills were the species that most discriminated between the permanent lower and seasonal sections, contributing 20.3% of the overall dissimilarity. The relative abundance of Brown Bullhead and Bluegills was greater in the permanent lower section, while the relative abundance of Rosyface Shiners was greater in the seasonal section. Yellow Perch, Rock Bass, and Spotfin Shiners *Cyprinella spiloptera* were the most discriminating species between the permanent upper and seasonal sections, contributing 23.9% of the overall dissimilarity. The relative abundances of Yellow Perch and Rock Bass were greater in the permanent upper section, while the relative abundance of Spotfin Shiners was greater in the seasonal section.

Approximately 44% of the individuals captured in the permanent lower section were species native to the Mohawk River watershed, compared with 57% in the seasonal section and 48% in the permanent upper section. High relative abundances of a number of native cyprinids in the seasonal section, such as Fallfish *Semotilus corporalis*, Rosyface Shiners, and Spotfin Shiners were largely responsible for this finding (Table S.2).

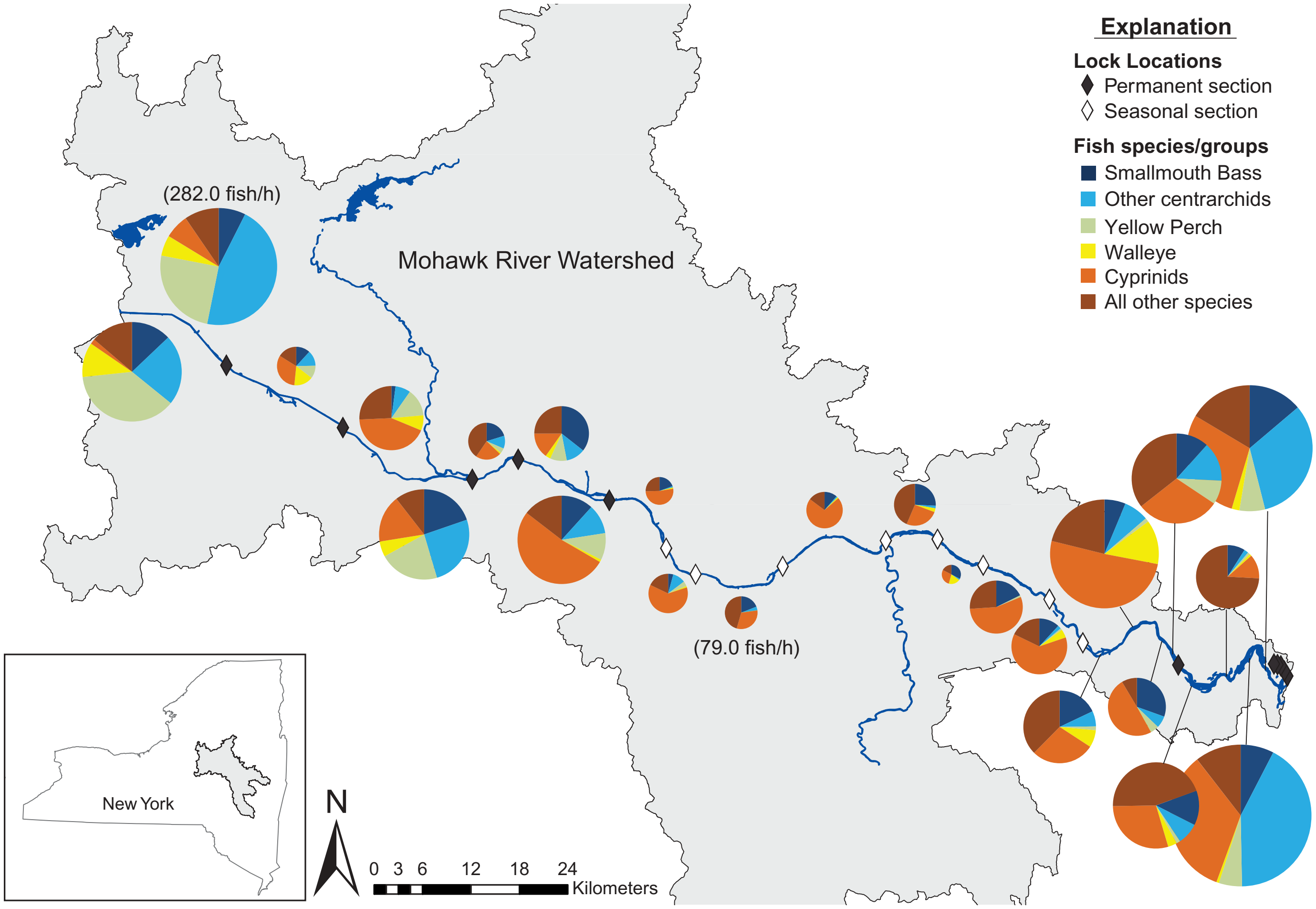

FIGURE 2. Composition of fish assemblages sampled from 24 sites on the Barge Canal, 2014–2015. Chart size reflects the total (all species) catch per unit effort.

