Are there Opportunities to Reintroduce Brook Trout at the Edge of their Original Range in Northwestern Pennsylvania?



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Submitted in fulfillment of the senior thesis requirements of the Department of Environmental Science at Allegheny College and approved by the senior thesis committee.

Scott A Wissinger	23 April 2014		4/23/14
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Pledge

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Major: Environmental Science
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Deforestation during the late 19th and early 20th centuries reduced and even extirpated many native brook trout (*Salvelinus fontinalis*) populations in Pennsylvania. In northwestern Pennsylvania, forest cover has increased over the past century and brook trout have returned to some, but not all, of their native streams in the region. The goal of this project was to identify tributaries of two of the western-most subwatersheds (Conneaut and Cussewago) in the French Creek watershed that do not have, but could, support brook trout. These subwatersheds are isolated by dams that block dispersal of non-native brown trout (*Salmo trutta*), which compete interspecifically with brook trout. Five main criteria were assessed at each candidate stream: maximum summer temperature, minimum summer dissolved oxygen, fine sediment loading, fish community composition, and macroinvertebrate prey composition. Land use, stream habitat, and water quality were also evaluated. These variables were compared to the literature and reference sites where trout currently exist in the French Creek watershed. Results suggest that there are several tributaries in the Conneaut subwatershed that are suitable candidates for restoring and returning brook trout populations to their native range, whether as part of the Trout in the Classroom program or other reintroduction efforts.

Introduction

History of Brook Trout Extirpation and Recovery

Pennsylvania is home to over 160 species of fish, many of which can be found in the Ohio River drainage (PFBC 2013). Trout, in particular, are a popular game fish in this region and have a tremendous amount of societal support. Trout are potadromous migrators, migrating within freshwater systems to upstream headwaters to spawn (Allan & Castillo 2007). The Ohio River drainage is no longer home to anadromous fish species, fish that migrate from the sea to freshwater headwaters, as barriers between Pennsylvania and the Gulf of Mexico have prevented their upstream movement (Allan & Castillo 2007). Anadromous fish extinction has made trout one of the top predators in northwestern Pennsylvania's (NWPA) stream food webs.

Three species of trout inhabit the freshwater streams of NWPA: brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Onchorhynchus mykiss*). Brook trout are native to the Appalachian region and are Pennsylvania's state fish and only native salmonid (PCTU 2013). Brook trout are extremely sensitive to stream degradation, as they prefer cool stream temperatures (high dissolved oxygen levels) and sand/gravel substrates (Pegan 2001). Their populations were greatly reduced and even extirpated throughout Pennsylvania in the late 19th and early 20th centuries, when most of the state was deforested for agriculture and development (Fig. 1) (Whitney 1994; Hudy et al. 2008; PCTU 2013). Nonnative brown and rainbow trout are less sensitive to stream degradation than brook trout and were introduced in its absence for recreational fishing purposes (PCTU 2013;). Brown trout populations, in particular, greatly distributed across the state (PCTU 2013).

The Clean Water Act (CWA) of 1972 has made substantial progress in protecting and improving stream systems affected by pollution throughout the United States (Pauslen et al. 2008; Brown & Froemke 2012). However, the majority of stressors controlled and regulated by the CWA are point sources of pollution, such as direct industrial waste input to a stream (Brown & Froemke 2012). Nonpoint sources of pollution, including secondary sewage effluent, agriculture, and development, remain unregulated (Brown & Froemke 2012). The three most prevalent stream stressors resulting from these nonpoint pollution sources include excess fine

sediment, nitrogen, and phosphorus, having direct effects on the biological organisms in stream ecosystems (Paulsen et al. 2008).

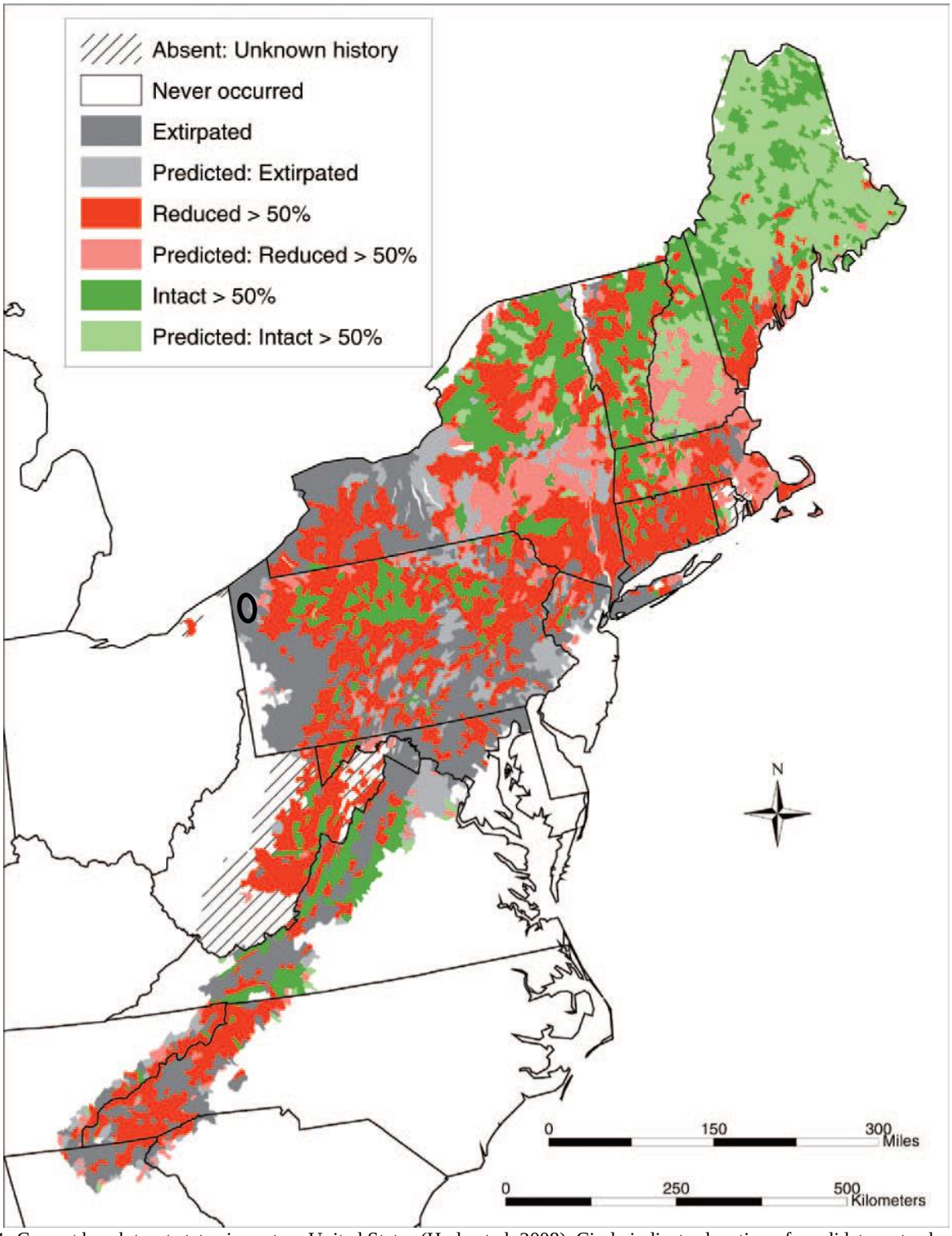


Fig. 1: Current brook trout status in eastern United States (Hudy et al. 2008). Circle indicates location of candidate watersheds.

Deforestation causes soils and sediment run off the terrestrial landscape of a watershed into streams. Sediment loading shallows pools as it covers the substrate, depleting prime trout spawning and benthic macroinvertebrate habitat (Bryce et al. 2010). Sedimentation rates in streams surrounded by agriculture, for example, were found to be more than five times greater than the rates of streams surrounded by forests (Gianessi et al. 1986; Sutherland et al. 2002). The increased runoff from deforested landscapes also impacts the flow regime of stream systems, as non-forested sites have higher flow rates during rainfall events (Sutherland et al. 2002). This increased stream discharge affects stream channel and bank structure, impacting trout and macroinvertebrate communities and habitat (Poff et al. 1997; Herrmann et al. 2012).

Non-point source nutrients can enter stream systems from increased association with agriculture, development, and roadways. Secondary sewage effluent consists of nitrogen, phosphorus, and total dissolved solids, which are not treated in sewage treatment facilities and are released back into waterways (Paulsen et al. 2008). In agricultural watersheds, nutrient concentrations (primarily nitrogen and phosphorus) from fertilizers and pesticides have been found to be nine times greater than those of forested watersheds (Omernik 1977). Nitrogen and phosphorus are vital for primary production in stream ecosystems (Brown & Froemke 2012). However, at high levels these two nutrients create cyanobacteria algal blooms that lead to decreased dissolved oxygen levels from eutrophication (Dauer et al. 2000).

Riparian zones can control the quantity of nonpoint-source pollution entering a stream system, as they serve as a border adjacent to the waterway. Riparian zones are ideally made up of trees and vegetation, which trap nutrients and sediment runoff from the surrounding landscape and provide allochthonous energy to stream systems throughout the year (Allan & Castillo 2007). These buffers also shade and insulate streams by trapping the air close to the water surface, which keeps stream temperatures and dissolved oxygen levels constant (Flosi et al. 1998; Poole & Berman 1999). In addition, the extensive root systems of trees and vegetation provide bank stability, significantly decreasing bank erosion levels (US EPA 2005). Riparian zones can also reduce the “flashiness” (how fast water enters a stream system during a period of rainfall) of streams. Significant efforts have been made by the Pennsylvania Department of Environmental Protection (PA DEP) to rebuild and protect riparian zones as a “best management

practice" in an attempt to conserve and restore stream integrity throughout Pennsylvania (US EPA 2005).

Forest cover has increased throughout NWPA, currently reaching levels of 50% in Crawford County after dwindling to as low as 10% during the early 20th century (Whitney & Decant 2003). This has created the opportunity for streams historically supporting brook trout populations to do so once again; however, brook trout have only returned to some of their native streams in the region (Hudy et al. 2008). Existing and reintroduced brook trout populations compete with brown trout for resources and habitat, which has led to decreased population distribution as well as decreased reproduction and overall success rates (Zimmerman & Vondracek 2006; Brenkman et al. 2008; Ohlund et al. 2008; Cucheroussett & Olden 2011). In addition, brown trout have higher physical and chemical tolerances to changes in stream condition than brook trout (Zimmerman & Vondracek 2007). Interspecific competition with brown trout pushes brook trout to upstream headwaters in search of their realized niche (Weigel & Sorenson 2001; Ohlund et al. 2008). These streams have cool water temperatures (high dissolved oxygen levels) from high stream gradient and groundwater input, which improve the internal functioning of brook trout (Ohlund et al. 2008). However, their small sizes lower the growth potential of brook trout (Ohlund et al. 2008).

Barriers and Reintroduction Efforts

The French Creek watershed, a subwatershed of the Ohio River drainage, is home to over 80 species of fish and is one of the most diverse waterways in the United States (FCC 2013). However, brook trout have been found to be extirpated from the western regions of the French Creek watershed (Fig. 1) (Hudy et al. 2008). The goal of this project was to identify tributaries of two of the western-most subwatersheds in the French Creek watershed that do not have, but could support brook trout. The Conneaut and Cussewago watersheds, extending through Crawford and Erie counties in NWPA, were chosen as they have anthropogenic barriers to fish dispersal at their downstream reaches (Fig. 2, p. 6). Barriers, in the case of this project, would be beneficial in that they block the dispersal of non-native brown trout, and create brook trout restoration opportunities upstream.

Many conservation efforts have been made attempting to restore brook trout populations. Hudy et al. (2008) highlighted the distribution, current status, and land use characteristics of native brook trout habitats (Fig. 1). Raleigh (1982) made a general brook trout habitat suitability index highlighting brook trout habitat requirements at various stages throughout their life cycle. Smith & Sklarew (2013) created a brook trout habitat suitability index for the Mid-Atlantic United States using in-stream and watershed metrics. Petty et al. (2014) looked at the "temperature-productivity squeeze" of brook trout in their native range. A previous study in NWPA surveyed potential sites for brook trout reintroduction using land use, water chemistry, and biomonitoring (Galleta 2007). However, this study did not focus on above-barrier stream ecosystems for their reintroduction and did not take into account the invasive behavior of brown trout. It is important to note that Galleta (2007) concluded that brook trout restoration efforts in Northwestern Pennsylvania are realistic.

Five main criteria were assessed at each candidate stream: maximum summer temperature, minimum summer dissolved oxygen, fine sediment loading, fish community composition, and macroinvertebrate prey composition. Land use, stream habitat, and base flow water chemistry were also evaluated. These variables were then compared to the literature and reference sites where trout currently exist in the French Creek watershed in order to make recommendations of streams suitable for brook trout reintroduction. Recommendations will be used by a Trout in the Classroom Program (sponsored by Trout Unlimited and PA Fish & Boat Commission) at Cochranton High School (Cochranton, PA) in Spring 2015 and/or other reintroduction efforts in order to return this species to its native range (PA TIC 2009). In addition, the Conneaut and Cussewago watershed fish community composition data was submitted in a report to the PA Fish & Boat Commission's Unassessed Waters Initiative (UWI). The UWI attempts to survey all wadeable Pennsylvania streams for trout in order for the PA DEP to properly regulate them (Weisburg 2011).

Trout are a popular game fish in NWPA, resulting in increased concern by Pennsylvanian residents for trout species abundance and diversity. In particular, brook trout are a very valued fish species due to their beauty and sensitivity. Restoring native brook trout populations will further increase biodiversity within the treasured French Creek watershed.

