EFFECTS OF A ROCK RAMP STRUCTURE ON SUMMER FISH ASSEMBLAGE IN THE SHIAWASSEE RIVER

By

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ABSTRACT

EFFECTS OF A ROCK RAMP STRUCTURE ON SUMMER FISH ASSEMBLAGE IN THE SHIAWASSEE RIVER

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The use of nature-like fishways to increase ecosystem connectivity has risen in recent years. In 2009, a rock ramp was constructed in the Shiawassee River to replace Chesaning Dam, formerly located in Chesaning, Michigan. The objective of my study was to evaluate the effects of the rock ramp on the summer fish assemblage. To accomplish this objective, I sampled fish in three rivers in the Saginaw Bay watershed, the Shiawassee (rock ramp), Cass (dammed), and Flint (free-flowing) in 2011 and 2012. I compared patterns of fish assemblage characteristics found in the rock ramp river to patterns in the dammed and free-flowing rivers. All three rivers had high similarity in species composition between upstream and downstream reaches. Patterns of species richness by site, mean CPUE, and proportional abundance in the rock ramp river had a higher similarity to the free-flowing river, while species richness by reach and species' impact factors had higher similarity to the dammed river. My findings suggest that the rock ramp has increased ecosystem connectivity for the summer fish assemblage, overall having fish assemblage characteristics patterns with higher similarity to the free-flowing river than the dammed river.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Dams are widespread throughout rivers and streams and were built primarily to provide social benefits such as electricity generation, flood control, water supply, and irrigation storage (Heinz Center 2002). However, dams negatively affect aquatic ecosystems by altering naturally occurring hydrogeomorphological processes, ultimately influencing the available habitat for aquatic biota (Poff et al. 1997). The infrastructure of dams negatively affects aquatic organisms by acting as a barrier that fragments stream habitats, preventing aquatic organisms from moving freely in the system. Prohibiting movement can prevent species from reaching habitats that are crucial to the different life stages, such as spawning and rearing habitats (Bednarek 2001). Habitat fragmentation can lead to a reduction in species richness and abundance; the collapse of salmon stocks in the Pacific Northwest being a prime example (Nehlsen et al. 1991). In addition to fragmenting habitats, dams cause a direct alteration of those habitats (Hayes et al. 2008). Dams alter naturally occurring temperature regimes, which changes downstream fish assemblage composition (Lessard and Hayes 2003; Hayes et al. 2008).

The expansive network of dams in the United States is ageing to the point where a large proportion are approaching or exceeding their expected design life, leaving dam owners and other stakeholders with the decision of removal or restoration (Heinz Center 2002). From an ecological standpoint, removal would restore riverine ecosystems to more natural conditions by reversing habitat alteration and fragmentation that dams cause (Bednarek 2001; Catalano et al. 2007). Removal allows streams to recover naturally, and can improve habitat quality and connectivity (Kanehl et al. 1997; Catalano et al. 2007; Burroughs et al. 2009). Improved connectivity increases access to habitats that are important to fish life history, resulting in higher fish abundances upstream and downstream of the removed dam (Burroughs et al. 2010; Gardner et al. 2013).

Despite the positive ecological effects of dam removal, social costs may outweigh ecological benefits, prohibiting removal in some cases (Heinz Center 2002). For instance, the Grand Coulee Dam in the Columbia River has a generating capacity of 6,809 megawatts making it the largest producer of electricity in the United State (Ortolano and Cushing 2002). When dam removal is not desired, dams can be retrofitted or built with fish passage structures, which in theory should improve ecosystem connectivity. Depending on the fish species targeted for passage over dams, several choices exist. Options for fish passage structures generally fit into two categories, conventional and nature-like fishways.

Conventional fishways (also referred to as technical fishways) are constructed using materials such as concrete, steel, or wood to create sloping or stepped channels that are partitioned by baffles, walls, weirs, and vanes (Katopodis et al. 2001). Some commonly used conventional fishways structures include pool and weir, vertical slot, and Denil. Research has shown that these fishways are successful in allowing upstream migration of anadromous salmonid species (Katopodis et al. 2001; Katopodis and Williams 2012). However, challenges remain with passage efficiency of fish with limited leaping abilities such as juvenile salmonids and small-bodied (e.g., darters) or large-bodied (e.g., sturgeon) species (Katopodis et al. 2001). With a growing interest for providing passage for all migratory species, there has been an increase in the use of nature-like fishways instead of conventional fishways (Katopodis and Williams 2012).

In contrast to conventional fishways, nature-like fishways are built with naturally occurring materials that mimic the slope, morphology, and hydraulic conditions found naturally in the system (Parasiewicz et al. 1998). Nature-like fishways are thought to mimic conditions that allow the passage of most species over their range of life stages (Katopodis and Williams 2012). Nature-like fishways can be further subdivided into two categories: nature-like bypass channels and rock ramps. Nature-like bypass channels are constructed as side channels that circumvent the dam structure, while rock ramps are constructed inside the stream channel, butting against and over the pre-existing dam and occupying the entire width of the stream channel (Gebler 1998; Harris et al. 1998; Weibel and Peter 2013)

Nature-like fishways are a successful means to pass salmonids (e.g., brown trout (*Salmo trutta*)) and non-salmonid species (e.g., alewives (*Alosa pseudoharengus*)) (Calles and Greenberg 2005; Roscoe and Hinch 2010; Franklin et al. 2012). However, other evaluations show low passage efficiencies for a variety of other species. Steffensen et al. (2013) found low passage efficiency for common shiner (*Luxilus cornutus*) (5.1%) and white sucker (*Catostomous commersonii*) (25%) in the Indian Creek nature-like bypass channel in Ontario, Canada. Low passage efficiencies in nature-like bypass channels are attributed to inadequate flows, the length of structure discouraging upstream migration (Aarestrup et al. 2003), and size selectivity (Calles and Greenberg 2007). Another concern for nature-like bypass channels is low attraction efficiency (Calles and Greenberg 2005), which decreases the probability that fish are able to locate the entrance of the bypass channel. Attraction efficiency is not a concern for rock ramps because rock ramps span the entire river channel width forcing all the water through the structure. However, evaluations of rock ramps also show variable passage efficiencies. Franklin et al. (2012) found that brown trout (*Salmo trutta*) had high passage efficiency over the Town Brook rock ramp in Massachusetts, but Harris et al. (1998) found low passage efficiencies for several native fish species over the Goondiwindi Weir rock ramp in Australia. Most evaluations conducted on rock ramps have focused on passage efficiency of specific species (Franklin et al. 2012; Weibel and Peter 2013) with few evaluations surveying the entire fish assemblage (Roscoe and Hinch 2010). Currently there is a knowledge gap regarding the effects of rock ramps on fish assemblages.

In 2009, a rock ramp was constructed in the Shiawassee River over the formerly existing Chesaning Dam in Chesaning, Michigan, USA. It was designed to allow fish passage and retain the dam's impoundment, which has socioeconomic value to the surrounding community. The overall goal of this study was to evaluate the effectiveness of the newly constructed rock ramp in increasing ecosystem connectivity between upstream and downstream reaches. I hypothesized that if the rock ramp allows fish passage, then patterns of fish species richness and relative abundance will resemble a river that is free-flowing, but if the structure impedes fish passage, then patterns of species richness and relative abundance will more resemble a fish assemblage typical of a dammed river. My objectives were to determine if 1) species richness and relative abundance differed upstream and downstream of the rock ramp, and 2) if patterns of fish assemblage structure in the river with the rock ramp (Shiawassee River) differ in comparison to a river that is dammed (Cass River) or free-flowing (Flint River).

In addition to these ecological goals, I also wanted to evaluate the adequacy of my sampling protocols in documenting patterns of species composition and proportional abundance in these fish assemblages. As such, I examined how various temporal and spatial subsampling intensities and various samples sizes affected the end conclusions. Specifically, I examined how sampling fewer sites, less frequently, or fewer fish would affect the outcome of my investigation.

STUDY AREA

The study area consisted of three rivers in the Saginaw Bay watershed located in Michigan in the Lake Huron Basin (Figure 1). Study rivers included the Shiawassee (rock ramp), the Cass (dammed), and the Flint (free-flowing, reference). The Shiawassee River has a rock ramp located in the town of Chesaning, Michigan, 72 km upstream of the mouth of the Saginaw River. The rock ramp is approximately 123 meters long and 58 meters wide with an overall slope of three percent. The first barrier upstream of the rock ramp that does not allow fish passage is the Corunna Dam, 44 kilometers away. The Cass River has a dam located in Frankenmuth, Michigan, 66 km upstream of the mouth of the Saginaw River. The Frankenmuth Dam is 73.2 meters wide and has a structural height of 4.3 meters. The first barrier upstream of the Frankenmuth dam that does not allow fish passage is the Caro Dam, 39 kilometers away. The Flint River was used as a reference river with a hypothetical barrier selected (well below the first upstream barrier in the city of Flint) in the town of Flushing, Michigan, 104 km upstream of the mouth of the Saginaw River. The first barrier that does not allow fish passage in the Flint River is Mott Dam, 27 kilometers upstream of the hypothetical barrier. There are no barriers between the mouth of the Saginaw River and the focal points (hypothetical barrier, rock ramp, and dam) on each river. During the summer sampling period, 27 June to 18 September in 2011 and 11 June to 29 August in 2012, the mean flow of the Shiawassee River was 5.2 $m^3 s^{-1}$, the Cass River was 3.3 $m^3 s^{-1}$, and the Flint River was 8.3 $m^3 s^{-1}$ (U.S. Geological Survey 2013).

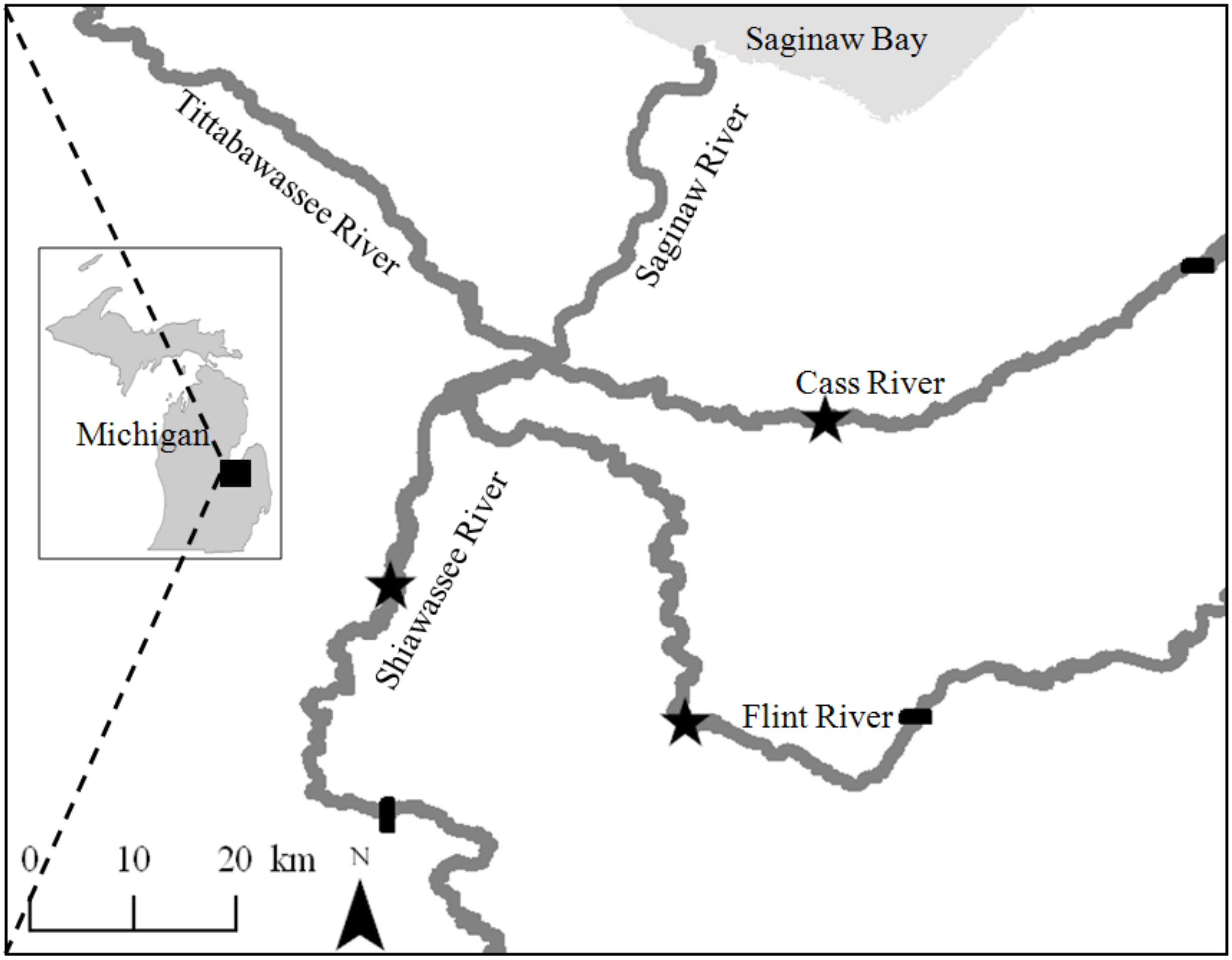

Figure 1. Locations of the rock ramp (Shiawassee River), dam (Cass River), and hypothetical barrier (Flint River). Stars represent focal points and rectangles represent the first complete fish barrier upstream of the focal points.

