Potential Reintroduction of Arctic Grayling in Michigan's Lower Peninsula: A Study of Biotic Factors in the Maple River

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EEB 486: Biology and Ecology of Fishes
8/15/2018
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Abstract

Arctic grayling (*Thymallus arcticus*) were once one of the most abundant salmonids in the northern Lower Peninsula of Michigan but were extirpated entirely from Michigan by the early 1900s due to overfishing, the introduction of non-native salmonids, and the logging industry. In recent history, an interest to reintroduce Arctic grayling back into Michigan has developed and multiple groups have begun studies to see suitability of Michigan streams and rivers for grayling. We performed an abiotic and biotic assessment of the West Branch Maple River in Emmet County, Michigan for potential grayling reintroduction. We found water temperatures to be within a suitable range and substrate within the river to be that preferred by grayling. Low abundance of competitive brown trout and high abundance of preferred prey of grayling also showed the viability of the West Branch Maple River for grayling. The results of this study show that the West Branch Maple River should be considered for the reintroduction of grayling but further, more extensive, studies of the river are needed to make sure of this. The removal of the Maple River Dam also presents an interesting case of a change in the Maple River that will also require further studies.

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Introduction:

Arctic grayling (*Thymallus arcticus*) used to inhabit all large streams in Michigan's Lower Peninsula north of a line between the White River to the west and the Rifle River to the east (Figure 1) (Vincent 1962). It was only recorded to have inhabited the Otter River in Michigan's Upper Peninsula (Vincent 1962). Primarily a stream-dwelling fish, arctic grayling was abundant in Lower Peninsula streams during the 1800's (Nuhfer 1992). By the 1870s, grayling were being overfished and brook trout (*Salvelinus fontinalis*) along with introduced brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) made their way into Lower Peninsula streams (Nuhfer 1992). At the same time, these salmonids made their way into grayling streams, logging activity increased, and grayling were mostly extirpated from Michigan streams by the end of the 1800s (Nuhfer 1992).

Attempts to restock grayling occurred shortly before their extirpation from Michigan but these failed (Nufher 1992). (Nufher 1992, Liermann 2001). The last attempt at reintroducing grayling into Michigan occurred between 1987 and 1991. Arctic grayling only managed to survive in lakes where few other species were present, but most of the grayling stocked in rivers disappeared within 6 months most likely due to competition and predation by other species (Nuhfer 1992). There has been renewed interest by the Michigan Department of Natural Resources to reintroduce Arctic grayling into Michigan and most recent studies have focused on the abiotic factors needed for grayling to survive (Danhoff *et al*. 2017, Nuhfer 1992). Only one study has examined biotic factors affecting grayling in a Michigan river system (Goble *et al*. 2018).

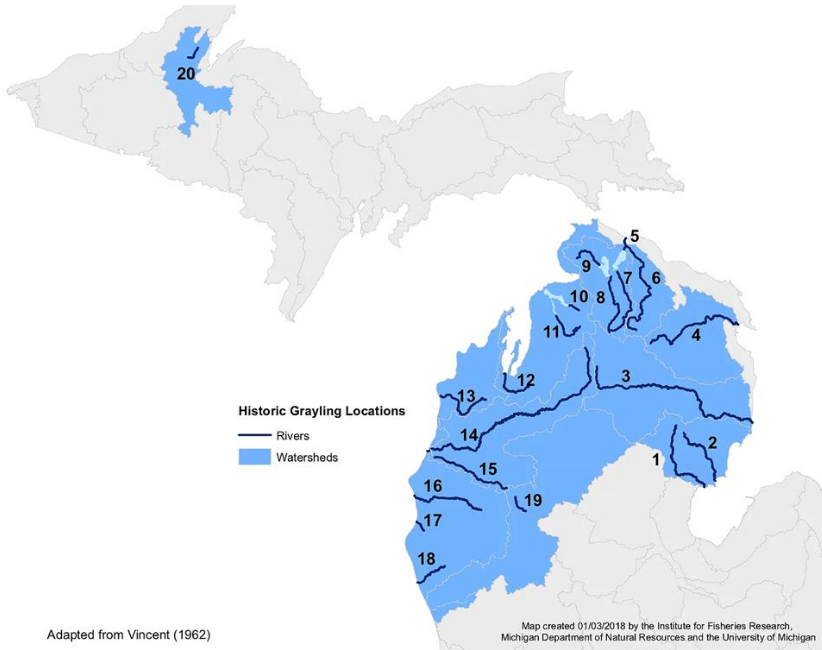


Figure 1. Map showing historical range of Arctic grayling (blue area shaded). For reference, the Maple River is marked as number 9 in the figure (Vincent 1962).

Grayling are considered a cold-water species and have a high sensitivity to temperature. Adult Arctic grayling can tolerate temperatures between 2.7 – 22.0 °C while juveniles tolerate a narrower range of 4.5 – 17.3 °C (Danhoff *et al*. 2017; Lohr 1996). In addition, their spawning behavior requires substrates with an abundance of pebbles. Contrary to brown and rainbow trout which excavate areas for their eggs, grayling produce eggs that stick to the rocky substrate. As such, recommended substrate cover for grayling ranges from coarse sand to large pebbles (Bishop 1971, Danhoff *et al*. 2017).

In terms of biotic factors, grayling are known to be opportunistic feeders that prey on a wide variety of macroinvertebrates. Grayling are visual predators, so they prefer to feed during the day at depths where light penetration is still strong. Adult grayling have a diverse diet and they will occasionally prey on fish eggs and fry as well (Stewart *et al*. 2007). Juvenile grayling tend to focus more on mayfly larvae and Diptera pupae (Stewart *et al*. 2007, Jones et al. 2003).

Grayling have been shown to compete with a variety of other fish, mostly other salmonids such as brook, brown, and rainbow trout (Vincent 1962). They have also been shown to have a strong diet overlap with sculpin (*Cottus spp.*) but grayling feed primarily at mid-water depths and at the surface while sculpin will feed at the bottom. As a result, competition between them might not be as strong.

Work done by past students at the University of Michigan focused on abiotic factors and the suitability of the Maple River as a potential habitat (Cogut *et al.*, 2017). Under suggestions made by these past groups, we focused on biotic factors within the West Branch Maple River as this river had been determined as a suitable site for Arctic grayling. The West Branch Maple River is a cold water, groundwater-fed river located in Emmet County, Michigan. It is dominated by brook trout which comprise at least 75% of the trout community in the river (DNR 2010). Further downstream, after Lake Kathleen and the Maple River Dam, the river is dominated by brown trout which comprise at least 90% of the trout community in the river (DNR 2014). Both DNR reports (2010 & 2014) mention the high suitability of the river for salmonids such as trout and Arctic grayling. The reports mention many abiotic factors that fall within known suitable grayling habitats. However, the high presence of other trout may indicate a potential for strong competition in the case of grayling reintroduction.

