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The Effects of Low-head Lamprey Barrier Dams on Stream Habitat and Fish Communities in Tributaries of the Great Lakes

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Hope R. Dodd

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THE EFFECTS OF LOW-HEAD LAMPREY BARRIER DAMS ON STREAM HABITAT AND FISH COMMUNITIES IN TRIBUTARIES OF THE GREAT LAKES

By

Hope R. Dodd

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ABSTRACT

THE EFFECTS OF LOW-HEAD LAMPREY BARRIER DAMS ON STREAM HABITAT AND FISH COMMUNITIES IN TRIBUTARIES OF THE GREAT LAKES

By

Hope R. Dodd

Low-head barrier dams are used to block adult sea lamprey (*Petromyzon marinus)* from reaching suitable spawning habitat. However, these dams are suspected to have several impacts on the stream fish communities. During the summer of 1996, twenty four stream pairs were sampled across the Great Lakes basin with each pair consisting of a stream with a low-head barrier and a nearby reference stream without a barrier. Barrier streams were deeper and wider on average and contained more species than reference streams. Barrier streams showed a peak in species richness directly downstream of the dams and a sharp drop in species richness above the dams, indicating a blocking of fish movement upstream. Barrier streams were more dissimilar in species composition between above and below sections relative to reference streams, implying they do have a minor impact on the fish community. Barrier effects on frequency of occurrence and abundance of yellow perch, tout-perch, logperch and black bullheads were evident, indicating their sensitivity to barriers. Rainbow trout (*Oncorhynchus myksis*) were younger and grew faster in barrier streams, while white suckers (*Catostomus commersoni*) were older in barrier streams but grew at similar rates among stream types, suggesting low-head dams are affecting the population dynamics of these two species.

To my family for their complete support and guidance.

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INTRODUCTION

The sea lamprey (*Petromyzon marinus*), a native of the Atlantic Ocean, invaded the Great Lakes following the construction of the Welland Canal (Pearce et al. 1980). It first appeared in Lake Erie in 1921 and soon spread to the upper Great Lakes (Applegate and Smith 1951; Lawrie 1970). This parasitic species, along with substantial fishing pressure, nearly eliminated native lake trout (*Salvelinus namaycush*) and populations of other large commercial fish in the Great Lakes, resulting in the need for control of sea lamprey (Lawrie 1970; Pearce et al. 1980; Smith and Tibbles 1980).

Since 1950, a variety of control methods have been instituted to reduce sea lamprey abundance in the Great Lakes. Currently, there are several methods used to control sea lamprey including chemical treatments, sterile male release, and construction of low-head barrier dams. Chemical control with 3-trifluoromethyl-4-nitrophenol (TFM) is the primary method utilized in Great Lakes tributaries. This lampricide targets the larval stage of the life cycle by killing ammocoetes buried in the stream bed (Applegate et al. 1957; Applegate et al. 1961; Hunn and Youngs 1980). Although TFM has little apparent effect on fish species other than lampreys, public sentiment along with high cost of chemical control has led the Great Lakes Fishery Commission to search for alternative control methods to reduce the use of lampricides by 50% by the end of this decade (Great Lakes Fishery Commission 1992).

To supplement chemical control methods, the sterile male release program has been instituted on Lake Superior tributaries and in the St. Mary's River. This method of control targets the spawning stage of the life cycle by releasing sterile adult males into the population to mate with females, producing abnormal sea lamprey embryos that eventually die. As the ratio of sterile males to normal males increases with consecutive releases, spawning success will decline, thereby decreasing sea lamprey numbers (Hanson 1981).

Another alternative to chemical treatment is the construction of barrier dams. These dams are built to prevent adult sea lamprey from migrating to suitable spawning habitat in Great Lakes tributaries. Early attempts at blocking spawning migrations included installation of mechanical weirs and traps and the use of electrical barriers (Applegate and Smith 1951; Smith and Tibbles 1980). These control methods were deemed as ineffective, costly, and caused mortality to non-target species and most were discontinued by the 1970s (Erkkila et al. 1956; McLain 1957; Dahl and McDonald 1980; Hunn and Youngs 1980).

By the mid-1970s, the Great Lakes Fishery Commission approved construction of low-head barrier dams as part of the integrated sea lamprey control program (Hunn and Youngs 1980). These dams range in height from approximately 60 to 300 cm with some having a two-level tier and others having only one. They also vary in shape with some having a "V" shape while others are build perpendicular to the stream (Figure 1). These low-head barrier dams were built as a more effective control mechanism than mechanical and electrical weirs while minimizing negative effects on non-target fish. Although low-head barrier dams do not appear to cause direct mortality of non-target species, they can have negative impacts at several different levels within the stream community (Pringle 1997). The most obvious impact is the blocking of fish movement during periods of spawning or seasonal movement to locate suitable habitat and food resources. This

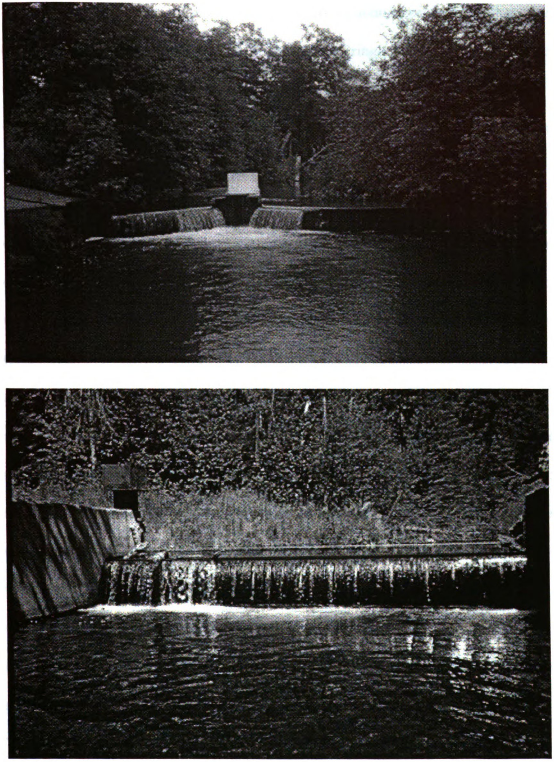


Figure 1. Photographs of low-head barriers in this study showing the "V" shape design (top photograph) and the straight line design (bottom photograph).

limitation on movement may reduce species diversity, abundance and gene flow causing a change in fish assemblage (Hunn and Youngs 1980; Pringle 1997). Low-head barriers may also indirectly affect fish communities by changing the habitat (diversity and substrate) and water quality (turbidity, temperature, and flow) of the stream (Ward and Stanford 1983; Pringle 1997).

In this paper, I discuss the evidence for an impact of low-head lamprey barrier dams on stream habitat and fish populations. My *a priori* hypothesis was that streams containing low-head dams will contain fewer species and show a greater loss of species upstream of the barrier when compared to upstream sections of nearby reference streams (those without a barrier). I hypothesized that abundance of some non-target species will decrease upstream of the dams due to habitat alteration or blocking of movement upstream, thereby altering fish community and population size composition. Based on previous studies of barrier dams and mechanical weirs, I postulated that the population age structure of white sucker (*Catostomus commersoni*), a non-jumping migratory species, would be skewed towards a younger age structure upstream of the dams and that growth would be affected by the barriers due to the dam acting as a source of mortality by allowing white suckers to traverse the barrier moving downstream but blocking movement upstream. Age and growth of rainbow trout (*Oncorhycus myksis*), a jumping migratory species, would not be affected by the barrier (Dahl and McDonald 1980; Hunn and Youngs 1980) because of their ability to pass the barrier in both the upstream and downstream direction.

STUDY AREA

This project was a cooperative study between Michigan State University, the University of Wisconsin – Madison, and the University of Guelph. Forty seven tributaries were sampled across the Great Lakes basin in the summer (June-August) of 1996, and 14 streams were re-sampled in summer of 1997 (Table 1, Figure 2). For sampling purposes, the streams in this study were divided among the three universities. Streams were paired, with each pair containing a low-head barrier stream and a nearby reference stream (without a barrier). Due to the lack of suitable reference streams, one reference stream was used twice in the Lake Erie drainage. Stream pairs were selected with the advice of sea lamprey control agents and technical experts. Reference streams were selected based on proximity and similarity to the barrier stream in terms of stream size, geology, and geography (Table 1). The majority of streams were sampled at six locations, three stream sites above and three below the barrier or a corresponding location on the reference stream (Figure 3). However, some streams were sampled with fewer sites when stream depth prevented safe sampling or the barrier was too close to the steam mouth to allow placement of three sampling sites below the barrier. Site location was primarily determined by access to streams with each site separated by at least 5-7 times the stream width. We excluded from our sampling the small reservoir just upstream of the barrier because water depth was too great to sample with our equipment. We also excluded the plunge pool directly downstream of the barrier due to the potential for fish to aggregate there unnaturally.

Table 1. Streams sampled in summer 1996 and re-sampled in summer 1997 (designated by *).
Note: stream pair 11 was not sampled and South Otter was used twice as a reference stream.
(Particle sizes: 1=clay; 2=silt 3=sand 4=gravel 5=cobble 6=boulder 7=bedrock).

Stream Pair	Stream Name	Stream Type	Location (State/Prov.)	Lake	Mean Width (m)	Mean Depth (cm)	Mean Particle	Mean Temp. (C)	Crew
1*	East Branch AuGres	Barrier	Michigan	Huron	10.2	69.3	3.4	17.9	MSU
1*	West Branch Rifle	Reference	Michigan	Huron	8.6	77.8	3.5	18.7	MSU
2*	Albany	Barrier	Michigan	Huron	6.1	51.2	3.6	14.0	MSU
2*	Beavertail	Reference	Michigan	Huron	3.9	65.5	2.9	16.7	MSU
3*	Echo	Barrier	Ontario	Huron	16.7	98.8	3.6	18.4	MSU
3*	Root	Reference	Ontario	Huron	10.2	52.4	4.5	18.8	MSU
4	Kuskawong	Barrier	Ontario	Huron	10.6	66.5	5.1	15.3	MSU
4	Brown	Reference	Ontario	Huron	3.6	32.9	4.0	18.3	MSU
5	Manitou	Barrier	Ontario	Huron	15.0	72.8	5.0	20.9	UG
5	Blue Jay	Reference	Ontario	Huron	10.3	57.3	4.9	15.5	UG
6	Sturgeon	Barrier	Ontario	Huron	8.8	78.2	2.8	18.3	UG
6	Mad	Reference	Ontario	Huron	11.1	93.7	2.5	21.0	UG
7	Betsie	Barrier	Michigan	Michigan	18.3	95.6	3.3	20.7	MSU
7	Upper Platte	Reference	Michigan	Michigan	17.7	61.1	3.6	19.5	MSU
8	Kewaunee	Barrier	Wisconsin	Michigan	20.0	65.3	4.8	18.7	UW
8	Ahnapee	Reference	Wisconsin	Michigan	14.1	47.7	3.8	20.7	UW
9	East Twin	Barrier	Wisconsin	Michigan	11.3	57.7	4.0	19.6	UW
9	Hibbards	Reference	Wisconsin	Michigan	6.1	43.6	3.3	17.4	UW
10*	West Branch Whitefish	Barrier	Michigan	Michigan	20.4	60.6	5.3	19.5	UW
10*	East Branch Whitefish	Reference	Michigan	Michigan	17.0	49.8	4.8	19.5	UW
12*	Miners	Barrier	Michigan	Superior	8.8	72.0	3.8	15.0	MSU
12*	Harlow	Reference	Michigan	Superior	5.8	61.6	3.4	16.3	MSU

Table 1. (cont'd)

Stream Pair No.	Stream Name	Stream Type	Location (State/Provence)	Lake	Mean Width (m)	Mean Depth (cm)	Mean article Si	Mean Temp. (C)	Crew
13	Big Carp	Barrier	Ontario	Superior	10.1	103.4	3.1	17.5	MSU
13	Little Carp	Reference	Ontario	Superior	5.1	45.6	3.2	15.5	MSU
14	Stokely	Barrier	Ontario	Superior	8.0	60.2	3.9	13.3	MSU
14	Pancake	Reference	Ontario	Superior	13.1	79.2	4.4	15.0	MSU
15	Days	Barrier	Michigan	Michigan	9.8	55.8	4.6	19.3	UW
15	Rapid	Reference	Michigan	Michigan	14.6	43.3	5.6	23.0	UW
16	Misery	Barrier	Michigan	Superior	9.6	69.9	3.4	13.8	UW
16	Firesteel	Reference	Michigan	Superior	14.2	72.2	3.5	14.6	UW
17*	Middle	Barrier	Wisconsin	Superior	11.7	46.6	5.0	22.3	UW
17*	Poplar	Reference	Wisconsin	Superior	7.4	35.1	5.2	23.9	UW
18	Neebing	Barrier	Ontario	Superior	11.8	87.8	3.2	18.2	UW
18	Whitefish	Reference	Ontario	Superior	15.7	69.1	4.4	18.1	UW
19	Clear	Barrier	Ontario	Erie	4.8	49.8	2.4	14.2	UG
19	South Otter	Reference	Ontario	Erie	2.7	33.9	2.9	18.6	UG
20*	Forestville	Barrier	Ontario	Erie	3.9	23.4	2.9	16.0	UG
20*	Fishers	Reference	Ontario	Erie	4.4	30.1	4.1	12.9	UG
21	Youngs	Barrier	Ontario	Erie	8.6	65.3	3.4	17.5	UG
21	South Otter	Reference	Ontario	Erie	2.7	33.9	2.9	18.6	UG
22	Duffins	Barrier	Ontario	Ontario	12.8	77.3	3.7	17.7	UG
22	Lynde	Reference	Ontario	Ontario	8.2	30.9	4.1	19.0	UG
23	Grafton	Barrier	Ontario	Ontario	4.4	32.8	4.3	15.0	UG
23	Salem	Reference	Ontario	Ontario	3.2	37.9	3.0	15.0	UG

Table 1. (cont'd)

Stream Pair No.	Stream Name	Stream Type	Location (State/Provence)	Lake	Mean Width (m)	Mean Depth (cm)	Mean article Si	Mean Temp. (C)	Crew
24	Little Salmon	Barrier	New York	Ontario	13.4	54.6	5.6	20.3	UG
24	Grindstone	Reference	New York	Ontario	11.1	33.8	5.1	20.7	UG
25	Shelter Valley	Barrier	Ontario	Ontario	8.9	54.6	3.8	16.8	UG
25	Wilmot	Reference	Ontario	Ontario	7.5	45.0	4.1	17.4	UG

Figure 2. Location of streams sampled in the Great Lakes Basin.