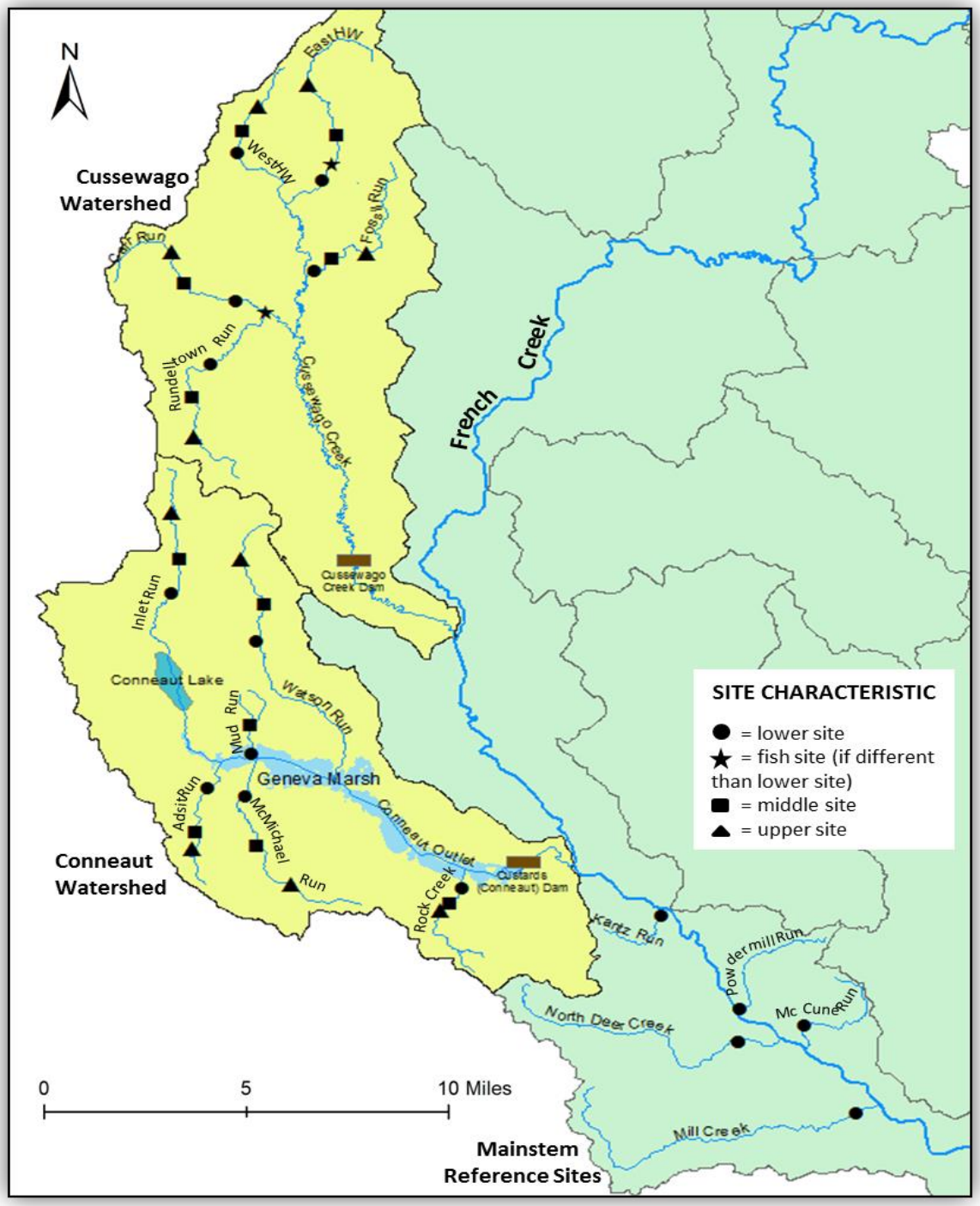


Fig. 2: Map depicting brook trout reintroduction candidate streams in Conneaut and Cussewago watersheds; their lower, middle, and upper sites; and mainstem French Creek local reference streams. See App.1 for site lat-longs and data collection sites.

Methods

Stream Site Selection

First to third order streams in the Conneaut and Cussewago watersheds were selected and analyzed for brook trout suitability. Six streams were selected in the Conneaut watershed: Inlet Run, Adsit Run, McMichael Run, Mud Run, Watson Run, and Rock Creek (Fig. 2, App. 1). Five streams were selected in the Cussewago Creek watershed: Rundelltown Run, Carr Run, West Branch Cussewago Creek, East Branch Cussewago Creek, and Fossil Run (Fig. 2, App. 1). Two sets of reference streams with trout were selected to compare to the candidate streams (Table 1). Local reference streams are of similar geospatial location to the candidate streams within the French Creek watershed and hold brown trout, brook trout, or both (Fig. 2, Table 1, App. 1). Basin-wide reference streams are dispersed throughout the French Creek watershed and hold only brook, or both brook trout and brown trout (Table 1, App. 1).

Table 1: Trout species found at local and basin-wide reference streams/100m stream reach. Note Kantz Run and McCune Run are both local and basin-wide reference streams. All fish community data obtained from previous studies.

	Stream	Study	Subwatershed	Brook Trout	Brown Trout
Local Reference	Kantz Run	Rieck 2008	Mainstem-Lower	1	0
	Powdermill Run	Unassessed 2012	Mainstem-Lower	0	0
	McCune Run	Unassessed 2012	Mainstem-Lower	3	7
	Mill Creek	Rieck 2008	Mainstem-Lower	0	4
	North Deer Creek	Rieck 2008	Mainstem-Lower	0	1
Basin-wide Reference	Armstrong Run	Galletta 2007	Sugar Creek	32	9
	Aster Run	Goetz 2006	Sugar Creek	1	7
	Baskin Run	Ressel 2013	South Branch	24	0
	Beatty Run	Goetz 2006	Sugar Creek	2	6
	Beaver Run	Galletta 2007	Muddy Creek	1	1
	Higby Run	Galletta 2007	Sugar Creek	1	0
	Kantz Run	Rieck 2008	Mainstem-Lower	1	0
	Kirik Run	Ressel 2013	South Branch	17	0
	McCune Run	Unassessed 2012	Mainstem-Lower	3	7
	Spencer Creek	Ressel 2013	South Branch	103	0
	Sugar West Branch	Stream 2011	Sugar Creek	1	14
	Trout Run	Goetz 2006	Sugar Creek	1	12
	Yellow Jacket Run	Goetz 2006	Sugar Creek	2	0

Summer Water Temperature, Dissolved Oxygen, and Channel Characteristics

Water temperature, dissolved oxygen (DO), and channel characteristics were observed during late June, early July, late July, and early August 2013 at lower, middle, and upper reaches of the candidate streams (App. 2). Sites at lower, middle, and upper reaches were determined

from differences in stream gradient, as the Conneaut and Cussewago watersheds are characteristic of low stream gradients at their upper and lower reaches, with increased gradient in their middle reaches. Water temperature, DO, and channel characteristics were also observed at the lower candidate stream and local reference sites in early September (App. 2). Summer air temperatures in Crawford County, PA were obtained from the National Oceanic and Atmospheric Administration; and summer water temperatures of French Creek were obtained from the United States Geological Survey for previous summer data analysis.

Fish IBI (FIBI)

Candidate streams were electrofished during September and October of 2013 at their lower sites (Fig. 2). Previous fish community data were obtained for local and basin-wide reference streams (Table 4, p. 19). A FIBI score was calculated for candidate and reference streams from total species richness, darter richness, lamprey richness, trout richness, sucker richness, tolerant taxa, sensitive taxa, sensitive cyprinid taxa (App. 3) (Goeller 2010; Kirk 2011).

Benthic Invertebrate IBI (BIBI)

Invertebrates were collected and identified from the candidate and local reference stream lower sites during early November 2013 (PA DEP 2003). A BIBI score was calculated from total taxa, mayfly taxa, stonefly taxa, caddisfly taxa, and tolerant taxa (App. 4) (modified from Lyle 1998). No previous invertebrate data exist for basin-wide reference streams.

Water Chemistry

Base flow water chemistry was measured at candidate and local reference stream lower sites during early November 2013. Temperature was measured using a handheld thermometer. pH was measured using a handheld EcoTestr2. Total dissolved solids and conductivity were measured using a handheld TDS Testr3. Dissolved oxygen was measured using the Winkler method (US EPA 1982). Alkalinity was measured using acid titration in the field (Wetzel & Likens 1991). Hardness was measured using a Hach HA-4P Test Kit. Previous water quality data were obtained for basin-wide reference streams if available (Table 2, p. 10).

Nutrients & Sediments

Nutrient and sediment data were collected from candidate and local reference stream lower sites during early November 2013. High and base flow turbidity was measured using a LaMotte turbidity meter. Fine sediment concentration was collected using a bulk sediment sampler (d=26.9 cm) (Sutherland et al. 2002; Sutherland et al. 2010). High and base flow total soluble phosphorus was collected using the Molybdenum Blue Technique (Strickland & Parsons 1967). No previous nutrient and sediment data exist for the basin-wide reference streams.

Habitat Assessment

Stream habitats were assessed at the candidate and local reference stream lower sites during September and October of 2013. Water Quality Network Habitat Assessment form (WQNHA) and the PA DEP and Riparian, Channel, and Environmental Inventory (RCE) form from Peterson (1992) were used to assess stream habitats (App. 5, 6). Previous habitat assessment data were obtained for the basin-wide reference streams if available (App. 7).

Hydrology

Stream hydrology was measured at the candidate and local reference stream lower sites during late November 2013 using a flowmeter (App. 8) (Gore 2006; Harrelson et al. 1994). No previous hydrology data exist for the basin-wide reference streams.

Geographic Information System (GIS)

ArcGIS 10.1 software was used to determine land use characteristics in the watersheds and upstream riparian zones of the candidate and local reference streams for forest, agriculture (row crop and pasture), and development (National 2011). Previous land use data were obtained for basin-wide reference streams if available (App. 8).

Statistics

Statview was used to analyze relationships between variables by regressions and analyses of variance (ANOVA). Fisher's post-hoc tests were conducted for all significant results. Additional tables/graphs were created in Microsoft Excel 2010.

Results

Water Quality

Relatively high, but variable conductivity (range 154 - 224 µS/cm), alkalinity (45 - 76 mg/L), hardness (68 - 120 mg/L), and total dissolved solids (100-150 mg/L) levels were observed at the candidate streams (Table 2). All candidate streams were circumneutral to slightly basic (7.9 - 8.7) (Table 2).

Table 2: Candidate, local reference, and basin-wide reference stream base flow water chemistry data.

Characteristic	Stream	Subwatershed	pH	Conductivity (µS/cm)	Alkalinity (mg/L)	Hardness (mg/L)	TDS (mg/L)
Candidate	Carr Run	Cussewago	7.9	224	72	120	150
Candidate	Rundelltown Run	Cussewago	8.0	207	68	86	140
Candidate	Cussewago Headwater East	Cussewago	8.2	155	45	68	100
Candidate	Fossil Run	Cussewago	8.5	154	48	86	100
Candidate	Inlet Run	Conneaut	8.1	194	69	86	130
Candidate	Watson Run	Conneaut	8.2	191	60	103	130
Candidate	Adsit Run	Conneaut	8.6	224	59	120	150
Candidate	McMichael Run	Conneaut	8.2	223	76	120	150
Candidate	Rock Creek	Conneaut	8.7	209	48	68	140
Local Reference	Kantz Run	Main Stem-Lower	8.8	246	75	120	170
Local Reference	Powdermill Run	Main Stem-Lower	8.9	327	99	154	220
Local Reference	McCune Run	Main Stem-Lower	8.5	222	77	120	150
Local Reference	Mill Creek	Main Stem-Lower	8.6	186	53	86	120
Local Reference	North Deer Creek	Main Stem-Lower	8.7	176	46	86	120
Basin-Wide Reference	Armstrong Run	Sugar Creek	8	-	34	-	60
Basin-Wide Reference	Aster Run	Sugar Creek	-	-	-	-	-
Basin-Wide Reference	Baskin Run	South Branch	8.1	172	56	86	110
Basin-Wide Reference	Beatty Run	Sugar Creek	-	-	-	-	-
Basin-Wide Reference	Beaver Run	Muddy Creek	8.2	306	90	137	196
Basin-Wide Reference	Higby Run	Sugar Creek	-	-	-	-	-
Basin-Wide Reference	Kantz Run	Mainstem-Lower	8.8	246	75	120	170
Basin-Wide Reference	Kirik Run	South Branch	7.8	112	30	69	72
Basin-Wide Reference	McCune Run	Mainstem-Lower	8.5	222	77	120	150
Basin-Wide Reference	Spencer Creek	South Branch	8	220	79	103	141
Basin-Wide Reference	Sugar West Branch	Sugar Creek	7.8	-	94	-	40
Basin-Wide Reference	Trout Run	Sugar Creek	8.3	-	34	-	50
Basin-Wide Reference	Yellow Jacket Run	Sugar Creek	7.4	-	51	-	80

Summer Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen (DO) were measured at 3 sites (lower, middle, and upper) along each candidate stream over four dates (late June, early July, late July, and early August) throughout the summer of 2013 (Fig. 2). In Conneaut and Cussewago candidate streams, DO decreased with increasing water temperature across all summer measurement dates and stream sites ($F_{1,69}$=20.27, P<0.0001 and $F_{1,59}$=13.79, P=0.0005, respectively) (Fig. 3). Conneaut watershed tributaries had higher DO levels at any given water temperature than Cussewago watershed tributaries (Fig. 3).

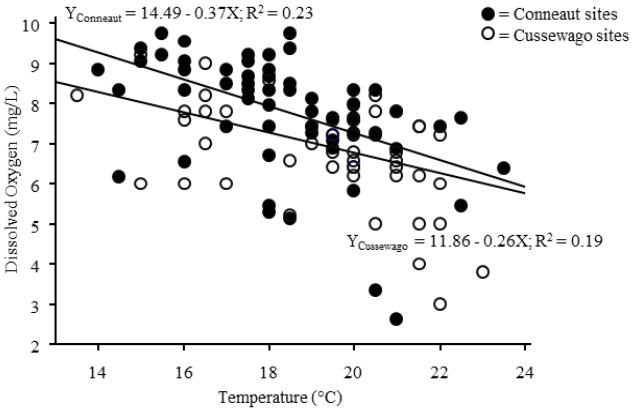


Fig. 3: Relationship between water temperature and DO level across all measurement dates and sites in Conneaut and Cussewago watershed tributaries during the summer of 2013.

Water temperature ($F_{1,106}$=33.68, P<0.0001) and DO ($F_{1,106}$=9.34, P=0.003) differed between the candidate stream watersheds over the summer measurement dates. Specifically, the tributaries of the Cussewago watershed had higher water temperatures (P<0.0001) and lower DO levels (P=0.001) than those of the Conneaut watershed (Fig. 4) (App. 2, 9).

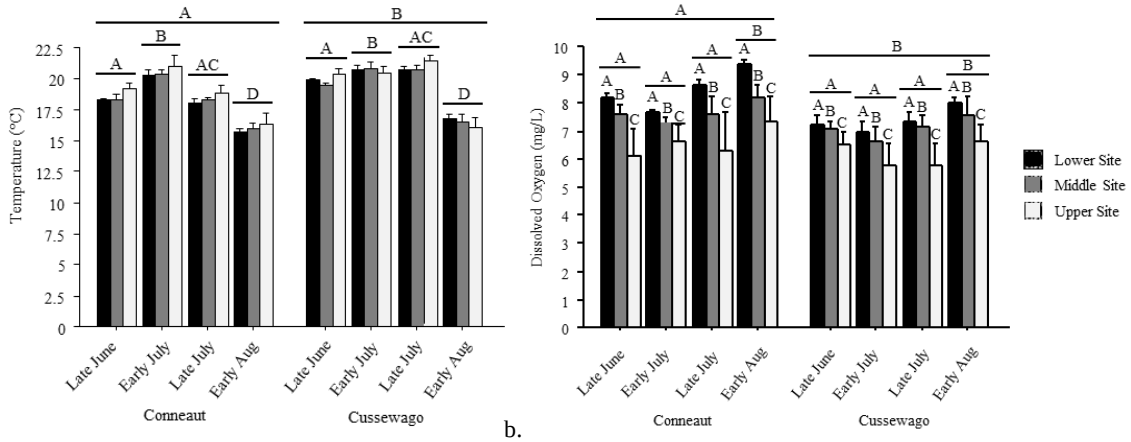


Fig. 4: a. Mean water temperature (±SE) and b. mean DO level (±SE) differences between measurement dates across all candidate stream sites in the Conneaut and Cussewago watersheds.