METHODS

Field Data Collection

Three sampling sites, roughly 145 meters long and at least 200 meters apart, were selected upstream and downstream of each focal point (Figure 2). Exact site locations depended on proximity to the barriers and impoundments (within three miles of barriers and outside of the impoundments), land access (private and public), feasibility of electrofishing with a tote barge electrofisher, and where habitat was judged to be representative of the average river habitat upstream and downstream of each focal point. Sampling sites were relatively close to the rock ramp and dam; therefore, the upstream and downstream fish assemblages within each river should be similar in species richness and relative abundance if the rock ramp or dam were not present. Upstream sites were above the impoundments to avoid sampling a lotic fish assemblage, and downstream sites were outside of the species-rich plunge pool directly below the dam (sites were at least 135 meters downstream of the barriers). Mean wetted widths of sites varied between upstream and downstream locations and across rivers (Table 1). In general, sites downstream of the rock ramp and dam were somewhat narrower, and sites in the free-flowing river were broader, but I judged all sites to be similar enough in width to allow for direct comparisons. Mean depth showed no clear pattern among sites; all sites averaged between 27.4 and 42.9 cm in depth.

Sampling was grouped into sampling events, where all rivers and sites were sampled once in a given time period, usually monthly. In 2011, flooding from heavy rains prevented me from sampling all sites in each river in a given month. Because of this, I combined sampling dates from 27 June to 20 July to create the July sampling event and dates from 15 August to 18 September for the August sampling event. In 2012, sampling was conducted in the rock ramp

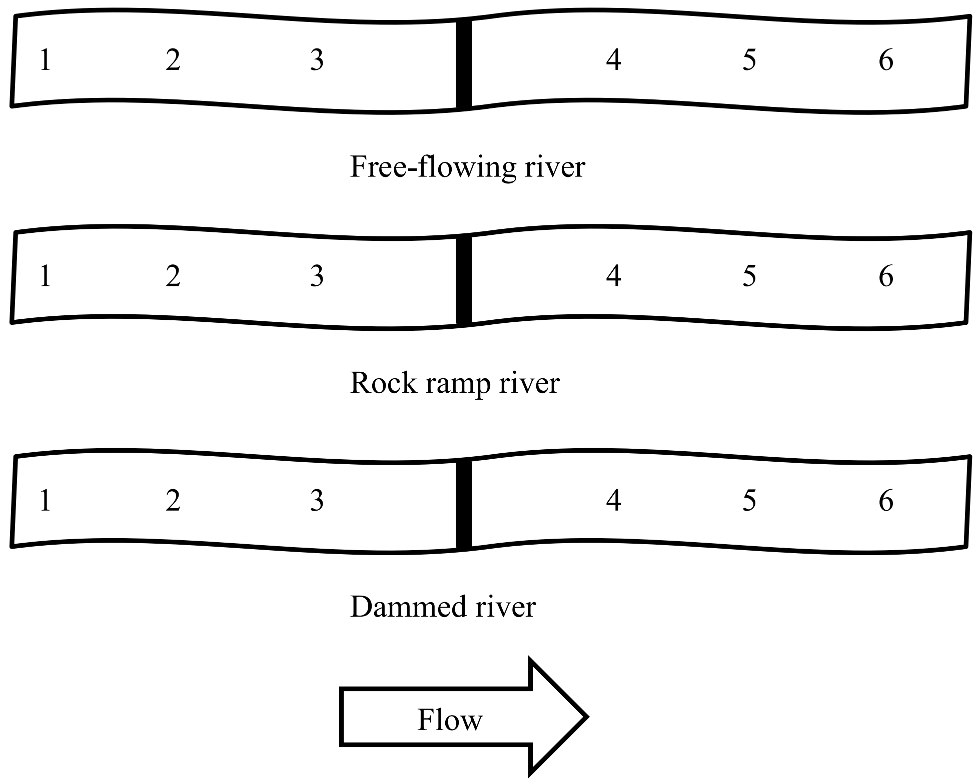

Figure 2. Location of sites within each river with the black boxes representing the locations of the hypothetical barrier, rock ramp, and dam. The arrow depicts the direction of water flow for each river.

Table 1. Description of the habitat conditions found upstream and downstream of each focal point. Mean (±SE) wetted width, depth, and velocities are provided; median substrate size from a pebble count is also provided. Number of samples taken at each position: wetted width 6 to 12, depth 156 to 311, velocity 139 to 270, and median substrate 294 to 515.

River name	River type	Position	Mean width (m)	Mean depth (cm)	Mean velocity (m/sec)	Median particle [a]
Flint	Free-flowing	Upstream	37.2 (2.7)	42.4 (2.3)	0.22 (0.01)	8
		Downstream	43.8 (5.3)	32.2 (1.1)	0.27 (0.02)	9
Shiawassee	Rock ramp	Upstream	32.5 (1.3)	34.2 (1.3)	0.24 (0.01)	8
		Downstream	24.6 (1.9)	42.9 (1.6)	0.25 (0.01)	5
Cass	Dammed	Upstream	37.8 (2.3)	38.4 (2.3)	0.06 (0.01)	7
		Downstream	28.2 (1.8)	27.4 (1.2)	0.14 (0.01)	6

[a] Substrate was ranked on following scale: 1 = organic, 2 = clay, 3 = silt, 4 = sand, 5 = very fine gravel, 6 = fine gravel, 7= medium gravel, 8 = coarse gravel, 9 = very coarse gravel, 10 = small cobble, 11 = large cobble, 12 = small boulder, 13 = medium boulder.

and dammed rivers in June, July, and August, but I could only sample the free-flowing river in June and August. Sampling did not occur during the month of July in the free-flowing river due to large rain events that created unsafe sampling conditions. In the dammed river only four sites were sampled during the July sampling event, two sites upstream and two sites downstream. This was due to high flows that prevented me from sampling the last two sites in the June sampling event.

A tote barge electrofisher was used to collect fish at each site by conducting upstream passes parallel to each other until the entire river channel width had been sampled. The tote barge electrofisher consisted of a 2,500 watt generator, a Smith-Root ® 2.5 gpp, and two anode probes. All fish collected were identified to species, counted, and measured (TL; nearest millimeter). Fish that were unidentifiable in the field were euthanized in MS-222, then preserved in 10% formalin and taken back to the lab and identified. Water temperature and turbidity levels were taken during each fish collection event.

Habitat measurements were collected at each site during summer sampling in 2012. Sampling sites were divided into habitat segments such as pools, riffles, and runs based on criteria by Hicks and Watson (1985). Transects were created at two random locations within each habitat segment. Transects were measured for wetted width and then divided into 50 equal sections where a water depth, water velocity, and a pebble count was recorded. Water velocity was measured at 60% of water depth from water surface using a Marsh-McBirney Model 201 portable water flow meter. The pebble count was done by using methods described by Kondolf and Li (1992).

Analysis of Fish Assemblage Composition

Several fish species were grouped together into one category or were removed from analysis because of issues associated with fish identification. Due to difficulty differentiating common shiner (*Luxilus cornutus*) and striped shiner (*Luxilus chrysocephalus*) (Roth et al. 2013), individuals of these species were grouped together in one category common/striped shiner. Suspected hybrid sunfish (e.g., bluegill/pumpkinseed hybrids) were also removed from analysis due to issues identifying backcrosses. Also, three aquarium trade fish, one plecostomus species and two cichlid species were collected, but were removed from analysis because low water temperatures prevents these fish from surviving the winter months when temperatures go below lethal limits (Shafland and Pestrak 1982; Schofield et al. 2010). After removing the fish listed above, I collected a total 61,387 fish from 59 species plus three aquarium trade fish species (Appendix A).

Species richness, total catch, and catch per unit of effort (CPUE) were used to compare upstream and downstream assemblages. Species richness was computed as total number of species collected in a site or combination of sites by collection year and across all months and years combined. Total catch was the total number of individual fish captured in a site for the 2011 and 2012 pooled data and CPUE was the number of individual fish captured in a site per sample event. I compared by total species richness and mean species richness per sample event because sampling intensity was not equal across sites or rivers (Table 2), and total species richness is dependent on sampling intensity and total catch. For instance, five monthly sampling events occurred in the rock ramp river, while only four monthly sampling events occurred in the free-flowing river. Computing mean species richness allowed me to detect patterns that might be confounded with sample size if total species richness was the sole metric. Mean species richness

Table 2. Sites sampled during sample events in the free-flowing, rock ramp, and dammed rivers. An X indicates that the site was sampled during the sample event.

		Site					
River	Sampling event	1	2	3	4	5	6
Free-flowing	July 2011	X	X	X	X	X	X
	August 2011	X	X	X	X	X	X
	June 2012	X	X	X	X	X	X
	July 2012						
	August 2012	X	X	X	X	X	X
Rock ramp	July 2011	X	X	X	X	X	X
	August 2011	X	X	X	X	X	X
	June 2012	X	X	X	X	X	X
	July 2012	X	X	X	X	X	X
	August 2012	X	X	X	X	X	X
Dammed	July 2011	X	X	X	X	X	X
	August 2011	X	X	X	X	X	X
	June 2012	X	X	X	X	X	X
	July 2012		X	X	X		X
	August 2012	X	X	X	X	X	X

per sampling event has the disadvantage that sites that contained the same species every sample event would have fewer total species than sites that contained different species each sampling event, which would not be apparent if only means were calculated.

To assess the potential effects of the rock ramp on the abundance of individual species, I computed impact factors for the 20 most abundant species found in all three rivers. Impact factors are the ratio of CPUE upstream compared to downstream. Thus, impact factors less than 1.00 indicate that abundance was less upstream than downstream and impact factors greater than 1.00 indicate abundance upstream was greater than downstream. Impact factors were grouped into three categories: less than 0.50, between 0.50 and 2.00, and greater than 2.00. These parameters were based on halving or doubling the impact factor value of 1.00, which represented having similar CPUE in both upstream and downstream reaches.