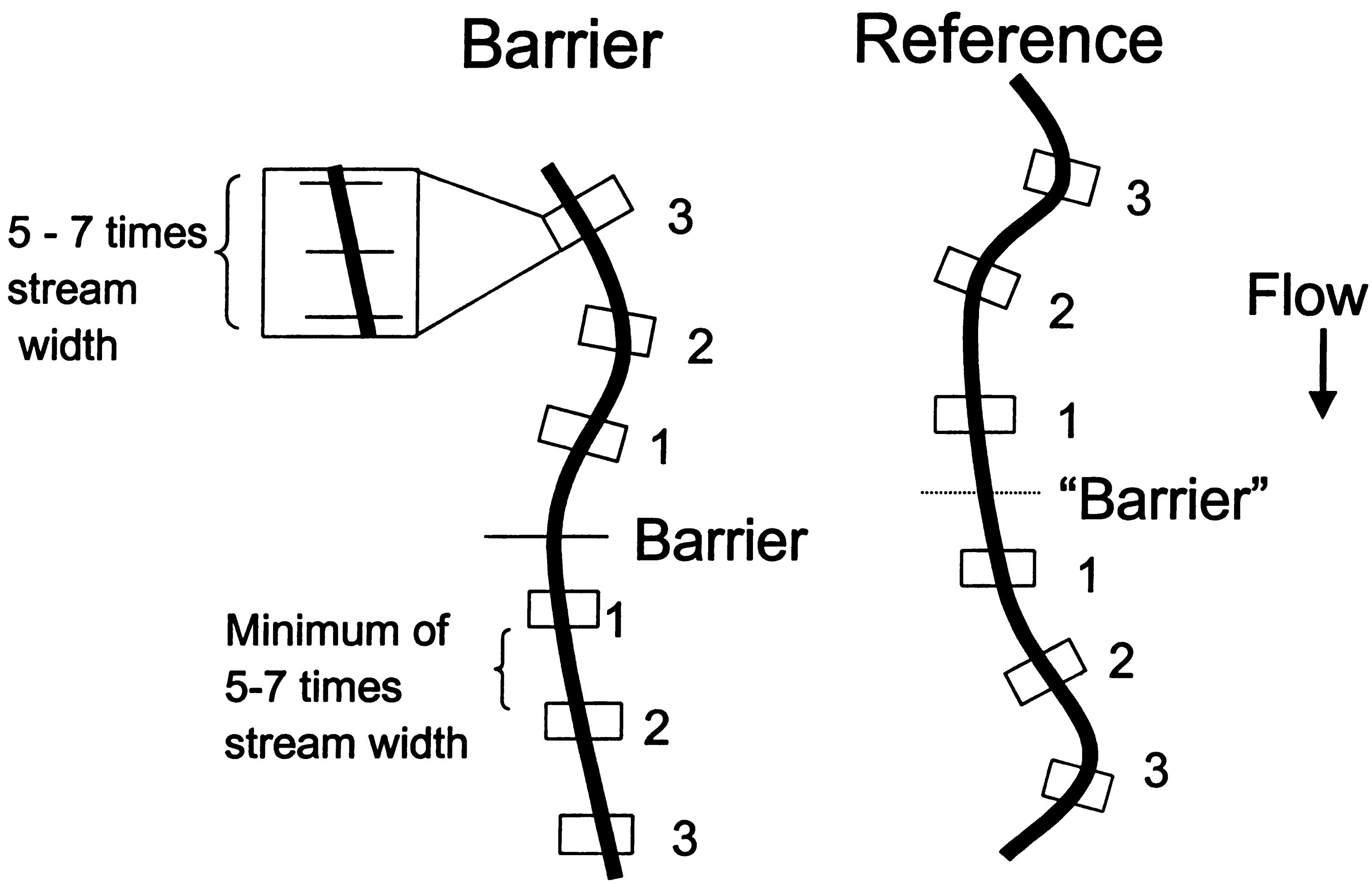


Figure 3. Location of sites within a stream pair with a enlarged view of site 3 showing the three transects.

METHODS

Field and Laboratory Methods

Each sampling site contained a downstream, upstream, and middle transect. The downstream transect was marked where the thalweg crossed the stream. The upstream and downstream transect were separated by 5-7 times the stream width (Figure 3). A middle transect was placed at approximately half the length of the site. At each transect, stream width, maximum depth, and a pebble count of 50 stream bed particles were measured to determine habitat characteristics. Pebble counts were taken by standing at one side of the stream bank and walking along the transect. At each step, the observer would reach down and determine the type of stream bed particle based on its size (Kondolf and Li 1992). In addition to the habitat measurements mentioned above, temperature and conductivity were also measured at time of sampling at the downstream transect only to aide in setting the electroshocking unit.

In order to sample fish composition within a site, one pass with a backpack electroshocker was made in an upstream direction with a zig-zag motion. This method is generally adequate in providing species composition, richness, and relative abundance (Simonson and Lyons 1995). Most fish were identified in the field and total length was measured. Fish that could not be immediately identified were fixed in 10% formalin and vouchered in 70% isopropyl alcohol for further identification in the laboratory. Specimens that could not be identified due to their extremely small size or to damage during transport and preservation were excluded in my analysis.

At time of fish measurement, rainbow trout scales were collected at a diagonal between the posterior end of the dorsal fin and the anterior end of the anal fin above the lateral line (Minard and Dye 1997). For white suckers, pectoral fin clips were taken making certain at least the first three fin rays were collected. The right pectoral fin was used when possible.

In the laboratory, scales were mounted between two glass slides for reading purposes. White sucker fin rays were embedded in epoxy, sectioned using a diamond blade saw, and mounted between glass slides (Scidmore and Glass 1953; Beamish and Harvey 1969). Glycerin was used as a clearing agent to aide in reading fin rays. To age and measure length of scales and fin rays, an Optimas imaging system was used.

Data Analysis

For data analysis, sites were combined into above and below stream sections. An α value (Type I error) of 0.05 was used for all statistical tests. To determine differences in width, maximum depth, particle type, and water temperature between barrier and reference streams, a nested mixed model analysis of variance (ANOVA) design was used treating stream pair, stream, and position (Above or Below) within each stream as random effects and stream type as the fixed effect. The relationship between stream habitat characteristics and species richness was examined with a nested mixed model analysis of covariance (ANCOVA) design again using pair, stream, and position as random effects and stream type as a fixed effect to compare differences in barrier and reference streams. For comparing differences in species richness among the above and below sections of barrier and reference streams and relating these differences to habitat, I also used a nested mixed model ANCOVA with pair and stream as random effects and stream position as the fixed effect. I estimated an average loss of species (impact value) due to the barrier using the formula:

$$I = (BA - BB) - (RA - RB), \qquad [1]$$

where I is the impact value for a stream pair and where all other variables refer to species richness within a stream position for a stream pair (BA = Barrier Above, BB = Barrier Below, RA = Reference Above, and RB = Reference Below). A two-tailed t-test was used to compare the observed impact to the expected impact of zero. In order to examine habitat influences on the number of species lost above the dams, regressions of average width and maximum depth were performed on loss of species calculated for each stream pair. The influence of age, time of last breach, and height of the dams on loss of species were also examined through regression analysis.

To determine impacts of barriers on fish community composition, Sϕrensen's similarity index (Sϕrensen 1948) was computed between stream sections

$$QS = 2C / (A + B), \qquad [2]$$

where QS is the index of community similarity, A is the number of species in one stream section, B is the number of species in the second stream section, and C is the number of species common to both stream sections. A Tukey's Studentized Range test was then used to evaluate differences between similarity indices. Similar to the calculation of an impact value for species richness, I estimated an average loss of fish community size (i. e. average length of all fish combined) above low-head barriers by substituting mean community size for richness in equation [1] and performed a two-tailed t-test to indicate differences in mean length due to the barrier.

Sensitivity of particular species to barriers was based on comparisons of frequency of occurrence, mean catch, and mean length for above and below sections of barrier and reference streams. For frequency of occurrence, two impact ratios were computed. The Barrier Impact compared frequency of occurrence between the barrier and reference stream, and the Above Impact compared the barrier above section with that of the reference stream. The Barrier Impact and Above Impact ratios for frequency of occurrence were calculated using the formulas:

$$BI_{freq} = (BA+BB) / (RA+RB), \qquad [3]$$

$$AI_{freq} = (BA/BB) / (RA/RB) \qquad [4]$$

where BI is the Barrier Impact ratio, AI is the Above Impact ratio, and where all other variables refer to the number of sites a particular species was found within a stream position (BA = Barrier Above, BB = Barrier Below, RA = Reference Above, and RB = Reference Below). The Impact score for both mean catch and mean length was calculated using equation [1], substituting mean catch or mean length for richness. Species were considered sensitive to barriers based on their magnitude of their Impact ratios and Impact scores.

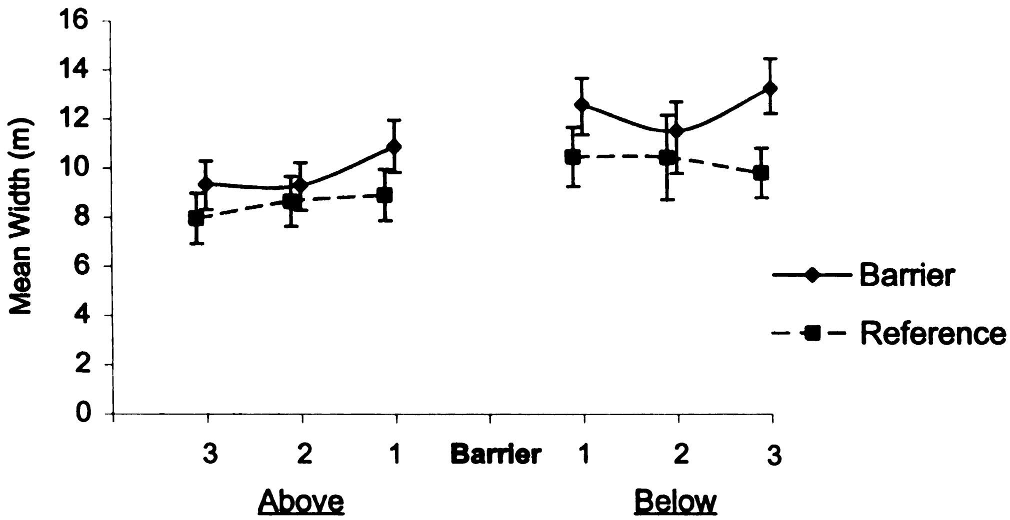
Differences in age between stream types and stream positions were determined by performing a mixed model ANOVA on mean age for both rainbow trout and white sucker. For growth analysis of rainbow trout and white sucker, the Hile method (a modified version of the Fraser-Lee method) of linear regression was used to compute length of the fish at scale (or fin ray) formation and back-calculations of lengths at age were computed (Francis 1990). From the back-calculated lengths at age, incremental growth for the previous year was calculated and previous length at age was regressed on incremental growth for each stream sampled. A mixed model ANCOVA was used to determine differences in the growth between barrier and reference streams by testing the slopes of the two regression lines for homogeneity. Catch curves were constructed for each stream and differences in instantaneous mortality rate (i.e. the slope of the regression) between barrier and reference streams for the two species was ascertained through an ANCOVA analysis. For age, growth, and mortality analyses, stream pair was treated as a random effect, and stream type and stream position were considered fixed effects. Rainbow trout structures were collected from two stream pairs, but the Miners and Harlow pair was removed from the analysis on instantaneous mortality due to a low number of age structures collected in Miners River. White sucker fin rays were collected and aged from four stream pairs. The West Whitefish/East Whitefish pair was excluded in the analysis of mortality rates due to the lack of white suckers older than age two in the East Whitefish River.