This finding raised interest in the presence of upstream riparian forest cover between the candidate stream watersheds, as riparian forest presence provides valuable shade to streams throughout the summer months (Poole & Berman 1999; Flosi et al. 1998). However, upstream riparian forest cover did not differ between the tributaries of the candidate watersheds ($F_{1,7}$=3.17, P=0.118) (Fig. 5).

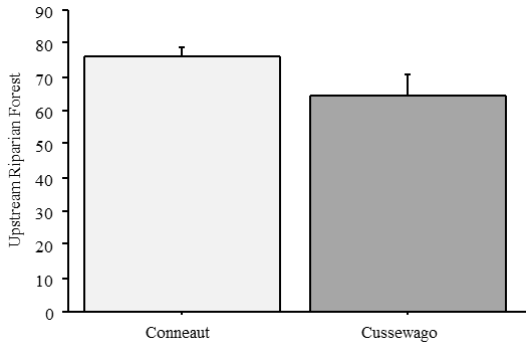


Fig. 5: No difference between the mean percent upstream riparian forest (±SE) between the tributaries of Conneaut and Cussewago watersheds.

In order to account for the fundamental niche constraints for brook trout survival and development, this study targeted the "bottleneck" period of the summer with the highest water temperatures and lowest DO levels. Water temperatures differed between measurement dates ($F_{3,106}$=93.85, P<0.0001) (Fig. 4a). Early July appears to be a "bottleneck" period as its water temperatures were warmer than those of late June (P<0.0001), late July (P=0.0004), and early August (P<0.0001) (Fig. 4a). Water temperature did not differ between candidate stream lower, middle, and upper sites ($F_{2,106}$=1.87, P=0.16) (Fig. 4a).

Results supporting early July as a "bottleneck" period in regards to DO levels were not found (Fig. 4b). However, no results were obtained in favor of a different "bottleneck" period, thus early July was retained. DO levels also differed between measurement dates ($F_{3,106}$=3.71, P=0.014) (Fig. 4b). Early August had higher DO levels and lower water temperatures than that of late June (P=0.028 and P<0.0001, respectively), early July (P=0.002 and P<0.0001, respectively), and late July (P=0.027 and P<0.0001, respectively) (Fig. 4). This could be explained by cool nightly air temperatures and increased rainfall events in the week prior to the early August measuring date. It is important to note that DO levels differed between candidate stream lower, middle, and upper sites ($F_{2,106}$=16.32, P<0.0001) (Fig. 4b). Specifically, lower

sites had higher DO levels than middle sites (P=0.035), and middle sites had higher DO levels than upper sites (P=0.0002) (Fig. 4b).

"Bottleneck" periods were found to visually differ between the summers of 2009-2012 in NWPA, indicating that air and water temperature peaks fluctuate between summers (Fig. 6, Fig. 7). This study assumes that candidate streams with the lowest water temperatures and highest DO levels during the early July 2013 "bottleneck" period will be the same during the "bottleneck" periods of future summers.

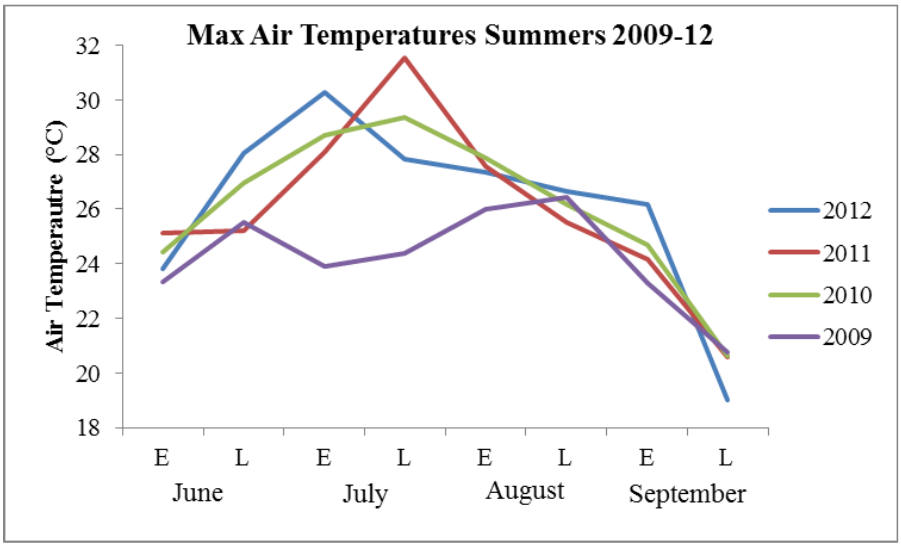


Figure 6: Mean maximum air temperatures in early (E) and late (L) June, July, August, and September from 2009-2012 in Crawford County, PA. Data obtained from the National Oceanic and Atmospheric Administration (NOAA 2014).

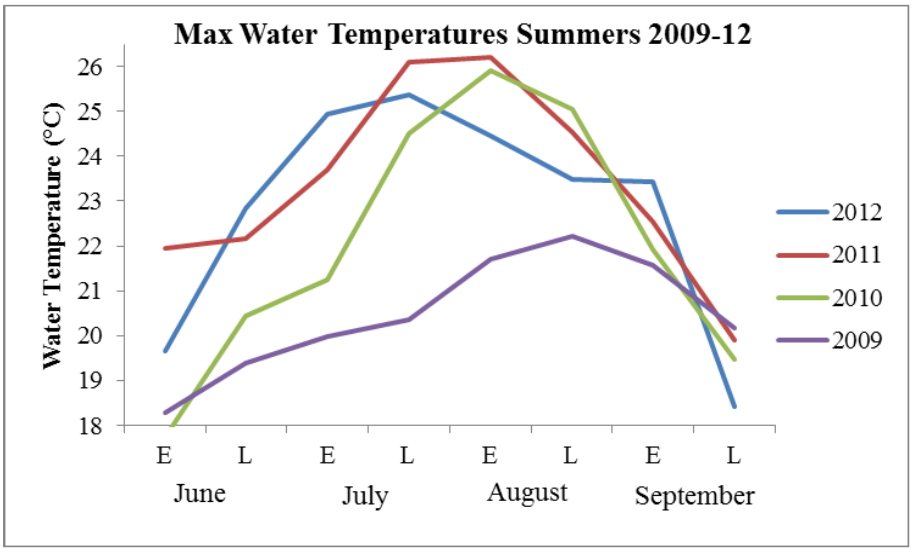
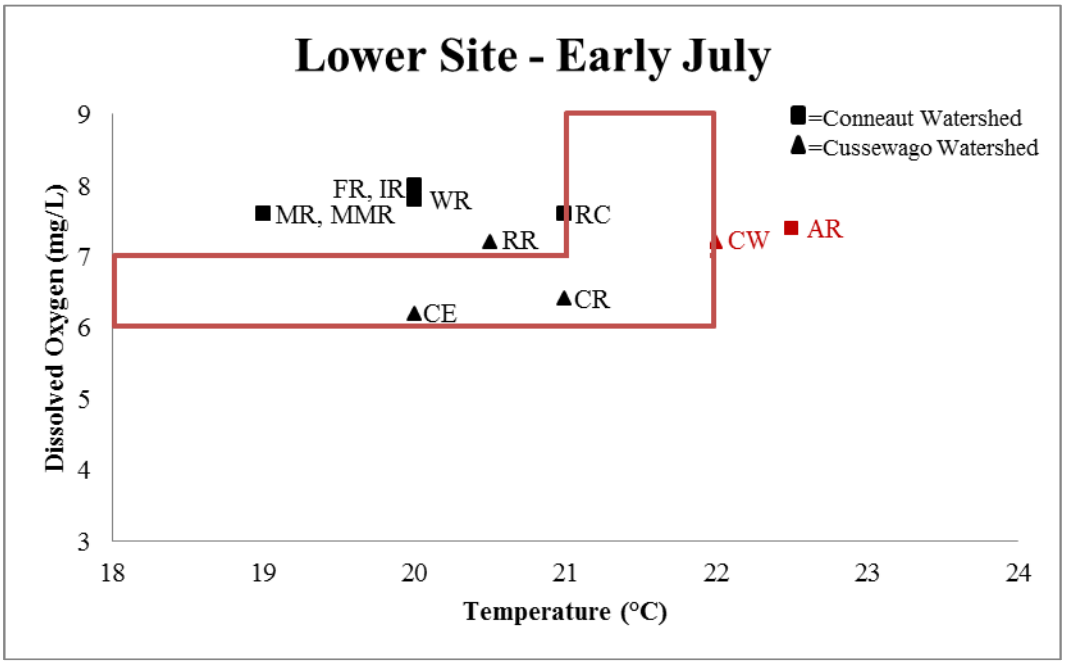


Figure 7: Mean maximum water temperatures in early (E) and late (L) June, July August, and September from 2009-2012 of Woodcock Creek (tributary of French Creek) at Blooming Valley, PA. Data obtained from the U.S. Geological Survey Water-Data Report (USGS 2014).

Early July water temperatures and DO levels at each candidate stream were analyzed for integrity at the lower and middle sites (Fig. 8).

a.



b.

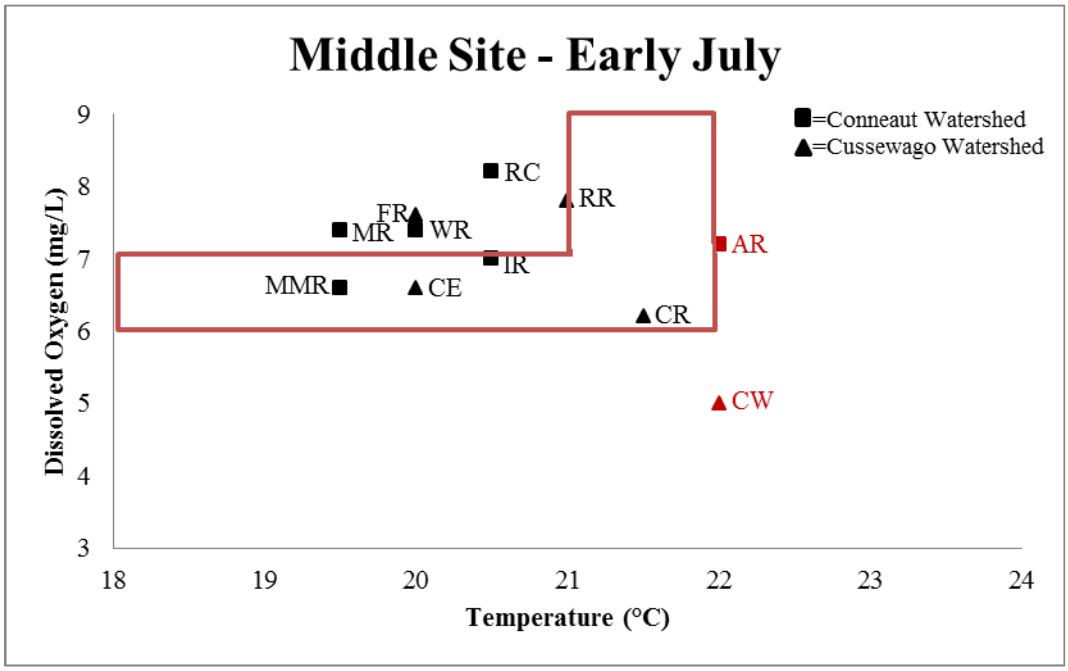


Fig. 8: Relationship between candidate stream water temperature and DO levels at a. lower and b. middle sites on the early July measurement date. Red box represents temperature and DO threshold for brook trout growth and development used by this study. Refer to Table 3 (p.17) for 2-letter stream code.

Cussewago Headwater West and Adsit Run were located outside of the threshold range used by this study at their lower and middle sites (Fig. 8). Mud Run and Cussewago Headwater West were dismissed following the summer 2013 measurement period (no further variables were measured) as they visibly lacked proper riffle/run habitat required for brook trout survival. The lower sites of the remaining nine candidate streams were tested against the local reference streams during Early September 2013 (Fig. 9).

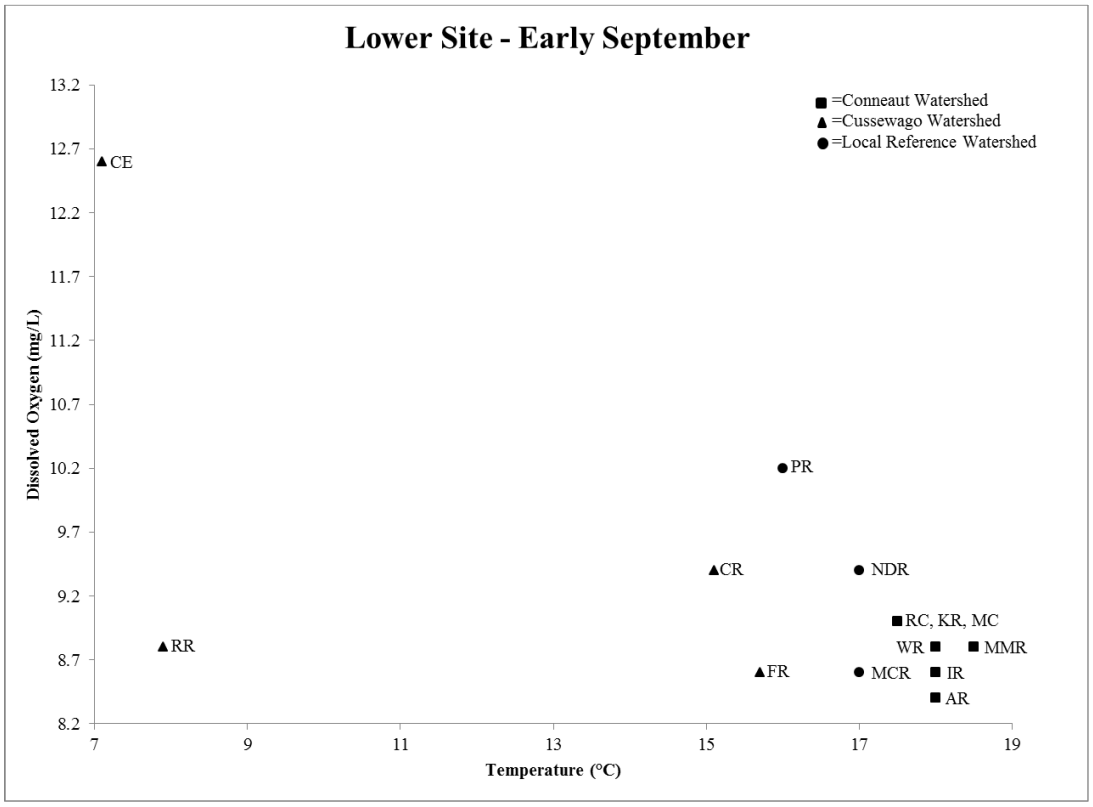


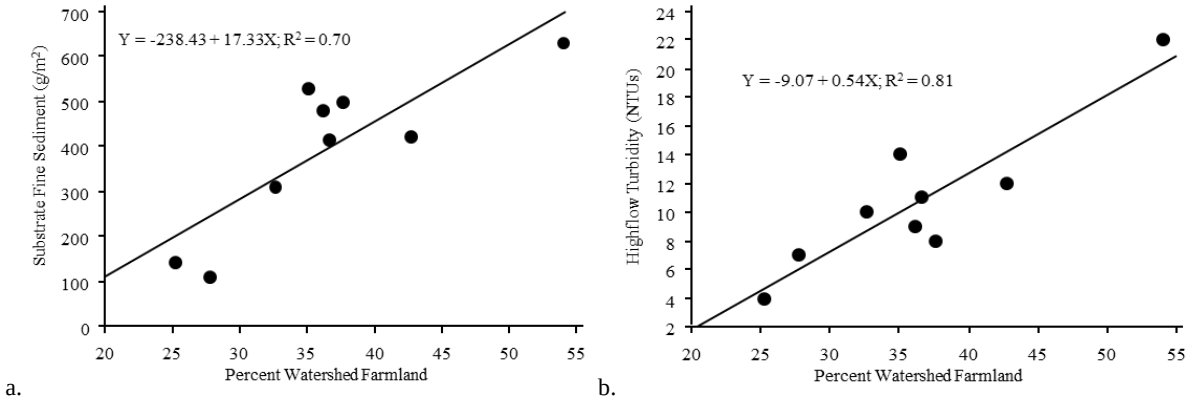
Fig. 9: Relationship between candidate and local reference stream temperatures and DO levels at lower sites during Early September. Refer to Table 3 (p.17) for 2-letter stream code.