DISCUSSION

The primary purpose of this investigation was to determine whether and how the drawdown resulting from removing temporary dams during the winter on a section of the Barge Canal affects fish assemblages. This was evaluated by first identifying a significant relationship between the relative abundance of fish and the drawdown amount in each impoundment and then by comparing fish assemblages at sites in the seasonally impounded section with those from sites in adjacent assemblages at sites in adjacent (bracketing) permanently impounded

TABLE 3. Mean, standard deviation, and ANOVA results for catch per unit effort (fish/h) of key species and groups (shown in Figure 2) by river section. Significant *P*-values are shown in bold italics; different lowercase letters denote significant differences among groups as determined from Tukey's test.

	Permanent upper		Seasonal		Permanent lower			
Species	Mean	SD	Mean	SD	Mean	SD	*F*-value	*P*-value
Smallmouth Bass	24.9	15.0	15.2	6.9	28.1	10.5	2.8	0.082
Other centrarchids	39.0	41.0	2.6	3.2	41.7	51.1	2.7	0.093
Yellow Perch	34.6 z	31.3	0.8 y	1.4	9.3 y	8.1	7.1	***0.004***
Walleye	11.1	8.7	2.7	3.4	8.1	11.6	2.0	0.165
Cyprinids	38.5	34.6	47.0	25.5	75.2	36.6	2.8	0.085
All other species	29.7 y	7.9	24.0 y	12.6	62.9 z	32.0	8.5	***0.002***
All species	177.7 z	71.0	92.3 y	29.6	225.2 z	72.3	9.8	***0.001***