RESULTS

Habitat Analysis

Most streams in this study were cool water tributaries to the Great Lakes. Both barrier and reference streams ranged widely in size (Table 1). Streams with low-head barriers had an average width of 11.0 m and an average maximum depth of 65.4 cm while the mean width and maximum depth for reference streams was 9.4 m and 52.2 cm. Barrier streams were significantly wider and deeper than reference streams (P_{width}=0.0236, P_{depth} = 0.0018) with a difference in mean width of 1.9 m and mean maximum depth of 13.9 cm. Average particle size for both barrier and reference streams was gravel with no significant difference in predominant substrate type between stream types (P=0.999). Mean water temperature for barrier streams was 17.5 °C and for reference streams was 18.1 °C with no significant difference between stream types (P=0.9027).

To further study habitat alteration by barrier dams, we calculated mean width, maximum depth, particle size, and temperature at the six sites sampled in reference and barrier streams. Average width and maximum depth gradually increased in a downstream direction for both stream types, however, barrier streams were generally wider and deeper at all sites (Figure 4). At sites just upstream of the dams, mean maximum depth was on average 15 cm greater than in the reference streams, suggesting that some effect of the impoundment extended upstream to these sites. Mean particle size and temperature were similar among sites for barrier and reference streams, although streams without dams tended to have slightly higher temperatures at all sites (Figure 5). Unlike width and depth, mean particle size and temperature did not show a downstream trend.



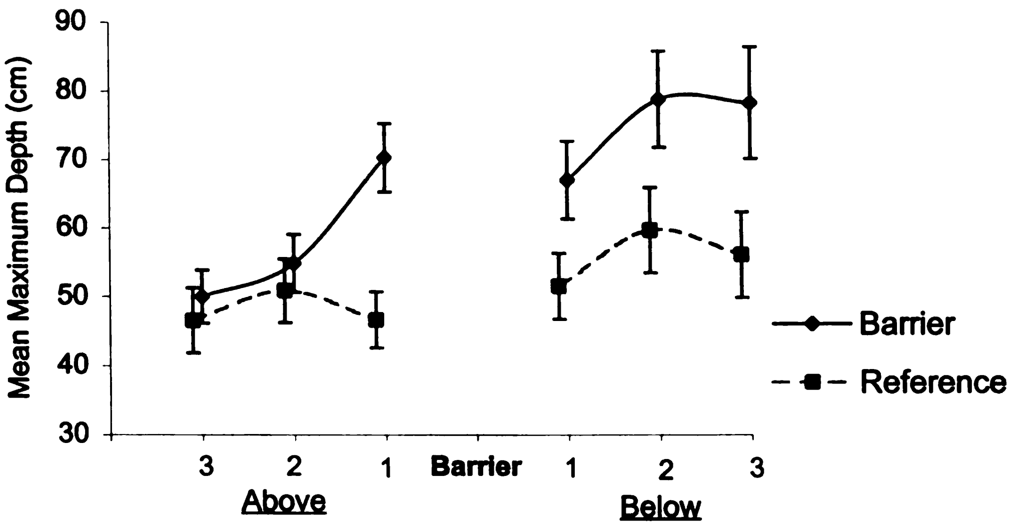
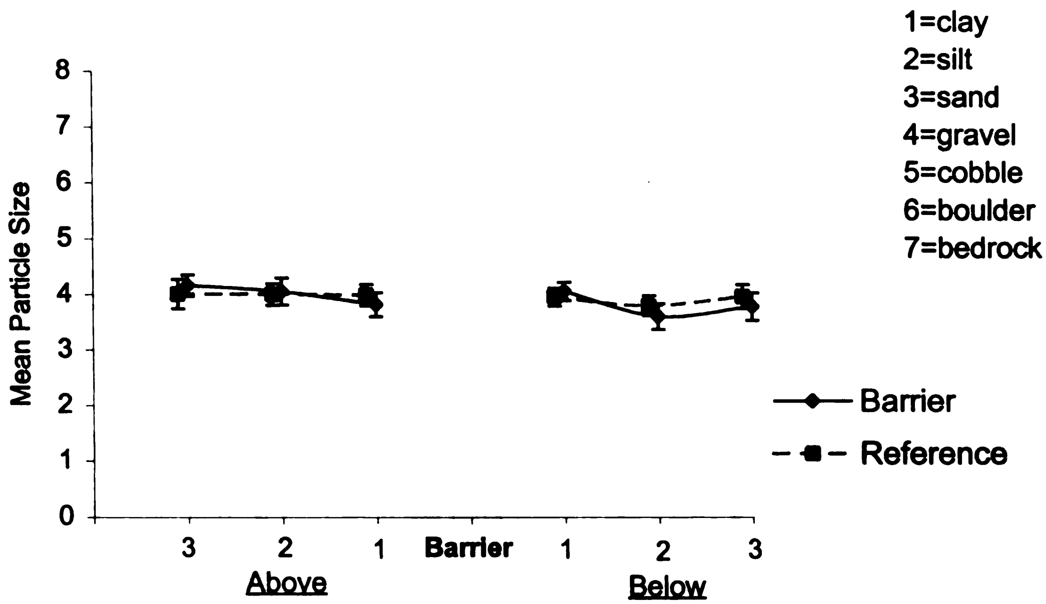


Figure 4. Trends in mean width (top) and mean maximum depth (bottom) (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.



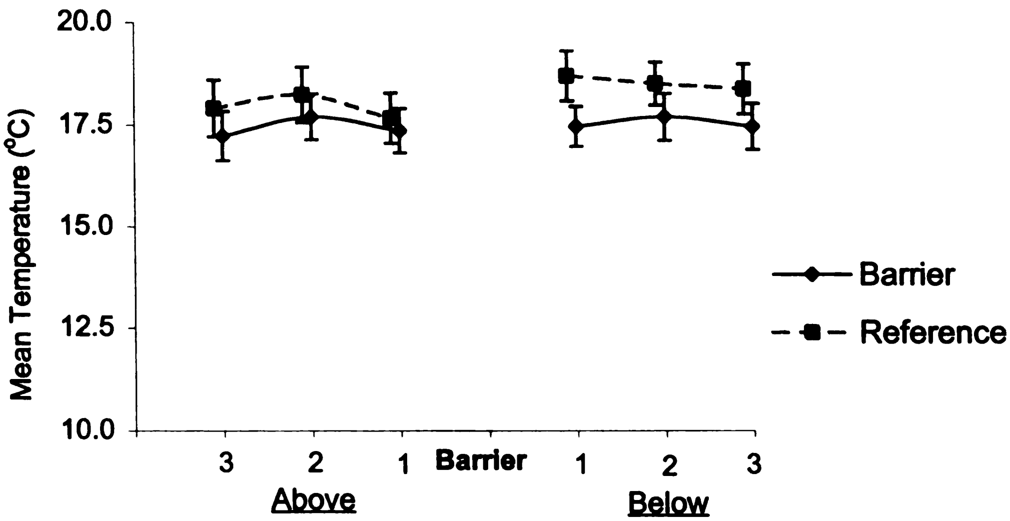


Figure 5. Trends in mean particle size (top) and mean temperature (bottom) (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.

Fish Community Composition and Size Structure

Overall, barrier streams contained a greater number of species than reference streams. A total of 14 and an average of 3.8 more species were caught in barrier streams compared to reference streams with higher species richness occurring in both above and below sections of barrier streams (Table 2). Difference in average richness was greater between the below sections of barrier and reference streams (3.8 species) when compared to that of the above sections (0.7 species). Moving upstream within a stream type, total and average species richness declined by 20 and 4.7 species in barrier streams, while in reference streams, total richness decreased by 14 species and average richness declined by 1.6 species.

There was little difference in average species richness between summer 1996 and 1997 among above and below sections of barrier and reference streams (Table 3). Average richness for the 24 barrier streams sampled in 1996 was 12.7 and for the seven re-sampled in 1997 was 11.2 species. Reference streams contained fewer species on average with 10.6 species in 1996 and 9.9 species in 1997. Comparing just those seven stream pairs that were sampled in both years, the barrier above sections differed by an average of 0.1 species and the barrier below differed by 2.1 species. Reference streams showed a difference in average richness of 0.9 species above and 1.8 species below between years.

To detect patterns in richness and associate those patterns with habitat differences between barrier and reference streams, I examined species richness at the site level. For reference streams, both total and average species richness generally increased in a downstream direction with the exception of the Above 1 and Below 2 sites (Figure 6).

Table 2. Total (top table) and mean (bottom table) number of species caught in above and below sections of barrier and reference streams for summer 1996 and 1997 combined.

	Barrier	Reference
Above	54	48
Below	74	62
Total	79	65

	Barrier	Reference
Above	11.3	10.6
Below	16.0	12.2
Total	18.6	14.8

Table 3. Number of species caught in above and below sections of barrier and reference streams (stream position) for summer 1996 and summer 1997 and average loss of species upstream of the barrier (mean impact). Note: Stream pairs with an * had less than three sites sampled in the below section of either the barrier or reference stream.

	Summer 1996				Summer 1997				
Stream Pair	Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Above	Barrier Below	Reference Above	Reference Below	Mean Impact (BA-BB) - (RA-RB)
1	9	18	18	17	10	18	15	12	-10.5
2	10	13	9	16	14	16	7	11	3.0
3	14	21	10	9	9	9	9	9	-4.0
4	10	14	7	12					1.0
5*	13	13	7	8					1.0
6*	8	21	5	5					-13.0
7	14	19	8	14					1.0
8	20	20	11	14					3.0
9	18	27	4	8					-5.0
10	9	20	14	14	12	17	10	16	-5.0
12	10	10	8	11	4	9	10	9	-1.5
13	10	9	9	10					2.0
14	5	9	9	5					-8.0
15	14	16	12	12					-2.0
16	9	10	11	14					2.0
17	8	13	10	13	10	15	13	9	-5.5
18	12	16	11	8					-7.0
19*	3	11	6	12					-2.0
20	6	11	3	5	6	7	2	6	0.0

Table 3 (cont'd)

	Summer 1996				Summer 1997				
Stream Pair	Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Above	Barrier Below	Reference Above	Reference Below	Mean Impact (BA-BB) - (RA-RB)
21*	3	8	6	12					1.0
22	15	15	14	13					-1.0
23	8	17	13	12					-10.0
24	13	12	19	17					-1.0
25*	11	13	9	12					1.0
Average	10.5	14.8	9.7	11.4	9.3	13.0	9.4	10.3	-2.5

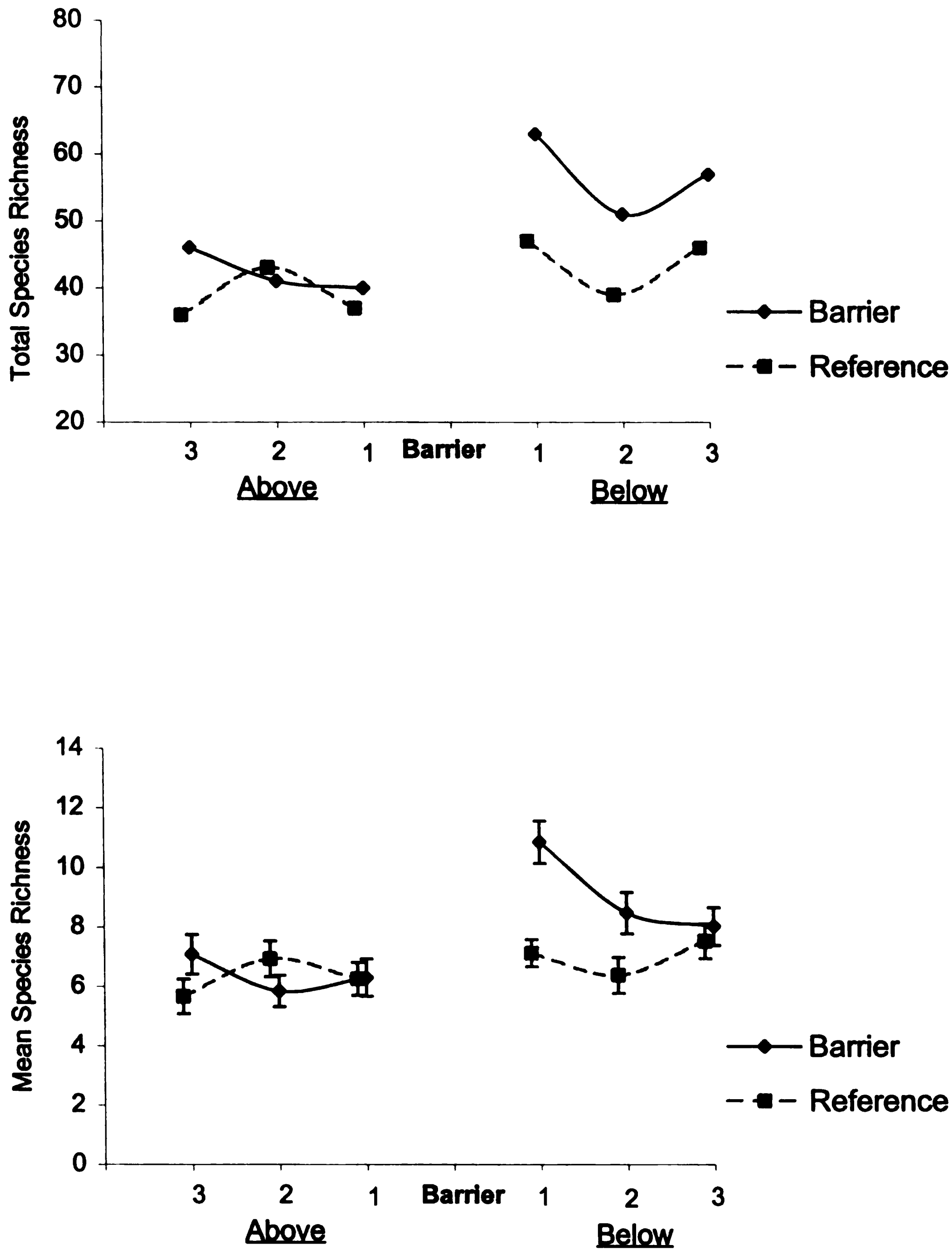


Figure 6. Trends in total (top) and mean (bottom) species richness (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.