The local reference and Conneaut candidate streams were measured on the same day in September, while the Cussewago candidate streams were measured on dates later in the month. Thus, time variation is likely a main contributor to the extraneous variables (CE, RR, CR, FR).

Evaluation of Substrate Fine Sediment and Habitats

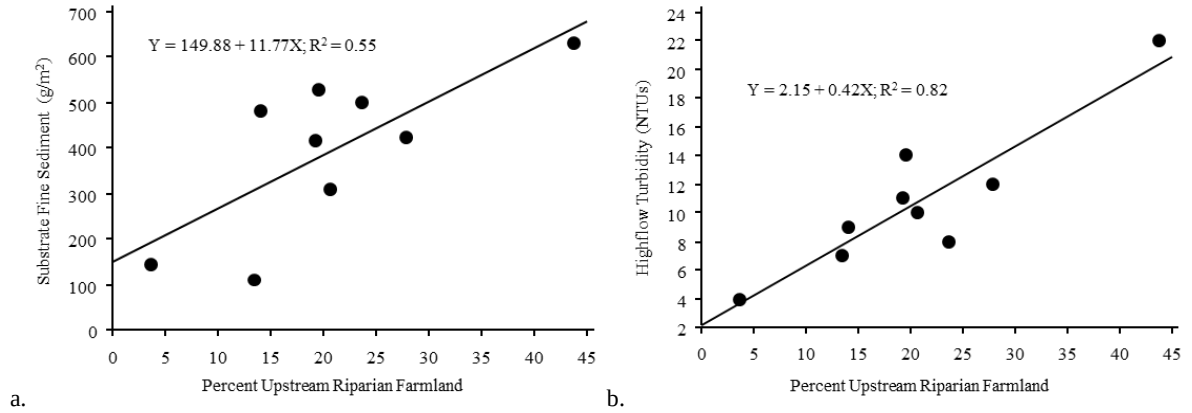
Candidate stream substrate fine sediment and highflow turbidity increased with farmland presence, both on a watershed ($F_{1,8}$=16.07, P=0.005 and $F_{1,8}$=29.07, P=0.001, respectively) and

upstream riparian based scale ($F_{1,8}$=8.71, P=0.021 and $F_{1,8}$=31.36, P=0.001, respectively) (Fig. 10, 11).



a. b.

Fig. 10: Relationship between percent watershed farmland and a. substrate fine sediment and b. highflow turbidity among the candidate streams.



a. b.

Fig. 11: Relationship between percent upstream riparian farmland and a. substrate fine sediment and b. highflow turbidity among candidate streams.

Tributaries of the Conneaut, Cussewago, and local reference watersheds differed in substrate fine sediment ($F_{2,11}$=4.15, P=0.0454) and highflow turbidity levels ($F_{2,11}$=11.19, P=0.0022) (Table 3, Fig. 12, 13). Specifically, the tributaries of the Cussewago watershed had higher substrate fine sediment levels than those of the local reference watershed (P=0.016), however not with those of the Conneaut watershed (P=0.071) (Fig. 12, App. 10). Rock Creek and McMichael Run had the lowest substrate fine sediments (Table 3).

Table 3: Candidate and local reference stream nutrient and sediment data. 2-letter stream code for Mud Run (MR) and Cussewago West Headwater (CW) not included.

Characteristic	Stream	Subwatershed	Turbidity Base Flow (NTU)	Turbidity High Flow (NTU)	Substrate Fines (g/m^2)	Base Flow Phosphorus (ug/L)
Candidate	Carr Run (CR)	Cussewago	2	22	629	22
Candidate	Rundelltown Run (RR)	Cussewago	2	14	530	69
Candidate	Cussewago East Headwater (CE)	Cussewago	< 1	12	423	21
Candidate	Fossil Run (FR)	Cussewago	< 1	11	414	11
Candidate	Inlet Run (IR)	Conneaut	< 1	10	310	12
Candidate	Watson Run (WR)	Conneaut	1	9	480	16
Candidate	Adsit Run (AR)	Conneaut	1	8	501	80
Candidate	McMichael Run (MMR)	Conneaut	< 1	7	109	17
Candidate	Rock Creek (RC)	Conneaut	< 1	4	142	22
Local Reference	Kantz Run (KR)	Main Stem-Lower	2	2	80	8
Local Reference	Powdermill Run (PR)	Main Stem-Lower	< 1	1	356	15
Local Reference	McCune Run (MR)	Main Stem-Lower	2	2	200	10
Local Reference	Mill Creek (MC)	Main Stem-Lower	5	9	160	15
Local Reference	North Deer Creek (NDC)	Main Stem-Lower	2	4	346	11

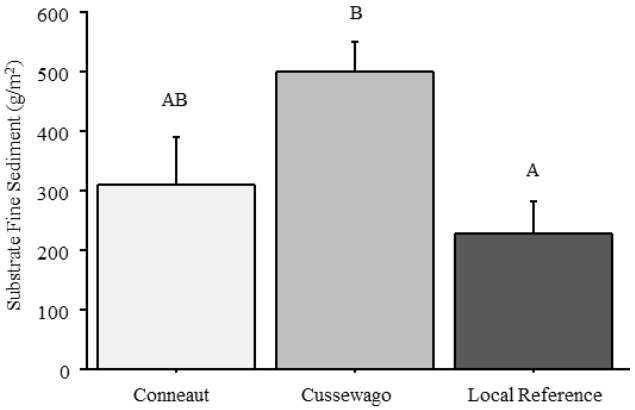


Fig. 12: Mean substrate fine sediment levels (±SE) between the tributaries of the Conneaut and Cussewago candidate watersheds and the local reference watershed.

The tributaries of the Cussewago watershed had higher highflow turbidity levels than those of the local reference (P=0.001) and Conneaut watersheds (P=0.012) (Fig. 13).

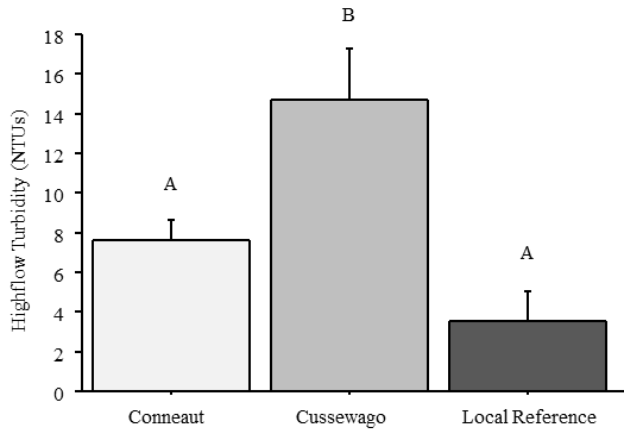


Fig. 13: Mean highflow turbidity levels (±SE) between the tributaries of the Conneaut and Cussewago candidate watersheds and the local reference watershed.

Rundelltown Run and Adsit Run had reasonably high base flow phosphorus compared to the rest of the candidate and local reference streams (Table 3). Base flow turbidity and TDS levels among the candidate streams were fair (Table 3).

The candidate stream RCE and WQNHA habitat assessment scores were highly correlated (R^2=0.49), thus the WQNHA habitat assessment form was used for the remaining analyses. Candidate stream WQNHA channel scores decreased with increased farmland presence, both on a watershed ($F_{1,8}$=11.45, P=0.012) and upstream riparian ($F_{1,8}$=5.68, P=0.049) based scale (Fig. 14, App. 7).

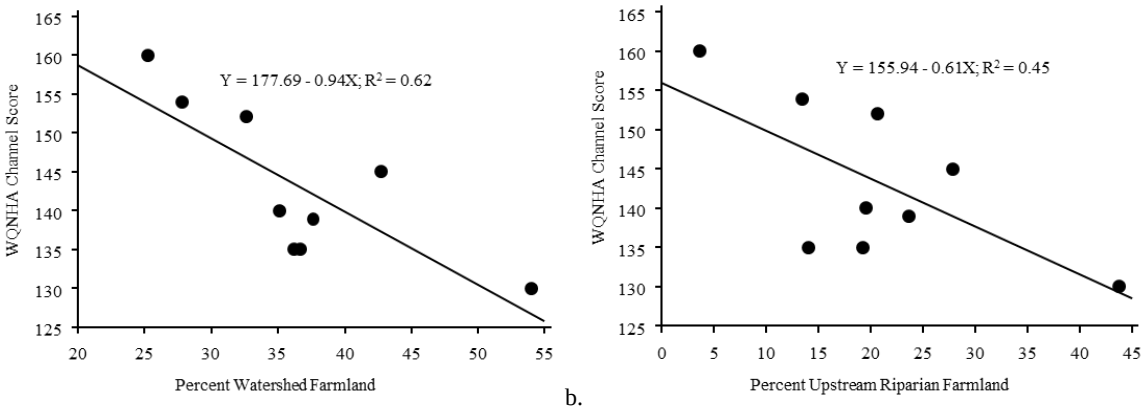


Fig. 14: Relationship between candidate stream WQNHA channel score and a. percent watershed farmland and b. percent upstream riparian farmland.

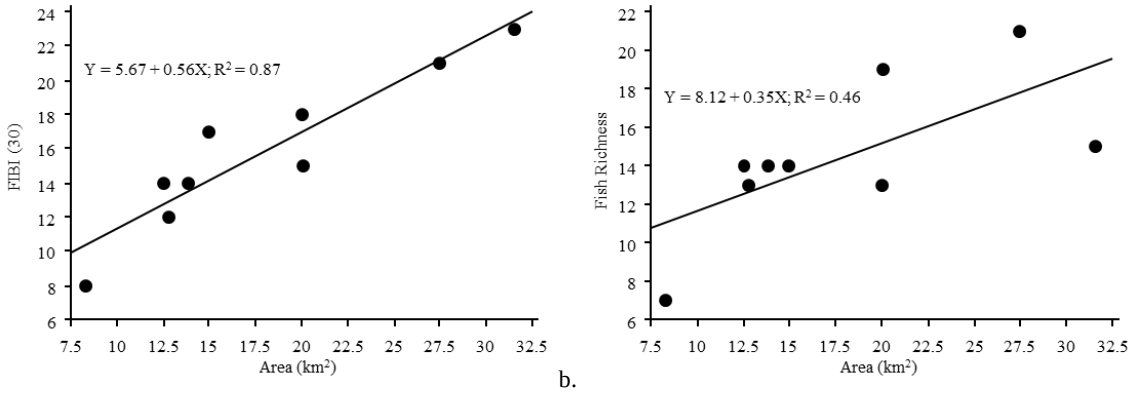
Candidate stream fish community composition

No trout, of any species, were found at any of the nine candidate streams (Table 4). Other candidate stream FIBI metrics were compared to those of local reference streams and basin-wide reference streams (Table 4). Previous data was thought to exist providing evidence of trout presence at Powdermill Run, however none was found. Powdermill Run was still used in the analysis as a local reference stream since trout have reportedly been found there based on its proximity to French Creek.

Table 4: Candidate, local reference, and basin-wide reference stream FIBI metrics (FIBI scoring sheet = App. 3, collected fishes identification list = App. 13).

Characteristic	Stream	Subwatershed	Fish IBI (0-30)	Fish Richness	Darter Richness	No. Lamprey	No. Trout	% Tolerant Taxa	% White Suckers	% Sensitive Taxa	% Sensitive Cyprinids
Candidate	Carr Run	Cussewago	21	21	5	1	0	7	1	40	0
Candidate	Rundelltown Run	Cussewago	18	13	4	0	0	23	1	49	2
Candidate	Cussewago East Headwater	Cussewago	23	15	5	3	0	23	1	62	1
Candidate	Fossil Run	Cussewago	12	13	2	0	0	28	5	56	2
Candidate	Inlet Run	Conneaut	14	14	4	0	0	40	4	2	0
Candidate	Watson Run	Conneaut	17	14	4	2	0	41	0	1	0
Candidate	Adsit Run	Conneaut	14	14	3	0	0	32	3	7	7
Candidate	McMichael Run	Conneaut	15	19	3	4	0	44	10	15	13
Candidate	Rock Creek	Conneaut	8	7	1	0	0	45	0	42	0
Local Reference	Kantz Run	Main Stem-Lower	21	21	4	0	1	9	2	52	5
Local Reference	Powdermill Run	Main Stem-Lower	14	8	3	0	0	18	0	75	0
Local Reference	McCune Run	Main Stem-Lower	28	16	3	0	10	17	0	77	0
Local Reference	Mill Creek	Main Stem-Lower	19	14	3	0	4	6	0	88	3
Local Reference	North Deer Creek	Main Stem-Lower	19	19	5	0	2	28	2	66	3
Basin-wide Reference	Armstrong Run	Sugar Creek	12	8	0	0	41	37	0	0	0
Basin-wide Reference	Aster Run	Sugar Creek	24	17	4	1	8	24	7	24	29
Basin-wide Reference	Baskin Run	South Branch	25	15	5	0	24	20	0	20	40
Basin-wide Reference	Beatty Run	Sugar Creek	24	21	4	1	8	19	6	33	50
Basin-wide Reference	Beaver Run	Muddy Creek	22	16	2	2	2	19	3	31	42
Basin-wide Reference	Higby Run	Sugar Creek	6	4	0	0	1	75	0	0	0
Basin-wide Reference	Kantz Run	Mainstem-Lower	21	21	4	0	1	9	2	52	5
Basin-wide Reference	Kirik Run	South Branch	10	4	0	0	17	50	0	0	0
Basin-wide Reference	McCune Run	Mainstem-Lower	28	16	3	0	10	17	0	77	0
Basin-wide Reference	Spencer Creek	South Branch	15	2	0	0	103	0	0	0	0
Basin-wide Reference	Sugar West Branch	Sugar Creek	24	19	4	1	15	26	1	21	28
Basin-wide Reference	Trout Run	Sugar Creek	21	15	2	0	13	26	1	20	29
Basin-wide Reference	Yellow Jacket Run	Sugar Creek	13	18	3	0	2	33	11	16	20

FIBI and fish richness varied considerably between the candidate streams, however were found to be a function of watershed area ($F_{1,8}$=46.95, P=0.0002 and $F_{1,8}$=5.94, P=0.045, respectively) (Fig. 15).



a. b.