Species composition and proportional abundance were examined by comparing assemblages upstream and downstream of each focal point. Comparisons between upstream and downstream assemblages were made using the Sørensen's similarity index (Sørensen 1948) and the Morisita's index (Kwak and Peterson 2007). The Sørensen's similarity index compares species composition between upstream and downstream assemblages using the equation:

$$S = \frac{2C}{A+B} \qquad (2)$$

where S is the similarity between two assemblages, A is the number of species found in upstream assemblage, B is the number of species found in downstream assemblage and C is the number of species found in both upstream and downstream assemblages (Sørensen 1948). The Morisita's index uses species proportional abundance estimates to compare assemblages upstream and downstream of the focal points using the formula:

$$C_{jk} = \frac{2\sum X_{ij}X_{ik}}{(\lambda_j + \lambda_k)N_jN_k} \qquad (3)$$

where C is the similarity between assemblage *j* and *k*. X_{ij} and X_{ik} are the number of individuals of a species *i* in assemblages *j* and *k,* and N_j and N_k are the total number of individuals in assemblage *j* and *k.* Lambda *j* is derived using equation (4).

$$\lambda_j = \frac{\sum [X_{ij}(X_{ij}-1)]}{N_j(N_j-1)} \qquad (4)$$

Lambda *k* can be derived using equation (5).

$$\lambda_k = \frac{\sum [X_{ik}(X_{ik}-1)]}{N_k(N_k-1)} \qquad (5)$$

X_{ij}, X_{ik}, N_j, and N_k for equation (4) and equation (5) are the same as equation (3). Both methods provide an index on a scale of 0 to 1, with 0 having no similarity and 1 having complete similarity (Kwak and Peterson 2007). I used these similarity indices because each examines different characteristics of fish assemblages. The Sørensen's similarity index is used to evaluate species composition similarity; are the species found in the downstream assemblage also found in the upstream assemblage? The Morisita's index is used to evaluate proportional abundance; for each species, are the number of individuals captured downstream similar to the number captured upstream? I chose to use these two similarity indices because barriers can cause species to become locally extinct in the upstream or downstream assemblages (Sørensen's similarity index will show dissimilarity) or barriers can reduce the abundances of species in the upstream or downstream assemblages (Morisita's index will show dissimilarity). I also used these indices to facilitate comparisons with previous studies of the effects of dams and dam removals on fish assemblages (Dodd et al. 2003; Hayes et al. 2008; Gardner et al. 2013).

Patterns of species composition and proportional abundance were also examined by evaluating the effects of distance between sites on the Sørensen's similarity index and Morisita's index. This was accomplished by deriving Sørensen's similarity index and Morisita's index values for each possible site to site comparison for each sampling event within a river (Appendix B). The similarity index values were categorized by river and whether the site to site comparison crossed or did not cross a focal point. For example, site 5 was 4 km from site 6 in the rock ramp river, and did not cross the rock ramp structure. Site 3 was 4.5 km from site 4 in the rock ramp river, but crossed the rock ramp structure. The index values were then graphed against the distances that separated sites. Patterns in the degree of similarity were examined to determine the effect of the distances between sites, and if crossing a focal point contributed to high or low similarity values.

Sampling Efficiency

Sampling efficiency was assessed by varying sample sizes to represent different sampling intensities. Collector's curves were generated similar to the one's used by Vinson and Hawkins (1996); however, taxa richness was replaced with Sørensen's similarity index and Morisita's index values. Sørensen's similarity index and Morisita's index values were computed on the full data set as well as sample sizes less than the entire data set. Sample size began with 100 individuals in the upstream and the downstream assemblages, then increased to 200, and continued to increase in increments of 200 until sample size reached 2,800 individuals.

Similarity index values were derived using a non-parametric bootstrap operation, with 1,000 replicates, which sampled individual fish randomly with replacement. From the bootstrapping results, mean similarity index values and 5% and 95% confidence intervals were graphed against the sample sizes used to generate the values.

Sampling efficiency was also assessed by deriving Sørensen's similarity index and Morisita's index values using different combinations of sample events to represent different sampling intensities. An example would be comparing Morisita's index values derived from a single month sample event to Morisita's index values derived from the combination of two monthly sample events. Combinations of sample events were created using various numbers of sites upstream and downstream, months, and years (Table 3). Once index values were derived using the different combinations of sample events, the standard deviation among combinations with equivalent sample sizes were determined. Additionally, I evaluated how the total number of sites sampled per stream affected the precision of similarity indices. An example of this would be using one site upstream and one site downstream for the combined June and July 2011 sample events. This would give me a total of four sites, two sites would be sampled in June 2011 and two sites would be sampled in July 2011. A regression on log-log transformed data was conducted to determine if the number of sites upstream and downstream, months, years, or total number of sites sampled had a significant relationship with variability in Sørensen's similarity index and Morisita's index. An alpha of 0.05 was used to determine if variables were significant.

RESULTS

Species Richness

Overall, the dammed river had the greatest species richness with 54 species caught across all sites and years. The rock ramp river had the second most species with a total of 48 and the

Table 3. The different combinations of sample events used to derive various Sørensen's similarity index and Morisita's index values. For each combination the number of years, months, and sites upstream and downstream used to derive the combination are given. Total sites are the total number of sites used to derive the combination.

Combinations	Years	Months	Sites	Total sites
1	1	1	1	2
2	1	1	2	4
3	1	1	3	6
4	1	2	1	4
5	1	2	2	8
6	1	2	3	12
7	1	3	1	6
8	1	3	2	12
9	2	1	1	4
10	2	1	2	8
11	2	1	3	12
12	2	2	1	8
13	2	2	2	16

free-flowing river had the smallest number of species with a total of 44. The pattern in number of species captured in upstream and downstream assemblages differed in each river (Table 4). In the dammed and rock ramp rivers, eight more species were captured in downstream reaches than in upstream reaches. In the free-flowing river, two more species were captured in the upstream reach than the downstream reach. Year-to-year patterns in species richness showed a consistent pattern of difference between upstream and downstream assemblages (Table 5). The free-flowing river had a difference of three more species captured upstream in both 2011 and 2012. The rock ramp river had more species captured in the downstream reach both years, with a difference of five species in 2011 and four species in 2012. In the dammed river, more species were captured in the downstream reach, but the difference was much greater at ten species in 2011 and eight species in 2012. The pattern in species richness in the rock ramp river was closer to that in the dammed river than the free-flowing river (Table 4, Table 5). Species richness in all streams was higher in 2012 compared to 2011.

Mean species richness per monthly sample event varied between the free-flowing, rock ramp, and dammed rivers. In the free-flowing river, the upstream reach contained an average of 24 species per monthly sample event, whereas the downstream reach contained an average of 20 species. In the rock ramp river, species richness was more uniform with an average of 23 species per monthly sample event in both the upstream and downstream reaches. The dammed river had the greatest difference in mean species richness per monthly sample event with an average of 20 species in the upstream reach and 27 species in the downstream reach. Mean species richness per monthly sample event was higher in 2012 compared to 2011, but the difference between upstream and downstream reaches in each river remained consistent (Table 6). In 2011, the rock ramp river had two more species per monthly sample event in downstream reaches and one more

Table 4. Number of species captured upstream and downstream of the focal points and for each river assemblage in the free-flowing, rock ramp, and dammed rivers.

	Upstream	Downstream	Total
Free-flowing	41	39	44
Rock ramp	37	45	48
Dammed	43	51	54

Table 5. Number of species captured upstream and downstream of each focal point and for all sites combined in the free-flowing, rock ramp, and dammed rivers in 2011 and 2012.

	2011			2012		
	Upstream	Downstream	Total	Upstream	Downstream	Total
Free-flowing	36	33	40	38	35	40
Rock ramp	29	34	36	36	40	44
Dammed	27	37	39	43	51	54

Table 6. Mean species richness per monthly sample event upstream and downstream of the focal points in the free-flowing, rock ramp, and dammed rivers in 2011 and 2012.

	2011		2012	
	Upstream	Downstream	Upstream	Downstream
Free-flowing	22	18	27	23
Rock ramp	18	20	26	25
Dammed	17	22	23	31

species in upstream reaches in 2012. The free-flowing river had four more species per monthly sample event in upstream reaches in both 2011 and 2012. The dammed river had the greatest dissimilarity between upstream and downstream reaches per monthly sample with downstream reaches containing five more species in 2011 and eight species in 2012.

I evaluated species richness at the individual site level to clarify spatial patterns relative to focal points in each river. In the free-flowing river, there was a peak in total species richness at the second site upstream of the hypothetical barrier, but in the rock ramp and dammed rivers the peak in total species richness occurred at the site immediately downstream of the structures (Figure 3). In the free-flowing and rock ramp rivers, total species richness was more uniform across sites then was observed in the dammed river. Mean species richness among sites showed distinctive longitudinal patterns in each river (Figure 4). In the free-flowing and rock ramp rivers, mean species richness was generally uniform from upstream to downstream sites, averaging approximately 20 to 25 species per site for all months and years combined. In the dammed river, there was clearly higher mean species richness, approximately 32 species, in the site immediately downstream of the dam in Frankenmuth. The two sites further downstream also contained more species, averaging approximately 23 to 25 species, then the sites upstream of the dam, which averaged approximately 19 to 22 species.

Relative Abundance

Total catch and mean CPUE (measured as total catch per sample event), varied among sites (Figure 5, Figure 6). The variation in total catch and mean CPUE between sites was the smallest in the free-flowing river, intermediate in the rock ramp river, and largest in the dammed river. In the free-flowing river there was a peak in total catch and mean CPUE at the second site upstream of the hypothetical barrier and in the rock ramp river the peak in total catch and mean

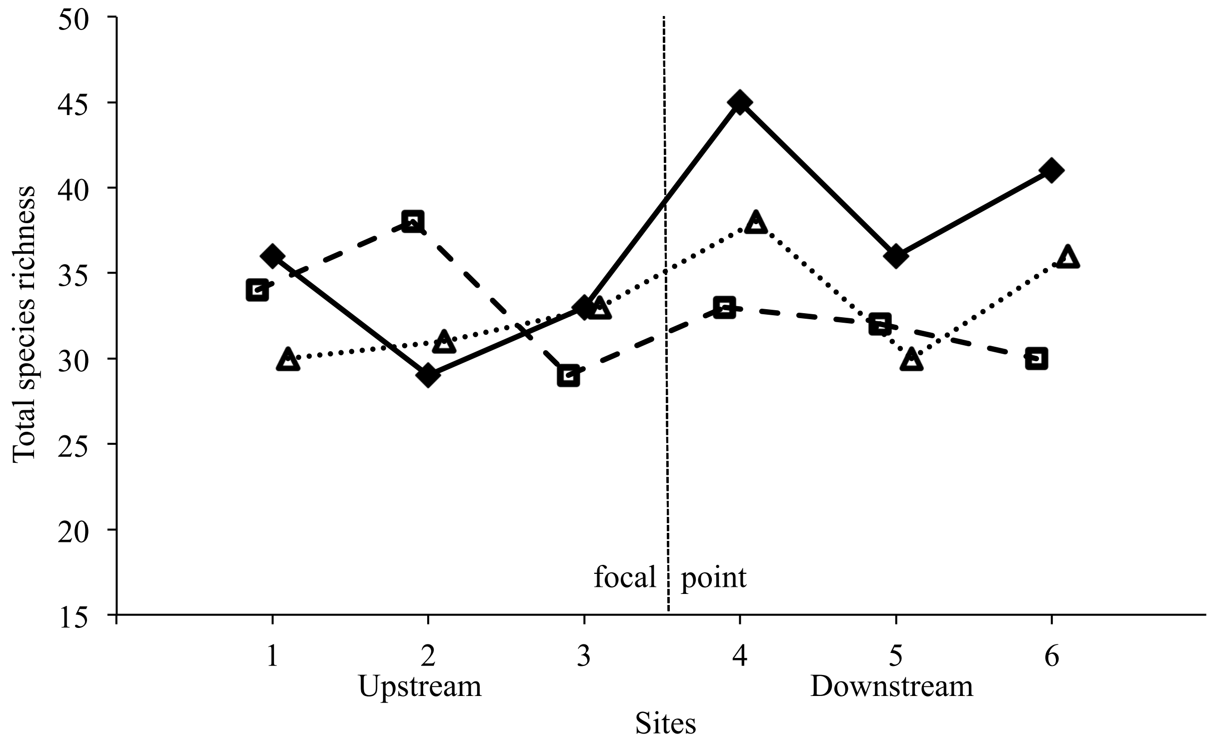

Figure 3. Total species richness at each site for years combined. Closed diamonds with solid line represent the dammed river, open triangles with dotted line represent the rock ramp river, and open squares with dashed line represent the free-flowing river.