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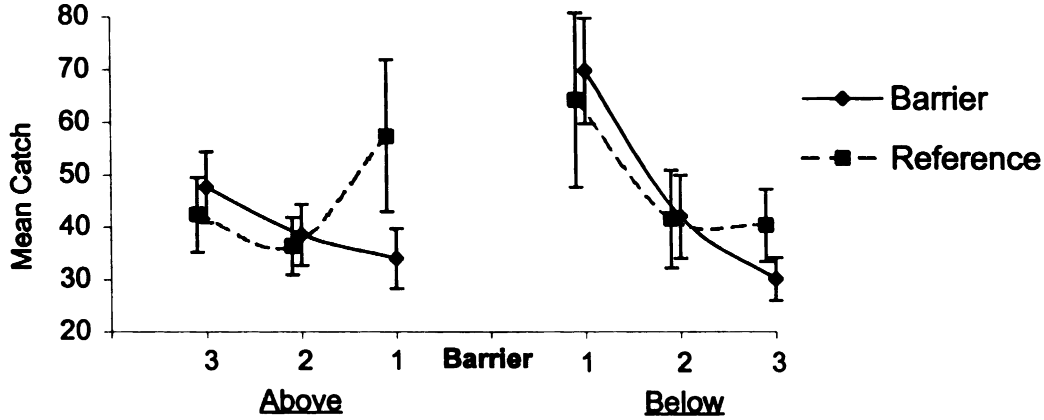
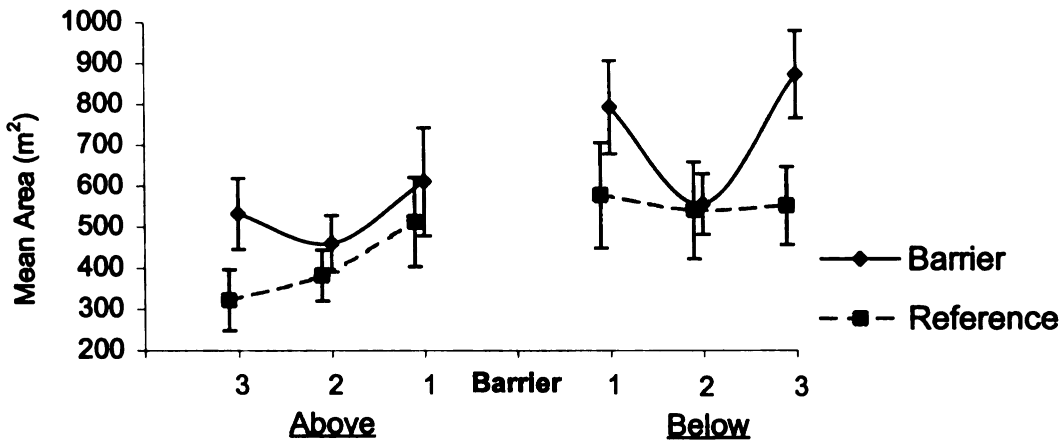
For barrier streams, a different pattern was apparent. Within barrier streams, above sites were similar in terms of total and average species richness although total richness shows a small decline towards the dam. However, the highest total and mean richness was seen at the site directly below the dam (Below 1) compared to all other sites. Barrier streams exhibited a distinct peak in mean richness of 10.8 species that then declined toward the mouth while reference streams showed a gradual increase downstream. Comparing barrier and reference streams, the above sites were more similar in both total and mean richness than below sites.

Due to the high peak in richness directly downstream of the dam, average catch at each site was computed across barrier and reference streams to detect influences of the dam on the relative fish abundance. The pattern seen for mean catch differed from that of average richness particularly for reference streams (Figure 7). In reference streams, mean catch increased towards the hypothetical barrier where it peaked directly below the hypothetical dam and then declined further downstream, but the average richness in reference streams showed a gradual increase from above to below sections. The mean catch in above sites of barrier streams show a trend opposite to that of reference streams with a decline in mean catch toward the dam. Both barrier and reference streams demonstrate a large number of fish caught at the site directly below the barrier (or hypothetical barrier) that then decreases rapidly in a downstream direction. However, the difference in mean catch traversing the barrier (i.e. from Below 1 to Above 1) is greater (35.8 fish) than traversing the hypothetical barrier (6.9 fish). Due to barrier streams being wider on average than reference streams, I took into account the area of the stream sampled at the six sites for barrier and references streams and computed a catch per area





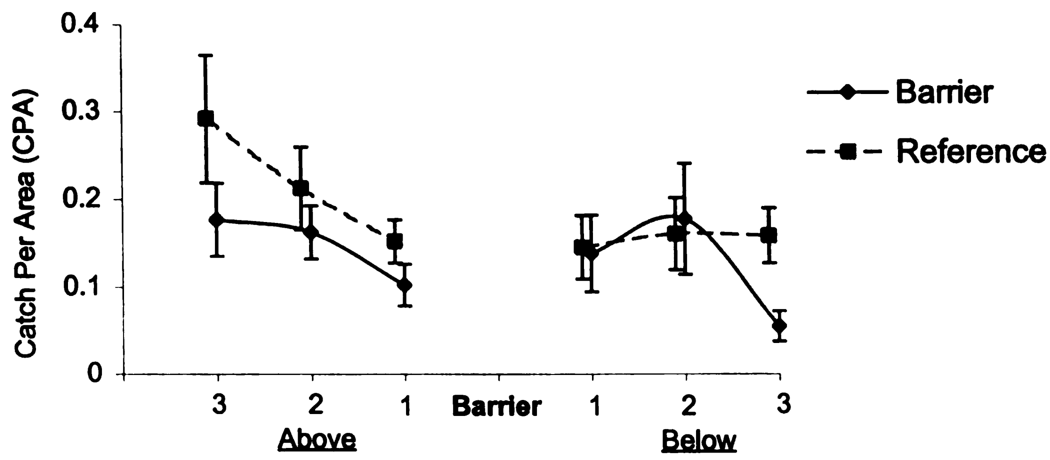
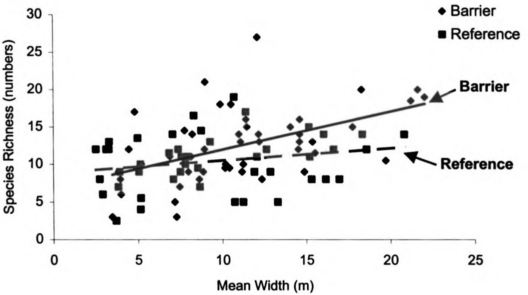


Figure 7. Trends in mean catch (top), mean area (middle), and mean catch per area (bottom) (+- one standard error) in barrier and reference streams at the six sites sampled for all streams and years combined.

(CPA). For both stream types, mean area generally increased in a downstream direction, but was larger at all sites in barrier streams. Comparing barrier and reference streams, above sites were more similar in mean area than below sites with the largest differences in mean area between stream types being at the Below 1 (235.4 m^2) and the Below 3 sites (322.1 m^2). By taking into account area when examining mean catch, I found that the Below 1 sites which had the highest mean catch for both stream types had a relatively small catch per area compared to all other sites. In both barrier and reference streams, catch per area generally declined in a downstream direction with reference streams having higher CPA at all sites except the Below 2 site. However, barrier streams were more similar in CPA across sites compared to reference streams which varied more widely.

Since stream width and depth differed significantly between barrier and reference streams, I examined the possibility of these habitat characteristics explaining the differences seen in average species richness and average catch. I first tested the relationship between the two habitat characteristics and species richness to determine if the slopes were heterogeneous between barrier and reference streams in terms of species richness (Figure 8). This analysis indicated that the slopes of the lines for barrier and reference streams were not significantly different from each other (P=0.8177). Because the slopes were similar, an ANCOVA analysis was then performed on differences in species richness between barrier and reference streams where the slopes were restricted to be equal (i.e. without interactions). The results of this test indicated that average species richness was significantly different between the two stream types ($P_{barrier}$=0.0334) with width and depth being significant covariates (P_{width}=0.0046, P_{depth}=0.0091). Although stream bed particle size and water temperature were not significantly different between



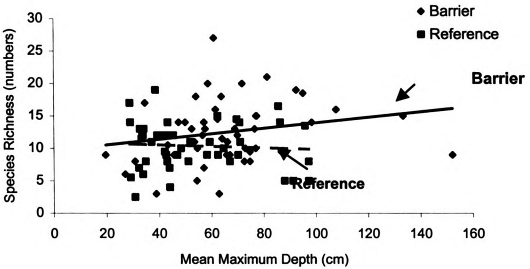
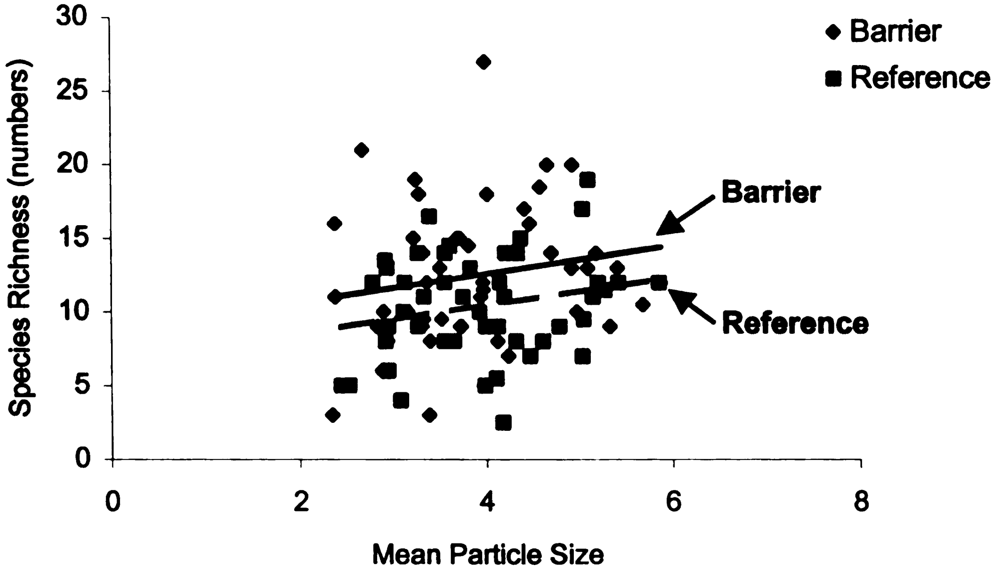


Figure 8. Influence of mean width (top) and mean maximum depth (bottom) on species richness in barrier and reference streams combining summer 1996 and 1997.

barrier and reference streams, I regressed these habitat variables against mean richness to determine possible influences on number of species caught and found that particle size and temperature could not explain the differences in species richness between stream types (Figure 9). For mean catch, I also used a slope heterogeneity test to determine the influence of width and depth on relative abundance (i.e. mean catch). From the ANCOVA, I determined that the slopes for barrier and reference streams were heterogeneous with mean width and all interactions being significant (P_{width}=0.001, $P_{width*barrier}$= 0.0248, $P_{depth*barrier}$=0.0386, $P_{width*depth}$=0.0012, $P_{width*depth*barrier}$=0.0215).

A slope heterogeneity test was also used to examine differences in species richness among above and below sections of barrier and reference streams (the four stream positions) that may be attributable to stream width and depth (Figure 10). The slopes of the lines were not significantly different from each other, indicating similar slopes between stream positions (P=0.4649). An ANCOVA performed on species richness where all four slopes were forced to be equal showed significant differences in average richness between the four stream positions ($P_{strmpos}$ =0.0334) with differences between the above and below barrier sections (BA vs. BB, P=0.001) and the below sections of barrier and reference streams (BB vs. RB, P=0.0057) being significant. In this analysis, stream width was the only significant covariate (P_{width}=0.0219).

