LAKE STURGEON (*Acipenser fulvescens)* IN TWO NORTHERN MICHIGAN RIVERS: A COMPARISON OF KNOWN SPAWNING SITES IN THE UPPER BLACK RIVER TO POTENTIAL SPAWNING SITES IN THE STURGEON RIVER

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Abstract

Lake sturgeon (*Acipenser fulvescens)* were once abundant in the Great Lakes basin. Poaching and habitat loss due to dam construction has significantly reduced the range of many populations around the United States, including the population in Black Lake, Michigan. A comparative assessment of known lake sturgeon spawning sites in the Upper Black River, Michigan to potential spawning sites in the Sturgeon River of Burt Lake, Michigan was conducted to determine whether or not habitat in the Sturgeon River was limiting the spawning and recruitment of the Burt Lake population. Examining average and substrate velocity, substrate composition and embeddedness, and proportions of prey and predatory macroinvertebrates, we determined that lake sturgeon spawning may be plausible in the Sturgeon River. Upper Black River contains two identified spawning sites, and only one Sturgeon River site examined in this study was comparable to the known spawning sites on the Upper Black River with regard to key spawning habitat characteristics. Despite this, other external factors such as human development and tourist activity may be impeding successful lake sturgeon spawning and recruitment in Sturgeon River. The results of this study may assist future studies in determining whether or not human activity has an impact on early life stages of lake sturgeon in the Sturgeon River.

Introduction

Lake sturgeon (*Acipenser fulvescens*) are large-bodied, primitive fish historically present in the Great Lakes basin, including inland rivers, lakes, and waterways (Peterson et al. 2006). Once abundant, lake sturgeon populations have been largely declining due to significant habitat loss and poaching for meat and caviar (Peterson et al. 2006; Baril et al. 2018). Having a historically large natural migration range of up to 200 km, lake sturgeon are particularly sensitive to habitat alteration and loss (Peterson et al. 2006). Lake sturgeon typically spawn upstream from their home waterbody and that migration for spawning has been impeded by human construction of dams and culverts, significantly decreasing available upstream spawning habitat (Peterson et al. 2006; Rochard et al. 1990).

Even without human impact, spawning is a delicate process for lake sturgeon considering the highly specific habitat requirements for successful egg development and larval rearing: they tend to only lay their eggs on rocky substrate with clean interstitial spaces, used as egg refuge, in streams with a specific range of temperature and velocity (Baril et al. 2018). Additionally, lake sturgeon are late-maturing - despite rapid growth during their juvenile stage - not reaching spawning age until 12-15 yrs for males and 18-27 yrs for females (Peterson et al. 2006). Late spawning allows for intense somatic growth in the first few years of life and increases fecundity at first spawning, but delays reproduction (Peterson et al. 2006). Furthermore, studies suggest that lake sturgeon only spawn every 4 to 7 years once they reach spawning age (Roussow 1957; Auer 1996) This strategy is successful in the absence of anthropogenic disturbance, though can present challenges to recruitment in habitats pressured by disturbance and stress (Peterson et al. 2006; Auer 1996).

During spawning, female lake sturgeon deposit adhesive eggs onto gravel or cobble substrate and return downstream (Peterson et al. 2006). The majority of the eggs hatch after 8-14 days and developing larvae rely on the interstitial spaces at the spawning location for refuge before dispersing downstream 13-19 days after hatching, remaining in their natal stream for up to a year (Peterson et al. 2006). Once laid, lake sturgeon eggs face risks such as predatory stoneflies (Walquist et al. 2015). Eggs that survive to hatch develop into larvae that feed on up to 90% soft-bodied insect larvae, mostly mayfly (Ephemeroptera) and midge (Chironomidae) (Peterson et al. 2006; Harkness & Dymond 1961).

Key components for successful lake sturgeon spawning and larval rearing include water velocity, water temperature and depth, substrate size, and availability and abundance of both predator and prey macroinvertebrates (Baril et al. 2018; Walquist et al. 2015). A meta-analysis across available data by Baril et al. (2018) concluded that the ideal ranges for some key components are depth-averaged velocities of 0.6m/s and substrate sizes of coarse gravel to cobble, and these results are supported by other studies (Peterson et al. 2006; Baril et al. 2018; LaHaye et al. 1992). Interstitial space has also been shown to influence spawning habitat selectivity, likely due to egg and larval refuge in the first month of life (Peterson et al. 2006).

A successfully self-sustaining population of lake sturgeon resides in Black Lake, situated in Cheboygan and Presque Isle counties, Michigan (Figure 1). Spawning occurs annually in the Upper Black River upstream from Black Lake, but Kleber Dam is situated approximately 5 miles upstream from Black Lake and cuts off Upper Black River from its historical course out to Lake Huron, preventing lake sturgeon and other fishes from migrating further. Despite this, the population of lake sturgeon in Black Lake is still successfully reproducing annually (Smith & Baker 2005). The Black Lake population is like most remaining populations of this species, restricted in movement by dams or navigation locks (Folz & Meyers 1985; Hay-Chmielewski 1987; Thuemler 1988).

Burt Lake in Cheboygan county, Michigan (Figure 2) also contains a population of lake sturgeon, though it is believed that recruitment is very low (Steenstra, D., personal communication). Of the four inflows to Burt Lake, only the Sturgeon River is deep enough at the mouth and throughout to be suitable for spawning sized sturgeon migrations upstream. It is assumed that lake sturgeon from Burt Lake do spawn in the Sturgeon River, as corroborated by witness reports, but scant data prevents full understanding of the Burt Lake population or its spawning behaviors in the Sturgeon River and potentially on the shores of the lake.