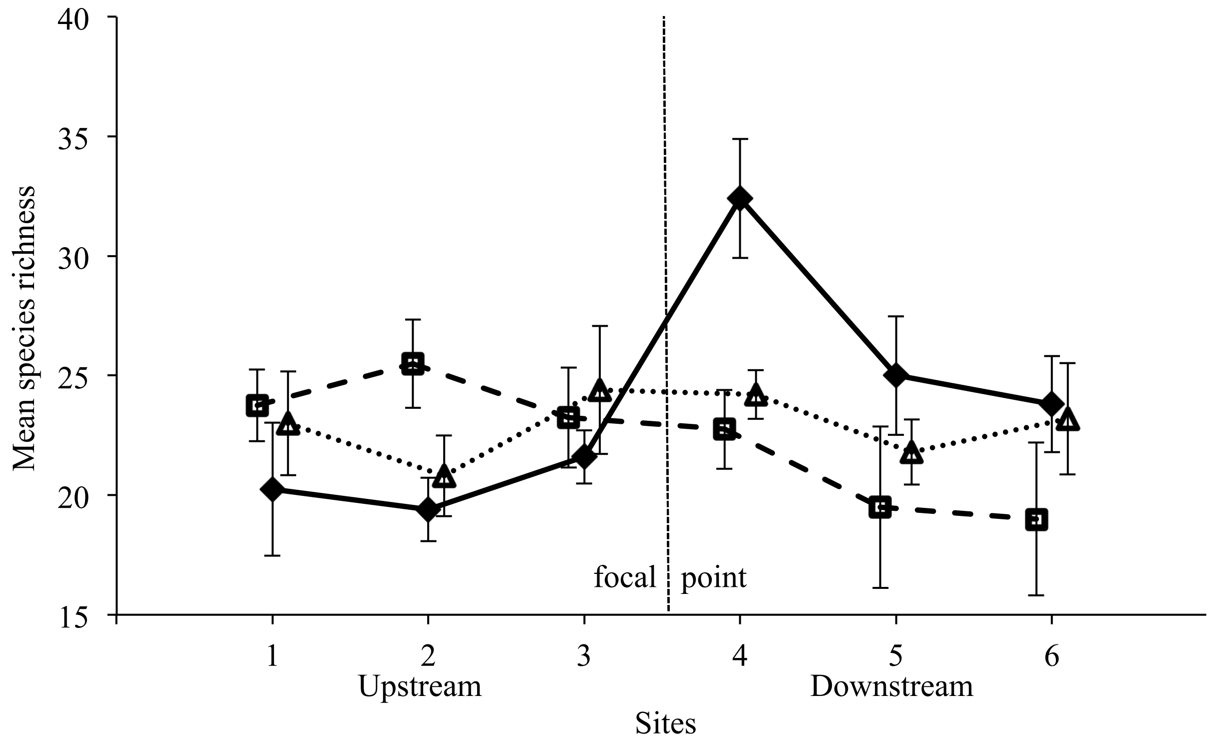

Figure 4. Mean species richness per monthly sample event at each site for years combined. Closed diamonds with solid line represent the dammed river, open triangles with dotted line represent the rock ramp river, and open squares with dashed line represent the free-flowing river. Error bars indicated standard error.

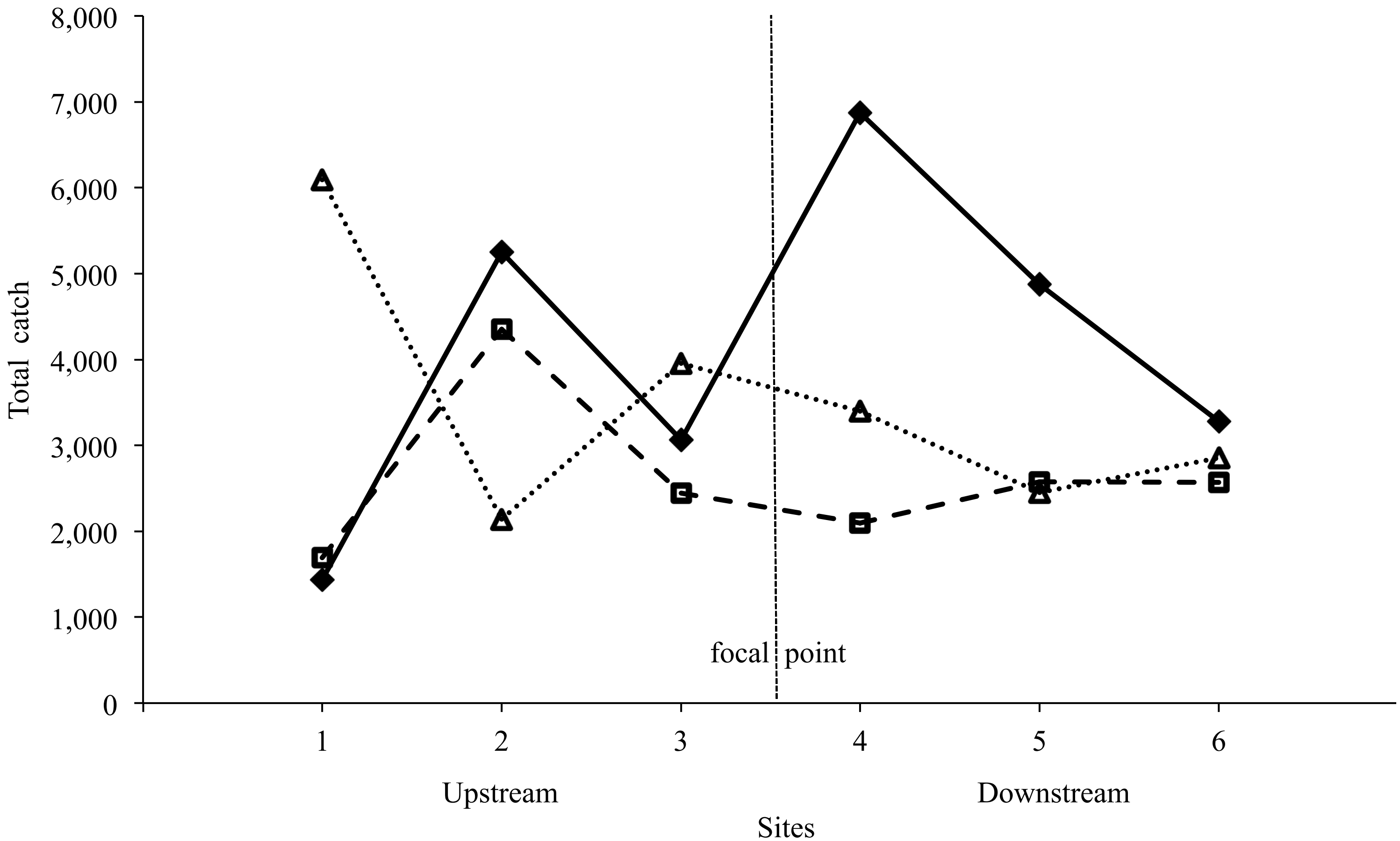

Figure 5. Total number of fish captured at each site using 2011 and 2012 pooled data. Closed diamonds with solid line represent the dammed river, open triangles with dotted line represent the rock ramp river, and open squares with dashed line represent the free-flowing river.

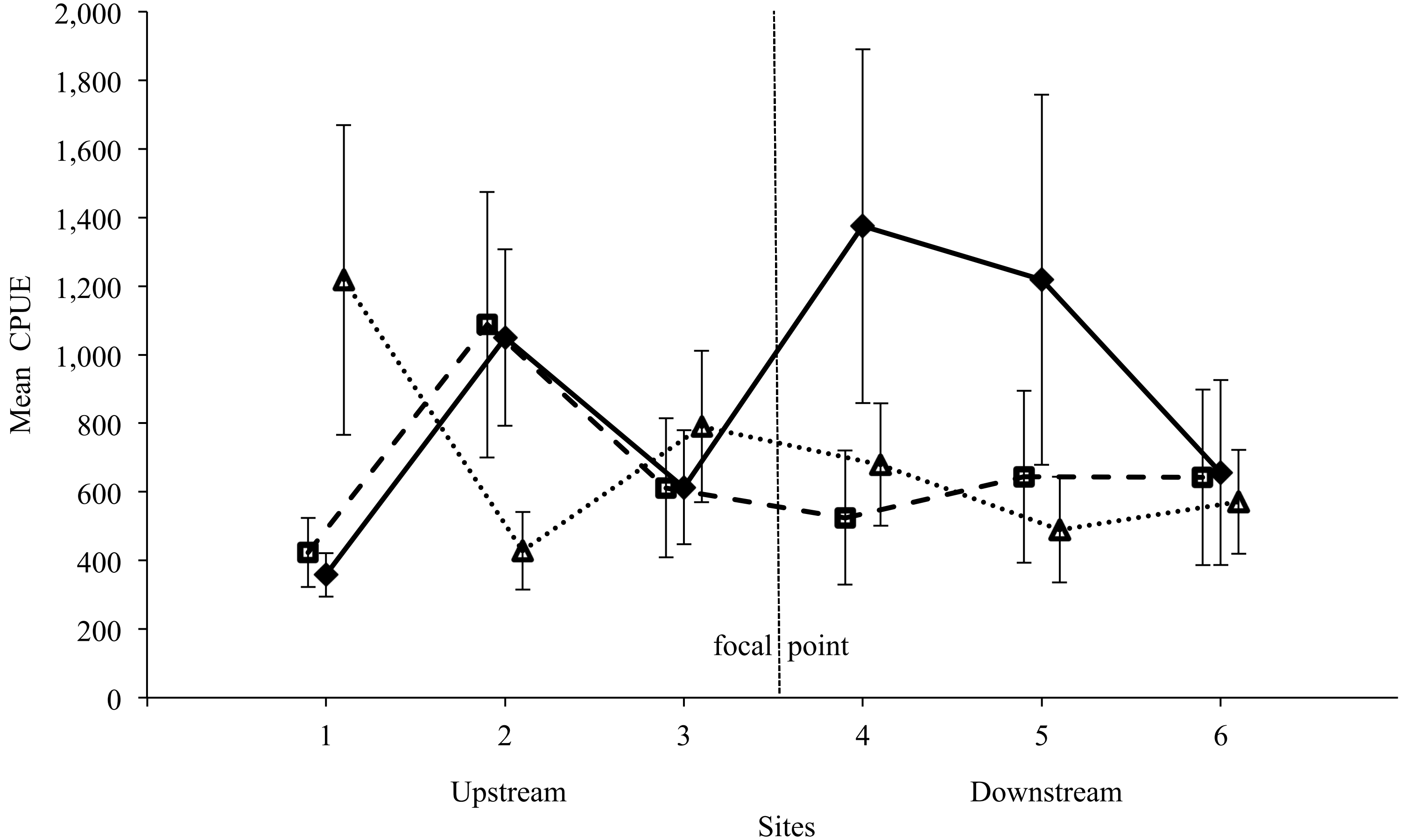

Figure 6. Mean CPUE (measured as total catch per sample event) at each site using 2011 and 2012 pooled data. Closed diamonds with solid line represent the dammed river, open triangles with dotted line represent the rock ramp river, and open squares with dashed line represent the free-flowing river. Error bars indicated standard error.

CPUE occurred at the third site upstream of the rock ramp. In the dammed river there was a peak in total catch and mean CPUE at the site immediately downstream of the dam, which was a similar pattern observed with total and mean species richness (Figure 3, Figure 4). Both total catch and mean CPUE in the dammed river decreased as sites were sampled further downstream; however, total catch showed a more linear decrease as sites were sampled further away from the dam then mean CPUE.

Of the 59 species that were captured during the two year study, only 36 were collected in all three rivers. Of those species, only 20 had catches greater than 30 individuals in each river. The five most abundant species were rock bass (*Ambloplites rupestris*; N = 10,003), emerald shiner (*Notropis atherinoides*; N = 6,655), mimic shiner (*Notropis volucellus*; N = 6,264), spotfin shiner (*Cyprinella spiloptera*; N = 5,622), and round goby (*Neogobius melanostomus*; N = 4,408) (Table 7). Rock bass and emerald shiners were also one of the five most abundant species in each river. In the free-flowing and dammed rivers, rock bass was the most abundant species while it ranked fourth in the rock ramp river. Emerald shiner was the third most abundant species in the rock ramp river and the fourth most abundant in the free-flowing and dammed rivers (Table 7). When examining the most abundant species as a percent of the total fish collected, the five most abundant species accounted for 53.7 % (Table 7). The next five most abundant species (smallmouth bass (*Micropterus dolomieu*), bluntnose minnow (*Pimephales notatus*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), and common/striped shiner) accounted for 22.5% of the total fish collected. I did not collect any species that are federally or state listed as threatened or endangered.