The purpose of our study was to measure biotic factors in the West Branch of the Maple River and determine if this river is a viable system for the reintroduction of Arctic grayling. We chose four sites on the river where we collected fish and macroinvertebrate communities and examined diets of potential competitors. We compared fish diets of salmonids and other potential competitors (sculpins and mudminnows) to historical grayling diets. We also measured abiotic factors such as substrate cover, discharge, and water temperature. Due to the abiotic factors that are already known to us from previous studies, we expect the West Branch of the Maple River to be a viable stream for an attempted reintroduction of Arctic grayling in Michigan's Lower Peninsula.

Methods:

Site selection

Figure 2. Map of the Maple River with sample sites marked. Starting at WMCC we move downstream to WMRR, WMUS, and WMPT. Roads are outlined in map. Purple lines describe flow in lakes such as Lake Kathleen through which the West Branch Maple River ends, and the Maple River begins.

Our study focused on the West Branch Maple River as a suitable river for potential Arctic grayling reintroduction. To asses this, we selected four sites along the river ranging from a tributary of the river (Cold Creek) to a site downstream of the Maple River Dam at Lake Kathleen. These sites were selected due to the ease of accessibility to them from nearby roads. Our four sites were Cold Creek at Ely Rd (WMCC; 45°34'45.8"N, 84°50'54.1"W), the West

Branch river access on Robinson Rd (WMRR; 45°33’02.6”N, 84°47’47.2”W), the West Branch river access on US-31 (WMUS; 45°32’24.3”N, 84°47’01.2”W), and the Maple River access at the end of Pine Trail (WMPT; 45°30’51.1”N, 84°46’18.3”W) (Figure 2). At each site, 100 meter transects were measured out and flagged. Each 100 meter transect was then divided into ten 10-meter sections marked by flags on the banks.

Abiotic factors

At each of the sites, we measured water temperature upon every visit to the site for sampling (at least three times for each site). Water temperature was then averaged out for each site and compared among sites via a one-way ANOVA. A Tukey post hoc test was also performed to assess which site(s) differed the most from others. Discharge was also measured at each of our sites using a Hach flow meter.

Substrate

To measure substrate, we divided each 100-meter transect into five 20-meter sections. We visually assessed the substrates throughout the entire 20-meter section and estimated percent cover of each substrate class after reaching a consensus among the group. Percent cover was added up at end to determine total percent cover for the entire 100-meter section.

Macroinvertebrate sampling

For the purposes of macroinvertebrate sampling we also divided each 100-meter transect into 20-meter section. We sampled benthic macroinvertebrates using 30cm x 30cm Serber samplers. Five samples were collected per 20-meter section of the 100-meter transect for a total of twenty-five samples per site. Macroinvertebrate samples were collected in proportion to substrate cover at each 20-meter section (e.g., if a 20-meter section was covered by 60% gravel, three of the five samples were taken in gravel covered areas). For each spot, the area within the 900cm^2 Serber sampler was disturbed for two minutes to dislodge macroinvertebrates within substrate. Once all five samples for a 20-meter section were collected, nets were emptied onto a white enamel pan where macroinvertebrates were picked for thirty person-minutes and stored in a vial containing 85% isopropyl alcohol. Vials were returned to the lab where macroinvertebrates were classified by order using a macroinvertebrate key (Stroud Water Research Center 2018). Total counts of macroinvertebrates per order were then recorded for each of our four sites. A Shannon diversity index was used to quantify macroinvertebrate diversity for each of our sites. A hierarchical cluster analysis was performed to determine similarity between our sites based on macroinvertebrate abundance and communities.

Fish communities

To look at fish communities, two methods of fish sampling were used at each site to eliminate sampling bias from each method. We performed a one-pass run using two Smith-Root battery-powered backpack electroshockers (Table 1). We also seined at each site using 6-ft and 10-ft seines. Both methods were performed moving upstream and on different days so as not to disturb fish at the site prior to sampling. All fish collected were identified to species in the field and total counts of each species were taken at each site. A Shannon diversity index was calculated to quantify fish species diversity for each of our sites. Percentage of each salmonid species (brown, brook, and rainbow trout) out of total salmonids present was also calculated. A hierarchical cluster analysis was performed to analyze how our sites were related to each other on the basis of fish communities. Finally, Pearson correlation coefficients were calculated, and a constellation plot based on these coefficients was made to see which fish species correlated most with each other.

Table 1. Voltage used for electroshocker and duration of shock period for each electroshocker for each site.

Site	Voltage (V)	Duration Electroshocker 1 (seconds)	Duration Electroshocker 2 (seconds)
WMCC	220	912	N/A
WMRR	225	3216	2145
WMUS	225	1335	1489
WMPT	225	2826	2337

Diet analysis

All salmonids captured during fish sampling and not identified as young-of-the-year (YOY) were taken back to the lab for diet analysis to a maximum of ten salmonids per site. These fish were put into an MS222 solution to be anesthetized before being put in a 10% Formalin solution to be preserved. Any salmonid not categorized as YOY but too large to be placed in jars was released after counts. Collected fish had stomachs excised and stomach contents were analyzed. Prey found in stomachs were identified to order and total counts of food items were taken. These data, along with total macroinvertebrate counts for each site, were used to quantify numerical, frequency of occurrence, and Ivlev’s electivity indices for each collected fish species for each site.

Results:

Abiotic factors

Table 2. Water temperature data and discharge measurements for each of the four sites. Data for water temperature was collected between 7/24/2018 and 8/06/2018.

Site	Mean Temp (°C)	High Temp (°C)	Low Temp (°C)	Discharge (m^3/s)
WMCC	20.7	22.0	18.3	0.032
WMRR	16.8	17.8	15.8	0.76
WMUS	16.2	16.7	15.4	0.89
WMPT	17.3	17.7	16.5	1.6

Mean water temperature significantly differed across our sites ($p = 0.001$). A Tukey post hoc test revealed that WMCC, our tributary site, had a significantly higher mean water temperature compared to all our other sites ($p = 0.003$ for WMRR, $p = 0.007$ for WMUS, and $p = 0.001$ for WMPT). Discharge increased as we went downstream with WMCC having the lowest discharge and WMPT having the largest discharge (Table 2).