I further examined the effect of low-head barrier dams on species richness by calculating a loss of species above the dam (impact values) for each stream pair. On average, barrier streams lost 4.04 species from below to above segments while reference streams lost only 1.52 species. The overall impact of the barriers on species richness was a decline of 2.52 species above the dam relative to reference streams (Table 3). This loss



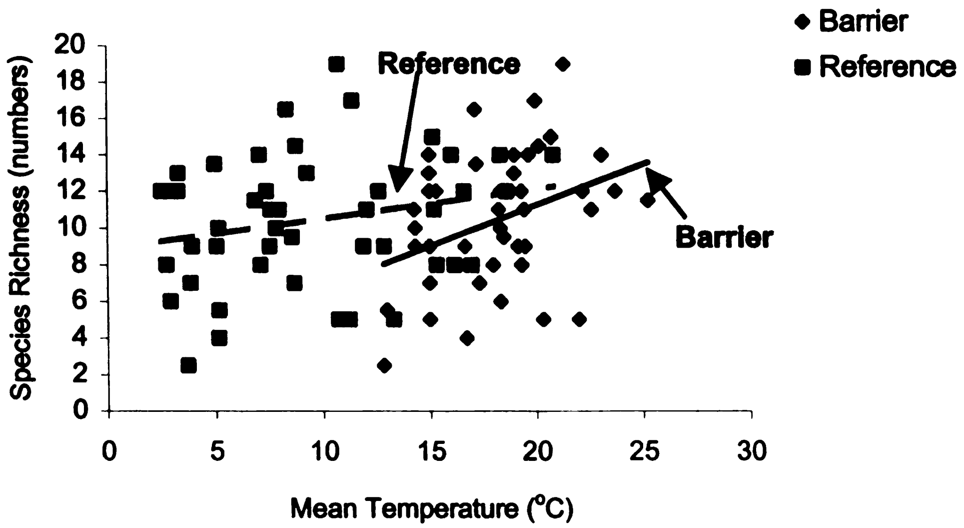
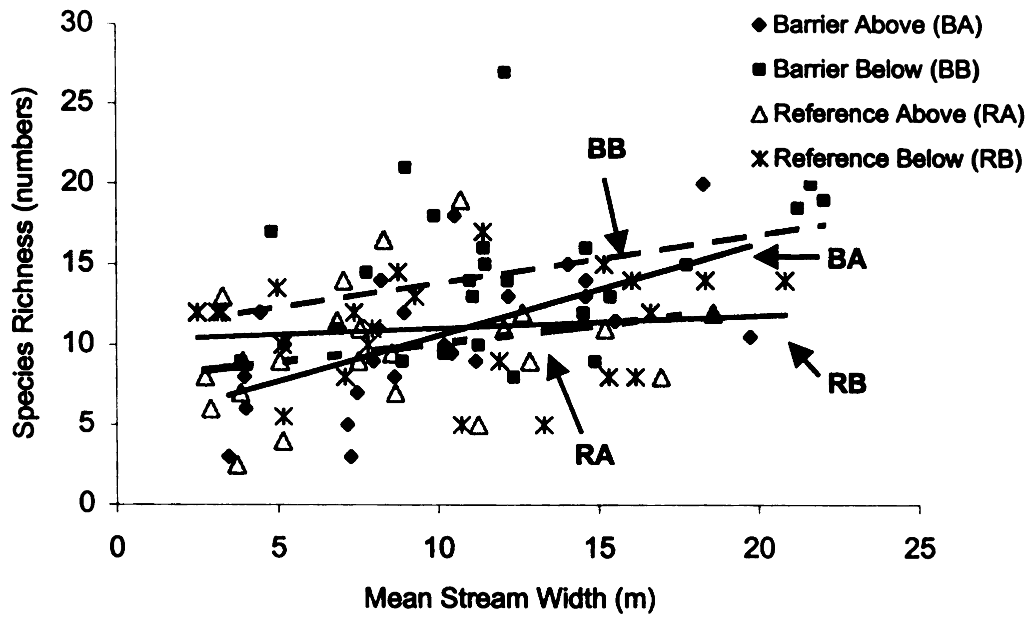


Figure 9. Influence of mean particle size (top) and mean temperautre (bottom) on species richness in barrier and reference streams combining summer 1996 and 1997.



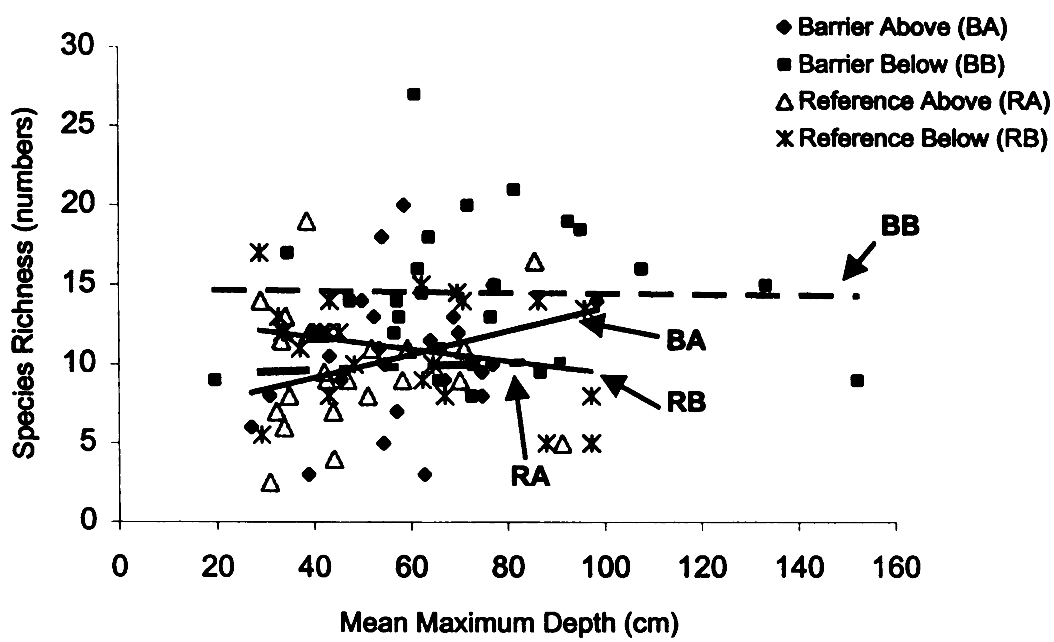
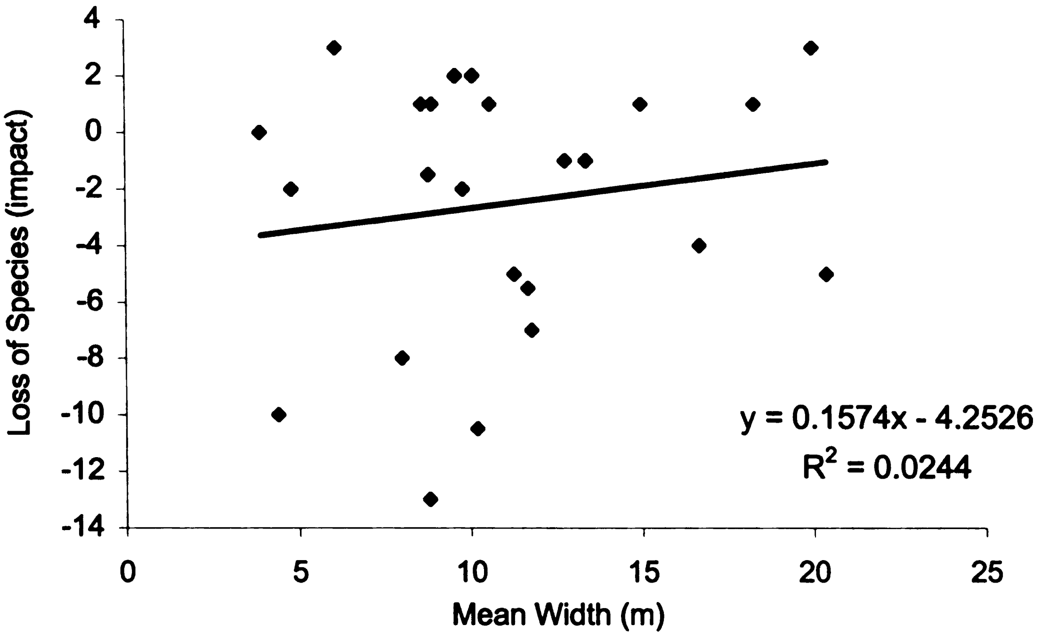


Figure 10. Influence of mean width (top) and mean maximum depth (bottom) on species richness in each stream position combining summer 1996 and 1997.

of species was significantly different from our expected value of zero under the null hypothesis of no impact on species richness by low-head dams ($P= 0.0126$). Although the distribution of impact values across the stream pairs were not normally distributed according to the Shapiro-Wilk normality test ($W = 0.909949$, $P=0.0346$), the boot strap method found that this significant difference in average impact score was robust. I explored the effect of habitat on the degree of species decline upstream through regressions of mean width and mean maximum depth on loss of species (i.e. impact). These regressions were not significant ($P_{width}=0.4194$, $P_{depth}=0.7535$) and showed substantial scattering of the data (Figure 11).

In this study, low-head barriers differed in terms of age, shape, height, and size of the impoundment. Location of barriers upstream of the mouth also varied between streams. Dams ranged in age from 2 to 26 years and in height from 20 to 430 cm. I analyzed the possible influence barrier characteristics may have on decline in species upstream of the dam by regressing barrier age, time of last breach, and head height on loss of species (Figure 12). I found that none of these characteristics were good predictors of species loss above low-head dams ($P_{age}=0.7952$, $P_{breach}=0.2938$, $P_{height}=0.7175$).

Sϕrensen's similarity index based on species presence/absence data was computed to compare fish community composition between above and below sections of barrier and reference streams. The highest similarity in species composition was within reference streams with a mean index value of 0.68 (Figure 13). Barrier streams were found to be the second highest in mean similarity of species composition. Comparing above and



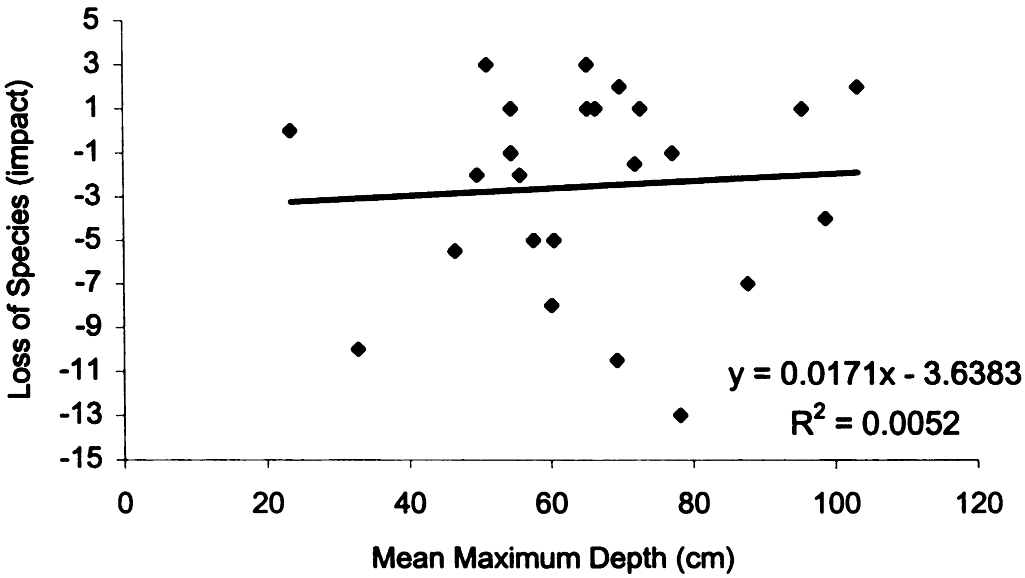


Figure 11. Influence of mean width (top) and mean maximum depth (bottom) on loss of species above the barrier (Impact) for 1996 and 1997 combined.

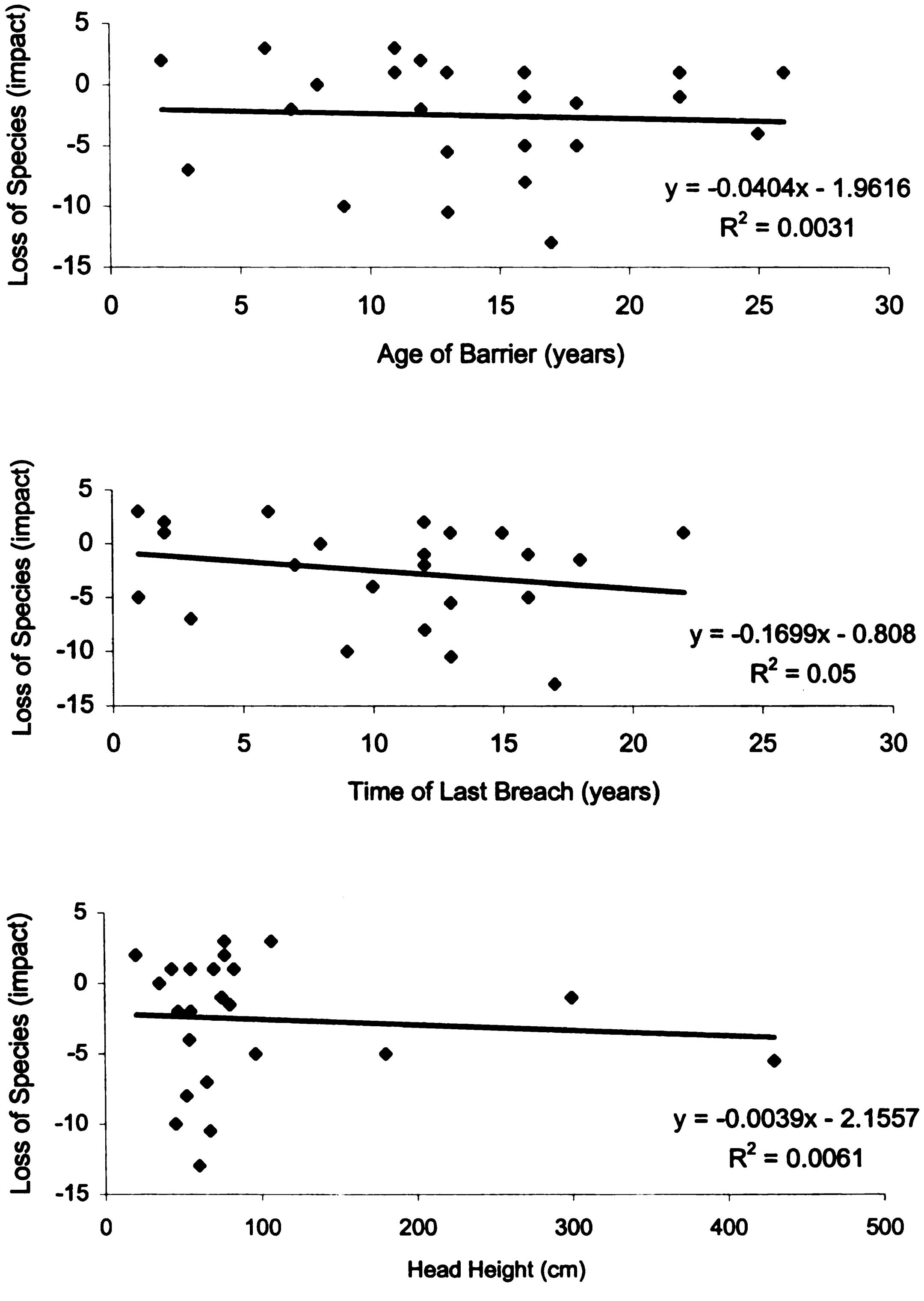


Figure 12. Influence of barrier age (top), time of last breach (middle) and head height (bottom) on loss of species above the barrier (Impact) for 1996 and 1997 combined.