The impact factors for individual species (Table 8), varied in each stream type (Table 9). The free-flowing river had the most species with impact factors between 0.50 and 2.00 (upstream

Table 7. The 20 most abundant species captured in the free-flowing, rock ramp, and dammed rivers with individuals species ranked () within each river from most abundance to least abundant. Percent of total fish captured is provided for each species.

Species	Free-flowing		Rock ramp		Dammed		Overall total	Percentage
Rock bass	3,876	(1)	2,465	(4)	3,662	(1)	10,003	16.29
Emerald shiner	1,833	(4)	2,482	(3)	2,340	(4)	6,655	10.84
Mimic shiner	123	(12)	3,016	(2)	3,125	(2)	6,264	10.20
Spotfin shiner	251	(8)	3,489	(1)	1,882	(6)	5,622	9.16
Round goby	2,234	(2)	204	(12)	1,970	(5)	4,408	7.18
Smallmouth bass	2,092	(3)	1,222	(5)	967	(8)	4,281	6.97
Bluntnose minnow	178	(11)	320	(10)	2,694	(3)	3,192	5.20
Bluegill	685	(7)	642	(8)	1,321	(7)	2,648	4.31
Green sunfish	1,169	(5)	303	(11)	519	(10)	1,991	3.24
Common/striped shiner	856	(6)	807	(6)	71	(18)	1,734	2.82
Rosyface shiner	43	(18)	787	(7)	326	(12)	1,156	1.88
Northern hogsucker	56	(17)	571	(9)	444	(11)	1,071	1.74
Logperch	108	(14)	89	(17)	733	(9)	930	1.51
Stonecat	241	(9)	169	(15)	131	(17)	541	0.88
Pumpkinseed	69	(15)	190	(13)	148	(15)	407	0.66
Central stoneroller	179	(10)	52	(20)	160	(14)	391	0.64
Blackside darter	30	(20)	74	(18)	262	(13)	366	0.60
Rainbow darter	38	(19)	189	(14)	131	(16)	358	0.58
Creek chub	121	(13)	145	(16)	64	(20)	330	0.54
Channel catfish	58	(16)	66	(19)	68	(19)	192	0.31

Table 8. Impact factors for the 20 most abundant species captured in the free-flowing, rock ramp, and dammed rivers.

Species	Free-flowing	Rock ramp	Dammed
Blackside darter	6.50	0.30	1.98
Bluegill	1.62	0.23	0.46
Bluntnose minnow	5.14	1.09	0.19
Central stoneroller	1.39	51.00	0.39
Channel catfish	3.83	0.12	0.06
Common/striped shiner	4.13	3.92	0.15
Creek chub	1.95	15.11	1.21
Emerald shiner	1.18	0.50	0.00
Green sunfish	1.29	0.28	0.40
Logperch	0.69	3.94	0.00
Mimic shiner	0.73	1.44	3.62
Northern hogsucker	1.24	5.34	0.82
Pumpkinseed	1.38	0.12	0.49
Rainbow darter	0.73	2.26	2.45
Rock bass	0.71	2.01	3.27
Rosyface shiner	2.07	24.39	0.96
Round goby	1.10	0.11	0.00
Smallmouth bass	0.91	2.47	1.44
Spotfin shiner	1.51	1.19	0.64
Stonecat	1.48	5.76	1.79

Table 9. Number of species within each impact factor category for the free-flowing, rock ramp, and dammed rivers.

Impact factor categories	Free-flowing	Rock ramp	Dammed
Between 0.50 and 2.00	15	3	7
Less than 0.50	0	7	10
Greater than 2.00	5	10	3

and downstream abundances similar), while the dammed river was intermediate, and the rock ramp river had the fewest. Species with impact factors values less than 0.50 (abundances greater downstream than upstream) were most prevalent in the dammed river, the free-flowing river had the fewest, and the rock ramp river was intermediate. The rock ramp river had the most species with impact factors greater than 2.00 (abundances greater upstream than downstream), the free-flowing river was intermediate, and the dammed river had the fewest. The rock ramp river had the most species with abundances that were dissimilar between upstream and downstream reaches (Table 9).

Similarity Indices

The Sørensen's similarity index values for all three rivers were high, indicating high similarity in species composition between upstream and downstream assemblages. When data were combined for both years sampled, the free-flowing river had the highest Sørensen's similarity index value of 0.90, the dammed river had an intermediate value of 0.85 and the rock ramp river had the lowest value of 0.83. Sørensen's similarity index values showed high similarity in upstream and downstream assemblages when data were broken into year collected. In 2011, the rock ramp river had the highest Sørensen's similarity index value of 0.86, the free-flowing river was 0.84, and the dammed river had the lowest value of 0.78. In 2012, the free-flowing river had the highest Sørensen's similarity index value of 0.90, and the dammed and rock ramp rivers were essential equivalent at 0.85 and 0.84, respectively.

Unlike the Sørensen's similarity index values, the Morisita's index did not indicate high similarity in proportional abundance for all three rivers. Combining data for both years, the free-flowing river had the highest Morisita's index value of 0.92, the rock ramp river's value was somewhat lower at 0.84, and the dammed river had the lowest value of 0.38. Morisita's index values were similar in value from 2011 to 2012 in all rivers. In 2011, the Morisita's index value for the free-flowing river was 0.91, the rock ramp river was 0.86, and the dammed river was 0.51. In 2012, the Morisita's index value for the free-flowing river was 0.92, the rock ramp river was 0.84, and the dammed river was 0.37. From 2011 to 2012, the free-flowing river Morisita's index increased by 0.01, the rock ramp river decreased by 0.02, and the dammed river had a much larger decrease of 0.14.

Site to site comparisons of the Sørensen's similarity index relative to the distance that separated sites showed no apparent pattern; low and high index values occurred across the range of distances sampled (Figure 7). All site to site comparisons had similar values independent of site to site comparisons crossing or not crossing the rock ramp or dam. However, two patterns emerged for the Morisita's index (Figure 8). All site to site comparisons in the rock ramp and free-flowing rivers were relatively consistent across distance that separated the sites or whether sites crossed the rock ramp. Conversely, Morisita's index values were noticeably lower when site to site comparisons crossed the dam compared to site to site comparisons that did not cross the dam (Figure 8).

Sampling Efficiency

Large sample sizes resulted in higher precision for estimates of Sørensen's similarity index and Morisita's index. However, less precision was obtained for the Sørensen's similarity index then the Morisita's index. The Sørensen's similarity index showed a high degree of bias with a sample size of 100 (Figure 9), with increases in sample sizes up to approximately 1,000 resulting in larger means and associated shifts in confidence intervals. At sample sizes above 1,000, the Sørensen's similarity index remained more consistent, and confidence intervals began to narrow around the mean. Morisita's index showed a different response; (Figure 10) means

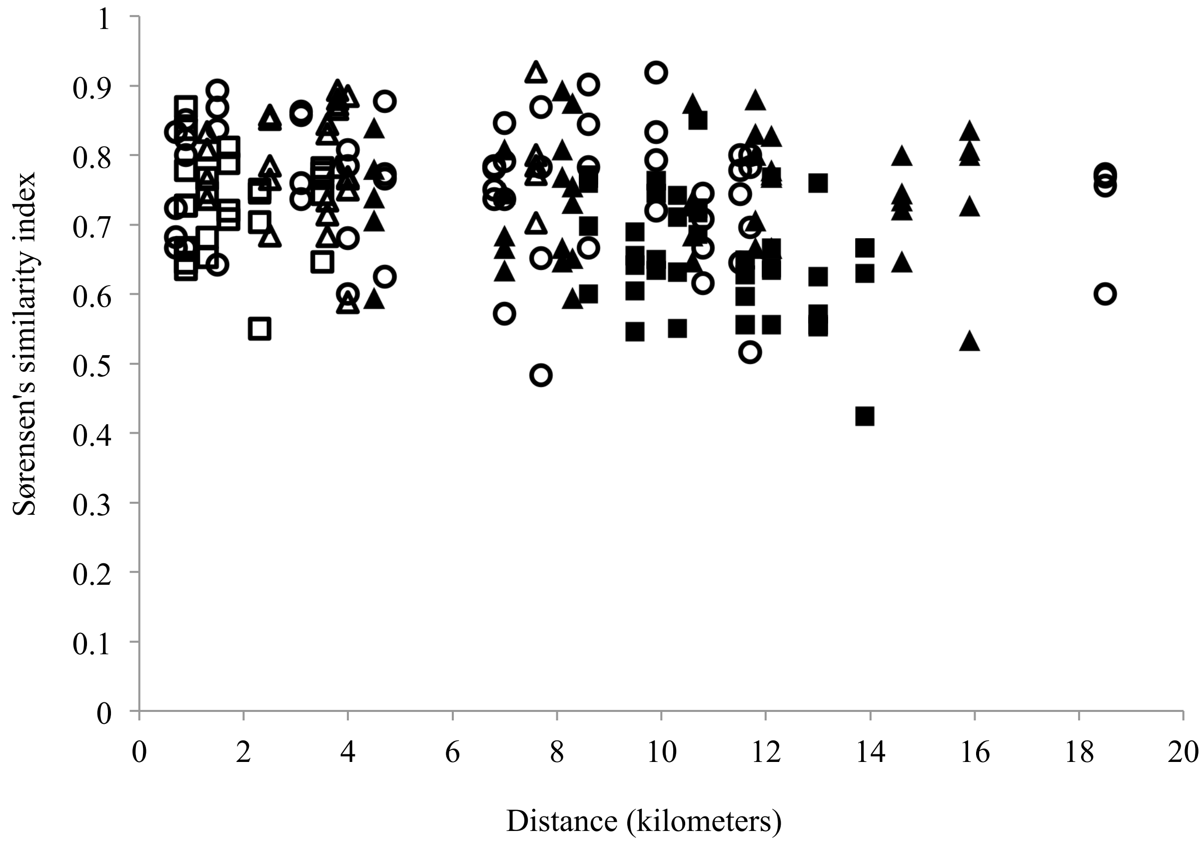

Figure 7. Sørensen's similarity index values for individual site to site comparisons in relation to the distance that separates the sites in the free-flowing, rock ramp, and dammed rivers. Open circles are values for site to site comparisons in the free-flowing river, open triangles are values for site to site comparisons that do not cross the rock ramp, closed triangles are values for site to site comparison that do cross the rock ramp, open squares are values for site to site comparisons that do not cross the dam, and closed squares are values for site to site comparisons that cross the dam.

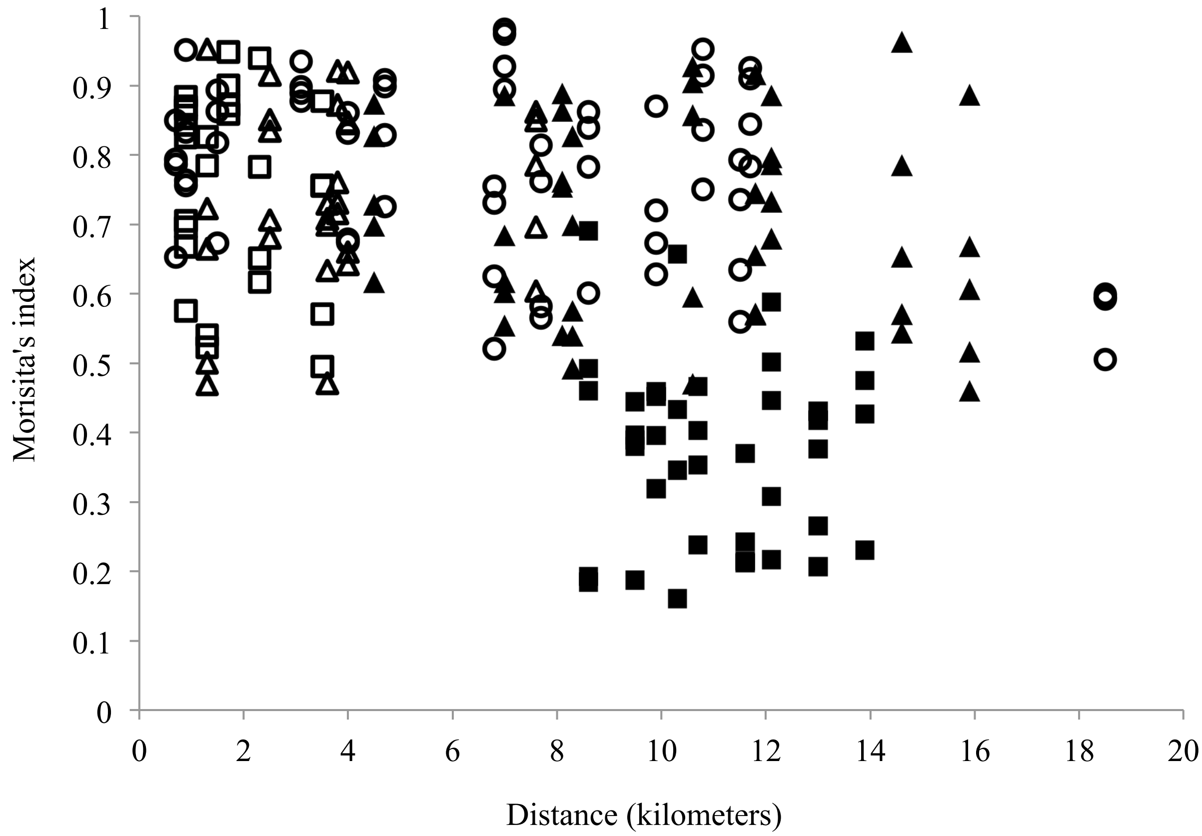

Figure 8. Morisita's index values for individual site to site comparisons in relation to the distance that separates the sites in the free-flowing, rock ramp, and dammed rivers. Open circles are values for site to site comparisons in the free-flowing river, open triangles are values for site to site comparisons that do not cross the rock ramp, closed triangles are values for site to site comparison that do cross the rock ramp, open squares are values for site to site comparisons that do not cross the dam, and closed squares are values for site to site comparisons that cross the dam.