Due to minimal data, assessment of the viability of the Sturgeon River for spawning of Burt Lake lake sturgeon is of interest to local groups such as Sturgeon For Tomorrow and the Burt Lake Preservation Association. To assess such viability, we conducted a comparative analysis between the Upper Black River and the Sturgeon River. Our study aimed to discern differences in average velocity and substrate velocity, substrate composition and embeddedness, and macroinvertebrate communities between known spawning sites on Upper Black River and potential sites on Sturgeon

River, as these have been determined to be the most important habitat characteristics for lake sturgeon spawning and larval rearing (Peterson et al. 2006; Baril et al. 2018).

Methods

Study Sites

During July and August of 2018, known spawning sites on the Upper Black River and visually-identified potential spawning sites on the Sturgeon River were comparatively assessed for viability of lake sturgeon spawning. The Black River is known to contain a self-sustaining spawning population of lake sturgeon, and sites for assessment were identified visually on a map and corroborated by findings of a previous study in the river (Smith & Baker 2005). Sites on the Black River included one “primary spawning site” and one “secondary spawning site” as identified by Smith & Baker (2005), and one site that was identified as a non-spawning site for comparison (Figure 1). Three sites on the Sturgeon River were selected based on the presence of appropriate substrate and velocity conditions as compared to sites on the Upper Black River, as well as accessibility by vehicle for sampling (Figure 2). All data were collected by establishing 3 transects per site, each stretching the width of the river at 10 meter intervals. Transect placement aimed to encompass the most apparently viable stretch of each site.

Discharge and Velocity

Discharge was calculated one time at each site by dividing the width of the river into 10 equal sections on one transect and recording the velocity at 60% depth (henceforth “velocity”, not to be confused with “substrate velocity”) at each endpoint of the subdivision. This was measured using a flowmeter. The area of the subdivision (depth*width) was multiplied by the velocity to get the discharge at one subdivision. Discharge across the river was calculated as the sum of the discharges at all the subdivisions. Substrate velocity (at benthos, or 0% depth) was recorded 5 times across each transect for a total of 15 times per site.

Substrate Classification

The substrate at each site was classified using the Wentworth Scale (Wentworth 1922). 5 visual estimates of grain size were recorded at each transect for a total of 15 times per site. Per the Wentworth scale, grains identified as boulders were between the size of a car and a basketball; cobbles were between a basketball and a tennis ball, pebbles between a tennis ball and a marble, gravel between a marble and a lady bug, and sand smaller than a ladybug. Percent cover of each grain size was estimated simultaneously by 3 researchers and values were averaged for a consensus estimate.

Substrate Embeddedness

Substrate embeddedness was visually estimated 5 times along each transect for a total of 15 estimates per site. A modified approach to the USGS method was used: once per quadrat, a random boulder or cobble was pulled from the water and the percent height of the boulder or cobble that was buried in the sediment was visually estimated (Fitzpatrick et al. 1998). The extent of discoloration was used to determine the height buried, as the portion of the boulder or cobble exposed to the water column was covered in a fine sediment, while the portion buried was bare of fine sediment. Consensus estimates were recorded in the same manner as substrate classification.

Macroinvertebrates

Surber samplers with an area of 0.09 m^2 were used to assess availability of benthic macroinvertebrates. Surber samples were taken twice along each transect for a total of 6 samples per site. Benthos within the area of the surber sampler was agitated for 2 minutes, and contents of the sample were emptied into an enamel pan on-site and picked for a total of 30 person-minutes. Macroinvertebrates picked from each sample were placed in a jar of 85% isopropanol and identified to order or family. Diversity of macroinvertebrates was assessed by calculation of a Shannon's diversity index for each order or taxa at a site. Community similarity was assessed using a Pearson Correlation with centroid linkage.

Statistical Analyses

ANOVAs with Tukey's post-hoc tests were used to compare the means among sites for substrate velocity, substrate classification, substrate embeddedness, and macroinvertebrate diversity. Macroinvertebrate abundance was assessed with the non-parametric Kruskal-Wallis test of differences among means. Data used in each ANOVA were checked for homogeneity of variance and normal distribution. In cases where ANOVA assumptions were not met, Welch's ANOVA was performed instead with Tamhane post-hoc tests. The null hypotheses in all ANOVAs were that the means of all sites were equal, and the alternative hypotheses were that the means were not equal. A hierarchical cluster analysis was used to determine the similarity of macroinvertebrate communities at each site.

Results

Discharge and Velocity

The Upper Black River had an average higher discharge (4.4 m^3/s) than the Sturgeon River (6.2 m^3/s) and was, on average, 6.8℃ warmer, 2.6 cm deeper, and 3.2 m wider than the Sturgeon River (Table 1). There was a significant difference in at least one average substrate velocity among the 6 sites: Fireline on the Upper Black River had a significantly lower average substrate velocity than Haakwood on the Sturgeon River (ANOVA: df = 89, F = 2.445, $p = 0.004$; Tukey's post-hoc $p = 0.025$). There was also a significant difference in at least one average velocity (Welch's ANOVA: df = 24.51, F = 9.070, $p < 0.001$): the average velocity was significantly lower at Fireline on the Upper Black River than both Wolverine (Tamhane post-hoc $p = 0.022$) and Haakwood (Tamhane post-hoc $p = 0.001$) on the Sturgeon River. Average velocity was also significantly lower at Waveland on the Upper Black River than at Haakwood on the Sturgeon River (Tamhane post-hoc $p = 0.003$). Average substrate velocity ± 2 SE is summarized in Figure 3, and average velocity ± 2 SE is summarized in Figure 4.