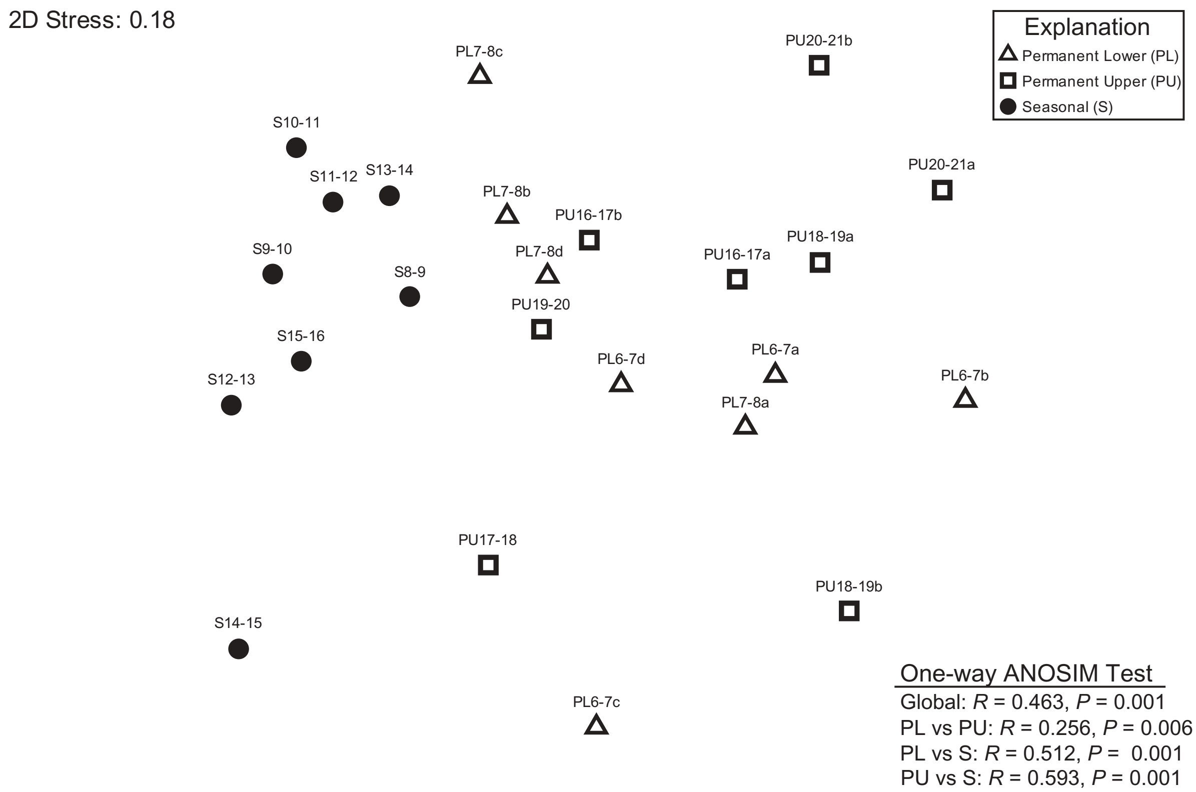

FIGURE 3. Nonmetric multidimensional scaling ordination and analysis of similarities (ANOSIM) results comparing fish assemblages between sections of the Barge Canal surveyed in 2014–2015.

sections. Our results indicate that the overall relative abundance of fish was lower in the seasonal section and that the composition of fish assemblages differed at those sites. Mean total CPUE at sites in the seasonal section was significantly lower than at sites in either of the permanently impounded sections, and the CPUE of many lentic species was markedly lower. These findings are consistent with those of McBride (1985), who found that the proportion of panfish was approximately one-third as great in the seasonal section of the Barge Canal as in the permanent lower section. In a similar vein, a recent study on the Ottawa River showed that littoral benthivores such as Pumpkinseed and Brown Bullhead were less abundant in or absent from impoundments that experienced an extensive winter drawdown (Haxton and Findlay 2009). An ongoing companion study to ours that is assessing macroinvertebrate communities in the Barge Canal (S. Johnson, Onondaga Environmental Institute, personal communication) should provide additional information as to how the abundance and composition of benthic prey available to insectivorous fishes varies by river section.

The data from the permanent upper section serve as a control against the possible confounding effects of watershed characteristics that change naturally across an upstream-to-downstream continuum unrelated to hydrologic manipulation. For example, the natural gradient in elevation, discharge, and productivity (Vannote et al. 1980) could conceivably cause differences in fish assemblages between the permanent lower and seasonal sections based simply on their positions in the watershed, thereby complicating the assessment of differing flow management practices. However, the results from the linear regressions indicate that differences in impoundment characteristics as well as river kilometer (which may serve as a surrogate for many changing characteristics along a gradient of watershed position) were not significant predictor variables of total CPUE. Furthermore, the similar fish assemblages at sites in the permanent lower and permanent upper sections suggest that the effects of natural longitudinal differences were minimal at the scale of our study area and are not primarily responsible for the observed differences in fish assemblages between the permanently and seasonally impounded sections. The high total CPUE and greater relative abundance of many lentic species (which were rare in the seasonal section) in the permanent upper section therefore provide a critical perspective for evaluating the effects of the winter drawdown.