Substrate

The WMCC site had a higher percentage of sand/silt cover compared to our other sites (60.0%). Rocky substrates (gravel, pebble, and cobble) tended to be found more frequently at our other sites, WMRR, WMUS, and WMPT. Pebble/gravel substrates appeared to cover at least a third of the areas sampled for WMRR, WMUS, WMPT with WMPT having the highest pebble coverage of all four sites (61.6%). Submerged woody debris seemed to decrease as we moved downstream (Figure 3).

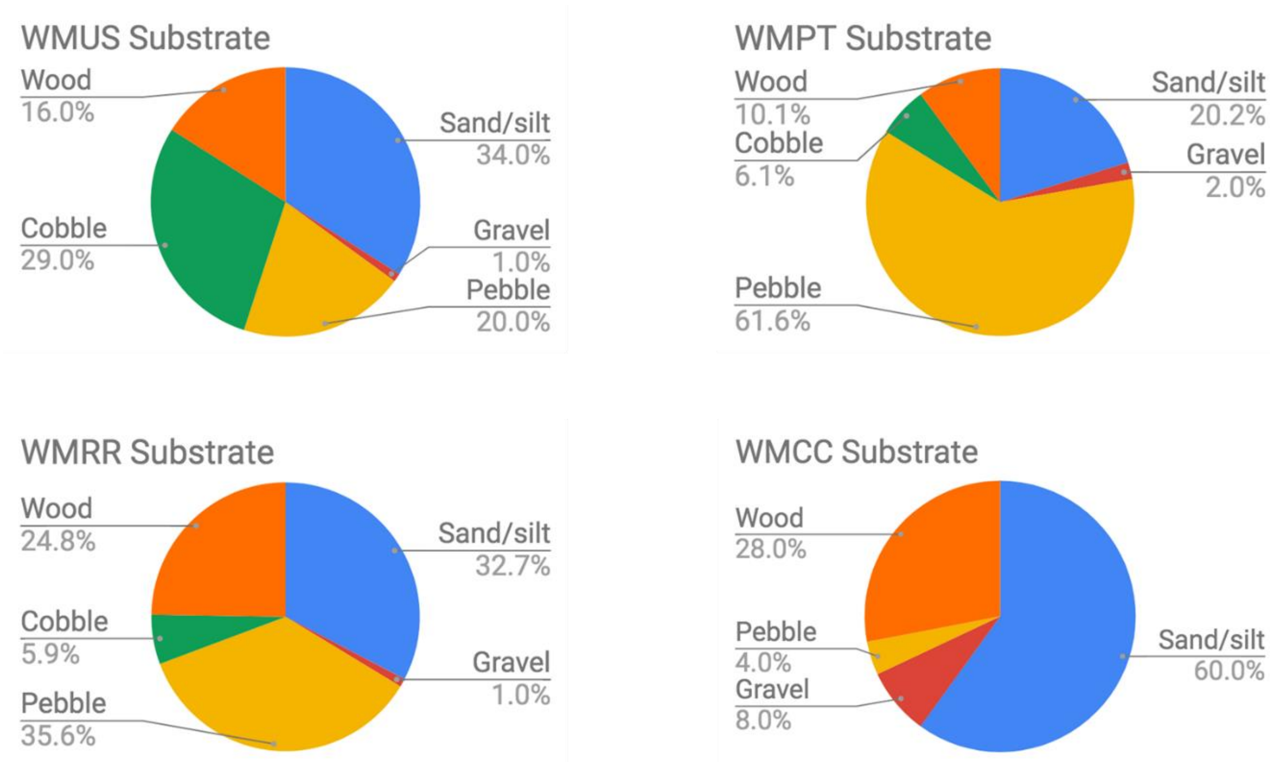


Figure 3. Pie charts showing mean percent substrate cover across each 100-meter transect.

Macroinvertebrates

Table 3. Shannon diversity index for macroinvertebrate communities at each site. Percentage of Ephemeroptera and Diptera for each site also shown in table.

Site	Shannon Diversity Index	% Ephemeroptera	% Diptera
WMCC	0.87	6%	5%
WMRR	0.67	27%	35%
WMUS	0.58	20%	33%
WMPT	0.70	25%	24%

Macroinvertebrate communities were more diverse at WMCC and lowest at WMRR and WMUS (Table 3). Percentage of both Ephemeroptera and Diptera was about the same at all sites except for WMCC. Diptera also seemed to decrease at WMPT compared to WMRR and WMUS (Table 3). The hierarchical cluster analysis showed that WMCC had the most distinct macroinvertebrate community and that WMRR, WMPT, WMUS were very similar to each other based on macroinvertebrate abundance and community (Figure 4).

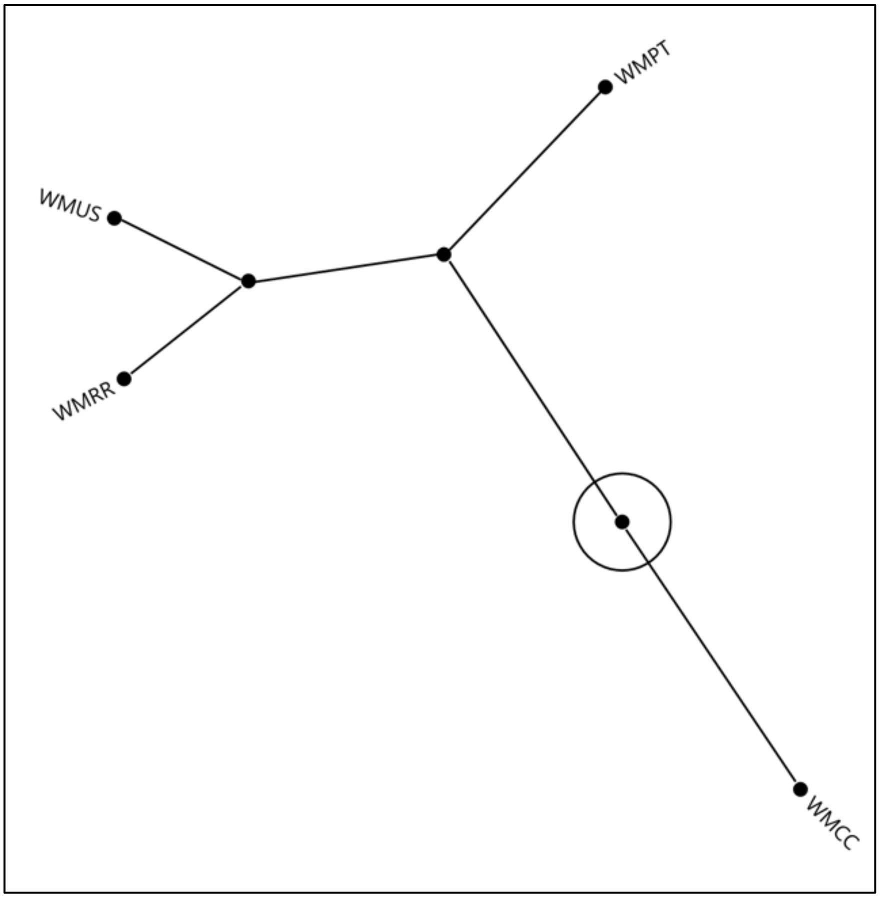


Figure 4. Constellation plot showing similarity between sites based on a hierarchical cluster analysis done on macroinvertebrate abundance and community.