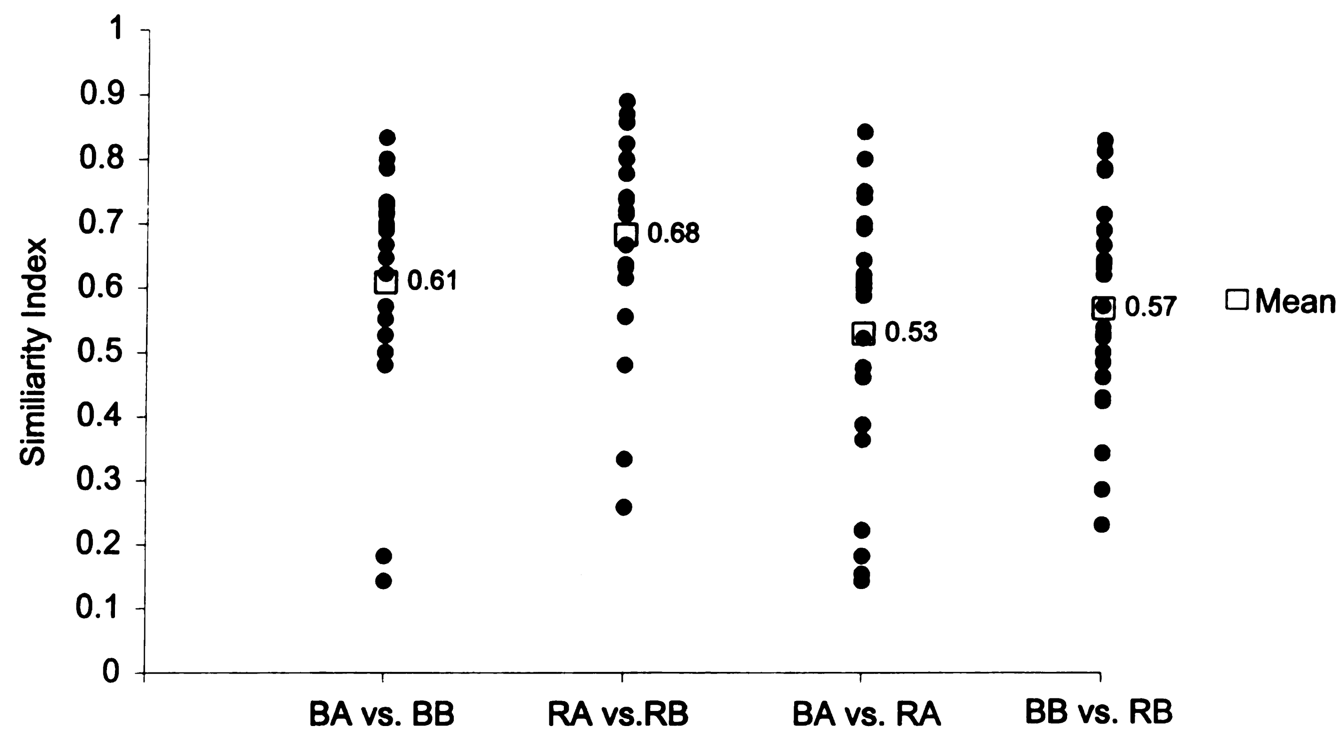


Figure 13. Distribution of Sϕrensen's Similarity Index comparing species composition between the four stream positions (BA=Barrier Above, BB=Barrier Below, RA=Reference Above, RB=Reference Below).

below sections between stream types, the below stream sections were more similar in species composition (0.57) than the above sections (0.53), although previously we found differences in total and mean species richness was shown to be greatest between the below sections (Table 2). A Tukey's Studentized Range test performed on mean similarities indicated the principal difference was between the highest (within reference stream) and lowest (between above sections) similarities only (P=0.0249).

Differences in mean fish community size composition between barrier and reference streams were determined by calculation of an impact value for each stream pair. In barrier streams, community size composition differed by 6.05 mm between above and below sections while reference streams showed a slightly smaller difference of 4.12 mm (Table 4). Overall, the fish community above the barrier was 1.86 mm smaller relative to the reference stream and was not significantly different from our expectation of zero under the null hypothesis of no effect (P=0.7302).

Impact on Individual Species

For each species, frequency of occurrence was calculated and two impact scores were computed for each to assess their sensitivity to low-head barrier dams. The Barrier Impact score identifies species which were caught more frequently in barrier (> 1) versus reference streams (< 1), indicating a whole system impact of the barrier. An Above Impact score identifies species which were found more (> 1) or less (< 1) often above the barrier dams, indicating an upstream impact of the dam. Based on frequency of occurrence data, the five species with the widest distribution (i.e. found in the most number of stream sections) were creek chub, mottled sculpin, blacknose dace, longnose dace, and rainbow trout (Table 5). These species did not appear to be impacted by the

Table 4. Mean community size composition and impact values for each stream pair for 1996 and 1997 combined.

Stream Pair	Barrier Above	Barrier Below	Reference Above	Reference Below	Mean Impact
1	85.00	87.04	77.48	81.40	1.88
2	61.85	75.77	64.97	66.43	-12.45
3	62.94	67.28	72.00	66.81	-9.53
4	69.96	67.12	69.52	67.47	0.79
5	73.97	63.79	68.57	54.67	-3.71
6	68.41	82.87	68.90	82.38	-0.98
7	78.42	92.13	101.58	122.05	6.76
8	91.77	96.53	87.83	132.31	39.72
9	60.39	123.75	50.42	83.92	-29.86
10	68.42	78.98	88.17	75.30	-23.42
12	78.68	69.56	77.68	100.21	31.65
13	73.01	69.78	80.01	57.56	-19.22
14	58.46	73.39	62.76	55.78	-21.91
15	72.89	71.86	67.44	69.68	3.28
16	73.72	67.03	59.49	51.41	-1.38
17	79.98	87.25	78.53	81.28	-4.53
18	65.80	55.57	61.40	58.12	6.95
19	36.22	85.85	65.56	78.80	-36.39
20	149.80	81.23	76.86	91.19	82.90
21	80.48	80.23	65.56	78.80	13.49
22	62.28	86.36	57.15	56.38	-24.84
23	90.94	72.02	93.91	80.50	5.51
24	61.58	78.20	69.58	73.77	-12.42
25	86.83	123.53	62.57	62.29	-36.98
Mean	74.66	80.71	72.00	76.19	-1.86

Table 5. Number of streams in which each species were caught for the four stream positions combining all streams and years.

Common Name	Scientific Name	Number of Streams: Barrier Above	Barrier Below	Reference Above	Reference Below
AMERICAN BROOK LAMPREY	*Lampetra appendix*	6	6	1	1
AMERICAN EEL	*Anguilla rostrata*	0	1	0	0
ATLANTIC SALMON	*Salmo salar*	0	0	0	1
BLACK BULLHEAD	*Ameiurus melas*	2	3	1	2
BLACK CRAPPIE	*Poxomis nigromaculatus*	1	1	0	1
BLACKCHIN SHINER	*Notropis heterodon*	1	1	0	2
BLACKNOSE DACE	*Rhinichthys atratulus*	20	21	14	15
BLACKNOSE SHINER	*Notropis heterolepis*	5	3	2	4
BLACKSIDE DARTER	*Percina maculata*	3	5	2	4
BLUEGILL	*Lepomis macrochirus*	1	1	3	3
BLUNTNOSE MINNOW	*Pimephales notatus*	4	9	4	3
BOWFIN	*Amia calva*	0	1	0	1
BRASSY MINNOW	*Hybognathus hankinsoni*	4	4	1	3
BROOK STICKLEBACK	*Culaea inconstans*	13	7	9	7
BROOK TROUT	*Salvelinus fontinalus*	8	8	7	5
BROWN BULLHEAD	*Ameiurus nebulosus*	3	1	0	1
BROWN TROUT	*Salmo trutta*	6	5	6	5
BURBOT	*Lota lota*	0	5	0	3
CENTRAL MUDMINNOW	*Umbra limi*	14	9	15	13
CHANNEL CATFISH	*Ictalurus punctatus*	0	1	0	0
CHESTNUT LAMPREY	*Ichthyomyzon castaneus*	1	0	0	0
CHINOOK SALMON	*Oncorhynchus tshawytscha*	0	0	1	2

Table 5. (cont'd)

Common Name	Scientific Name	Number of Streams: Barrier Above	Barrier Below	Reference Above	Reference Below
COHO SALMON	*Oncorhynchus kisutch*	2	2	2	2
COMMON CARP	*Cyprinus carpio*	2	3	2	3
COMMON SHINER	*Notropis cornutus*	11	14	9	10
CREEK CHUB	*Semotilus atromaculatus*	19	20	17	15
CUTLIPS MINNOW	*Exoglossum maxilingua*	1	1	1	1
EMERALD SHINER	*Notropis atherinoides*	0	2	0	0
FALLFISH	*Semotilus corporalis*	1	1	1	1
FANTAIL DARTER	*Etheostoma flabellare*	2	4	3	3
FATHEAD MINNOW	*Pimephales promelas*	3	8	2	2
FINESCALE DACE	*Phoxinus neogaeus*	1	3	2	0
FLATHEAD CATFISH	*Pylodictis olivaris*	0	1	0	0
GOLDEN REDHORSE	*Moxostoma crythrurum*	0	1	0	1
GOLDEN SHINER	*Notemigonus crysoleucus*	0	2	0	1
GRASS PICKEREL	*Esox americanus vermiculatus*	0	0	0	1
GREATER REDHORSE	*Moxostoma valenciennesi*	1	0	0	1
GREEN SUNFISH	*Lepomis cyanellus*	1	2	0	0
HORNYHEAD CHUB	*Nocomis biguttatus*	4	5	5	5
IOWA DARTER	*Etheostoma exile*	1	2	1	1
JOHNNY DARTER	*Etheostoma nigrum*	15	19	14	15
LAKE CHUB	*Couesius plumbeus*	1	1	0	0
LAKE TROUT	*Salvelinus namaycush*	0	1	0	0
LARGEMOUTH BASS	*Micropterus salmoides*	1	4	1	2

Table 5. (cont'd)

Common Name	Scientific Name	Number of Streams			
		Barrier Above	Barrier Below	Reference Above	Reference Below
LARGESCALE STONEROLLER	*Campostoma anomalum oligolepis*	0	2	0	0
LOGPERCH	*Percina caprodes*	3	15	7	10
LONGNOSE DACE	*Rhinichthys cataractae*	14	19	16	20
MIMIC SHINER	*Notropis volucellus*	0	2	0	0
MOTTLED SCULPIN	*Cottus bairdi*	17	19	17	18
NINESPINE STICKLEBACK	*Pungitius pungitius*	0	1	0	1
NORTHERN BROOK LAMPREY	*Ichthyomyzon fossor*	2	1	0	0
NORTHERN HOG SUCKER	*Hypentelium nigricans*	2	2	3	2
NORTHERN PIKE	*Esox lucius*	3	6	5	2
NORTHERN REDBELLY DACE	*Phoxinus eos*	6	8	2	1
PEARL DACE	*Margariscus margarita*	4	4	1	2
PUGNOSE MINNOW	*Opsopoeodus emilie*	0	1	0	3
PUMPKINSEED	*Lepomis gibbosus*	5	11	6	5
RAINBOW DARTER	*Etheostoma caeruleum*	2	2	2	2
RAINBOW TROUT	*Oncorhynchus mykiss*	17	16	17	17
RED SHINER	*Notropis lytrensis*	1	0	0	0
REDSIDE DACE	*Clinostomus elongatus*	0	1	0	0
RIVER CHUB	*Nocomis micropogon*	0	0	1	0
RIVER DARTER	*Percina shumardi*	0	1	0	0
ROCK BASS	*Amblophites rupestris*	9	19	10	15
ROSYFACE SHINER	*Notropis rubellus*	2	2	2	1
RUFFE	*Gymnocephalus cemuus*	0	2	0	0