Extreme drawdowns and the resulting differences in available winter habitat are the most logical explanation for the differences in fish assemblages among the three river sections. A number of studies have found that populations of warmwater fishes in large rivers are often limited by the quality and accessibility of winter habitat (Raibley et al. 1997; Karchesky and Bennett 2004).

At cold temperatures, many warmwater species are unable to forage or even swim effectively and generally seek refuge in bays or backwaters that are protected from currents and that stratify thermally, providing water temperatures around 4°C (Sheehan et al. 1990). Such areas allow fish to expend less energy to maintain their position while providing more favorable temperatures for performing basic physiological functions. Carlson (1992) estimated that five wintering areas supported 59% of the Largemouth Bass over the entire 166-km freshwater portion of the Hudson River estuary. A similar study on the Mississippi River indicated that three wintering areas supported nearly all of the Largemouth Bass in a 29-km river section (Pitlo 1992). When water levels are drawn down in the winter, fish may lose access to vital refuges and face adverse conditions in the remaining habitat or become stranded in backwaters and experience winterkill (Pitlo 1992; Raibley et al. 1997). For example, although a winter drawdown of 2.9 m on the Pend Oreille River in Idaho reduced the wetted surface area by only 11%, this may have been sufficient to prevent the use of backwater habitats by Largemouth Bass (Karchesky and Bennett 2004). On the seasonally impounded section of the Barge Canal, water levels are not traditionally drawn down; instead, the uprights and gates that comprise the movable dams are lifted from the riverbed, resulting in a 1.5–5.8-m drop in water levels, a 36–56% reduction of the wetted surface area, and an abrupt transition from impounded to riverine habit (McBride 1987). This may eliminate many possible winter refuges and expose fish to shallower, flowing waters with temperatures near 0°C and extensive ice formation. Thus, it is likely that the differences in fish assemblages observed between river sections are due primarily to the reduction of winter habitat available in the seasonal section after the drawdown.

Native fish species may be better adapted to the riverine conditions in the seasonally impounded section and appear to compete less successfully with nonnative species in the permanently impounded sections of the Barge Canal. Although the CPUE of many lentic centrarchids and other game fishes was lower in the seasonal section, the percentage of individuals from species that are native to the Mohawk River watershed was greater in this section. This is not surprising, since the native fish assemblage evolved under preimpoundment conditions in which the Mohawk River flowed freely with shallower and more typical riverine habitat (McBride 1994). Consequently, winter conditions in the seasonal section after the dams are lifted may resemble the natural riverine environment more closely and could provide a competitive advantage to native cyprinids and other riverine fishes, at least relative to the sections in which water levels are impounded year-round. This idea is consistent with the body of literature indicating that the changes in habitat resulting from the impoundment of free-flowing rivers generally favor nonnative, lentic fishes (Poff et al. 1997; Pringle et al. 2000; Bunn and Arthington 2002). Nonnative species, whether introduced intentionally to provide a sport fishery or by accident, can reduce or extirpate native riverine species in impoundments (Poff et al. 1997). Furthermore, the habitat in impoundments may not be adequate for native riverine species that depend on shallow, moving water for critical parts of their life history (Bunn and Arthington 2002). The seasonal section, therefore, may support a greater percentage of native individuals because they are better adapted to the riverine winter conditions, depend on specific riverine habitats that are maintained by the drawdown, or face less predation or competition from nonnative lentic species which are disadvantaged by the winter conditions.