Fish communities

We found that Salmonidae fish species, primarily brook trout (*Salvelinus fontinalis*) (26% of total fish caught), and sculpin (*Cottus spp.*) (32% of total fish caught) dominated the river across our four sites (Table 4). Fish communities seemed to be more diverse at WMRR and least diverse at WMUS (Table 5). WMCC was found to only contain brook trout which differed from all other sites. Brown and rainbow trout numbers seemed to increase as we moved downstream, and brown trout dominated at the WMPT site (75% of total salmonids) (Table 5).

Table 4. Total number and percentage of species caught throughout all four sites. All species found were listed in table. Table also states what sites each species was found at and what capture method(s) each fish were caught by.

Species	Streams	Method of Capture	Count	Percentage of total catch
Salvelinus fontinalis	All	All	184	25.95
Salmo trutta	WMRR, WMUS, WMPT	All	79	11.14
Oncorhynchus mykiss	WMRR, WMUS, WMPT	All	18	2.54
Catostomus comersonii	WMCC, WMRR, WMUS	All	39	5.50
Umbra limi	WMCC, WMRR, WMPT	All	78	11.00
Cottus spp.	WMRR, WMUS, WMPT	All	227	32.02
Semotilus atromaculatus	WMCC, WMRR	All	20	2.82
Phoxinus eos	WMCC, WMRR	All	30	4.23
Pimephales notatus	WMRR	Electrofisher	1	0.14
Pimephales promelas	WMRR	Electrofisher	1	0.14
Culaea inconstans	WMCC, WMRR	All	5	0.71
Lethenteron appendix	WMRR, WMUS	Electrofisher	18	2.54
Perca flavescens	WMPT	Electrofisher	6	0.85
Micropterus salmoides	WMPT	Seines	3	0.42

Table 5. Shannon diversity index values for fish communities at each site. Percentage of individual salmonid species counts out of total salmonids caught at each site is also shown in table.

Site	Shannon Diversity Index	% *Salvelinus fontinalis*	% *Salmo trutta*	% *Onchorhyncus mykiss*
WMCC	0.31	100%	0%	0%
WMRR	0.39	68%	26%	6%
WMUS	0.19	50%	38%	13%
WMPT	0.28	9%	75%	16%

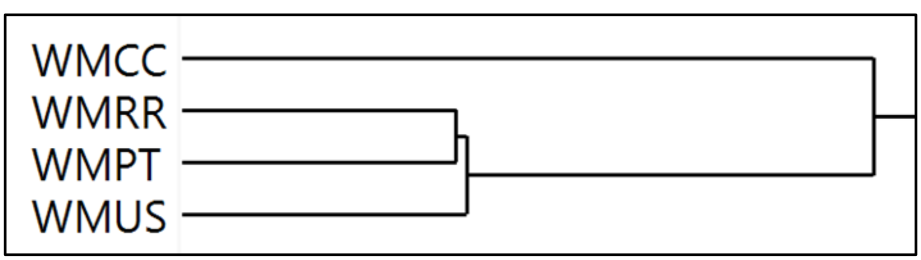


Figure 5. Dendrogram showing relationship between sites based on fish communities found at each site.

The hierarchical cluster analysis showed that WMCC had the most distinct fish community and that WMRR, WMPT, WMUS were very similar to each other (Figure 5) based on fish communities. The Pearson correlation coefficients calculated found that both YOY brown and rainbow trout were found to be strongly correlated with each other while brook trout were strongly uncorrelated with other trout species. Brook trout seemed to be more correlated with brook lamprey and minnows (Figure 6).