Substrate Classification

On average, the Upper Black River substrate consisted of 13% more cobble, 22% less pebble, and the same amount of gravel compared to the Sturgeon River (Table 2). There was at least one significant difference in the mean percent composition of cobble (Welch's ANOVA: df = 34.26, F = 6.257, $p < 0.001$) and pebble (ANOVA: df = 74, F = 6.637, $p < 0.001$) among sites, but no significant differences among the mean percent compositions of gravel. Fisher Woods on the Sturgeon River had significantly less cobble than both Fireline (Tukey's post-hoc $p = 0.03$) and Waveland (Tukey's post-hoc p = 0.004) on the Upper Black River. Haakwood on the Sturgeon River had significantly more pebble than Wolverine on the Sturgeon River (Tukey's post-hoc p = 0.046), and both Fireline (Tukey's post-hoc p = 0.034) and Waveland (Tukey's post-hoc p = 0.004) on the Upper Black River. Fisher Woods on the Sturgeon River had significantly more pebble than Waveland on the Upper Black River (Tukey's post-hoc p = 0.014).

Substrate Embeddedness

Grains in the Upper Black River were, on average, 3% more embedded than those on the Sturgeon River (Table 2), though at least one significant difference in average percent embeddedness existed among sites (df = 74, F = 6.761, p = < 0.001). Substrate at Wolverine on the Sturgeon River was embedded significantly more than at both Fisher Woods (Tukey's post-hoc p < 0.001) and Haakwood (Tukey's post-hoc p = 0.002), also on the Sturgeon River.

Macroinvertebrates

There were not significant differences in macroinvertebrate diversity or abundance among any sites, though similarity assessment using a Pearson Correlation with centroid linkage determined that Kleber Dam on the Upper Black River had the most dissimilar macroinvertebrate community compared to all other sites (Figure 6).

The percentage of macroinvertebrates in the order Plecoptera in the Upper Black River (1.7%) was functionally the same as in the Sturgeon River (1.6%), as was the percentage in the family Chironomidae in the Upper Black (5.7%) compared to the Sturgeon (7.2%) (Table 3). While not statistically significant, the percentage of macroinvertebrates in the order Ephemeroptera in the Upper Black River (32%) was nearly twice that of the Sturgeon River (15.9%) (Table 3).

Discussion

Viability of Potential Spawning Sites in the Sturgeon River

Substrate velocity was not significantly different among sites except Waveland on the Upper Black River and Haakwood on the Sturgeon River (Figure 3). Because there was not a difference among other sites, it may be plausible to suggest that, in terms of substrate velocity, both Wolverine and Fisher Woods on the Sturgeon River are suitable for lake sturgeon spawning, particularly egg deposition, as the substrate velocity at these locations is not significantly different from Fireline, a “primary spawning location” (Smith & Baker, 2005).

Velocity was significantly different at Wolverine and Haakwood on the Sturgeon River as compared to Fireline and Waveland, identified spawning habitats (Smith & Baker 2005) on the Upper Black River (Figure 4). Fisher Woods on the Sturgeon River was the only site that was not significantly different from the spawning sites on the Upper Black River, suggesting that Fisher Woods is the only suitable spawning site on the Sturgeon River of the 3 that we examined. However, because we sampled in the summer and spawning occurs in the spring, the flow and velocity of the two rivers is likely lower than it would be in the spring due to snow melt. Lake sturgeon spawn in the spring, and it is possible that increased flow and velocity during that time could push velocities on the Sturgeon River out of the suitable range of 0.5 - 1.3 m^2/s (Baril et al. 2018; Peterson et al. 2006) (Figure 4). This could ultimately make Sturgeon River unsuitable for lake sturgeon spawning, though sampling in the spring would be necessary to confirm this.

Embeddedness was significantly varied among sites on the Sturgeon River (Figure 5), with Wolverine having a much higher percent embeddedness of substrate grains than Haakwood and Fisher Woods. Both Haakwood and Fisherwoods sites had substrate embeddedness that was comparable to the two identified spawning sites on the Upper Black, Fireline and Waveland (Smith & Baker 2005). This may suggest that in terms of substrate embeddedness, an important characteristic that determines the amount lake sturgeon egg and larval refuge, Haakwood and Fisher Woods on the Sturgeon River and suitable spawning locations in comparison with spawning sites on the Upper Black River.

Substrate composition was significantly different among sites in terms of cobble and pebble, but not gravel (Figure 6). Fisher Woods on the Sturgeon River did have significantly less cobble than both Waveland and Fireline on the Upper Black River, though did not differ in terms of pebble from Fireline on the Upper Black. This may suggest that Fisher Woods is suitable for lake sturgeon spawning if the amount of cobble in the substrate is increased to levels comparable with Fireline and Waveland.

Macroinvertebrate communities were not significantly different among any of the sites sampled on the Sturgeon and Upper Black rivers, though Waveland on the Upper Black River and Haakwood on the Sturgeon River did have the most similar communities in terms of macroinvertebrate abundance, while Kleber was the most dissimilar (Figure 7). This is promising, as it suggests that the 3 sites sampled on the Sturgeon River (Wolverine, Haakwood, Fisher Woods) are more similar to the two spawning sites on the Upper Black (Fireline, Waveland) than to the non-spawning site (Kleber), even suggesting that the three sites on the Sturgeon are functionally the same as the two spawning sites on the Upper Black in terms of macroinvertebrate communities. Additionally, while not statistically tested specifically, the proportions of stoneflies (Plecoptera) were so similar between the Sturgeon and the Upper Black that we can suggest egg predation risk by stoneflies is functionally the same in the two rivers, a risk identified by (Walquist et al. 2015).