Table 5. (cont'd)

Common Name	Scientific Name	Number of Streams: Barrier Above	Barrier Below	Reference Above	Reference Below
SAND SHINER	*Notropis stramineus*	0	2	0	0
SAUGER	*Stizostedion canadense*	0	1	0	1
SEA LAMPREY	*Petromyzon marinus*	0	7	3	6
SILVER REDHORSE	*Moxostoma anisurum*	0	1	0	1
SILVER SHINER	*Notropis photogenis*	0	0	0	1
SLIMY SCULPIN	*Cottus cognatus*	3	3	1	1
SMALLMOUTH BASS	*Micropterus dolomieui*	1	5	1	4
SOUTHERN REDBELLY DACE	*Phoxinus erythrogaster*	1	0	0	0
SPOTFIN SHINER	*Cyprinella spilopterus*	2	2	1	1
STONECAT	*Noturus flavus*	2	3	1	2
STRIPED SHINER	*Luxilus chrysocephalus*	0	2	2	0
THREESPINE STICKLEBACK	*Gasterosteus aculeatus*	0	2	0	2
TROUT-PERCH	*Percopsis omiscomaycus*	0	4	1	1
WALLEYE	*Stizostedion vitreum*	0	2	0	0
WHITE BASS	*Morone chrysops*	0	1	0	1
WHITE SUCKER	*Catostomus commersoni*	16	20	14	17
YELLOW BULLHEAD	*Ameiurus natalis*	1	0	0	0
YELLOW PERCH	*Perca flavescens*	0	6	5	3

dam in terms of the number of sites in which they were caught (Table 6). Several species did appear to be negatively impacted by the barrier. Sea lamprey, yellow perch, and trout-perch were not caught above the dam in any of the study streams, but sea lamprey and trout-perch were captured more frequently in barrier streams as indicated by their Barrier Impact ratios (1.11 and 1.25, respectively) (Table 6). Northern pike, largemouth bass, and logperch were seen less frequently in the above barrier sites relative to the other three stream sections with northern pike and largemouth bass showing higher occurrence overall in barrier streams (Barrier Impact = 1.09 and 2.00, respectively) while logperch showed a slightly higher occurrence in reference streams (Barrier Impact = 0.82). Other fish species appeared to be positively impacted by the barrier (i.e. seen more frequently in above sections of barrier streams). Blacknose shiner, brassy minnow, american brook lamprey, and northern brook lamprey were caught more frequently in barrier streams particularly in sites above the dams. Black bullhead were also found more often above the barrier relative to the reference stream (Above Impact = 2.67), but occurred equally as frequent in barrier and reference streams as a whole (Barrier Impact=1.00).

As with frequency of occurrence data, mean catch in each stream position and decline in mean catch (i.e. Impact) was computed for each species (Table 7). For this impact score, a negative value indicates a loss in mean catch while a positive score shows a gain in number of fish upstream of the dam. Although their frequencies were not affected by the dams, mean catch of longnose dace and central mudminnow, two of the most widely distributed species, showed a decline in catch above barrier dams (-3.57 and -0.87, respectively). Logperch, a species which occurred less often in the above section of barrier streams, also declined in numbers above barriers on average relative to reference

Table 6. Number of sites in which each species was caught and impact values calculated for the barrier stream (Barrier Impact = (BA+BB)/(RA+RB)) and the barrier above stream section (Above Impact = (BA/BB)/(RA/RB)). Missing values represent those which could not be computed due to division by zero.

	Number of Sites					
Common Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Impact	Above Impact
AMERICAN BROOK LAMPREY	12	9	3	3	3.50	1.33
AMERICAN EEL	0	1	0	0		
ATLANTIC SALMON	0	0	0	1	0.00	
BLACK BULLHEAD	2	3	1	4	1.00	2.67
BLACK CRAPPIE	1	1	0	1	2.00	
BLACKCHIN SHINER	1	2	0	2	1.50	
BLACKNOSE DACE	47	47	34	36	1.34	1.06
BLACKNOSE SHINER	6	5	3	5	1.38	2.00
BLACKSIDE DARTER	6	10	3	4	2.29	0.80
BLUEGILL	2	2	3	5	0.50	1.67
BLUNTNOSE MINNOW	6	13	5	6	1.73	0.55
BOWFIN	0	1	0	1	1.00	
BRASSY MINNOW	5	5	2	4	1.67	2.00
BROOK STICKLEBACK	16	12	14	7	1.33	0.67
BROOK TROUT	16	9	15	11	0.96	1.30
BROWN BULLHEAD	4	1	0	1	5.00	
BROWN TROUT	8	5	13	11	0.54	1.35
BURBOT	0	12	0	3	4.00	
CENTRAL MUDMINNOW	23	17	28	18	0.87	0.87

Table 6. (cont'd)

Common Name	Barrier Above	Number of Sites Barrier Below	Reference Above	Reference Below	Barrier Impact	Overall Impact
CHANNEL CATFISH	0	1	0	0		
CHESTNUT LAMPREY	1	0	0	0		
CHINOOK SALMON	0	0	1	3	0.00	
COHO SALMON	4	4	5	3	1.00	0.60
COMMON CARP	3	6	3	3	1.50	0.50
COMMON SHINER	21	25	16	16	1.44	0.84
CREEK CHUB	41	41	34	33	1.22	0.97
CUTLIPS MINNOW	3	3	3	3	1.00	1.00
EMERALD SHINER	0	2	0	0		
FALLFISH	1	2	1	1	1.50	0.50
FANTAIL DARTER	5	7	8	6	0.86	0.54
FATHEAD MINNOW	3	11	3	2	2.80	0.18
FINESCALE DACE	2	3	2	0	2.50	
FLATHEAD CATFISH	0	1	0	0		
GOLDEN REDHORSE	0	1	0	1	1.00	
GOLDEN SHINER	0	2	0	1	2.00	
GRASS PICKEREL	0	0	0	2	0.00	
GREATER REDHORSE	1	0	0	1	1.00	
GREEN SUNFISH	2	5	0	0		
HORNYHEAD CHUB	8	11	7	11	1.06	1.14
IOWA DARTER	2	3	1	1	2.50	0.67
JOHNNY DARTER	30	40	28	32	1.17	0.86

Table 6. (cont'd)

Common Name	Number of Sites Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Impact	Overall Impact
LAKE CHUB	3	3	0	0		
LAKE TROUT	0	2	0	0		
LARGEMOUTH BASS	1	7	2	2	2.00	0.14
LARGESCALE STONEROLLER	0	5	0	0		
LOGPERCH	4	27	14	24	0.82	0.25
LONGNOSE DACE	27	41	39	42	0.84	0.71
MIMIC SHINER	0	3	0	0		
MOTTLED SCULPIN	45	46	44	44	1.03	0.98
NINESPINE STICKLEBACK	0	1	0	1	1.00	
NORTHERN BROOK LAMPREY	4	2	0	0		
NORTHERN HOG SUCKER	2	2	7	4	0.36	0.57
NORTHERN PIKE	3	9	9	2	1.09	0.07
NORTHERN REDBELLY DACE	7	12	3	1	4.75	0.19
PEARL DACE	4	6	1	2	3.33	1.33
PUGNOSE MINNOW	0	1	0	3	0.33	
PUMPKINSEED	5	17	6	8	1.57	0.39
RAINBOW DARTER	4	4	6	5	0.73	0.83
RAINBOW TROUT	34	34	37	38	0.91	1.03
RED SHINER	1	0	0	0		
REDSIDE DACE	0	2	0	0		
RIVER CHUB	0	0	1	0	0.00	
RIVER DARTER	0	1	0	0		

Table 6. (cont'd)

Common		Number of Sites				
Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Impact	Overall Impact
ROCK BASS	17	37	18	28	1.17	0.71
ROSYFACE SHINER	2	3	3	3	0.83	0.67
RUFFE	0	2	0	0		
SAND SHINER	0	2	0	0		
SAUGER	0	2	0	1	2.00	
SEA LAMPREY	0	10	3	6	1.11	0.00
SILVER REDHORSE	0	1	0	1	1.00	
SILVER SHINER	0	0	0	1	0.00	
SLIMY SCULPIN	7	6	1	1	6.50	1.17
SMALLMOUTH BASS	3	9	2	5	1.71	0.83
SOUTHERN REDBELLY DACE	1	0	0	0		
SPOTFIN SHINER	3	3	2	1	2.00	0.50
STONECAT	4	4	2	2	2.00	1.00
STRIPED SHINER	0	2	2	0	1.00	
THREESPINE STICKLEBACK	0	2	0	2	1.00	
TROUT-PERCH	0	5	2	2	1.25	0.00
WALLEYE	0	3	0	0		
WHITE BASS	0	1	0	1	1.00	
WHITE SUCKER	30	44	28	31	1.25	0.75
YELLOW BULLHEAD	1	0	0	0		
YELLOW PERCH	0	9	10	6	0.56	0.00

Table 7. Mean catch (+- one standard error) and mean loss of fish due to the barrier (Impact = (BA-BB) - (RA-RB)) for each species caught within the four stream positions for all streams and years combined.

Species Name	Barrier Above	Barrier Below	Reference Abov	Reference Below	Impact
AMERICAN BROOK LAMPREY	0.65 (0.23)	0.65 (0.32)	0.07 (0.04)	0.05 (0.03)	-0.01
AMERICAN EEL	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.01
ATLANTIC SALMON	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)	0.02
BLACK BULLHEAD	0.05 (0.04)	0.03 (0.01)	0.02 (0.02)	1.66 (1.32)	1.66
BLACK CRAPPIE	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.01
BLACKCHIN SHINER	0.04 (0.04)	0.04 (0.03)	0.00 (0.00)	0.39 (0.36)	0.40
BLACKNOSE DACE	5.98 (1.03)	4.95 (1.14)	5.95 (1.26)	5.54 (0.96)	0.61
BLACKNOSE SHINER	0.44 (0.30)	0.08 (0.04)	0.03 (0.01)	0.06 (0.03)	0.40
BLACKSIDE DARTER	0.20 (0.10)	0.43 (0.14)	0.03 (0.02)	0.07 (0.04)	-0.20
BLUEGILL	0.03 (0.02)	0.04 (0.03)	0.03 (0.01)	0.26 (0.14)	0.22
BLUNTNOSE MINNOW	0.18 (0.09)	0.50 (0.21)	0.06 (0.03)	0.16 (0.09)	-0.22
BOWFIN	0.00 (0.00)	0.02 (0.02)	0.00 (0.00)	0.01 (0.01)	-0.01
BRASSY MINNOW	0.15 (0.10)	0.09 (0.04)	0.03 (0.02)	0.06 (0.04)	0.10
BROOK STICKLEBACK	1.16 (0.36)	0.45 (0.18)	0.48 (0.20)	0.13 (0.06)	0.37
BROOK TROUT	0.98 (0.31)	0.12 (0.04)	0.90 (0.34)	0.50 (0.22)	0.45
BROWN BULLHEAD	0.07 (0.04)	0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.07
BROWN TROUT	0.10 (0.04)	0.08 (0.04)	1.86 (0.92)	2.29 (1.07)	0.45
BURBOT	0.00 (0.00)	0.82 (0.47)	0.00 (0.00)	0.06 (0.04)	-0.76
CENTRAL MUDMINNOW	1.79 (0.51)	0.62 (0.16)	2.49 (0.91)	0.45 (0.14)	-0.87
CHANNEL CATFISH	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.01
CHESTNUT LAMPREY	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01
CHINOOK SALMON	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.05 (0.04)	0.04

Table 7. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Abov	Reference Below	Impact
COHO SALMON	0.08 (0.05)	0.11 (0.09)	0.63 (0.36)	0.23 (0.20)	-0.43
COMMON CARP	0.12 (0.08)	0.22 (0.10)	0.05 (0.03)	0.04 (0.02)	-0.11
COMMON SHINER	1.89 (0.84)	1.79 (0.46)	0.98 (0.37)	1.07 (0.29)	0.19
CREEK CHUB	2.61 (0.53)	2.96 (0.58)	2.42 (0.54)	3.23 (0.65)	0.47
CUTLIPS MINNOW	0.21 (0.13)	0.41 (0.24)	0.09 (0.06)	0.04 (0.03)	-0.25
EMERALD SHINER	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.00 (0.00)	-0.03
FALLFISH	0.02 (0.02)	0.03 (0.02)	0.03 (0.03)	0.01 (0.01)	-0.04
FANTAIL DARTER	0.91 (0.61)	0.40 (0.18)	1.13 (0.62)	0.89 (0.49)	0.27
FATHEAD MINNOW	0.03 (0.02)	0.20 (0.06)	0.14 (0.09)	0.02 (0.01)	-0.28
FINESCALE DACE	0.06 (0.03)	0.04 (0.02)	0.02 (0.01)	0.00 (0.00)	0.01
FLATHEAD CATFISH	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.01
GOLDEN REDHORSE	0.00 (0.00)	0.04 (0.04)	0.00 (0.00)	0.01 (0.01)	-0.03
GOLDEN SHINER	0.00 (0.00)	0.04 (0.03)	0.00 (0.00)	0.01 (0.01)	-0.03
GRASS PICKEREL	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.03 (0.02)	0.03
GREATER REDHORSE	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.02
GREEN SUNFISH	0.03 (0.02)	0.19 (0.12)	0.00 (0.00)	0.00 (0.00)	-0.17
HORNYHEAD CHUB	0.79 (0.38)	0.68 (0.24)	0.34 (0.21)	0.61 (0.27)	0.38
IOWA DARTER	0.17 (0.10)	0.11 (0.10)	0.01 (0.01)	0.03 (0.02)	0.07
JOHNNY DARTER	1.62 (0.37)	1.90 (0.37)	1.50 (0.44)	2.17 (0.53)	0.39
LAKE CHUB	0.16 (0.11)	1.18 (0.84)	0.00 (0.00)	0.00 (0.00)	-1.03
LAKE TROUT	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.02
LARGEMOUTH BASS	0.01 (0.01)	0.12 (0.05)	0.03 (0.02)	0.06 (0.05)	-0.08
LARGESCALE STONEROLLER	0.00 (0.00)	0.10 (0.05)	0.00 (0.00)	0.00 (0.00)	-0.10