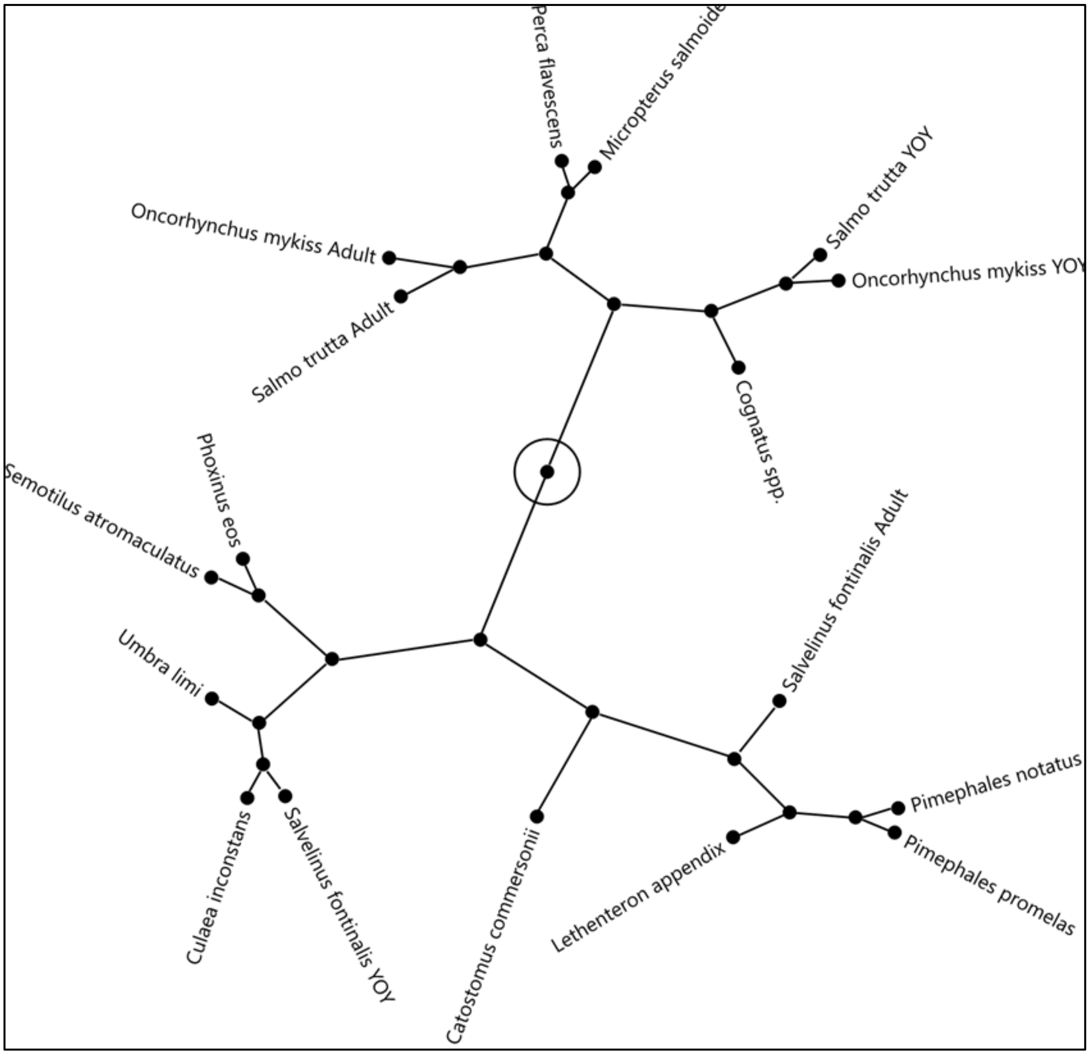


Figure 6. Constellation plot showing correlations between all species found within our sites in. the Maple River. Species grouped closely together are more correlated to each other and are likely to be found together. Constellation plots was built using Pearson correlation coefficients found from our fish abundance data.

Figures 7A. Ivlev's electivity index for Ephemeroptera per species per site.

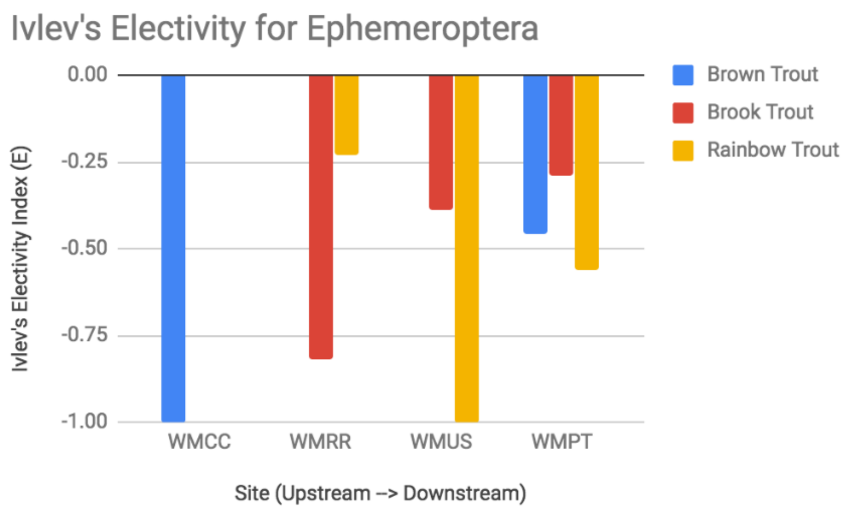


Figure 7B. Ivlev's electivity index for Diptera per species per site.

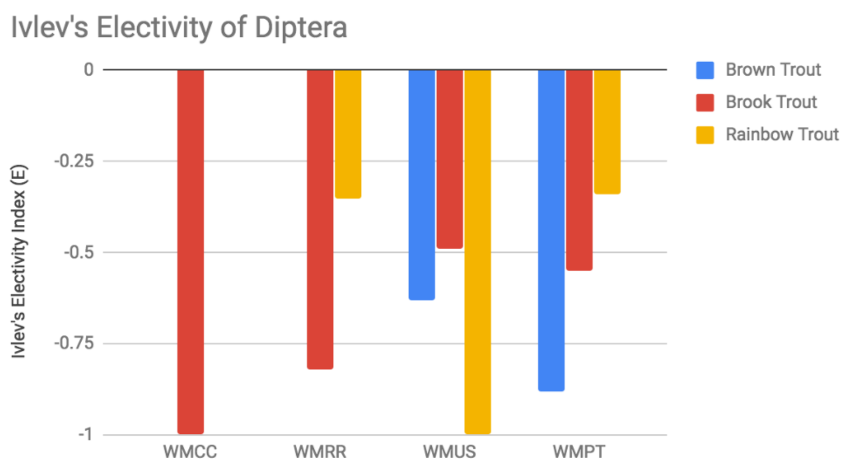
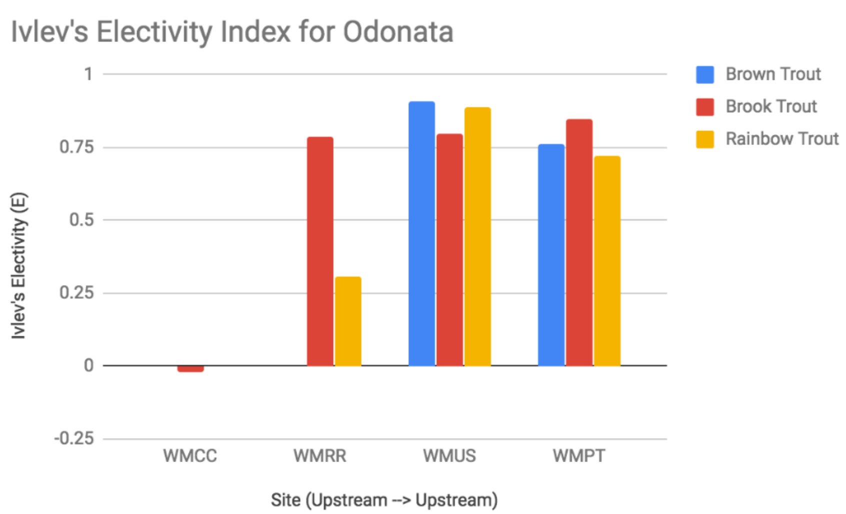


Figure 7C. Ivlev's electivity index for Odonata per species per site.



Diet Analysis

All species of trout were observed to select against both Ephemeroptera and Diptera prey across all sites (Figures 7A and 7B). All trout species selected heavily for Odonata prey across all sites, except for WMCC (Figure 7C). Brook trout had highly varied diets but consumed more Mollusca than other salmonids. Trichoptera was also found to be a large part of all salmonids' diets at both WMUS and WMPT. Odonata also composed a high percentage of diets for all salmonids at WMPT.