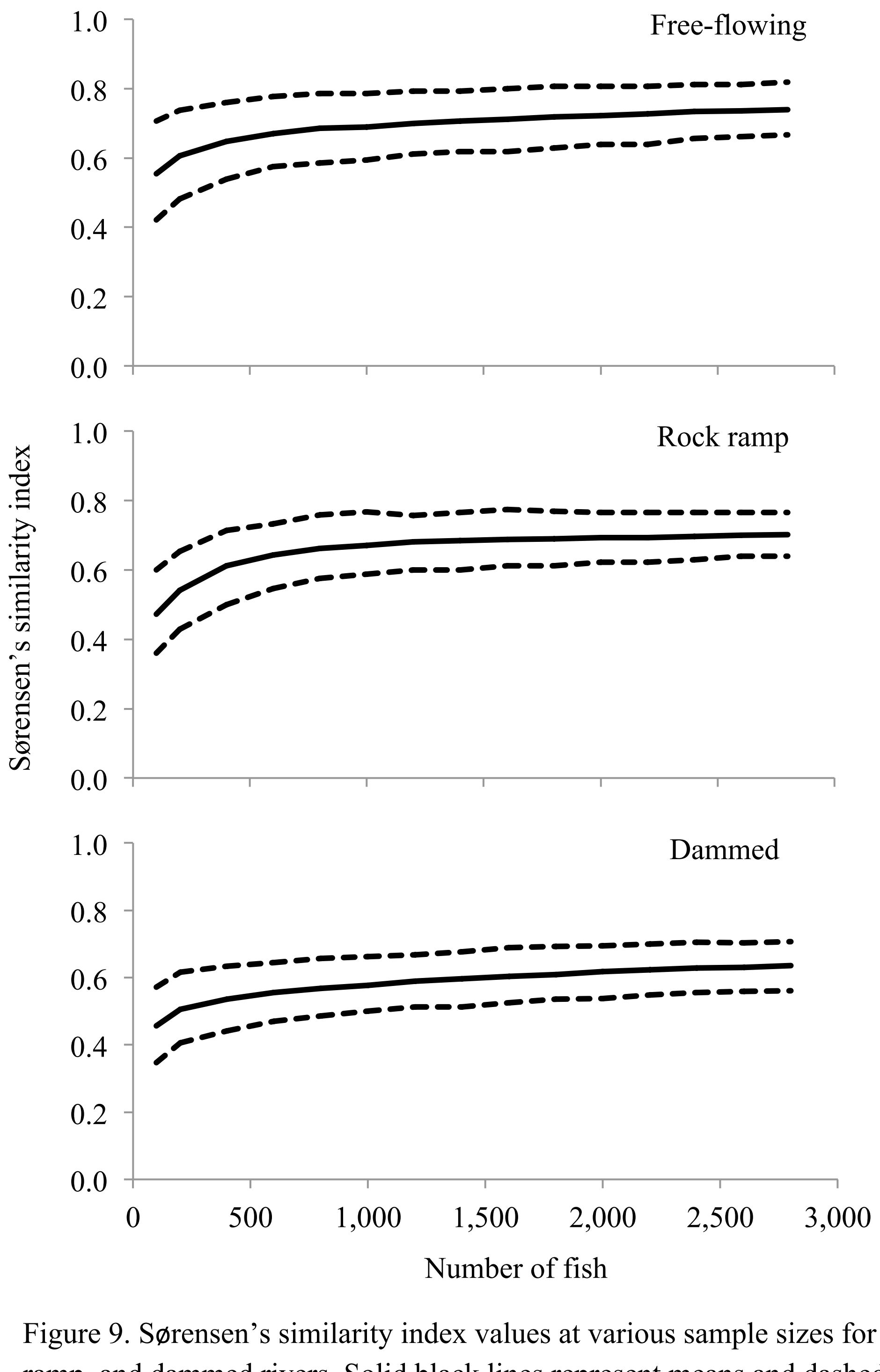

Figure 9. Sørensen's similarity index values at various sample sizes for the free-flowing, rock ramp, and dammed rivers. Solid black lines represent means and dashed lines represent the 5% and 95% confidence intervals.

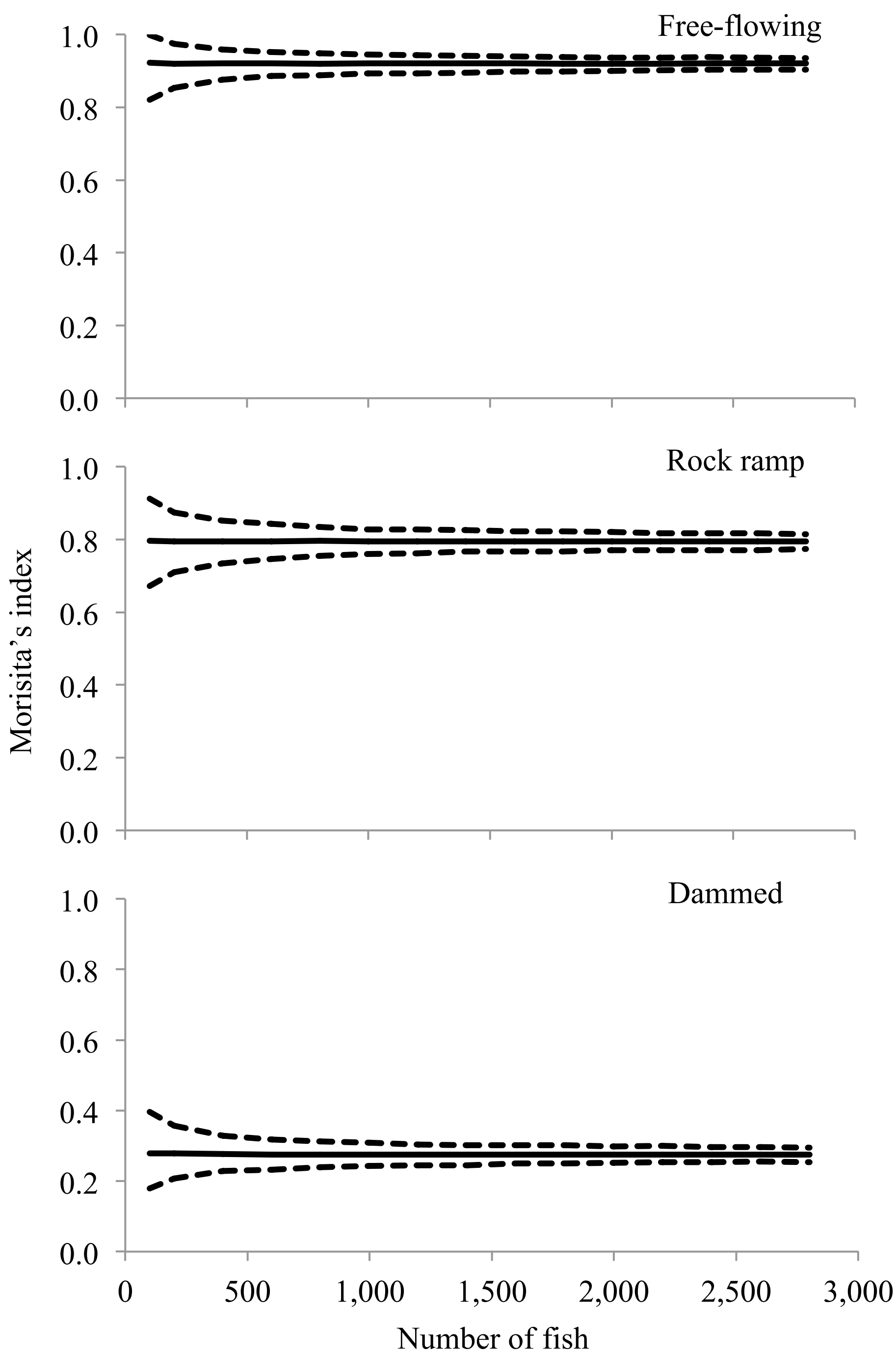

Figure 10. Morisita's index values at various sample sizes for the free-flowing, rock ramp, and dammed rivers. Solid black lines represent means and dashed lines represent the 5% and 95% confidence intervals.

were consistent and only varied by a total of 0.01 within each river across a range of sample sizes from 100 to 2,800. As sample size increased from 100 to approximately 500, confidence intervals quickly narrowed, giving a higher precision estimate than the Sørensen's similarity index. After a sample size of 500, confidence intervals continued to narrow, but in much smaller increments. At a sample size of 2,800 the difference between the 5% and 95% confidence intervals for the free-flowing and dammed rivers was 0.03 and the rock ramp river was of 0.04.

Sampling efficiency was also examined by evaluating the significance of the number of months, years, sites upstream and downstream, and the total numbers of sites sampled in relation to the variability in Sørensen's similarity index and Morisita's index. For the Sørensen's similarity index, the relationship between precision and the number of years and number of sites upstream and downstream were non-significant, while the number of months and the total number of sites sampled were significant at alpha 0.05 (Table 10). The Morisita's index differed in that the number of years and the number of months were non-significant, while the number of sites upstream and downstream and the total number of sites sampled were significant at alpha 0.05 (Table 10). The total number of sites sampled was the only variable that was significantly important when calculating both a Sørensen's similarity index and Morisita's index.

DISCUSSION

The overall goal of the rock ramp was to reconnect previously fragmented fish assemblages and increase ecosystem connectivity. Several different fish assemblage characteristics were examined in this study to determine if the rock ramp was closer in similarity to a free-flowing river or a dammed river. The rock ramp river had more fish assemblage characteristics that were closer to a free-flowing river than a dammed river (Table 11). Patterns of species richness in the rock ramp river showed a mixed response. Specifically, the rock

Table 10. Sampling efficiency linear regression intercepts, slopes, and *p*-values for corresponding sampling variables.

Similarity Index	Sampling variable	*P*-value	Intercept	Slope
Sørensen's similarity index	Number of years	0.2105	-3.0541	-0.3254
Sørensen's similarity index	Number of months	0.0008	-2.8764	-0.6635
Sørensen's similarity index	Number of sites upstream and downstream	0.1400	-2.9890	-0.2852
Sørensen's similarity index	Total number of sites	<.0001	-1.9945	-0.6261
Morisita's index	Number of years	0.1501	-2.6906	-0.6629
Morisita's index	Number of months	0.2868	-2.6922	-0.4064
Morisita's index	Number of sites upstream and downstream	0.0072	-2.4050	-0.8865
Morisita's index	Total number of sites	<.0001	-1.0652	-0.9819

Table 11. Fish assemblage characteristics and the similarity to the rock ramp river relative to the free-flowing and dammed rivers. An X indicates pattern in the rock ramp river is closer to the free-flowing river or the dammed river, or no pattern is apparent.