Fig. 15: Relationship between watershed area and a. FIBI and b. fish species richness among candidate streams.

Differences in darter richness, number of lamprey individuals, and percentage of white suckers and sensitive cyprinids were not found between the candidate and reference streams. However, percent sensitive fish taxa differed between the tributaries of the Conneaut, Cussewago, local reference, and basin-wide reference watersheds ($F_{3,23}$=11.28, P<0.0001). Specifically, the tributaries of the Cussewago (P=0.006 and P=0.013, respectively) and local

reference watersheds (P<0.0001 and P<0.0001, respectively) had a greater percentage of sensitive fish taxa than those of the Conneaut and basin-wide reference watersheds (Fig. 16, App. 11). Rock Creek was the only Conneaut watershed stream with a reasonable percentage of sensitive fish taxa (Table 4).

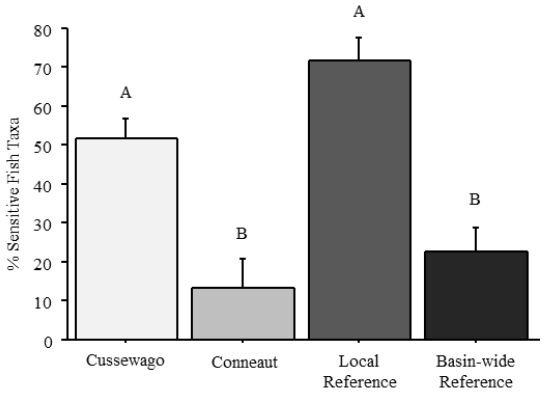


Fig. 16: Mean percent sensitive fish taxa (±SE) between tributaries of the Cussewago, Conneaut, local reference, and basin-wide reference watersheds.

Percent tolerant fish taxa did not differ between the tributaries of the Conneaut, Cussewago, local reference, and basin-wide reference watersheds ($F_{3,23}$=2.67, P=0.072) (Fig. 17).

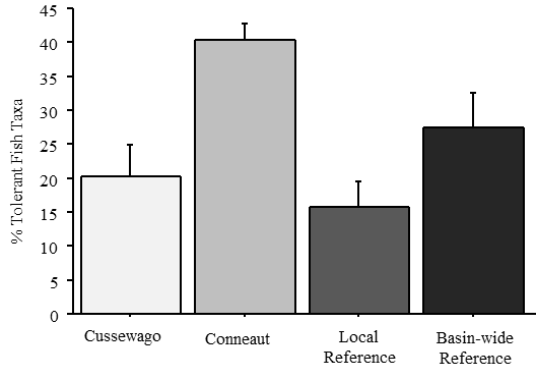


Fig. 17: No difference between the mean percent tolerant fish taxa (±SE) between tributaries of the Cussewago, Conneaut, local reference, and basin-wide reference watersheds.

Basin-wide reference streams were analyzed in order to observe potential patterns of fish species commonly coexisting with brook trout. Mottled sculpin (*Cottus bairdi*), blacknose dace (*Rhinichthys atratulus*), and creek chubs (*Semolitus atromaculatus*) were found in 92% of the basin-wide reference streams. Among the candidate streams, mottled sculpin were present in every Cussewago stream, yet absent in every Conneaut stream except for Rock Creek, likely due

to barriers (Fig. 2). Blacknose dace and creek chubs were found in the majority of the candidate streams (App. 13).

Macroinvertebrates

Benthic invertebrate IBI (BIBI) scores were similar between the tributaries of the candidate and local reference watersheds (Table 5). However, percentage of *Ephemeroptera* (stonefly), *Plecoptera* (mayfly), and *Trichoptera* (caddisfly) taxa (%EPTs) differed ($F_{2,11}$=10.04, P=0.003) between the tributaries of the candidate and local reference watersheds (Fig. 18). Specifically, the tributaries of the local reference watershed had higher EPT percentages than those of the Conneaut (P=0.002) and Cussewago (P=0.004) watersheds (Fig. 18) (App. 12). The tributaries of the Cussewago watershed had visibly lower amounts of stonefly taxa than the Conneaut and local reference watersheds (Table 5).

Table 5: Candidate and local reference stream BIBI metrics.

Characteristic	Stream	Subwatershed	Benthic IBI (0-30)	Total Taxa	Mayfly Taxa	Stonefly Taxa	Caddisfly Taxa	% EPT	% Tolerants
Candidate	Carr Run	Cussewago	22	15	2	1	7	71	4
Candidate	Rundelltown Run	Cussewago	18	13	3	1	2	41	0
Candidate	Cussewago East Headwater	Cussewago	24	16	4	1	4	76	1.5
Candidate	Fossil Run	Cussewago	24	16	4	3	4	42	0
Candidate	Inlet Run	Conneaut	28	22	3	6	4	52	0
Candidate	Watson Run	Conneaut	20	14	1	1	6	53	0
Candidate	Adsit Run	Conneaut	26	18	4	4	3	56	0
Candidate	McMichael Run	Conneaut	26	19	5	2	4	55	0
Candidate	Rock Creek	Conneaut	24	14	6	3	2	70	0
Local Reference	Kantz Run	Main Stem-Lower	24	17	3	3	5	77	0
Local Reference	Powdermill Run	Main Stem-Lower	26	20	2	2	8	81	4
Local Reference	McCune Run	Main Stem-Lower	28	17	4	4	6	90	0
Local Reference	Mill Creek	Main Stem-Lower	26	20	2	5	6	88	0
Local Reference	North Deer Creek	Main Stem-Lower	24	15	3	3	5	93	0

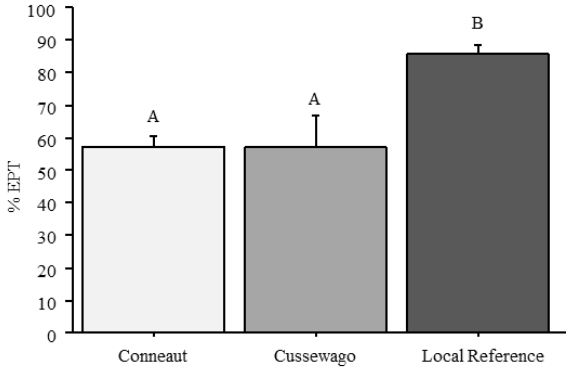


Fig. 18: Mean %EPT (±SE) between the tributaries of the Conneaut and Cussewago candidate and local reference watersheds

% EPTs increased with inceasing WQNHA channel scores among the local reference streams ($F_{1,4}$=12.583, P=0.038) (Fig. 19).

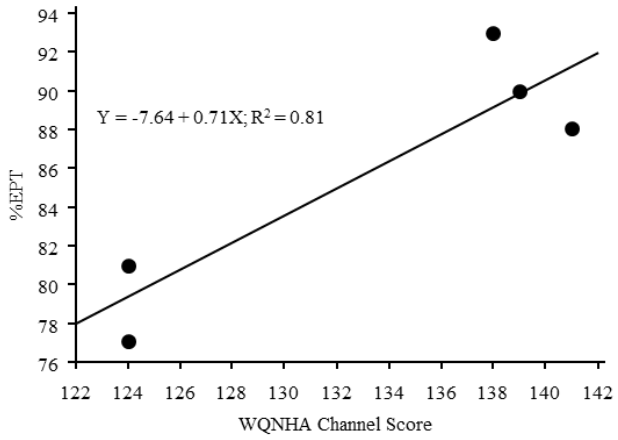


Fig. 19: Relationship between local reference stream % EPT and WQNHA channel score.

Discussion

Weighted Ranking

Brook trout suitability criteria were tested against thresholds established from the literature and local and basin-wide reference streams (Table 7). These criteria were weighted based on their vitality to brook trout survival and success (Table 6).

Table 6: Brook trout suitability criteria valued in this study. In the weighted ranking: primary criteria holds a value of five, secondary criteria a value of three, and tertiary criteria a value of one (Table 8).

Primary Criteria (5)	**Secondary Criteria (3)**	**Tertiary Criteria (1)**
Trout Presence	% Watershed Agriculture	High flow Phosphorus
Maximum Summer Water Temperature	% Riparian Agriculture	% Watershed Development
Minimum Summer Dissolved Oxygen	% Waterhed Forest	% Riparian Development
Fine Sediment	% Riparian Forest	
% EPT	WQNHA Riparian Score	
	WQNHA Channel Score	
	% Sensitive Fish Taxa	
	% Tolerant Fish Taxa	

Table 7: Comparison of candidate stream brook trout suitability against literature and local and basin-wide reference streams. *=condition not suitable for brook trout.

								Cussewago Watershed				Conneaut Watershed				
		Optimal	Threshold	Source	Local Reference Mean (±SD)	Basin-wide Reference Mean (±SD)	Burkhart 2014 Threshold	Carr Run	Rundelltown Run	Cussewago East Headwater	Fossil Run	Inlet Run	Watson Run	Adsit Run	McMicheal Run	Rock Creek
Physical Variables	Max Summer Temperature (°C)	-	20°C	Smith & Sklarew 2012; Petty & Merriam 2012	-	-	21-22°C	21.25*	20.75	22*	20	20.25	20	22.25*	19.25	20.75
		11-16°C	24°C	Raleigh 1982												
		15-21°C	25°C	EBTJV 2005												
	Minimum Summer DO (mg/L)	9 mg/L	-	Raleigh 1982	-	-	6-7 mg/L	6.3*	7.5	6.1*	7.8	7.5	7.6	7.3	7.1	7.9
		-	5 mg/L	Kerr 2000; Mills 1971												
		8-12 mg/L	-	Allan & Castillo 2007												
	Fine Sediment (g/m^2)	-	-	-	228 ± 120 g/m^2	-	228 ± 120 g/m^2	629*	530*	423*	414*	310	480*	501*	109	142
	Highflow Turbidity (NTU)	-	30 NTU	Raleigh 1982	3 ± 3 NTU	-	30 NTU	22	14	12	11	10	9	8	7	4
	Highflow Phosphorus (ug/L)	-	-	-	12 ± 3 ug/L	-	22 ug/L	22	69*	21	11	12	16	80*	17	22
	% Watershed Agriculture	20%	40%	Smith & Sklarew 2012	41 ± 11%	32 ± 11%	35%	54*	35	43*	37*	33	36*	38*	28	25
		<19%	30-35%	Hudy et al. 2008												
	% Watershed Forest	-	65-70%	Hudy et al. 2008	51 ± 10%	67 ± 15%	60%	40*	59*	50*	56*	61	57*	58*	63	67
	% Watershed Development		4%	Stranko et al. 2008	7 ± 3%	-	4%	4	6*	6*	7*	6*	6*	4	6*	6*
	% Riparian Farmland	-	-	-	20 ± 9%	-	35%	44*	20	28	19	21	14	24	13	4
	% Riparian Forest	-	-	-	73 ± 9%	79 ± 15%	75%	46*	71*	65*	75	74*	71*	73*	75	87
	% Riparian Development	-	4%	Stranko et al. 2008	6 ± 3%	-	4%	4	8*	5*	5*	5*	4	1	4	7*
	WQNHA Riparian Score	-	-	-	68 ± 4	61 ± 14	80	52*	60*	80	57*	60*	64*	65*	87	75
	WQNHA Channel Score	-	-	-	133 ± 8	127 ± 12	152	130*	140*	145*	135*	152	135*	139*	154	160
Biological Variables	Brown/Brook Trout Present	N	-	-	Both	Brook	N	N	N	N	N	N	N	N	N	N
	% Sensitive Fish Taxa	-	-	-	72 ± 13%	23 ± 23%	40%	40	49	62	56	2*	1*	7*	15*	42
	% Tolerant Fish Taxa	-	-	-	16 ± 9%	23 ± 19%	25%	7	23	23	28*	40*	41*	32*	44*	45*
	% EPT	-	-	-	86 ± 7%	-	70%	71	41*	76	42*	52*	53*	56*	55*	70

In the weighted ranking, if a candidate stream's criteria met their established threshold, it received a full score (Table 8). If a candidate stream's criteria did not meet their established threshold, they received a score of zero (Table 8).

Table 8: Candidate stream brook trout suitability weighted ranking. Higher scores indicate streams most suitable for brook trout.

		Carr Run	Rundelltown Run	Cussewago East Headwater	Fossil Run	Inlet Run	Watson Run	Adsit Run	McMichael Run	Rock Creek
Physical Variables	Max Summer Temperature (°C)	0	5	0	5	5	5	0	5	5
	Minimum Summer DO (mg/L)	0	5	0	5	5	5	5	5	5
	Fine Sediment (g/m^2)	0	0	0	0	5	0	0	5	5
	Highflow Phosphorus (ug/L)	1	0	1	1	1	1	0	1	1
	% Watershed Agriculture	0	3	0	0	3	0	0	3	3
	% Watershed Forest	0	0	0	0	3	0	0	3	3
	% Watershed Development	1	0	0	0	0	0	1	0	0
	% Upstream Riparian Farmland	0	3	3	3	3	3	3	3	3
	% Upstream Riparian Forest	0	0	0	3	0	0	0	3	3
	% Upstream Riparian Development	1	0	0	0	0	1	1	1	0
	WQNHA Riparian Score	0	0	3	0	0	0	0	3	3
	WQNHA Channel Score	0	0	3	0	3	0	0	3	3
Biological Variables	% Sensitive Fish Taxa	3	3	3	3	0	0	0	0	3
	% Tolerant Fish Taxa	3	3	3	0	0	0	0	0	0
	% EPT	5	0	5	0	0	0	0	0	5
	TOTALS	14	22	21	20	28	15	10	35	42

Water quality characteristics between candidate and reference streams

NWPA is located in a glacial till drift zone. High bicarbonate levels in soils buffer carbonic, sulfuric, and nitric acid in streams, neutralizing pH levels. Conductivity, alkalinity, hardness, and total dissolved solids levels were also characteristic of the sedimentary rock present in NWPA (Table 2). Similarity among these variables between the candidate and reference streams suggests the absence of point source pollution and allows comparisons to be made (Table 2). Their variation is likely due to their position along the stream continuum.