In consideration of all components examined in this study, Fisher Woods on the Sturgeon River seems to be the most suitable lake sturgeon spawning site: it does not differ from Fireline on the Upper Black River, a “primary spawning site” (Smith & Baker 2005), in substrate velocity, average velocity, embeddedness, or macroinvertebrate community composition. It does have less cobble substrate than both Fireline and Waveland on the Upper Black River, though this habitat characteristic is the easiest to manipulate. Velocities, embeddedness, and macroinvertebrate presence are factors that are too difficult or impossible to manipulate, making management strategies involving these characteristics costly or unavailable.

Potential Management Strategies

Increased lake sturgeon spawning and recruitment after implementing artificial substrate was demonstrated by a study in the St. Lawrence River, where 2 to 4 inch limestone pieces (pebble on the Wentworth scale) were deposited on the benthos of areas where lake sturgeon of spawning size had been seen (Johnson et al. 2006). Similar work was done in the St. Clair River and Upper Black River in which artificial cobble and boulder-sized substrate was implemented, resulting in some success in increased subsequent spawning events and recruitment (Kerr et al. 2010) Procedures in these studies could be modified to the Burt and Black Lakes systems; cobble that approximates the size of grains found at the primary spawning site on the Upper Black (Fireline) could be implemented to make the substrate composition at Fisher Woods more closely resemble that of Fireline, presumably making Fisher Woods an even more suitable spawning site.

It is worth mentioning the difference in human development, activity, and potential influence on the Sturgeon River as compared to the Upper Black River. The land use of area surrounding the Sturgeon River is much more developed than that of the Upper Black (Figure 8). Sturgeon River also has many public access points used by the local tourism sector for river floats and kayak tours, while the Upper Black has significantly fewer access points and no tourist activity due to its short 5-mile course above the Kleber Dam. While the tourism on the Sturgeon River likely comprised a significant portion of the local economy, it may be necessary to consider the trade-off between economic and ecological importance of the Sturgeon River and species like lake sturgeon that reside in it. Future studies will be required to assess the impact of human activity in mid- and late-summer months on larval and early stage juvenile lake sturgeon still in the river, prior to migration back down to Burt Lake.

Ultimately, we have concluded it may be possible to make the Sturgeon River a more hospitable environment for lake sturgeon spawning and larval rearing. Despite significant differences in some non-modifiable factors like velocity and embeddedness at some of the Sturgeon River sites, Fisher Woods on the Sturgeon appears to be comparable to the primary spawning site identified by Smith & Baker (2005) on the

Upper Black River with regard to almost every key characteristic. It is possible to increase the amount of preferred cobble substrate at Fisher Woods in the Sturgeon River to make it more comparable to Fireline on the Upper Black.

However, this minor change may not be enough to increase sturgeon spawning and recruitment as there may be external factors affecting sturgeon success in the Sturgeon River throughout the summer, when larvae and early stage juveniles would be present along the benthos foraging (Peterson et al. 2006). It is essential that further research, in conjunction with the results of this study, be conducted on the effect of human development and mid- to late-summer tourist activity in the Sturgeon River on larvae and early stage juvenile lake sturgeon. Resulting conclusions from furthers studies, alongside this one, may be able to recommend definitive action that could increase lake sturgeon spawning and recruitment in the Sturgeon River and ultimately in Burt Lake.

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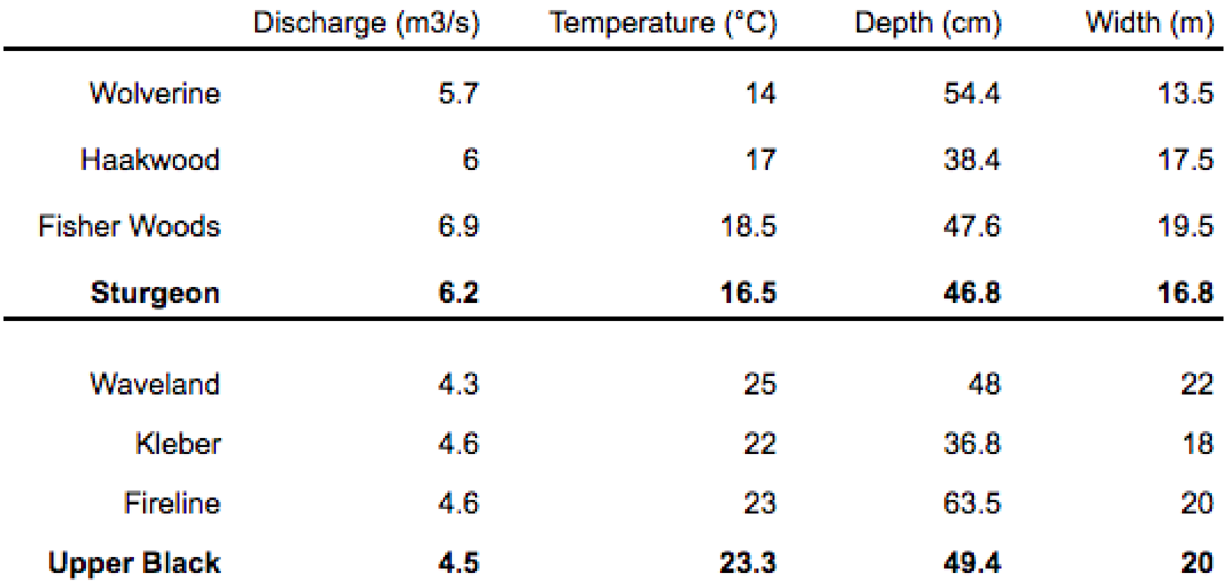
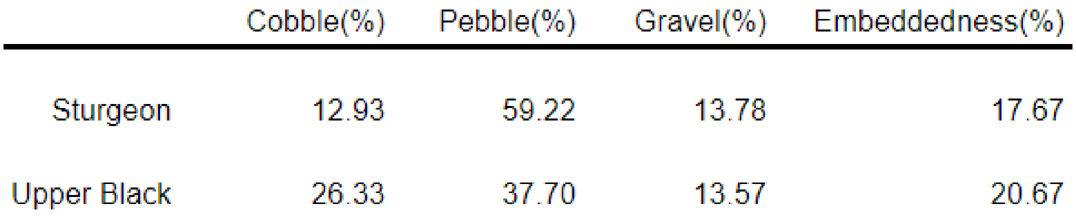
Tables & Figures