	Higher similarity		
Fish assemblage characteristics	Free-flowing river	Dammed river	All three rivers
Species richness upstream vs. downstream		X	
Mean species richness by site	X		
Mean CPUE	X		
Impact factors		X	
Sørensen's similarity index			X
Morisita's index	X		

ramp's pattern of species richness by site was more similar to a free-flowing river, but species richness by reach had a higher similarity to a dammed river. Other fish assemblage characteristics in the rock ramp river that had a higher similarity to the dammed river included impact factors. However, patterns of proportional abundance and mean CPUE in the rock ramp river had a higher similarity to a free-flowing river. All three rivers had high similarity in species composition between upstream and downstream reaches. This body of evidence suggests that the rock ramp has increased ecosystem connectivity for the summer fish assemblage over the former existing Chesaning Dam (Table 11), but has not fully restored connectivity to the level seen in a nearby free-flowing river.

Assemblage Composition

Patterns of total and mean species richness by reach in the rock ramp river were closer in similarity to a river that is dammed than a river that is free-flowing. Typically, in dammed rivers there is a large dissimilarity in the number of species found upstream of the dam compared to downstream, but in rivers that are free-flowing reaches are generally similar (Dodd et al. 2003; Hayes et al. 2008; Gardner et al. 2013). This was true for this study where I found that the dammed river had the largest dissimilarity between the upstream and downstream reaches for both total and mean species richness. The free-flowing river had the greatest similarity between the upstream and downstream reaches for total species richness, while the rock ramp river had the greatest similarity for mean species richness. However, the dissimilarity between the upstream and downstream reaches in the rock ramp river was closer to the dammed river than to the free-flowing river, providing evidence that the rock ramp is not fully allowing summer fish passage.

Similar to previous studies, I found that there was a peak in mean species richness at the first site downstream of the dam. Dodd et al. (2003) and Harding et al. (2013) both obtained similar results in their studies, attributing the peak in species richness to blockage of fish migration by dams. The rock ramp river did not show a distinct peak in mean species richness at the first site downstream of the rock ramp; however, it did show a peak when examining total species richness. This peak in total species richness could have occurred because the rock ramp is blocking fish passage for a few species. One explanation for why the peak occurred for total species richness and not for mean species richness is each site contained a similar number of species during each sample event; however, the site below the rock ramp had a larger turnover of species during various sample events, giving it greater total species richness. It is difficult to distinguish the cause in the observed peak because the variation in species richness among sites is much smaller in the rock ramp river then in the dammed river. All sites in the rock ramp and the free-flowing rivers had similar numbers of species, while the dammed river had much larger difference between sites. If the rock ramp was a complete barrier, I would expect to see a peak in both mean and total species richness at the first site downstream of the rock ramp.

Of all three rivers, the dammed river contained the most species (Table 4). Dodd et al. (2003) found similar results in that streams with low-head sea lamprey barriers contained on average more species then non-barrier reference streams. Because habitat was similar in all reaches in their study, they suggested there was a mechanism other than habitat differences between barrier and reference streams that caused this occurrence. One plausible explanation is that the reservoir is a "refuge" and acts as additional habitat type increasing habitat complexity. If this explanation was valid, I would expect to see a decrease in species richness as sites were sampled further upstream of the reservoir, which was not the case (Figure 3, Figure 4). Another explanation is the total number of fish captured was the largest in the dammed river, which could have increased overall species richness. However, total catch and mean CPUE in the upstream sites of the dammed river were lower than in sites upstream of the rock ramp (Figure 5 Figure 6). In 2011, the upstream assemblage of the dammed river contained the fewest species compared to the other two rivers (Table 5) and when examining mean species richness, the upstream assemblage contained fewer species on average compared to the free-flowing and rock ramp rivers (Table 6). Because the dammed river did not always have the greatest total catch, mean CPUE, or greatest species richness, it cannot be that the greater fish abundance in the dammed river resulted in greater species richness. A third explanation is that the dam created a "Barrier Effect." Dodds et al. (2003) proposed the "Barrier Effect," whereby species accumulate downstream of the dam, preventing them from moving further upstream, increasing the number of species in sites downstream of the dam. This explanation appears most plausible as I found the greatest mean species richness and mean CPUE at the first site downstream of the dam (Figure 4, Figure 6). Also, the second site downstream of the dam had the second greatest mean species richness and mean CPUE of all sites within the dammed river. These patterns were not present in the rock ramp river suggesting that the rock ramp is permeable.

Studies evaluating the effects of dams, dam removals, and rock ramps on individual species have shown variable results, such as increases or decreases to species abundances (Harris et al. 1998; Dodd et al. 2003; Burroughs et al. 2010). This was true for this study where some species were negatively affected by the rock ramp and dam, while other species were not. In the free-flowing river most species had impact factors between 0.50 and 2.00, indicating similar abundances between upstream and downstream reaches; however, in the rock ramp and dammed rivers most species had impact factors that showed a greater degree of impact. This suggests that the rock ramp has some effect on passage for a variety of species. Low impact factor values in both the rock ramp and dammed rivers suggest that some species are sensitive to barriers; however, more replication would help elucidate the response of individual species. One important concept derived from the impact factors analysis is that individual species response to rock ramps and dams can be highly variable from species to species so an assemblage-based analysis might help lessen the variability that is seen with individual species.

Similarity Indices

Sørensen's similarity index values for the rock ramp, free-flowing, and dammed rivers were high compared to other studies examining the effects of dams on fish assemblages. Porto et al. (1999) considered matched stream pairs to be reasonably similar when the Sørensen's similarity index values were greater than 0.62. Another study examining the effects of dams on fish assemblages found that streams without dams had Sørensen's similarity index values averaging 0.69 (Hayes et al. 2008). The lowest Sørensen's similarity index value for this study was 0.78 for the dammed river, which is higher than the values of 0.62 and 0.69 given by other studies as high similarity. This provides evidence that there was high similarity in species composition between upstream and downstream assemblages in each of my study rivers independent of barrier presence. This suggests that the rock ramp and dam in these systems has a smaller impact on species composition than elsewhere. One explanation for this is the rivers in this study are large enough to contain various habitat types that will allow most species to fulfill their various life stages.

The low Morisita's index values of the dammed river in my study are consistent with dams blocking upstream movement, causing greater dissimilarity between upstream and downstream assemblages. Morisita's index values for the rock ramp river were closer to the values derived for the free-flowing river indicating that the rock ramp is providing connectivity for the summer fish assemblage. Hayes et al. (2008) found that streams with low-head lamprey barriers and hydrodams had low Morisita's index values (0.52, 0.37), compared to stream without barriers (0.75). The high Morisita's index values of the free-flowing river are consistent with other rivers that have no fish barriers allowing fish to move freely. The overall Morisita's index value for the rock ramp river was 0.84, which is much closer to value derived for the free-flowing river than the dammed river.

The Sørensen's similarity index did not show any apparent patterns of low or high values as a function of the distance that separated sites. This suggests that the sites were close enough to each other that there was no shift in the fish assemblage composition due to distance as proposed in the River Continuum Concept (Vannote et al. 1980). However, when examining the effects of distance using the Morisita's index, I found that site to site comparisons crossing the dam resulted in noticeably lower Morisita's index values. This provides evidence that the dam is negatively affecting proportional abundances by acting as a barrier preventing fish movement, but that my sample reaches were overall in a similar position within the river continuum. If the rock ramp was acting as a barrier and not allowing fish passage then I would have expected the rock ramp's Morisita's index values to show a similar pattern, which does not occur.

Sampling Efficiency

Varying sample sizes affected Sørensen's similarity index and Morisita's index values differently, but higher precision was achieved with larger sample sizes for both. Small sample sizes, less than 1,000 individuals, resulted in low-biased Sørensen's similarity index means and confidence intervals estimates, while sample sizes larger than 1,000 resulted in unbiased and more precise estimates. The Morisita's index responded differently in that the mean did not increase or decrease with an increase in sample size, but increases in sample size did result in narrower confidence intervals. I suggest that assessments of fish assemblages using the Sørensen's similarity index require at least 1,000 individuals to derive unbiased estimates in species-rich streams like I studied. I hypothesize that assemblages with fewer species should require a smaller sample size because the number of specimens needed to represent the majority of species will be fewer. To derive reasonable estimates for the Morisita's index only 500 individuals will need to be collected because the Morisita's index is unbiased and sample size is affecting the precision of the estimate. These suggested sample sizes are for rivers similar in species richness and relative abundance to ones evaluated in this study. This also provides evidence that during this study a large enough sample size was used to detect unbiased similarity measurements between two fish assemblages.

The total number of sites sampled was the only tested variable that had a significant relationship on the variability of both the Sørensen's similarity index and the Morisita's index. This demonstrated that when determining similarity between two assemblages, increasing the total number of sites sampled will increase the precision of the similarity estimate. Several other variables such as number of months, years, and number of sites upstream and downstream did not always show a significant relationship when deriving similarity index values; however, this could be partially due to the small sample sizes of years and months. From this analysis it appears that increasing the number of sites sampled, whether it be six sites one year or three sites two years, will result in higher precision similarity index estimates.

CONCLUSIONS

In this study, I determined that the rock ramp re-established connectivity for the summer fish assemblage across the former Chesaning Dam, an indication that these structures could be used in other streams to increase ecosystem connectivity. Patterns of species richness by site, mean CPUE, and proportional abundance in the rock ramp river had a higher similarity to a river that is free-flowing versus a river that is dammed. However, species richness by reach and species' impact factors showed that the rock ramp has some negative affect on some species. The rock ramp has allowed the Chesaning Dam to remain in place and maintained economic benefits to the surrounding community. However, this study only examined one rock ramp structure so the results may not be true for all rock ramps. Also, this study only examined the effects on the summer fish assemblage and did not examine the effects in other seasons. If these structures are to be used to increase ecosystem connectivity, more research is needed to examine the effects on all other seasonal assemblages. Spring assemblages typically have more migrating species that might alter the result that were found in this study. This study does however provide evidence that these structures can be used to restore ecosystem connectivity for the summer fish assemblage, but to fully restore ecosystem connectivity; there is no substitution for complete dam removal. Dam removal reverses habitat alterations and fragmentations caused by dams.

APPENDIX

Table A1. Number of individuals for each species captured upstream and downstream of the hypothetical barrier in the free-flowing river, the rock ramp in the rock ramp river, and the dam in the dammed river.

			2011		2012	
River type	Common name	Scientific name	Upstream	Downstream	Upstream	Downstream
Free-flowing	Black bullhead	*Ameiurus melas*	2	0	2	0
Free-flowing	Black crappie	*Pomoxis nigromaculatus*	2	1	16	1
Free-flowing	Blackside darter	*Percina maculata*	14	3	12	1
Free-flowing	Bluegill	*Lepomis macrochirus*	169	129	255	132
Free-flowing	Bluntnose minnow	*Pimephales notatus*	22	4	127	25
Free-flowing	Brook silverside	*Labidesthes sicculus*	0	1	1	0
Free-flowing	Central stoneroller	*Campostoma anomalum*	6	0	98	75
Free-flowing	Channel catfish	*Ictalurus punctatus*	23	4	23	8
Free-flowing	Common carp	*Cyprinus carpio*	24	0	9	5
Free-flowing	Common/striped shiner		115	26	574	141
Free-flowing	Creek chub	*Semotilus atromaculatus*	13	4	67	37
Free-flowing	Emerald shiner	*Notropis atherinoides*	384	395	610	444
Free-flowing	Fathead minnow	*Pimephales promelas*	0	0	4	0
Free-flowing	Freshwater drum	*Aplodinotus grunniens*	1	0	0	0
Free-flowing	Gizzard shad	*Dorosoma cepedianum*	68	2	176	0
Free-flowing	Green sunfish	*Lepomis cyanellus*	100	36	558	475
Free-flowing	Greenside darter	*Etheostoma blennioides*	7	5	7	25
Free-flowing	Hornyhead chub	*Nocomis biguttatus*	105	100	370	185

Table A1 (cont'd).