Summer water temperature and dissolved oxygen "bottleneck" period

NWPA has a humid continental climate, characteristic of hot, humid summers and cold winters (Yaworski et al. 1979). Water temperature and dissolved oxygen (DO) are two of the most important abiotic determinants of brook trout distribution in streams, especially during the summer months. Water temperature and DO have an inverse relationship and can vary along stream continuums (Fig. 3) (USGS 2014). This variation is seen among the candidate streams throughout the summer of 2013, as lower and middle sites had higher DO levels than upper sites (Fig. 4). This suggests the optimal summer habitat range for brook trout to be between the middle and lower sites (and even lower in the stream continuum). In addition, Conneaut

tributaries had higher DO levels for any given temperature than Cussewago tributaries, suggesting a higher stream gradient and/or groundwater input at Conneaut tributaries (Fig. 3).

The candidate streams with the lowest water temperatures and highest DO levels during the summer 2013 early July "bottleneck" period are assumed to be consistent throughout the "bottleneck" periods of future summers (Fig. 4, 6, 7). Brook trout congregate to the coolest and most oxygenated areas along the stream continuum during these stressful periods (Fig. 8). Optimal brook trout growth and development occurs between 11-21°C and 8-12mg/L (Raleigh 1982; EBTJV 2005; Allan & Castillo 2007; Smith & Sklarew 2012; Petty & Merriam 2012). Any water temperature above 24-25°C and DO below 5mg/L can prove lethal to brook trout (Mills 1971; Raleigh 1982; Kerr 2000; EBJTV 2005).

Based on the literature, I established a water temperature and DO threshold of 21-22°C and 6-7 mg/L (Fig. 8) (Raleigh 1982). It is important to note that candidate stream temperatures and DO levels could be suitable for trout as they are similar to those of local reference streams (Fig. 9). For the ranking system, lower and middle site water temperatures and DO levels of early July were averaged and compared against the established threshold (Table 7). Carr Run and Cussewago East Headwater did not meet the water temperature or DO threshold, and Adsit Run did not meet the water temperature threshold (Table 7, 8).

Candidate stream land use and its effect on stream habitat, sedimentation, and nutrient loading

Brook trout require low sediment and nutrient levels in streams in order to survive and achieve reproductive success (Raleigh 1982; Argent & Flebbe 1999; Petty & Merriam 2012). Agriculture has been found to increase the amount of sediment and nutrients in streams, affecting brook trout functionality (Fig. 10, 11) (Raleigh 1982; Sutherland et al. 2002). Hudy et al. (2008) found brook trout to be extirpated (or predicted extirpated) in watersheds with greater than 30-35% agriculture. Other literature supports watersheds with 20% agriculture to be 'good' and 40% to be 'poor' for brook trout suitability (Smith & Sklarew 2012).

Tributaries of the Cussewago watershed had visibly higher agricultural presence and higher substrate fine sediment than those of the Conneaut watershed (Fig. 12, Table 3, App. 8). Based on the literature, I established a watershed agriculture threshold at 35% (Table 7). In addition, I established a substrate fine sediment threshold at one standard deviation from the

local reference stream mean substrate fine sediment level (Table 7). McMichael Run, Rock Creek, and Inlet Run were the only candidate streams meeting both thresholds (Table 7, 8). The upstream riparian agriculture threshold was set at 35% as well, and Carr Run was the only candidate stream that did not meet all three thresholds as it had the highest watershed and upstream riparian agriculture and substrate fine sediment of the candidate streams (Table 7). Tributaries of the Cussewago watershed also had higher high flow turbidity than those of the Conneaut watershed (Fig. 13, Table 3). Raleigh (1982) suggested the optimal high flow turbidity range for brook trout be between 0-30 NTU. Since all candidate stream high flow turbidities fell within this range, high flow turbidity was not included as part of the ranking system (Table 7).

Rundelltown Run met the watershed agriculture threshold. However, Rundelltown and Adsit Run (only 3% more watershed agriculture than Rundelltown) had unusually high high flow phosphorus values for their low percentages of agriculture (Table 3). It is also interesting to note that Rundelltown and Adsit Run have some of the highest substrate fine sediment levels among the candidate streams (Table 3). This could suggest the presence of point source pollution upstream of the measurement sites. Therefore, I established a high flow phosphorus threshold in order to exclude these streams (Table 7, 8).

Impervious surfaces also provide nutrient runoff to streams as they can increase the rate at which water enters streams during rainfall events, effecting stream channel and bank characteristics (Poff et al. 1997; Sutherland et al. 2002; Herrmann et al. 2012). Stranko et al. (2008) recommended that a watershed development influence of 4% or less is suitable for brook trout. Based on this literature, I established a watershed and upstream riparian development threshold at 4% (Table 7). Adsit Run was the only stream meeting both thresholds (Table 7, 8).

Conversely, highly forested watersheds have less sediment and nutrient runoff and cooler temperatures than highly deforested watersheds (Pegan 2001). Hudy et al. (2008) suggests watersheds with lower than 65-70% forest cover are less suitable for brook trout. Based on the literature and the mean watershed forest cover of the local and basin-wide reference streams, I established a percent watershed forest threshold at 60% (Table 7, App. 8). Forested riparian zones are even more important for brook trout survivability as they directly protect streams from the surrounding landscape. Based on the mean riparian zone forest cover of the local and basin-wide reference streams, I established an upstream riparian forest threshold at 75% (Table 7).

McMichael Run and Rock Creek were the only candidate streams meeting both forest thresholds (Table 7, 8).

The WQNHA habitat assessment form is broken up into two components: riparian and channel characteristics. The riparian component encompasses riparian zone vegetation, bank condition/stability, and surrounding land use. The channel component encompasses in-stream cover (important fish and macroinvertebrate habitat), sediment deposition, depth variation, and riffle/pool frequency (1:1 ideal for brook trout) (Karr 1991; EBTJV 2005). Candidate stream WQNHA channel scores decreased as agricultural presence increased, likely due to increased sedimentation (Fig. 10a, 11a, 14). Candidate stream WQNHA scores were much higher than those of local and basin-wide reference stream scores, most likely due to variation among data collectors. Thus, I established a WQNHA channel score threshold of 152 and riparian score of 80 in order to encompass the outlying best scores in each category (Table 7). McMichael Run and Rock Creek were the only candidate streams meeting both WQNHA thresholds (Table 7, 8).

Candidate stream fish community characteristics

No trout, of any species, were found in the candidate streams, keeping all streams eligible for brook trout reintroduction (Table 4, App. 13). Trout presence was not included in the ranking system as a trout stream would automatically be dismissed. FIBI and fish richness were not used in the ranking system either as they are functions of watershed size (Fig. 15).

Blacknose dace, mottled sculpin, and creek chubs were the most commonly recurring fish species coexisting with brook trout in the basin-wide reference streams. These species are all very common in streams in NWPA and are found in many of the candidate streams; and literature supports that brook trout can coexist with these species (Scarols 1973; Zimmerman & Vondracek 2006). It is also important to note that low (non-trout) brook trout predator abundance was observed among the candidate streams (App. 13). None of these variables were considered in the weighted ranking system.

Percent sensitive and tolerant fish taxa were the only notable differences in candidate stream fish fauna. Brook trout are extremely sensitive to stream degradation; therefore, streams with higher sensitive fish presence and lower tolerant fish presence are thought to be more suitable for brook trout. Tributaries of the Conneaut watershed had fewer sensitive fish taxa and

visibly more tolerant fish taxa than those of the Cussewago and local reference watersheds (Fig. 16, 17). Based on the local and basin-wide reference streams, I established a sensitive fish taxa threshold at 40% and a tolerant fish taxa threshold at 25% (Table 7). Carr Run, Rundelltown Run, and Cussewago East Headwater were the only candidate streams meeting both thresholds (Table 7, 8).

Candidate stream macroinvertebrate community characteristics

Brook trout rely on macroinvertebrates as their main source of prey, specifically: mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and caddisflies (*Trichoptera*) (EPTs) (EBJTV 2005). Similar to brook trout, EPTs are very sensitive to stream degradation, as % EPTs increased with WQNHA channel score at the local reference streams (Fig. 19). The Benthic IBI (BIBI) used in this study is calculated from total taxa, mayfly taxa, stonefly taxa, caddisfly taxa, % EPTs, and % tolerant taxa (Table 5, App. 4). Not much variation between the candidate and reference streams was found in any of these variables, indicating similar macroinvertebrate communities (Table 5). However, local reference streams had higher % EPTs than candidate streams, suggesting increased prey communities and/or better stream conditions in the local reference streams (Fig. 18). Variation in macroinvertebrate sorters/identifiers could be the source of this variation. Thus, I established a % EPT threshold of 70% in order to encompass the outlying highest EPT percentages (Table 7). Cussewago East Headwater, Carr Run, and Rock Creek met the % EPT threshold (Table 7, 8). It is also important to note that stonefly taxa was visibly lower among the Cussewago candidate streams (Table 5).

Candidate stream recommendations for brook trout restoration

It is difficult to find streams in nature that are perfectly suitable for brook trout. Thus is why this study implemented a weighted ranking system in order to most accurately evaluate each tributary, not ruling out a stream because it did not meet a certain criteria. Based on the weighted ranking, I recommend that the restoration of brook trout populations in the western region of French Creek should begin in the Conneaut watershed, as its tributaries are moderately forested and have medium gradients. Specifically, Rock Creek and McMichael Run appear most suitable for brook trout (Table 8). Both Conneaut watershd tributaries have consistent water temperatures and DO levels throughout the summer, low substrate fine sediment, acceptable riparian and

channel habitat, and low agricultural influence (Table 7). McMichael Run had a slightly lower brook trout suitability score than Rock Creek because it did not meet the primary criteria % EPT threshold. However, brook trout are thought to still experience success despite lower EPT presence in McMichael Run. Brook trout should be released at the Rock Creek and McMichael Run lower sites, in addition to above the waterfall (located above the middle site) at Rock Creek (App. 1).

Primary brook trout restoration efforts: Rock Creek and McMichael Run.



Fig. 19: Rock creek lower site (left) and Rock Creek waterfall (right), located between its middle and upper sites.



Fig. 20: McMichael Run lower site.

If secondary brook trout restoration efforts were to be made in the Conneaut watershed, Inlet Run would be a viable candidate. It holds most of the same physical and biological characteristics as Rock Creek and McMichael Run; however, it lacks the riparian forest needed to meet the upstream riparian forest and WQNHA riparian score thresholds (Table 7). In addition, similar to McMichael Run, it did not meet the % EPT threshold (Table 7). Brook trout should be released above the Inlet Run lower site (App. 1).

Secondary brook trout restoration efforts: Inlet Run.



Fig. 20: Inlet Run lower site.

Brook trout stocking procedure recommendations

The lifespan for native brook trout is approximately three years, and even shorter for stocked populations (Bonney 2009). Post-stocking survival rates of hatchery-reared brook trout are low (Kerr 2000). The life stages of brook trout stocked in streams are mainly fry and fingerlings, with fingerlings (0-45.6%) having a greater success rate than fry (3.6-19.7%) (Kerr 2000). In addition, hatchery-reared brook trout have the highest mortality rates the first summer after their reintroduction (Latta 1963). I recommend that if native brook trout cannot be reintroduced, hatchery-reared brook trout fingerlings be reintroduced to Rock Creek, McMichael Run, and Inlet Run, as they will have the highest chance of survival according to the literature.

Recommendations for Future Studies

Once brook trout are reintroduced to Rock Creek, McMichael Run, and/or Inlet Run, their population success/distribution rates should be monitored. In addition, if the Cussewago watershed forest cover increases in the coming years, its tributaries should be reanalyzed for brook trout suitability. Lastly, headwater tributaries isolated by barriers throughout the French Creek watershed (and beyond) should be tested for brook trout suitability in order to increase the biodiversity of the region.

Acknowledgments

I would like to thank the Unassessed Waters Initiative and the PA Fish & Boat Commission for their support, Class of ’39 Fund for funding this project, the fall 2013 Stream Ecology class for their help with fall field data collection, Chris Shafer for his help in the GIS lab, Dr. Milt Ostrofsky for his help with data analyzation in the lab, Scott Kirk for his help with summer field data collection, David Olson for re-sorting and identifying macroinvertebrate samples, and my “comp group” for their help and advice throughout the senior project process (in particular Kirsten Ressel). Lastly, I would like thank Dr. Scott Wissinger for his assistance during this project and for being such an influential mentor over the past four years.

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Appendix 1: Candidate, local reference, and basin-wide reference stream lat-longs for lower, middle, upper, electrofishing, and data collection sites. Lower, middle, and upper sites refer summer 2013 water temperature and DO data collection. Fish = electrofishing site fall 2013 . Previous fish = electrofishing site according to previous study where fish data was obtained (Table 1). Data = data collection site fall 2013. Previous data = data collection site according to previous study where data was obtained (Table 1).