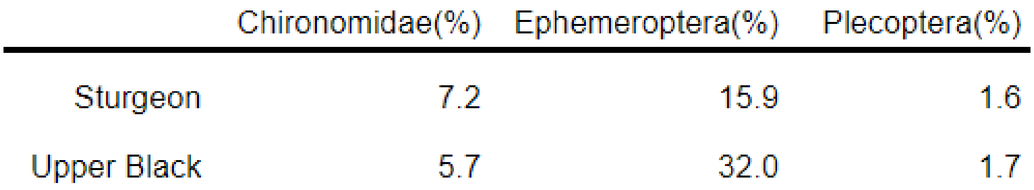
	Discharge (m3/s)	Temperature (°C)	Depth (cm)	Width (m)
Wolverine	5.7	14	54.4	13.5
Haakwood	6	17	38.4	17.5
Fisher Woods	6.9	18.5	47.6	19.5
Sturgeon	**6.2**	**16.5**	**46.8**	**16.8**
Waveland	4.3	25	48	22
Kleber	4.6	22	36.8	18
Fireline	4.6	23	63.5	20
Upper Black	**4.5**	**23.3**	**49.4**	**20**

Table 1: A summary of the average discharge, temperature, depth, and width at each study site on the Sturgeon (Wolverine, Haakwood, Fisher Woods) and Upper Black (Waveland, Kleber, Fireline), as well as the averages across sites on each river.



	Cobble(%)	Pebble(%)	Gravel(%)	Embeddedness(%)
Sturgeon	12.93	59.22	13.78	17.67
Upper Black	26.33	37.70	13.57	20.67

Table 2: The average percent composition of substrate and embeddedness in the Sturgeon and Upper Black rivers.



	Chironomidae(%)	Ephemeroptera(%)	Plecoptera(%)
Sturgeon	7.2	15.9	1.6
Upper Black	5.7	32.0	1.7

Table 3: The average percent Chironomidae, Ephemeroptera, and Plecoptera of total macroinvertebrates sampled in the Sturgeon and Upper Black rivers.

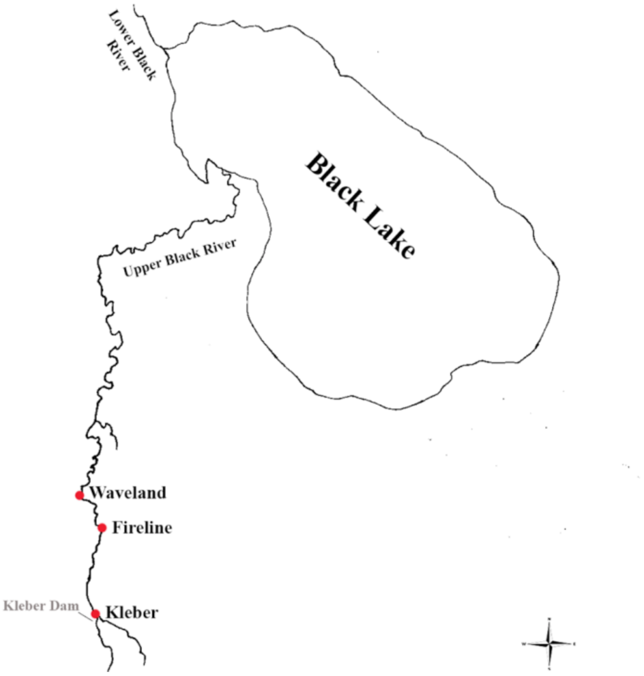


Figure 1: Study sites on Upper Black River below Black Lake, Michigan: Waveland, Fireline, and Kleber. Fireline and Waveland sites were identified as “primary” and “secondary” spawning sites by Smith & Baker (2005).

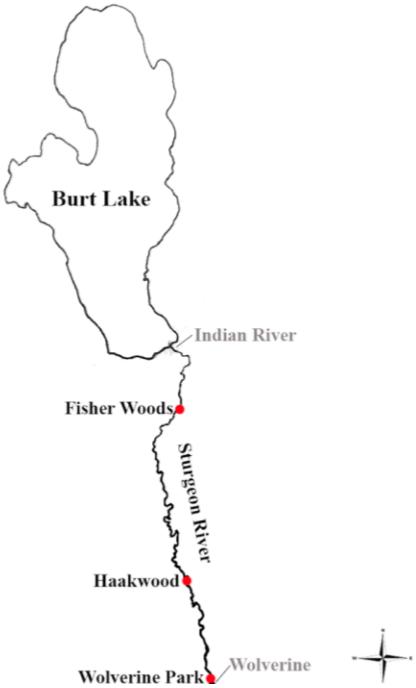


Figure 2: Study sites on Sturgeon River below Burt Lake, Michigan: Fisher Woods, Haakwood, and Wolverine. Sturgeon River is a primary inflow of Burt Lake. Sites were chosen to model identified spawning sites on the Upper Black River.