			2011		2012	
River type	Common name	Scientific name	Upstream	Downstream	Upstream	Downstream
Free-flowing	Johnny darter	*Etheostoma nigrum*	0	2	9	2
Free-flowing	Lamprey sp.	*Ichthyomyzon fossor*	0	1	0	0
Free-flowing	Largemouth bass	*Micropterus salmoides*	3	5	26	5
Free-flowing	Logperch	*Percina caprodes*	38	39	6	25
Free-flowing	Longear sunfish	*Lepomis megalotis*	0	1	1	1
Free-flowing	Mimic shiner	*Notropis volucellus*	17	25	35	46
Free-flowing	Northern hogsucker	*Hypentelium oblongus*	19	13	12	12
Free-flowing	Northern pike	*Esox lucius*	0	0	1	1
Free-flowing	Pumpkinseed	*Lepomis gibbosus*	6	11	34	18
Free-flowing	Quillback	*Carpiodes cyprinus*	33	3	25	1
Free-flowing	Rainbow darter	*Etheostoma caeruleum*	3	1	13	21
Free-flowing	Rock bass	*Ambloplites rupestris*	443	652	1169	1612
Free-flowing	Rosyface shiner	*Notropis rubellus*	1	5	28	9
Free-flowing	Round goby	*Neogobius melanostomus*	173	83	999	979
Free-flowing	Sand shiner	*Notropis stramenius*	1	2	0	0
Free-flowing	Shorthead redhorse	*Moxostoma macrolepidotum*	4	4	2	1
Free-flowing	Silver redhorse	*Moxostoma anisurum*	1	0	0	0
Free-flowing	Smallmouth bass	*Micropterus dolomieu*	231	227	767	867
Free-flowing	Spotfin shiner	*Cyprinella spiloptera*	45	22	106	78

Table A1 (cont'd).

			2011		2012	
River type	Common name	Scientific name	Upstream	Downstream	Upstream	Downstream
Free-flowing	Stonecat	*Noturus flavus*	31	19	113	78
Free-flowing	Walleye	*Sander vitreum*	2	0	3	2
Free-flowing	Warmouth	*Lepomis gulosus*	0	0	0	1
Free-flowing	White perch	*Morone americana*	0	0	0	1
Free-flowing	White sucker	*Catostomus commersoni*	14	11	21	11
Free-flowing	Yellow bullhead	*Ameiurus catus*	31	44	55	41
Free-flowing	Yellow perch	*Perca flavescens*	1	0	2	0
Rock ramp	Black bullhead	*Ameiurus melas*	0	0	0	2
Rock ramp	Black crappie	*Pomoxis nigromaculatus*	0	3	0	0
Rock ramp	Black redhorse	*Moxostoma duquesnei*	0	0	0	3
Rock ramp	Blacknose dace	*Rhinichthys atratulus*	0	0	2	1
Rock ramp	Blackside darter	*Percina maculata*	1	15	16	42
Rock ramp	Bluegill	*Lepomis macrochirus*	26	145	95	376
Rock ramp	Bluntnose minnow	*Pimephales notatus*	15	36	152	117
Rock ramp	Bowfin	*Amia calva*	0	0	2	0
Rock ramp	Brown bullhead	*Ameiurus nebulosus*	0	1	0	0
Rock ramp	Central mudminnow	*Umbra limi*	0	0	2	0
Rock ramp	Central stoneroller	*Campostoma anomalum*	0	1	51	0
Rock ramp	Channel catfish	*Ictalurus punctatus*	4	14	3	45

Table A1 (cont'd).

River type	Common name	Scientific name	2011 Upstream	2011 Downstream	2012 Upstream	2012 Downstream
Rock ramp	Cichlidae sp.		0	0	0	2
Rock ramp	Common carp	*Cyprinus carpio*	2	1	6	1
Rock ramp	Common/striped shiner		72	18	571	146
Rock ramp	Creek chub	*Semotilus atromaculatus*	1	0	135	9
Rock ramp	Emerald shiner	*Notropis atherinoides*	61	108	765	1548
Rock ramp	Freshwater drum	*Aplodinotus grunniens*	0	0	0	1
Rock ramp	Golden redhorse	*Moxostoma erythurum*	16	56	25	116
Rock ramp	Golden shiner	*Notemigonus crysoleucas*	0	0	1	0
Rock ramp	Goldfish	*Carassius auratus*	0	0	1	1
Rock ramp	Grass pickerel	*Esox americanus vermiculatus*	0	1	0	0
Rock ramp	Greater redhorse	*Moxostoma valenciennesi*	5	2	12	6
Rock ramp	Green sunfish	*Lepomis cyanellus*	1	11	66	225
Rock ramp	Hornyhead chub	*Nocomis biguttatus*	62	6	507	39
Rock ramp	Largemouth bass	*Micropterus salmoides*	0	0	0	1
Rock ramp	Logperch	*Percina caprodes*	8	2	63	16
Rock ramp	Longear sunfish	*Lepomis megalotis*	0	13	7	78
Rock ramp	Mimic shiner	*Notropis volucellus*	116	125	1665	1110
Rock ramp	Northern hogsucker	*Hypentelium oblongus*	133	19	348	71
Rock ramp	Northern pike	*Esox lucius*	2	6	3	3

Table A1 (cont'd).

River type	Common name	Scientific name	2011 Upstream	2011 Downstream	2012 Upstream	2012 Downstream
Rock ramp	Plecostomus sp.		0	0	0	1
Rock ramp	Pumpkinseed	*Lepomis gibbosus*	3	46	18	123
Rock ramp	Quillback	*Carpiodes cyprinus*	0	0	6	65
Rock ramp	Rainbow darter	*Etheostoma caeruleum*	5	10	126	48
Rock ramp	River chub	*Nocomis micropogon*	89	8	465	32
Rock ramp	Rock bass	*Ambloplites rupestris*	411	267	1236	551
Rock ramp	Rosyface shiner	*Notropis rubellus*	66	0	690	31
Rock ramp	Round goby	*Neogobius melanostomus*	3	23	17	161
Rock ramp	Sand shiner	*Notropis stramenius*	65	111	970	635
Rock ramp	Shorthead redhorse	*Moxostoma macrolepidotum*	0	2	0	1
Rock ramp	Silver redhorse	*Moxostoma anisurum*	1	2	0	5
Rock ramp	Smallmouth bass	*Micropterus dolomieu*	84	37	786	315
Rock ramp	Spotfin shiner	*Cyprinella spiloptera*	222	246	1672	1349
Rock ramp	Stonecat	*Noturus flavus*	21	4	123	21
Rock ramp	Walleye	*Sander vitreum*	0	1	0	0
Rock ramp	Warmouth	*Lepomis gulosus*	0	0	0	2
Rock ramp	White sucker	*Catostomus commersoni*	7	2	62	31
Rock ramp	Yellow bullhead	*Ameiurus catus*	3	12	9	7
Rock ramp	Yellow perch	*Perca flavescens*	0	0	0	9

Table A1 (cont'd).

			2011		2012	
River type	Common name	Scientific name	Upstream	Downstream	Upstream	Downstream
Dammed	Black bullhead	*Ameiurus melas*	0	0	0	6
Dammed	Black crappie	*Pomoxis nigromaculatus*	3	9	7	10
Dammed	Black redhorse	*Moxostoma duquesnei*	0	0	73	11
Dammed	Blacknose dace	*Rhinichthys atratulus*	0	0	0	1
Dammed	Blackside darter	*Percina maculata*	29	29	145	59
Dammed	Bluegill	*Lepomis macrochirus*	121	193	293	714
Dammed	Bluntnose minnow	*Pimephales notatus*	50	210	380	2054
Dammed	Brook silverside	*Labidesthes sicculus*	1	4	19	61
Dammed	Central mudminnow	*Umbra limi*	0	0	1	0
Dammed	Central stoneroller	*Campostoma anomalum*	0	11	45	104
Dammed	Channel catfish	*Ictalurus punctatus*	0	8	4	56
Dammed	Common carp	*Cyprinus carpio*	0	0	2	5
Dammed	Common/striped shiner		3	19	6	43
Dammed	Creek chub	*Semotilus atromaculatus*	0	1	35	28
Dammed	Emerald shiner	*Notropis atherinoides*	1	192	1	2146
Dammed	Fathead minnow	*Pimephales promelas*	0	0	0	3
Dammed	Flathead catfish	*Pylodictis olivaris*	0	0	0	6
Dammed	Freshwater drum	*Aplodinotus grunniens*	0	0	0	14
Dammed	Gizzard shad	*Dorosoma cepedianum*	0	22	0	25

Table A1 (cont'd).

River type	Common name	Scientific name	2011 Upstream	2011 Downstream	2012 Upstream	2012 Downstream
Dammed	Golden redhorse	*Moxostoma erythurum*	95	232	114	269
Dammed	Golden shiner	*Notemigonus crysoleucas*	0	0	0	2
Dammed	Greater redhorse	*Moxostoma valenciennesi*	17	3	9	18
Dammed	Green sunfish	*Lepomis cyanellus*	30	62	118	309
Dammed	Greenside darter	*Etheostoma blennioides*	80	89	277	234
Dammed	Hornyhead chub	*Nocomis biguttatus*	0	0	1	5
Dammed	Iowa darter	*Etheostoma exile*	2	0	1	0
Dammed	Johnny darter	*Etheostoma nigrum*	6	0	3	2
Dammed	Lamprey sp.		0	0	1	1
Dammed	Largemouth bass	*Micropterus salmoides*	10	4	13	24
Dammed	Logperch	*Percina caprodes*	0	79	0	654
Dammed	Longear sunfish	*Lepomis megalotis*	2	10	17	200
Dammed	Longnose gar	*Lepisosteus osseus*	0	2	0	4
Dammed	Mimic shiner	*Notropis volucellus*	222	93	2227	583
Dammed	Northern hogsucker	*Hypentelium oblongus*	71	44	129	200
Dammed	Northern pike	*Esox lucius*	10	6	5	11
Dammed	Pumpkinseed	*Lepomis gibbosus*	11	48	38	51
Dammed	Quillback	*Carpiodes cyprinus*	0	0	4	6
Dammed	Rainbow darter	*Etheostoma caeruleum*	26	2	67	36

Table A1 (cont'd).

River type	Common name	Scientific name	2011 Upstream	2011 Downstream	2012 Upstream	2012 Downstream
Dammed	Redfin shiner	*Lythrurus umbratilis*	0	0	1	0
Dammed	River chub	*Nocomis micropogon*	0	0	1	3
Dammed	Rock bass	*Ambloplites rupestris*	799	243	2006	614
Dammed	Rosyface shiner	*Notropis rubellus*	21	5	139	161
Dammed	Round goby	*Neogobius melanostomus*	0	330	0	1640
Dammed	Sand shiner	*Notropis stramenius*	78	117	466	714
Dammed	Shorthead redhorse	*Moxostoma macrolepidotum*	0	3	1	8
Dammed	Silver redhorse	*Moxostoma anisurum*	0	1	1	3
Dammed	Smallmouth bass	*Micropterus dolomieu*	156	70	414	327
Dammed	Spotfin shiner	*Cyprinella spiloptera*	88	130	649	1015
Dammed	Stonecat	*Noturus flavus*	25	9	59	38
Dammed	Walleye	*Sander vitreum*	0	13	3	16
Dammed	White perch	*Morone americana*	0	0	0	4
Dammed	White sucker	*Catostomus commersoni*	3	4	12	1
Dammed	Yellow bullhead	*Ameiurus catus*	0	2	1	4
Dammed	Yellow perch	*Perca flavescens*	0	10	2	211

Table B1. Site to site comparison combinations for all possible pairwise comparisons (sites 1-6) for all sampling events for distance analysis.

River type	Year	Months	Site comparison combination
Dammed	2011	July, August	All possible pairwise comparisons
Dammed	2012	June, August	All possible pairwise comparisons
Dammed	2012	July	2 vs. 3, 2 vs. 4, 2 vs. 6, 3 vs. 4, 3 vs. 6, 4 vs. 6
Rock ramp	2011	July, August	All possible pairwise comparisons
Rock ramp	2012	June, July, August	All possible pairwise comparisons
Free-flowing	2011	July, August	All possible pairwise comparisons
Free-flowing	2012	June, August	All possible pairwise comparisons

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