Discussion:

Overall, we found that abiotic factors measured in our study were in line those preferred by Arctic grayling. Temperature for all sites fell within the tolerable range of temperature for adult Arctic grayling (2.7 – 22.0 °C) (Danhoff *et al*. 2017). We also saw that WMRR, WMUS, and WMPT had temperatures within the tolerable range for juvenile Arctic grayling as well (4.5 – 17.3 °C) (Danhoff *et al*. 2017; Lohr 1996). It is also important to note that these temperature readings were taken during late July and early August where water temperatures in both West Branch Maple River and Maple River are at their annual maximum (DNR, 2014) thus indicating temperatures in river did not surpass tolerable range of temperature for Arctic grayling during annual max water temperatures in the river.

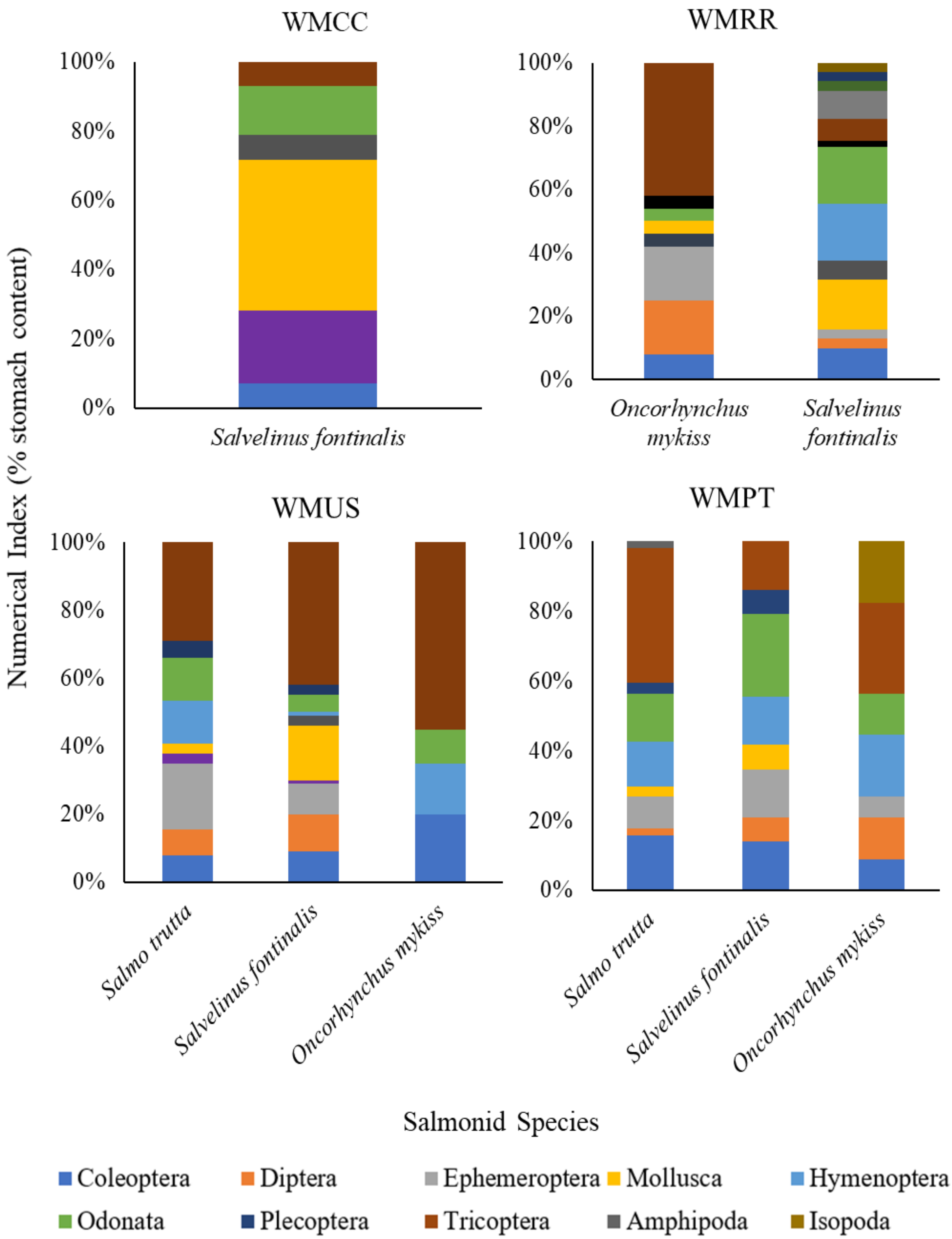


Figure 8. Numerical indices for each species per site. Legend for prey items is shown below x-axis. Numerical indices are an indicator of diet composition for each fish species.

We also observed a high presence of rocky substrates at all our sites apart from WMCC which had sand/silt substrate covering the majority of its transect. As a reminder, grayling require rocky substrates to spawn since their eggs must stick to the rocks to develop (Bishop 1971, Danhoff *et al*. 2017). As a result, WMRR, WMUS, and WMPT present viable spawning locations for grayling were they to be reintroduced into the river.

Another sign of viability of the West Branch Maple River was shown via the percentage of both Ephemeroptera and Diptera found across all sites apart from WMCC. At all other sites, these two orders combined made up a large part of the macroinvertebrate community ($\geq$ 49%). This is important as Arctic grayling, especially juveniles, select heavily for Ephemeroptera nymphs and Diptera larvae (Stewart *et al. 2007*) which was commonly found throughout our sites. These results show that prey favored by Arctic grayling is readily available in the river.

Brook trout was the most common salmonid within the West Branch Maple River with it being the only trout species found at WMCC. Reports by Michigan DNR had previously stated brook trout was the main species of trout in the river (DNR 2010) and this seems to have remained unchanged. After the river passes through Lake Kathleen and the Maple River Dam, the river switches from a brook trout dominated river to a brown trout dominated river which falls in line with Michigan DNR reports from 2014 (DNR 2014). The low abundance of brown trout within the West Branch Maple is a good indicator for Arctic grayling reintroduction as this species has been shown to compete strongly with them (Degerman *et al.* 2000, Vincent 1962). Additionally, studies have shown that Artic grayling successfully live in sympatry with brook trout and grayling growth rates are not affected by their presence (Byorth and Magee 1998) so presence of brook trout would most likely not disrupt Arctic grayling introduced into the river.