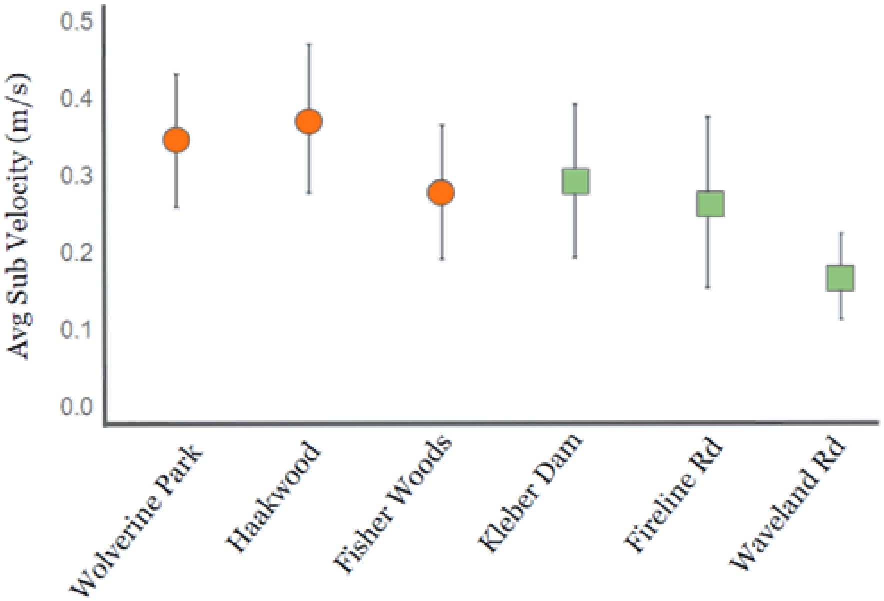


Figure 3: The average substrate velocity at each site on the Sturgeon (circle) and Upper Black (square) rivers ± 2 SE. Fireline on the Upper Black River had a significantly lower average substrate velocity than Haakwood on the Sturgeon River (Tukey's post-hoc p = 0.025).

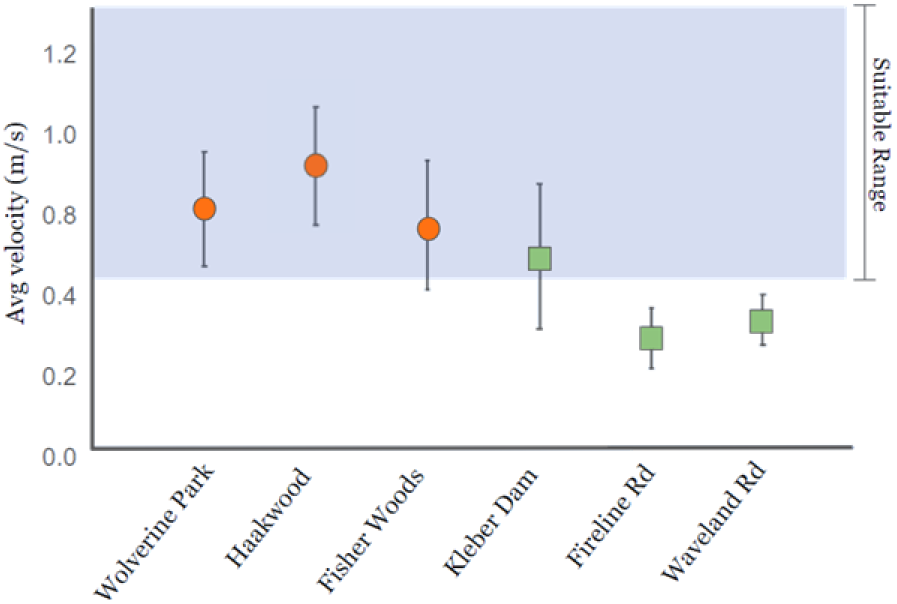


Figure 4: The average velocity at each site on the Sturgeon (circle) and Upper Black (square) rivers ± 2 SE. Average velocity was significantly lower at Fireline on the Upper Black River than both Wolverine (Tamhane post-hoc p = 0.022) and Haakwood (Tamhane post-hoc p = 0.001) on the Sturgeon River. Average velocity was also significantly lower at Waveland on the Upper Black River than at Haakwood on the Sturgeon River (Tamhane post-hoc p = 0.003).