Characteristic	Stream	Subwatershed	Site	Latitude	Longitude
Candidate	Carr Run	Cussewago	Lower	41.785653	-80.271553
			Fish + Data	41.781108	-80.255149
			Middle	41.793708	-80.297632
			Upper	41.807609	-80.303874
Candidate	Rundelltown Run	Cussewago	Lower + Fish + Data	41.758607	-80.283892
			Middle	41.744280	-80.293748
			Upper	41.727201	-80.293137
Candidate	Cussewago Headwater West	Cussewago	Lower	41.850331	-80.269453
			Middle	41.859885	-80.266908
			Upper	41.870136	-80.258738
Candidate	Cussewago Headwater East	Cussewago	Lower	41.838243	-80.226924
			Fish + Data	41.845224	-80.221628
			Middle	41.857787	-80.219693
			Upper	41.879902	-80.233707
Candidate	Fossil Run	Cussewago	Lower	41.798917	-80.231014
			Middle + Fish + Data	41.803904	-80.222624
			Upper	41.806515	-80.205260
Candidate	Inlet Run	Conneaut	Lower + Fish + Data	41.658861	-80.305559
			Middle	41.673990	-80.301214
			Upper	41.694117	-80.304453
Candidate	Mud	Conneaut	Lower	41.589023	-80.265299
			Middle	41.601837	-80.266007
Candidate	Watson Run	Conneaut	Lower + Fish + Data	41.637752	-80.262296
			Middle	41.653898	-80.258263
			Upper	41.673687	-80.269697
Candidate	Adsit Run	Conneaut	Lower + Fish + Data	41.574521	-80.287699
			Middle	41.555595	-80.294135
			Upper	41.548018	-80.295975
Candidate	McMicheal Run	Conneaut	Lower + Fish + Data	41.570629	-80.268592
			Middle	41.549465	-80.263340
			Upper	41.532258	-80.246126
Candidate	Rock Creek	Conneaut	Lower + Fish + Data	41.530138	-80.159729
			Middle	41.523521	-80.166507
			Upper	41.520907	-80.170718
Local Reference, Basin-wide Reference	Kantz Run	Main Stem-Lower	Previous Fish + Data	41.517549	-80.059378
Local Reference	Powdermill Run	Main Stem-Lower	Previous Fish + Data	41.476567	-80.020222
Local Reference, Basin-wide Reference	McMCune Run	Main Stem-Lower	Previous Fish + Data	41.469261	-79.987816
Local Reference	Mill Creek	Main Stem-Lower	Previous Fish + Data	41.430714	-79.962327
Local Reference	North Deer Creek	Main Stem-Lower	Previous Fish + Data	41.462249	-80.021337
Basin-wide Reference	Armstrong Run	Sugar Creek	Previous Fish + Previous Data	-	-
Basin-wide Reference	Aster Run	Sugar Creek	Previous Fish + Previous Data	41.539011	-79.858803
Basin-wide Reference	Baskin Run	South Branch	Previous Fish + Previous Data	41.919382	-79.717779
Basin-wide Reference	Beatty Run	Sugar Creek	Previous Fish + Previous Data	41.476415	-79.892859
Basin-wide Reference	Beaver Run	Muddy Creek	Previous Fish + Previous Data	41.894071	-79.737323
Basin-wide Reference	Higby Run	Sugar Creek	Previous Fish + Previous Data	-	-
Basin-wide Reference	Kirik Run	South Branch	Previous Fish + Previous Data	41.921862	-79.694157
Basin-wide Reference	Spencer Creek	South Branch	Previous Fish + Previous Data	41.928145	-79.678489
Basin-wide Reference	Sugar West Branch	Sugar Creek	Previous Fish + Previous Data	41.585961	-79.871289
Basin-wide Reference	Trout Run	Sugar Creek	Previous Fish + Previous Data	41.547984	-79.896948
Basin-wide Reference	Yellow Jacket Run	Sugar Creek	Previous Fish + Previous Data	41.573494	-79.950279

Appendix 2: Candidate stream lower, middle, and upper site water temperature and dissolved oxygen measurements during late June, early July, late July, and early August 2013. Candidate and local reference stream lower site water temperature and dissolved oxygen measurements during early September 2013.

Characteristic	Stream	Subwatershed	Site	Water Temperature (°C)				Dissolved Oxygen (mg/L)				DO	Temp
				Late June	Early July	Late July	Early August	Late June	Early July	Late July	Early August	Early September	
Candidate	Carr Run	Cussewago	Lower	20	21	21	16.5	6.4	6.4	6.4	8.2	9.4	15.1
			Middle	19.5	21.5	21	16	6.4	6.2	6.6	6	-	-
			Upper	21	20	21	17	6.8	6.4	6.6	6	-	-
Candidate	Rundelltown Run	Cussewago	Lower	19.5	20.5	20.5	16.5	7.2	7.2	7.8	7.8	8.8	7.9
			Middle	19	21	20.5	15	7.4	7.8	8.2	9.2	-	-
			Upper	19	19.5	20	13.5	7	7.2	7.2	8.2	-	-
Candidate	Cussewago West Headwater	Cussewago	Lower	19.5	20	20	16	6.8	6.2	6.8	7.6	-	-
			Middle	19	20	20	16.5	7.4	6.6	7.2	7	-	-
			Upper	21	20.5	21.5	15	6.2	5	4	6	-	-
Candidate	Cussewago East Headwater	Cussewago	Lower	20	22	21.5	17	7.6	7.2	7.4	7.8	12.6	7.1
			Middle	20	22	22	18.5	6.6	5	6	6.6	-	-
			Upper	21.5	22	23	18.5	5	3	3.8	5.2	-	-
Candidate	Fossil Run	Cussewago	Lower	20.5	20	20.5	18	8.2	8	8.2	8.6	8.6	15.7
			Middle	20	20	20.5	16.5	7.6	7.6	7.8	9	-	-
			Upper	19.5	20.5	21..5	16	7.6	7.2	7.4	7.8	-	-
Candidate	Inlet Run	Conneaut	Lower	18.5	20	18	16	8.2	8	8.2	9.6	8.6	18
			Middle	19	20.5	17.5	15.5	7.4	7	8	9.2	-	-
			Upper	20	21	18	17.5	5.4	6.6	7.2	9	-	-
Candidate	Mud	Conneaut	Lower	18	19	17	15.5	8	7.6	8.8	9.8	-	-
			Middle	16	19.5	17.5	14.5	8.2	7.4	8.6	8.2	-	-
Candidate	Watson Run	Conneaut	Lower	18.5	20	20	16	8.4	7.8	8.2	9.6	8.8	18
			Middle	18.5	20	19	17.5	8.2	7.4	7.8	9.2	-	-
			Upper	19	20	19	17	7.2	7	7.6	8.4	-	-
Candidate	Adsit Run	Conneaut	Lower	18	22.5	17.5	15	8.2	7.4	8.4	9.4	8.4	18
			Middle	19.5	22	18	16	6.8	7.2	4.8	6.2	-	-
			Upper	19	23.5	18	14.5	7	6	5	5.8	-	-
Candidate	McMicheal Run	Conneaut	Lower	18	19	17.5	16	7.8	7.6	9	9	8.8	18.5
			Middle	18	19.5	19	17	6.4	6.6	7	7.2	-	-
			Upper	20.5	22.5	21	18.5	2.6	5	1.8	4.6	-	-
Candidate	Rock Creek	Conneaut	Lower	18	21	18	16	8.8	7.6	9.2	8.8	9	17.5
			Middle	18	20.5	18.5	15	8.6	8.2	9.4	9	-	-
			Upper	17.5	18	18.5	14	8.2	8.6	9.8	8.8	-	-
Local Reference	Kantz Run	Main Stem-Lower	Lower	19	21.5	19	16.5	8	8.2	9.2	9.2	9	17.5
Local Reference	Powdermill Run	Main Stem-Lower	Lower	-	-	-	-	-	-	-	-	10.2	16
Local Reference	McMCune Run	Main Stem-Lower	Lower	-	-	-	-	-	-	-	-	8.6	17
LocalReference	Mill Creek	Main Stem-Lower	Lower	-	-	-	-	-	-	-	-	9	17.5
Local Reference	North Deer Creek	Main Stem-Lower	Lower	-	-	-	-	-	-	-	-	9.4	17

Appendix 3: Fish IBI scoring sheet (Goeller 2010; Kirk 2011).

Finalized Fish IBI (2012MK)
Site Name:
Stream Size (km²):
Date:
Field Collectors:

Metric	5	3	1	0	Value	Score
1. Total Species Richness	≥15	14-9	≤8	0		
2. Darter Richness	≥ 4	2-3	1	0		
3. No. of Lamprey individuals	≥ 5	2-4	1	0		
4. No. of Trout individuals	≥ 6	3-5	1-2	0		
5. % Tolerant Taxa	≤ 25%	26-35%	36-50%	> 50%		
6. % White Suckers	≤ 4%	5-10	10-15	>15%		
					Total ►	0

Alternative Metrics	*5*	3	1	0	Value	Score
7. % Sensitive Taxa	≥ 25%	24-18	17-10	> 10%		
8. % Sensitive Cyprinid Taxa	≥ 40%	39-30	29-21	≤ 20%		
9. Number of Piscivores	Score using the Piscivore Regression					

% white sucker does not include sculpin counts in the denominator
% tolerant and sensitive taxa includes all taxa in the denominator
Lamprey and Trout individuals counted from both the quant and qual
% sensitive cyprinid includes only total cyprinid richness in the denominator

The six metrics and their corresponding scores above work best in the 10-26 km² range.

Any site above 33 km² should score metrics 1 and 2 using the stream size regressions.
Metric 5 should be replaced entirely with Metric 9 and scored using the Piscivore regression.

Appendix 4: Benthic invertebrate IBI scoring sheet.

Stream _____ Collectors _____

Benthic IBI for 3rd Order Streams in French Creek Watershed

(modified from Lyle 1998)

Metric	Rating Criteria				value -	Rating
	5	**3**	**1**	**0**		
1. Total taxa	>20	11-20	≤10	0	_____	_____
2. Mayfly taxa	> 3	2 – 3	1	0	_____	_____
3. Stonefly taxa	> 3	2 – 3	1	0	_____	_____
4. Caddisfly taxa	> 3	2 – 3	1	0	_____	_____
5. % EPT_1	≥ 50%	25-49	24 - 10%	< 10%	_____	_____
6. % $tolerants_2$	< 10%	25-10	25 – 35	> 35%	_____	_____
					TOTAL	_____

1. not including hydropsychid caddisflies
2. tolerants only = red chironomid midges & annelids

Rating Scores – good 30 – 24

average 23 – 15

degraded < 15

Appendix 5: WQNHA habitat assessment scoring sheet. Channel score = questions 1-8, riparian score = questions 9-12.

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pennsylvania

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF WATER STANDARDS AND FACILITY REGULATION

WATER QUALITY NETWORK
HABITAT ASSESSMENT

WATERBODY NAME _____ STR CODE/RMI _____

STATION NUMBER _____ LOCATION _____

DATE _____ TIME _____

AQUATIC ECOREGION _____ COUNTY _____

INVESTIGATORS _____

FORM COMPLETED BY _____ ***RIFFLE/RUN PREVALENCE***

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Instream Cover (Fish)	Greater than 50% mix of boulder, cobble, submerged logs, undercut banks, or other stable habitat.	30-50% mix of boulder, cobble, or other stable habitat; adequate habitat.	10-30% mix of boulder, cobble, or other stable habitat; habitat availability less than desirable.	Less than 10% mix of boulder, cobble, or other stable habitat; lack of habitat is obvious.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
2. Epifaunal Substrate	Well developed riffle and run, riffle is as wide as stream and length extends two times the width of stream; abundance of cobble.	Riffle is as wide as stream but length is less than two times width; abundance of cobble; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than two times the stream width; gravel or large boulders and bedrock prevalent; some cobble present.	Riffles or run virtually nonexistent; large boulders and bedrock prevalent; cobble lacking.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
3. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
4. Velocity/Depth Regimes	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow).	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score lower than if missing other regimes).	Dominated by 1 velocity/depth regime (usually slow-deep).
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
5. Channel Alteration	No channelization or dredging present.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	New embankments present on both banks; and 40-80% of stream reach channelized and disrupted.	Banks shored gabion or cement; over 80% of the stream reach channelized and disrupted.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Total Side 1 _____				

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RIFFLE/RUN PREVALENCE

Habitat Parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
6. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.					Some new increase in bar formation, mostly from coarse gravel; 5-30% of the bottom affected; slight deposition in pools.					Moderate deposition of new gravel, coarse sand on old and new bars; 30-50% of the bottom affected; sediment deposits at obstruction, constriction, and bends; moderate deposition of pools prevalent.					Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
7. Frequency of Riffles	Occurrence of riffles relatively frequent; distance between riffles divided by the width of the stream equals 5 to 7; variety of habitat.					Occurrence of riffles infrequent; distance between riffles divided by the width of the stream equals 7 to 15.					Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.					Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is between ratio >25.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
8. Channel Flow Status	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.					Water fills > 75% of the available channel; or <25% of channel substrate is exposed.					Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed.					Very little water in channel and mostly present as standing pools.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
9. Condition of Banks	Banks stable; no evidence of erosion or bank failure.					Moderately stable; infrequent, small areas of erosion mostly healed over.					Moderately unstable; up to 60% of banks in reach have areas of erosion.					Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; on side slopes, 60-100% of bank has erosional scars.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
10. Bank Vegetative Protection	More than 90% of the streambank surface covered by vegetation.					70-90% of the stream-bank surface covered by vegetation.					50-70% of the stream-bank surfaces covered by vegetation.					Less than 50% of the streambank surface covered by vegetation.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
11. Grazing or Other Disruptive Pressure	Vegetative disruption, through grazing or mowing, minimal or not evident; almost all plants allowed to grow naturally.					Disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.					Disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.					Disruption of vegetation is very high; vegetation has been removed to 2 inches or less in average stubble height.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
12. Riparian Vegetative Zone Width	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.					Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.					Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.					Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.				
SCORE _____	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Total Side 2 _____																				
Total Score _____																				

Appendix 6: RCE habitat assessment scoring sheet. Channel score = questions 5-12, riparian score = questions 1-4.

RIPARIAN, CHANNEL, AND ENVIRONMENTAL INVENTORY (RCE)

(modified from Petersen (1992)

BASIC DATA

Stream name: _____ **Watershed:** _____

Date: _____ **Time:** _____

EXACT Location:

_____

_____

Observers:

_____

_____

Approximate stream width: _____ **m** **Approximate stream depth:** _____ **m**

Stream flow condition: high medium low very low

Days since last significant rain: 0 1 2 3 4-7 8+

Initial Rating: excellent very good good fair poor

INVENTORY

Determine the condition of the stream I. **RIPARIAN ZONE** and II. **CHANNEL STRUCTURE** at which you are standing and up to **50 m upstream and downstream (100 m total)**. Estimate the average condition over that distance and select ONE of the four scores for each characteristic. Indicate your selection by writing an X next to your choice. Refer to the **Glossary** in the **Guide to RCE**.