The results presented here suggest that seasonal dam use on the Barge Canal has measurable effects on fish assemblages and that these effects should be interpreted within the context of the management objectives for the watershed. A key goal of the 2012–2016 Mohawk River Basin Action Agenda is the conservation of fish, wildlife, and their habitats while giving people the opportunity to enjoy the basin's natural resources (NYSDEC 2012). From an angling perspective, the seasonal section appears to offer poorer opportunities to catch many species, including Smallmouth Bass and Walleyes, which were identified as the most popular targets among anglers on the Barge Canal (McBride 1983). Similarly, the lower relative abundance of Largemouth Bass, Yellow Perch, Bluegills, Pumpkinseeds, and Rock Bass in the seasonal section should also adversely affect angling opportunities. From the perspective of conserving native biodiversity, however, the greater percentage of native individuals in the seasonal section suggests that it serves as a refuge from nonnative competitors and predators or provides critical riverine habitats. Although none of the species captured in the study are listed as endangered, threatened, or of special concern by the New York State Department of Environmental Conservation, the fish assemblages in the seasonal section may be more similar to the assemblage that prevailed prior to canalization. Ultimately, natural resource managers will have to determine which fish assemblage—and therefore which drawdown practice—is most desirable and consistent with management objectives while balancing the system's use for transportation and recreation, the generation of hydropower, and flood mitigation.

Although significant differences in fish assemblages were noted between the permanently and seasonally impounded sections of the Barge Canal, the present study has several limitations that should be considered. First, our fish surveys were conducted exclusively by means of boat electrofishing. Although this is generally viewed as the single most effective method for assessing lotic fish assemblages (Moulton et al. 2002), it is biased toward the capture of larger individuals (Dolan and Miranda 2003; Reynolds and Kolz 2012) and likely led to underestimates of the abundance of small species and the early life stages of many species. Additionally, by only sampling nearshore habitats we likely underestimated the abundance of certain benthic and pelagic species that use open water or deeper habitats (Miranda and Boxrucker 2009). This could explain why no Round Goby were captured despite being first identified in the western edge of the study area in September 2014. Second, although CPUE data are frequently used as a surrogate for abundance in large freshwater habitats where quantitative surveys are impractical, this approximation assumes that the number of fish captured is proportional to the effort expended and that capture probabilities are similar between sites and species (Hubert and Fabrizio 2007; Hayes et al. 2012; Hubert et al. 2012). While these assumptions may not always be met in practice, the relationship between CPUE and abundance can be improved through standardization of survey methods (Hubert and Fabrizio 2007). We attempted to do this by sampling only nearshore habitats during the same 2-week period each year and by using multiple subreaches within sites to further reduce the variance caused by random differences in the surveyed habitats. Despite this, unknown bias is inevitably introduced when CPUE is used to approximate abundance and capture probabilities are unknown (Hubert and Fabrizio 2007). Finally, the results described above are correlative or observational; they do not describe findings from a manipulative study. It would only be possible to truly establish a causal relationship by manipulating the current drawdown regime over some time period and investigating the effects.

Despite these limitations, the investigation presented here provides important information that can inform decisions by natural resource managers and policymakers and provide an impetus for further research on the Mohawk River and Barge Canal system. Our findings have regional implications for areas like the Hudson River portion of the Champlain Canal (parts of which experience an extensive annual winter drawdown), but they are also relevant on a broader scale because the effects of water-level manipulation in reservoirs is a topic of great concern (Ploskey 1986; Wlosinski and Koljord 1996). However, typical reservoir drawdowns do not transform aquatic habitats from lentic to lotic, and thus the unique nature of our study area makes an important contribution to the field of water-level management. Additionally, the data collected during this study will serve as a baseline to identify future changes to fish assemblages in the Mohawk River and Barge Canal system. Climate change, as well as recent improvements to the movable dams enabling them to be quickly lifted during the navigation season in anticipation of major storms, may alter the frequency, timing, and magnitude of low- and high-flow events and water temperatures in the Mohawk River watershed in the future (Rosenzweig et al. 2011; Peterson et al. 2013). Therefore, the baseline data provided by this study will not only help identify future changes to fish assemblages but also determine whether such changes are attributable to specific factors such as invasive species (e.g., Round Goby) or changes in flow management practices. It would be prudent, therefore, to conduct similar fish surveys in the future in order to make valid temporal comparisons with this data set while employing additional sampling techniques to obtain more information on the populations of benthic and pelagic fishes in this river–canal system.

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