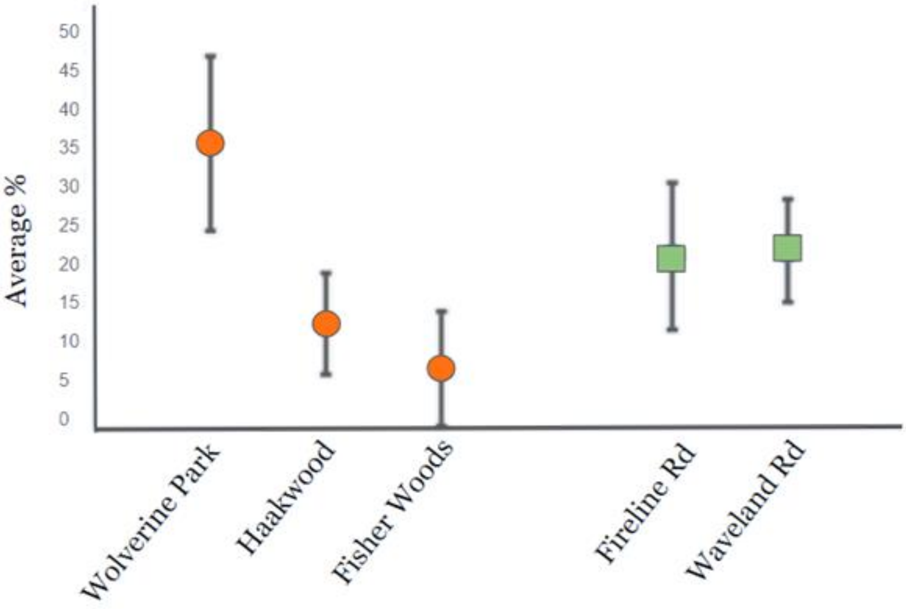


Figure 5: The average percent embeddedness of grains of boulder or cobble in the Sturgeon (circle) and Upper Black (square) rivers ± 2 SE. Substrate at Wolverine on the Sturgeon River was embedded significantly more than at both Fisher Woods (Tukey's post-hoc $p < 0.001$) and Haakwood (Tukey's post-hoc $p = 0.002$), also on the Sturgeon River.

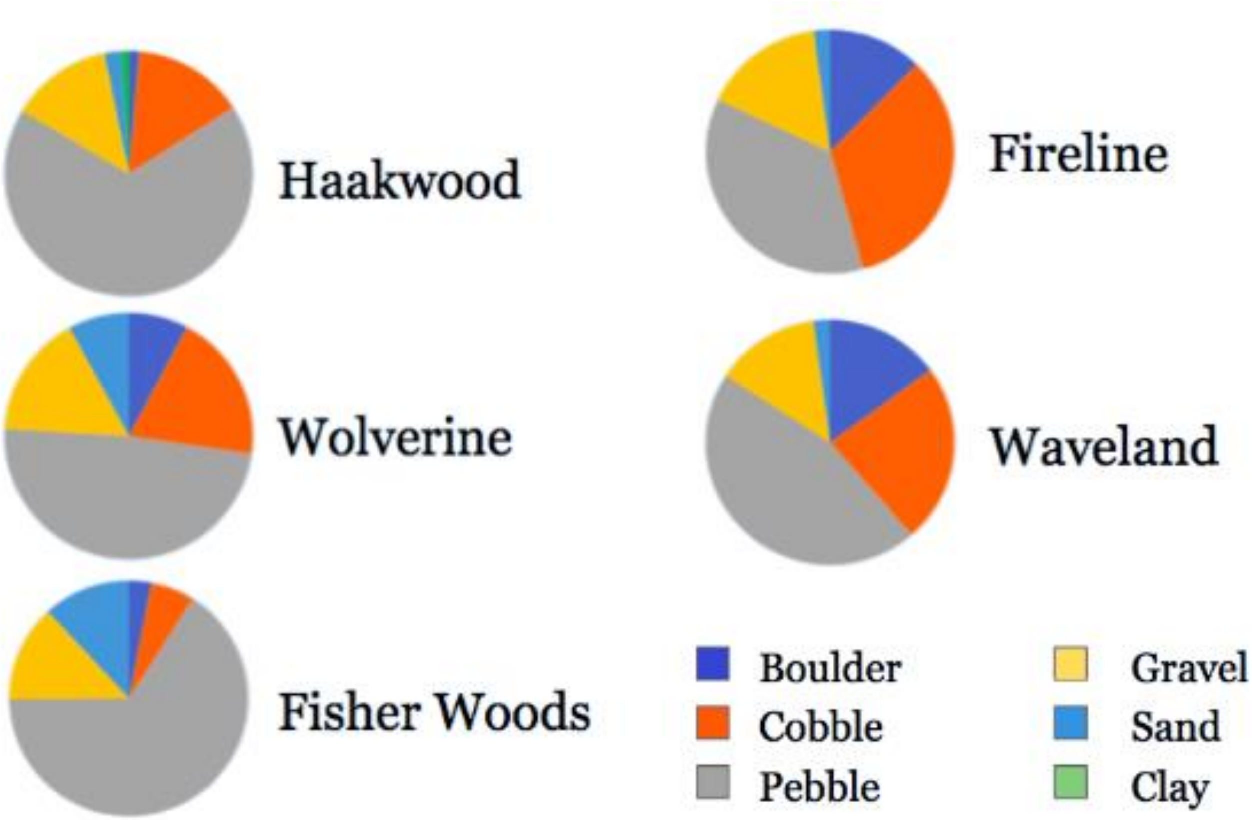


Figure 6: The percent composition of substrate size (per the Wentworth scale) at sites on the Sturgeon River (Wolverine, Haakwood, Fisher Woods) and Upper Black River (Fireline and Waveland). Fisher Woods had significantly less cobble than both Fireline (Tukey's post-hoc p = 0.03) and Waveland (Tukey's post-hoc p = 0.004). Haakwood had significantly more pebble than Wolverine (Tukey's post-hoc p = 0.046), Fireline (Tukey's post-hoc p = 0.034) and Waveland (Tukey's post-hoc p = 0.004). Fisher Woods had significantly more pebble than Waveland (Tukey's post-hoc p = 0.014).