Brook trout populations were found to be separate from other trout species based on the Pearson correlation coefficients found. Adult and juvenile communities of both brown and rainbow trout were found to be closely correlated indicating these two species tended to be found together in the same area. Juvenile brown and rainbow trout communities were also found to be in the same area as species of sculpin and all of these species have been shown to have strong dietary overlap with Arctic grayling (Stewart *et al*. 2007). What this means is that any of the species would be good indicators of potential competition for grayling within the river.

Dietary overlap is another important factor that will affect grayling if they are to be reintroduced into the West Branch Maple River. All trout species seemed to select heavily for Odonata while avoiding Ephemeroptera and Diptera which are preferred grayling prey (Stewart *et al. 2007*). We also observed that trout species were eating Trichoptera and Odonata heavily while Ephemeroptera and Diptera composed small percentages of their diet. Overall, trout species were shown to have highly varied diets, but they exhibited low diet overlap to historical grayling diets. An interesting observation made was that brook trout were eating many Mollusca, especially Gastropoda, at both WMUS and WMPT which indicated a higher activity of benthic feeding by brook trout that are known to feed more off drift and the water column. This might be an indication that they were undergoing resource portioning in the presence of other trout species as has been shown to occur with brook trout in the presence of other salmonids (Mookerji *et al*., Byorth *et al*. 1998). As a result, this could be evidence of competitive pressure by brown and rainbow trout on brook trout and potentially on Arctic grayling.

Overall, we believe the West Branch Maple River serves as a viable site for reintroduction of Arctic grayling as water temperature, substrate cover, prey availability, and low presence of competitive brown trout across the river favor the grayling. The high number of juvenile brook trout at WMCC indicated that this could have been a good rearing site for juvenile grayling but the warmer temperatures and low abundance of Ephemeroptera and Diptera reduces the chance juvenile grayling could survive in the tributary. WMPT, located downstream of the Maple River Dam, had a large presence of brown trout which would potentially outcompete grayling and, as such, we believe the main Maple River would not be a good reintroduction site for the grayling, but further studies are merited. Additionally, the Maple River Dam is scheduled for removal this summer of 2018 and this could potentially affect fish communities both downstream and upstream of the dam.

As the removal of the Maple River Dam is imminent, further studies are needed on the effect this dam removal will have on fish communities both downstream and upstream of the dam. We believe removal of the dam will allow the high population of brown trout in the main Maple River to move upstream and into the West Branch. However, studies have shown that abundance of multiple species, mostly fluvial species, increase after a dam removal. The removal of dams also allows populations to spread out farther thus competition for habitat use decreases as well (Burroughs *et al*. 2010). As a result, the dam removal might work in favor of grayling populations as they are a fluvial species of fish.

Finally, it is important to note that our study was conducted entirely during the summer so seasonal variance in fish communities and prey availability is unknown for both the West Branch and main Maple River. We were also limited on the number of sites to sample and we suggest there be more comprehensive studies of the Maple River as a potential river system for Arctic grayling reintroduction. We suggest these studies look at seasonal variance of the variables we measured and the effect the dam removal has on the river system.

Literature Cited:

Bishop FG. 1971. Observations on Spawning Habits and Fecundity of the Arctic Grayling. The Progressive Fish-Culturist 33:12-19.

Burroughs BA, Hayes DB, Klomp KD, Hansen JF, Mistak J. 2010. The Effects of the Stronach Dam Removal on Fish in the Pine River, Manistee County, Michigan. Transactions of the American Fisheries Society 139:1595–1613.

Byorth PA, Magee JP. 1998. Competitive Interactions between Arctic Grayling and Brook Trout in the Big Hole River Drainage, Montana. Transactions of the American Fisheries Society 127:921–931.

Cogut G, Sealey B, McGinnis R, La Guttata M, and Schrank AJ. 2017. The return of Grayling to the Maple River watershed: a preliminary investigation of water quality, habitat, and food sources available to support a successful reintroduction. University of Michigan Biological Station; Rivers, Lakes, and Wetlands.

Danhoff BM, Huckins CJ, Auer NA, Goble CW, Ogren SA, Holtgren JM. 2017. Abiotic Habitat Assessment for Arctic Grayling in a Portion of the Big Manistee River, Michigan. Transactions of the American Fisheries Society 146:645–662.

Degerman E, Naslund I, Sers B. 2000. Stream habitat use and diet of juvenile (0+) brown trout and grayling in sympatry. Ecology of Freshwater Fish 9:191–201.

DNR. 2010. Status of the Fishery Resource Report: West Branch Maple River.

DNR. 2014. Status of the Fishery Resource Report: Maple River.

Goble CW, Auer NA, Huckins CJ, Danhoff BM, Holtgren JM, Ogren SA. 2018. Fish Distributions and Habitat Associations in Manistee River, Michigan, Tributaries:

Implications for Arctic Grayling Restoration. North American Journal of Fisheries Management 38:469–486.

Jones NE, Tonn WM, Scrimegeour GJ. 2003. Selective feeding of age-0 Arctic grayling in lake outlet streams of the Northwest Territories, Canada.

Liermann BW. 2001. An evaluation of the reintroduction of fluvial Arctic grayling into the upper Ruby River [thesis].

Lohr SC, Byorth PA, Kaya CM, Dwyer WP. 1996. High-Temperature Tolerances of Fluvial Arctic Grayling and Comparisons with Summer River Temperatures of the Big Hole River, Montana.

Mookerji N, Weng Z, Mazumder A. 2004. Food partitioning between coexisting Atlantic salmon and brook trout in the Sainte-Marguerite River ecosystem, Quebec. Journal of Fish Biology 64:680–694.

Nuhfer AJ. 1992. Evaluation of the Reintroduction of the Arctic Grayling, into Michigan Lakes and Streams.

Stewart DB, Mochnacz NJ, Reist JD, Carmichael TJ, and Sawatzky CD. 2007. Fish diets and food webs in the Northwest Territories: Arctic grayling (*Thymallus arcticus*). Report of Fisheries and Aquatic Sciences 2796.

Stroud Water Research Center. 2018. Identification Guide to Freshwater Macroinvertebrates.

Vincent RE. 1962. Biogeographical and ecological factors contributing to the decline of arctic grayling, thymallus arcticus (pallas), in Michigan and Montana [dissertation].

Whelan GE. 2004. A Historical Perspective on the Philosophy behind the Use of Propagated Fish in Fisheries Management: Michigan’s 130-year Experience.