I. LAND USE at the local reach scale

1. Land-use pattern beyond the immediate riparian zone
   - Undisturbed, consisting of forest and/or natural wetlands 30 _____
   - Permanent pasture mixed with woodlots and wetlands; few buildings and roads 20 _____
   - Mixed row crops and pasture, or mixed grass lawn and homes 10 _____
   - Mainly row crops, or mostly streets, pavement, buildings, and parking lots 1 _____

2. Width of riparian zone from stream edge to field
   - Marshy or woody riparian zone >30 m wide 30 _____
   - Marshy or woody riparian zone varying from 5 to 30 m 20 _____
   - Marshy or woody riparian zone 1-5m 5 _____
   - Marshy or woody riparian zone absent 1 _____

3. Completeness of riparian zone
   - Riparian zone intact without breaks in vegetation along entire 100m zone 30 _____
   - Areas without vegetation occur at intervals of > 50 m (fragmented riparian zone) 20 _____
   - Areas without vegetation frequent with some erosion (gullies and scars) every 50 m 5 _____
   - Many areas without vegetation, erosion occurring (gullies, scars) along entire length 1 _____

4. Vegetation of riparian zone within 10 m of the channel
   - >90% plant density of mature trees or shrubs, or native marsh plants 25 _____
   - Mixed young tree species along channel and mature trees behind 15 _____
   - Vegetation of mixed grasses and sparse young tree or shrub species 5 _____
   - Vegetation consisting mostly of grasses, few trees & shrubs; low plant density; 1 _____

Total for Reach Scale Riparian Land Use _____

II. PHYSICAL STRUCTURE OF STREAM
(reflects combined effects of upstream land use & riparian intactness + local riparian habitat)

5. Debris dams (fallen trees, logs, limbs, and rock material wedged in or along channel)
   - Channel with old debris dams - old logs and rocks firmly set in place 15 _____
   - Logs and rocks present but back filled with some sediment 10 _____
   - Debris dams loose, probably moving with floods 5 _____
   - Debris dams sparse, easily moved; or debris dams absent 1 _____

6. Channel Width to Depth ratio (width and depth measured as if channel was full to banks)
   - if answer is < 7 channel should be ample for present and annual peak flows 15 _____
   - if answer is 8-15; channel adequate, overbank flows rare 10 _____
   - if answer is 16-25; channel barely contains common high flows 5 _____
   - if answer is >25 or stream is artificially channelized; overbank flow common 1 _____

7. Channel bars
   - Little channel width enlargement (bank erosion, undercutting) gravel bars present 15 _____
   - Some gravel bars, pore spaces between rocks well washed with little silt present 10 _____
   - Sediment bars of rocks, sand, and silt common 5 _____
   - Channel divided into braids* around sediment bars; or stream is channelized 1 _____

8. Stream-bank stability
   - Banks stable, of rock and soil held firmly by grasses, shrubs, and tree roots 25 _____
   - Banks firm but loosely held by grass and shrubs 15 _____
   - Banks loose, held by a sparse layer of grass and shrubs 5 _____
   - Banks unstable, of loose soil or sand easily disturbed 1 _____

9. Bank undercutting
   - Little or none evident or restricted to areas with tree root support 20 _____
   - Band undercutting* only on curves or narrow channel areas 15 _____
   - Band undercutting common, some banks falling in 5 _____
   - Severe bank undercutting along channel, banks falling in 1 _____

10. Stony substrate; feel and appearance
   - Stones clean, rounded (smooth pebbles, cobbles); may have blackened color 25 _____
   - Stones without sharp edges and with slight gritty feel 15 _____
   - Some stones with sharp edges, obvious gritty feel 5 _____
   - Stones bright; silt and grit covering them, sharp edges common 1 _____

11. Fine sediments in riffles & runs
   - Various sized rocks, gravel, and sand mixture; open spaces common between rocks 25 _____
   - Loose stony bottom with some silt having settled in spaces between rocks 15 _____
   - Mixture of silt and fine sand; few open spaces between rocks; bottom firm in places 5 _____
   - Uniform bottom of silt & sand and silt held loosely together 1 _____

12. Riffles and pools
   - Riffles distinct, occurring at intervals of 5-7 times the stream width (not channel width) 25 _____
   - Riffles and pools irregularly spaced 20 _____
   - Long pools separating short riffles 10 _____
   - Riffles and pools absent or stream channelized 1 _____

Total for Reach Scale Riparian Land Use _____

Total RCE _____

Appendix 7: Candidate, local reference, and basin-wide reference stream WQNHA and RCE habitat assessment form scores.

Characteristic	Stream	Subwatershed	WQNHA Channel Score	WQNHA Riparian Score	RCE Channel Score	RCE Riparian Score
Candidate	Carr Run	Cussewago	130	52	125	55
Candidate	Rundelltown Run	Cussewago	140	60	155	50
Candidate	Cussewago East Headwater	Cussewago	145	80	150	115
Candidate	Fossil Run	Cussewago	135	57	131	85
Candidate	Inlet Run	Conneaut	152	60	115	85
Candidate	Watson Run	Conneaut	135	64	110	65
Candidate	Adsit Run	Conneaut	139	65	115	95
Candidate	McMicheal Run	Conneaut	154	87	135	85
Candidate	Rock Creek	Conneaut	160	75	145	105
Local Reference	Kantz Run	Main Stem-Lower	124	66	135	85
Local Reference	Powdermill Run	Main Stem-Lower	124	63	135	75
Local Reference	McCune Run	Main Stem-Lower	139	72	130	95
Local Reference	Mill Creek	Main Stem-Lower	141	73	150	105
Local Reference	North Deer Creek	Main Stem-Lower	138	66	150	95
Basin-wide Reference	Armstrong Run	Sugar Creek	-	-	-	-
Basin-wide Reference	Aster Run	Sugar Creek	-	-	-	-
Basin-wide Reference	Baskin Run	South Branch	136	37	-	-
Basin-wide Reference	Beatty Run	Sugar Creek	-	-	-	-
Basin-wide Reference	Beaver Run	Muddy Creek	129	68	-	-
Basin-wide Reference	Higby Run	Sugar Creek	-	-	-	-
Basin-wide Reference	Kantz Run	Mainstem-Lower	124	66	-	-
Basin-wide Reference	Kirik Run	South Branch	114	76	-	-
Basin-wide Reference	McCune Run	Mainstem-Lower	139	72	-	-
Basin-wide Reference	Spencer Creek	South Branch	142	59	-	-
Basin-wide Reference	Sugar West Branch	Sugar Creek	128	72	-	-
Basin-wide Reference	Trout Run	Sugar Creek	105	43	-	-
Basin-wide Reference	Yellow Jacket Run	Sugar Creek	125	54	-	-

Appendix 8: Candidate, local reference, and basin-wide reference hydrology and land use data.

					Land Use - Total Watershed			Land Use - Upstream Riparian		
Characteristic	**Stream**	**Subwatershed**	**Discharge (m/s^3)**	**Area (km^2)**	**% Forest**	**% Farmland**	**% Developed**	**% Forest**	**% Farmland**	**% Developed**
Candidate	Carr Run	Cussewago	0.241	27.5	40	54	4	46	44	4
Candidate	Rundelltown Run	Cussewago	0.201	20.0	59	35	6	71	20	8
Candidate	Cussewago East Headwater	Cussewago	0.297	31.5	50	43	6	65	28	5
Candidate	Fossil Run	Cussewago	0.148	12.8	56	37	7	75	19	5
Candidate	Inlet Run	Conneaut	0.152	13.8	61	33	6	74	21	5
Candidate	Watson Run	Conneaut	0.101	15.0	57	36	6	71	14	4
Candidate	Adsit Run	Conneaut	0.138	12.5	58	38	4	73	24	0
Candidate	McMicheal Run	Conneaut	0.142	20.1	63	28	6	75	13	4
Candidate	Rock Creek	Conneaut	0.099	8.3	67	25	6	87	4	7
Local Reference	Kantz Run	Main Stem-Lower	0.109	9.9	47	47	7	74	21	4
Local Reference	Powdermill Run	Main Stem-Lower	0.060	10.5	39	53	9	58	34	8
Local Reference	McCune Run	Main Stem-Lower	0.074	10.3	63	24	12	77	12	10
Local Reference	Mill Creek	Main Stem-Lower	0.595	32.7	58	37	5	82	13	5
Local Reference	North Deer Creek	Main Stem-Lower	0.240	26.6	51	44	5	75	19	4
Basin-wide Reference	Armstrong Run	Sugar Creek	-	9.2	69	-	-	50	-	-
Basin-wide Reference	Aster Run	Sugar Creek	-	-	75	24	-	95	5	-
Basin-wide Reference	Baskin Run	South Branch	-	11.6	57	39	-	78	-	-
Basin-wide Reference	Beatty Run	Sugar Creek	-	-	76	24	-	84	16	-
Basin-wide Reference	Beaver Run	Muddy Creek	-	15.1	42	46	-	49	-	-
Basin-wide Reference	Higby Run	Sugar Creek	-	6.5	96	-	-	99	-	-
Basin-wide Reference	Kantz Run	Mainstem-Lower	0.109	9.9	47	47	7	74	21	4
Basin-wide Reference	Kirik Run	South Branch	-	1.8	62	35	-	87	-	-
Basin-wide Reference	McCune Run	Mainstem-Lower	0.074	10.3	63	24	12	77	12	10
Basin-wide Reference	Spencer Creek	South Branch	-	7.4	70	26	-	79	-	-
Basin-wide Reference	Sugar West Branch	Sugar Creek	-	25.6	83	16	-	88	11	-
Basin-wide Reference	Trout Run	Sugar Creek	-	6.1	51	48	-	86	14	-
Basin-wide Reference	Yellow Jacket Run	Sugar Creek	-	6.4	76	24	-	84	16	-

Appendix 9: Three-way ANOVA and Fisher's PLSD table for summer 2013 water temperature and dissolved oxygen (***=data of high significance, **=data of medium significance, *=data of low significance).

	Summer Water Temperature			Summer Dissolved Oxygen		
Statistic	**Watershed**	**Date**	**Site**	**Watershed**	**Date**	**Site**
df	1,106	3,106	2,106	1,106	3,106	2,106
F	33.68	93.85	1.87	9.34	3.713	16.32
P	**<0.0001*** **	**<0.0001*** **	0.159	**0.0028****	**0.0138***	**<0.0001*** **

		p-value	
		Summer Water Temperature	**Summer Dissolved Oxygen**
Watershed	Conneaut, Cussewago	**<0.0001*** **	**0.001****
Date	Late June, Early July	**<0.0001*** **	0.279
	Late June, Late July	0.117	0.954
	Late June, Early August	**<0.0001*** **	**0.028***
	Early July, Late July	**0.0004****	0.313
	Early July, Early August	**<0.0001*** **	**0.002****
	Late July, Early August	**<0.0001*** **	**0.027***
Site	Lower, Middle	0.924	**0.035***
	Lower, Upper	0.044	**<0.0001*** **
	Middle, Upper	0.055	**0.0002****

Appendix 10: ANOVA and Fisher's PLSD table for substrate fine sediment and high flow turbidity (**=data of medium significance, *=data of low significance).

Statistic	**Substrate Fine Sediment**	**Highflow Turbidity**
df	2,11	2,11
F	4.15	11.2
P	**0.045***	**0.002****

		p-value	
		Substrate Fine Sediment	**Highflow Turbidity**
Watershed	Conneaut, Cussewago	0.071	**.012***
	Conneaut, Local Reference	0.393	0.101
	Cussewago, Local Reference	**.016***	**.0006****

Appendix 11: ANOVA and Fisher's PLSD tables for % sensitive and % tolerant fish taxa (***=data of high significance, **=data of medium significance, *=data of low significance).

Statistic	% Sensitive Taxa	% Tolerant Taxa
df	3,23	3,23
F	11.28	2.67
P	**<0.0001*** **	0.072

		p-value	
		% Sensitive Taxa	% Tolerant Taxa
Watershed	Cussewago, Conneaut	**.006** **	0.053
	Cussewago, Local Reference	0.132	0.641
	Cussewago, Basin-wide Reference	**.013***	0.409
	Conneaut, Local Reference	**<0.0001*** **	0.014
	Conneaut, Basin-wide Reference	0.365	0.104
	Local Reference, Basin-wide Reference	**<0.0001*** **	0.144

Appendix 12: ANOVA and Fisher's PLSD tables for %EPTs (**=data of medium significance).

Statistic	%EPTs
df	2,11
F	10.55
P	**0.0028** **

		p-value
Watershed	Conneaut, Cussewago	**0.003** **
	Conneaut, Local Reference	**0.002** **
	Cussewago, Local Reference	0.948

Appendix 13: Diversity of fishes collected from candidate and local reference streams. Red indicates a tolerant species, green indicates an intolerant species, blue indicates trout species. Refer to Table 3 (p.17) for 2-letter stream code: 1–CR, 2–RR, 3–CE, 4–FR, 5–IR, 6–WR, 7–AR, 8–MMR, 9–RC, 10–KR, 11–PR, 12–MR, 13–MC, 14

Family	Common Name	Scientific Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Catostomidae	White sucker	*Catostomus commersoni*	X	X	X	X	X		X	X		X	X	X	X	X
	Northern hog sucker	*Hypentelium nigricans*	X	X	X	X	X	X		X		X		X	X	X
Centrarchidae	Rock bass	*Ambloplites rupestris*	X		X									X		
	Green sunfish	*Lepomis cyanellus*	X												X	
	Pumpkinseed	*Lepomis gibbosus*	X	X		X	X	X	X	X	X	X		X		X
	Bluegill	*Lepomis macrochirus*	X			X					X					
	Largemouth bass	*Micropterus salmoides*							X							
	Smallmouth bass	*Micropterus dolomieu*	X	X				X		X						X
Cottidae	Mottled sculpin	*Cottus bairdi*	X	X	X	X					X	X	X	X	X	X
Cyprinidae	Central stoneroller	*Campostoma anomalum*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Redside dace	*Clinostomus elongates*		X	X	X			X	X		X				X
	Striped shiner	*Luxilus chrysocephalus*	X							X		X		X	X	
	Common shiner	*Luxilus cornutus*	X	X					X	X		X		X		
	Redfin shiner	*Lythrurus umbratilis*										X				
	River chub	*Nocomis micropogon*										X			X	
	Silverjaw minnow	*Notropisbuccatus*	X	X					X							
	Sand shiner	*Notropis ludibundus*	X							X						
	Rosyface shiner	*Notropis rubellus*					X					X				
	Mimic shiner	*Notropis volucellus*		X						X		X				
	Southern redbelly dace	*Phoxinus erythrogaster*					X		X	X						
	Bluntnose minnow	*Pimephales notatus*	X	X	X	X	X	X		X		X				X
	Blacknose dace	*Rhinichthys atratulus*		X	X	X	X	X	X	X	X	X	X	X	X	X
	Longnose dace	*Rhinichtys cataractae*							X						X	X
	Creek chub	*Semotilus atromaculatus*	X	X	X	X	X	X	X	X	X		X	X	X	X
Esocide	Grass pickerel	*Esox americanus vermiculatus*										X				
	Northern pike	*Esox Lucius*								X						
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	X			X		X				X		X		X
Percidae	Greenside darter	*Etheostoma blennioides*	X	X	X			X				X		X		X
	Rainbow darter	*Etheostoma caeruleum*	X	X	X		X	X	X	X		X	X	X	X	X
	Fantail darter	*Etheostoma flabellare*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Johnny darter	*Etheostoma nigrum*	X	X	X	X	X	X	X	X		X	X		X	X
	Banded darter	*Etheostoma zonale*	X													
	Log perch	*Percina caprodes*			X		X									
	Blackside darter	*Percina maculata*														X
Salmonidae	Brown trout	*Salmo trutta*												X	X	X
	Brook trout	*Salvelinus fontinalis*										X				
	Rainbow Trout	*Onchorhynchus mykiss*												X		X
Petromyzontidae	Ohio lamprey	*Ichthyomyzon bdellium*	X					X		X						
	American brook lamprey	*Lampetra appendix*						X								