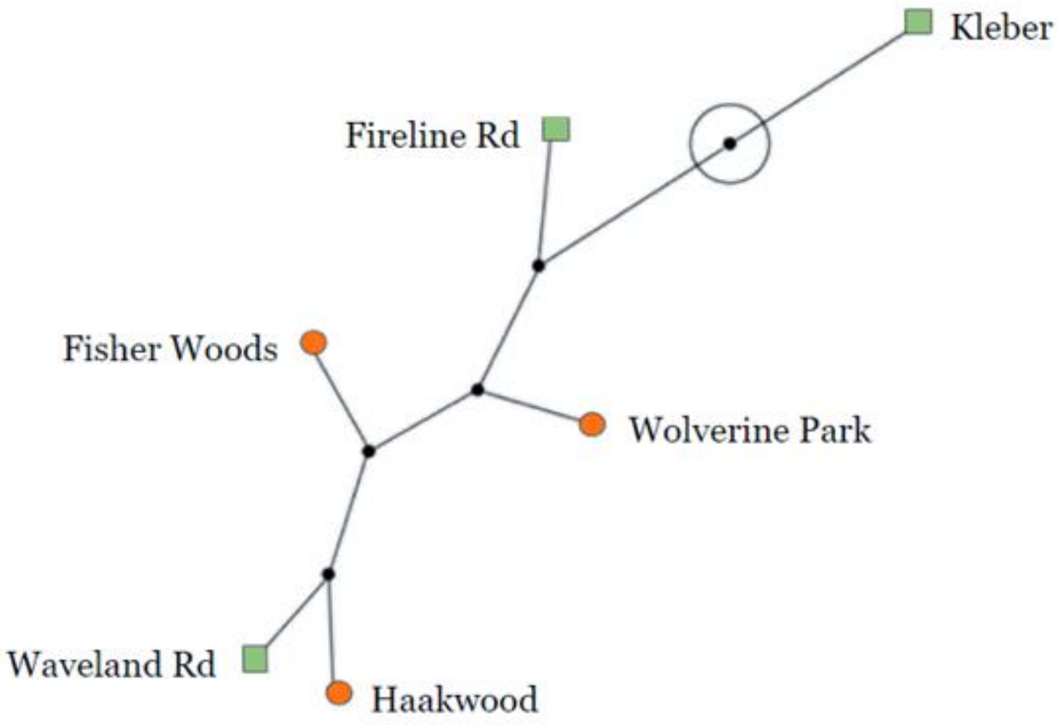


Figure 7: A constellation plot, formed from a Pearson Correlation with centroid linkage, modeling the similarity between macroinvertebrate communities at sites on the Sturgeon (circle) and Upper Black (square) rivers. The origin (dot + circle) separates the most dissimilar group from the other more similar groups. Groups farthest away from the origin are most similar to one another and the most dissimilar from the point on the other side of the origin. Waveland and Haakwood are the most similar groups, and Kleber is the most dissimilar.

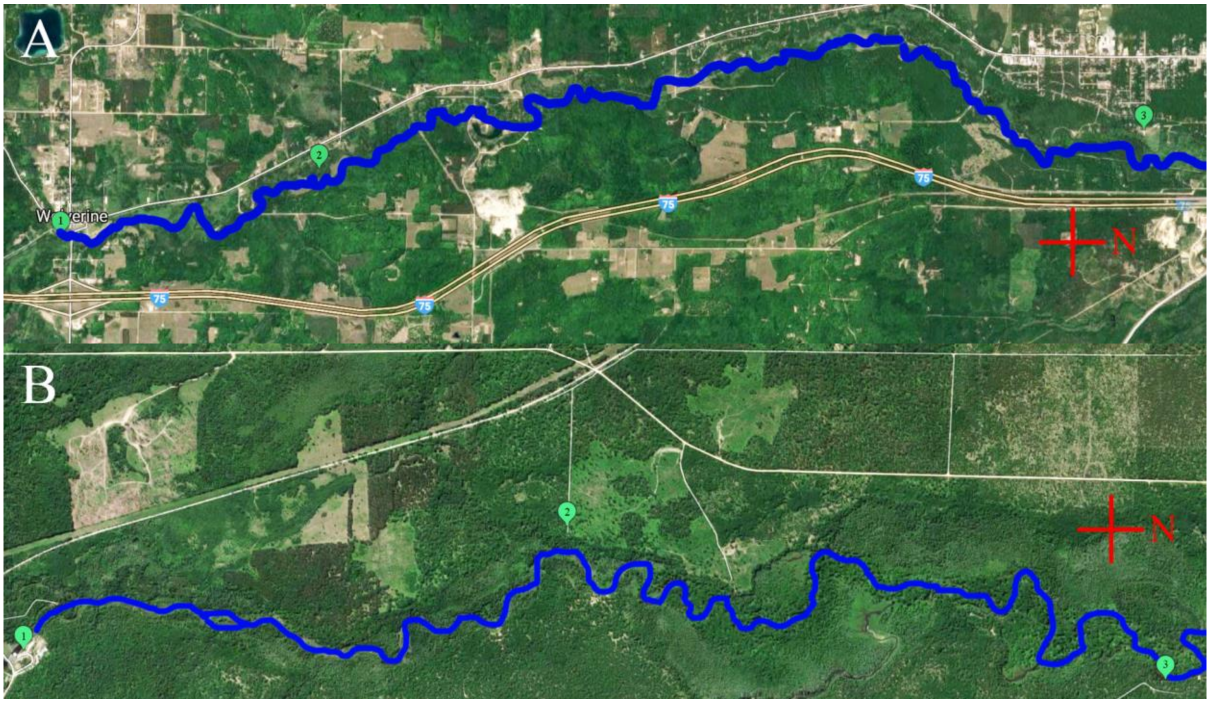


Figure 8: Satellite imagery showing the development surrounding the Sturgeon (A) and Upper Black (B) rivers. The flow of each river is from right to left in the aerial imagery. There is significantly more development surround the Sturgeon River, including the interstate, local highways and roads, and several farmlands.