Appendix

Numerical Index WMCC

Macroinvertebrate order	***Salvelinus fontinalis***	***Umbra limi***
Coleoptera	.07	1.00
Diptera	--	--
Ephemeroptera	--	--
Fish	.21	--
Mollusca	.43	--
Hemiptera	.07	--
Hymenoptera	--	--
Odonata	.14	--
Tricoptera	.07	--
Amphipoda	--	--
Decapoda	--	--
Plecoptera	--	--
Isopoda	--	--

Frequency of Occurrence WMCC

Macroinvertebrate order	***Salvelinus fontinalis***	***Umbra limi***
Coleoptera	.17	.50
Diptera	--	--
Ephemeroptera	--	--
Fish	.33	--
Mollusca	.50	--
Hemiptera	.17	--
Hymenoptera	--	--
Odonata	.33	--
Tricoptera	.17	--
Amphipoda	--	--
Decapoda	--	--
Plecoptera	--	--
Isopoda	--	--

Ivlev's Electivity WMCC

Macroinvertebrate order	***Salvelinus fontinalis***	***Umbra limi***
Coleoptera	.33	.93
Diptera	-1.00	-1.00
Ephemeroptera	-1.00	-1.00
Amphipoda	-1.00	-1.00
Mollusca	.06	-1.00
Hemiptera	.57	-1.00
Megaloptera	-1.00	-1.00
Odonata	-.02	-1.00
Plecoptera	-1.00	-1.00
Tricoptera	-.30	-1.00
Decapoda	.86	-1.00
Annelida	-1.00	-1.00
Hirudinea	-1.00	-1.00

Numerical Index WMRR

Macroinvertebrate order	***Oncorhynchus mykiss***	***Salvelinus fontinalis***
Coleoptera	.08	.10
Diptera	.17	.03
Ephemeroptera	.17	.03
Arachnida	.04	--
Mollusca	.04	.16
Hemiptera	--	.06
Hymenoptera	--	.18
Odonata	.04	.18
Polydesmida	.04	.02
Tricoptera	.42	.07
Amphipoda	--	.09
Decapoda	--	.03
Plecoptera	--	.03
Isopoda	--	.03

Frequency of Occurrence WMRR

Macroinvertebrate order	*Oncorhynchus mykiss*	*Salvelinus fontinalis*
Coleoptera	1.00	.78
Diptera	1.00	.22
Ephemeroptera	1.00	.11
Arachnida	1.00	--
Mollusca	1.00	.44
Hemiptera	--	.33
Hymenoptera	--	.44
Odonata	1.00	.89
Polydesmida	1.00	.22
Tricoptera	1.00	.56
Amphipoda	--	.44
Decapoda	--	.33
Plecoptera	--	.11
Isopoda	--	.22

Ivlev's Electivity WMRR

Macroinvertebrate order	*Oncorhynchus mykiss*	*Salvelinus fontinalis*
Coleoptera	.35	.44
Diptera	-.35	-.82
Ephemeroptera	-.23	-.82
Amphipoda	--	1.00
Mollusca	.63	.89
Hemiptera	--	1.00
Hymenoptera	--	1.00
Megaloptera	-1.00	-1.00
Odonata	.31	.79
Plecoptera	-1.00	.25
Tricoptera	.24	-.57
Decapoda	--	1.00
Polydesmida	1.00	1.00
Isopoda	-1.00	-.09

Numerical Index WMUS

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.08	.09	.20	--
Diptera	.08	.11	--	.50
Ephemeroptera	.20	.09	--	.33
Fish	.03	.01	--	--
Mollusca	.03	.16	--	--
Hemiptera	--	.03	--	--
Hymenoptera	.13	.01	.15	--
Odonata	.13	.05	.10	--
Plecoptera	.05	.03	--	--
Tricoptera	.30	.42	.55	--
Isopoda	--	--	--	.17

Frequency of Occurrence WMUS

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.67	.75	.67	--
Diptera	.67	.50	--	1.00
Ephemeroptera	.67	.25	--	1.00
Fish	.33	.25	--	--
Mollusca	.33	.50	--	--
Hemiptera	--	.25	--	--
Hymenoptera	.33	.25	.33	--
Odonata	.67	.50	.33	--
Plecoptera	.33	.25	--	--
Tricoptera	1.00	.75	1.00	--
Isopoda	--	--	--	.50

Ivlev's Electivity WMUS

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.19	.27	.59	-1.00
Diptera	-.63	-.49	-1.00	.21
Ephemeroptera	0.00	-.39	-1.00	.25
Fish	1.00	1.00	--	--
Mollusca	.63	.93	-1.00	-1.00
Hemiptera	-1.00	.80	-1.00	-1.00
Hymenoptera	1.00	1.00	1.00	--
Megaloptera	-1.00	-1.00	-1.00	-1.00
Odonata	.91	.80	.89	-1.00
Plecoptera	1.00	1.00	--	--
Tricoptera	-.13	.03	.17	-1.00
Isopoda	--	--	--	1.00

Numerical Index WMPT

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.16	.14	.09	--
Diptera	.02	.07	.12	.14
Ephemeroptera	.09	.14	.06	.09
Mollusca	.03	.07	--	--
Hymenoptera	.13	.14	.18	--
Odonata	.14	.24	.12	--
Plecoptera	.03	.07	--	--
Tricoptera	.39	.14	.26	.77
Amphipoda	.02	--	--	--
Isopoda	--	--	.18	--

Frequency of Occurrence WMPT

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.33	.50	.50	--
Diptera	.17	.50	.50	.67
Ephemeroptera	.50	1.00	1.00	.33
Mollusca	.17	.50	--	--
Hymenoptera	.67	1.00	1.00	--
Odonata	.67	1.00	50	--
Plecoptera	.17	.50	--	--
Tricoptera	.83	1.00	1.00	.67
Amphipoda	.17	--	--	--
Isopoda	--	--	.18	--

Ivlev's Electivity WMPT

Macroinvertebrate order	***Salmo trutta***	***Salvelinus fontinalis***	***Oncorhynchus mykiss***	***Cottus spp.***
Coleoptera	.41	.35	.14	-1.00
Diptera	-.88	-.55	-.34	-.28
Ephemeroptera	-.46	-.29	-.62	-.47
Amphipoda	.13	-1.00	-1.00	-1.00
Mollusca	.18	.52	-1.00	-1.00
Hymenoptera	.96	.96	.97	-1.00
Megaloptera	-1.00	-1.00	-1.00	-1.00
Odonata	.76	.85	.72	-1.00
Plecoptera	-.04	.34	-1.00	-1.00
Tricoptera	.06	-.43	-.13	.38
Isopoda	--	--	1.00	--