Table 7. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Abov	Reference Below	Impact
LOGPERCH	0.03 (0.02)	1.04 (0.33)	0.31 (0.09)	0.65 (0.18)	-0.67
LONGNOSE DACE	3.61 (0.84)	7.66 (1.55)	5.53 (1.04)	6.01 (1.31)	-3.57
MIMIC SHINER	0.00 (0.00)	0.04 (0.03)	0.00 (0.00)	0.00 (0.00)	-0.04
MOTTLED SCULPIN	4.79 (0.68)	5.64 (1.04)	4.18 (0.73)	4.26 (0.93)	-0.78
NINESPINE STICKLEBACK	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.02 (0.02)	0.01
NORTHERN BROOK LAMPREY	0.13 (0.08)	0.04 (0.02)	0.00 (0.00)	0.00 (0.00)	0.10
NORTHERN HOG SUCKER	0.02 (0.01)	0.03 (0.01)	0.61 (0.50)	0.24 (0.16)	-0.38
NORTHERN PIKE	0.03 (0.02)	0.11 (0.04)	0.18 (0.07)	0.02 (0.01)	-0.24
NORTHERN REDBELLY DACE	0.31 (0.12)	0.39 (0.16)	0.26 (0.18)	0.01 (0.01)	-0.33
PEARL DACE	0.24 (0.17)	0.18 (0.11)	0.03 (0.03)	0.02 (0.01)	0.05
PUGNOSE MINNOW	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.04 (0.03)	0.04
PUMPKINSEED	0.07 (0.04)	0.68 (0.24)	0.06 (0.02)	0.46 (0.33)	-0.21
RAINBOW DARTER	0.18 (0.11)	0.24 (0.19)	1.34 (0.74)	1.68 (0.81)	0.29
RAINBOW TROUT	3.86 (0.91)	2.51 (0.56)	4.52 (1.59)	3.17 (1.26)	0.00
RED SHINER	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01
REDSIDE DACE	0.00 (0.00)	0.04 (0.03)	0.00 (0.00)	0.00 (0.00)	-0.04
RIVER CHUB	0.00 (0.00)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	-0.02
RIVER DARTER	0.00 (0.00)	0.02 (0.02)	0.00 (0.00)	0.00 (0.00)	-0.02
ROCK BASS	0.72 (0.29)	1.53 (0.36)	0.52 (0.16)	0.80 (0.16)	-0.53
ROSYFACE SHINER	0.05 (0.04)	0.26 (0.18)	0.18 (0.15)	0.54 (0.50)	0.14
RUFFE	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.02
SAND SHINER	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	-0.02
SAUGER	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.01 (0.01)	-0.02

Table 7. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Abov	Reference Below	Impact
SEA LAMPREY	0.00 (0.00)	0.17 (0.06)	0.03 (0.02)	0.06 (0.03)	-0.14
SILVER REDHORSE	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00
SILVER SHINER	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.04)	0.04
SLIMY SCULPIN	0.66 (0.23)	0.14 (0.06)	0.03 (0.03)	0.01 (0.01)	0.50
SMALLMOUTH BASS	0.05 (0.03)	0.24 (0.10)	0.02 (0.01)	0.07 (0.03)	-0.14
SOUTHERN REDBELLY DACE	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01
SPOTFIN SHINER	0.38 (0.23)	0.03 (0.02)	0.04 (0.03)	0.01 (0.01)	0.32
STONECAT	0.09 (0.06)	0.10 (0.05)	0.02 (0.01)	0.02 (0.01)	-0.01
STRIPED SHINER	0.00 (0.00)	0.02 (0.01)	0.06 (0.04)	0.00 (0.00)	-0.08
THREESPINE STICKLEBACK	0.00 (0.00)	0.57 (0.56)	0.00 (0.00)	0.02 (0.01)	-0.55
TROUT-PERCH	0.00 (0.00)	0.05 (0.02)	0.02 (0.01)	0.10 (0.07)	0.03
WALLEYE	0.00 (0.00)	0.03 (0.02)	0.00 (0.00)	0.00 (0.00)	-0.03
WHITE BASS	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00
WHITE SUCKER	1.02 (0.28)	1.66 (0.29)	0.93 (0.20)	1.33 (0.24)	-0.25
YELLOW BULLHEAD	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01
YELLOW PERCH	0.00 (0.00)	0.16 (0.06)	0.14 (0.05)	0.31 (0.15)	0.01

streams (-0.67). However, other species were found to have a higher mean catch upstream of the dams. Black bullhead were not only found more often above barriers but were greater in mean catch as well (1.66). Another species with higher mean catch upstream of the dams was slimy sculpin with an impact score of 0.50. Mean length was also tabulated for each species. However, high variability among fish lengths did not allow a clear pattern to be detected for any individual species (Table 8).

Age and Growth Analysis

Rainbow trout ranged in age from zero to three years for all four streams sampled with most fish being young of the year (age zero) (Table 9). Age four and five rainbow trout were caught but excluded from the analysis due to these fish being lake run steelhead which were not a part of the stream community during the time of this study. Mean age ranged from 0.2 to 1.0 years with rainbow trout being significantly older on average in reference streams compared to barrier streams (P=0.0016). For the East Branch AuGres/West Branch Rifle pair, mean age of rainbow trout was higher in the above sections while, in the Miners/Harlow pair, mean age was lower in above sections. Taking into account both stream pairs, I found a significant difference among the four stream positions (P=0.0001). Rainbow trout in the above section of barrier streams were significantly older than those in the below section by approximately 0.5 years (P=0.0005). There was also a significant difference between the below sections of barrier and reference streams with the reference below section containing older rainbow trout (P=0.0001).

For growth analysis of rainbow trout, a regression of fish length on scale radius was used to determine the length at which scale formation occurred (Figure 14). The x –

Table 8. Mean length for each stream position and loss of mean length above the barrier (Impact = (BA-BB)-(RA-RB) for each species caught for all streams and all years combined.

Species Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Impact (BA-BB) - (RA-RB)
AMERICAN BROOK LAMPREY	114.36	119.36	122.25	126.33	-0.91
AMERICAN EEL	0.00	470.00	0.00	0.00	-470.00
ATLANTIC SALMON	0.00	0.00	0.00	131.50	131.50
BLACK BULLHEAD	137.50	155.67	160.50	116.35	-62.32
BLACK CRAPPIE	145.00	135.00	0.00	114.00	124.00
BLACKCHIN SHINER	53.40	65.17	0.00	40.95	29.19
BLACKNOSE DACE	60.44	55.90	57.50	58.35	5.39
BLACKNOSE SHINER	48.87	50.33	41.50	46.46	3.49
BLACKSIDE DARTER	61.67	70.33	59.50	50.81	-17.35
BLUEGILL	86.67	91.20	103.67	107.65	-0.55
BLUNTNOSE MINNOW	60.87	66.19	68.13	66.03	-7.41
BOWFIN	0.00	118.00	0.00	135.00	17.00
BRASSY MINNOW	62.47	67.93	60.67	66.92	0.79
BROOK STICKLEBACK	40.98	47.68	45.97	41.65	-11.02
BROOK TROUT	130.51	160.17	116.58	92.65	-53.59
BROWN BULLHEAD	106.10	225.00	0.00	133.00	14.10
BROWN TROUT	271.00	267.45	149.51	167.65	21.69
BURBOT	0.00	127.39	0.00	119.50	-7.89
CENTRAL MUDMINNOW	63.04	74.61	65.22	70.53	-6.26
CHANNEL CATFISH	0.00	442.00	0.00	0.00	-442.00
CHESTNUT LAMPREY	94.00	0.00	0.00	0.00	94.00
CHINOOK SALMON	0.00	0.00	82.00	73.40	-8.60

Table 8. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Impact (BA-BB) - (RA-RB)
COHO SALMON	49.00	55.63	63.81	68.85	-1.58
COMMON CARP	559.94	513.21	629.30	418.33	-164.23
COMMON SHINER	78.92	84.72	84.03	73.77	-16.06
CREEK CHUB	79.74	85.78	86.21	71.80	-20.46
CUTLIPS MINNOW	83.24	89.74	105.18	106.40	-5.29
EMERALD SHINER	0.00	50.25	0.00	0.00	-50.25
FALLFISH	302.50	69.33	135.50	222.00	319.67
FANTAIL DARTER	54.00	51.35	50.93	47.80	-0.48
FATHEAD MINNOW	58.17	58.17	55.49	58.50	3.01
FINESCALE DACE	51.14	69.50	51.00	0.00	-69.36
FLATHEAD CATFISH	0.00	715.00	0.00	0.00	-715.00
GOLDEN REDHORSE	0.00	411.00	0.00	419.00	8.00
GOLDEN SHINER	0.00	66.67	0.00	77.00	10.33
GRASS PICKEREL	0.00	0.00	0.00	55.67	55.67
GREATER REDHORSE	181.00	0.00	0.00	82.00	263.00
GREEN SUNFISH	66.00	76.75	0.00	0.00	-10.75
HORNYHEAD CHUB	71.86	79.29	61.75	74.29	5.11
IOWA DARTER	49.00	54.46	58.00	39.75	-23.71
JOHNNY DARTER	54.59	52.66	53.29	50.17	-1.19
LAKE CHUB	70.00	53.97	0.00	0.00	16.03
LAKE TROUT	0.00	222.50	0.00	0.00	-222.50
LARGEMOUTH BASS	46.00	87.59	46.33	47.83	-40.09

Table 8. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Impact (BA-BB) - (RA-RB)
LARGESCALE STONEROLLER	0.00	87.30	0.00	0.00	-87.30
LOGPERCH	88.67	94.17	96.31	95.16	-6.66
LONGNOSE DACE	79.31	68.46	74.31	72.71	9.25
MIMIC SHINER	0.00	52.58	0.00	0.00	-52.58
MOTTLED SCULPIN	60.07	58.58	64.05	63.47	0.92
NINESPINE STICKLEBACK	0.00	65.00	0.00	62.00	-3.00
NORTHERN BROOK LAMPREY	119.53	133.50	0.00	0.00	-13.97
NORTHERN HOG SUCKER	54.50	146.25	155.48	179.66	-67.57
NORTHERN PIKE	131.67	85.60	142.08	124.00	27.99
NORTHERN REDBELLY DACE	52.12	55.93	51.56	67.00	11.63
PEARL DACE	54.48	60.74	43.00	47.00	-2.26
PUGNOSE MINNOW	0.00	47.00	0.00	43.00	-4.00
PUMPKINSEED	62.25	62.14	75.50	68.92	-6.47
RAINBOW DARTER	51.53	40.94	41.35	40.02	9.26
RAINBOW TROUT	107.21	128.68	98.58	103.42	-16.62
RED SHINER	95.00	0.00	0.00	0.00	95.00
REDSIDE DACE	0.00	68.80	0.00	0.00	-68.80
RIVER CHUB	0.00	0.00	143.00	0.00	-143.00
RIVER DARTER	0.00	71.50	0.00	0.00	-71.50
ROCK BASS	92.51	109.56	81.33	101.01	2.63
ROSYFACE SHINER	59.50	68.43	69.50	66.72	-11.71
RUFFE	0.00	106.00	0.00	0.00	-106.00

Table 8. (cont'd)

Species Name	Barrier Above	Barrier Below	Reference Above	Reference Below	Impact (BA-BB) - (RA-RB)
SAND SHINER	0.00	63.00	0.00	49.00	-14.00
SAUGER	0.00	168.67	0.00	135.00	-33.67
SEA LAMPREY	0.00	427.71	342.83	349.25	-421.30
SILVER REDHORSE	0.00	412.00	0.00	87.00	-325.00
SILVER SHINER	0.00	0.00	0.00	40.00	40.00
SLIMY SCULPIN	63.49	61.26	70.00	63.00	-4.77
SMALLMOUTH BASS	120.67	229.32	72.00	130.44	-50.22
SOUTHERN REDBELLY DACE	71.50	0.00	0.00	0.00	71.50
SPOTFIN SHINER	73.95	74.75	78.40	52.00	-27.20
STONECAT	109.27	129.87	141.50	184.00	21.90
STRIPED SHINER	0.00	129.00	52.21	0.00	-181.21
THREESPINE STICKLEBACK	0.00	55.79	0.00	60.50	4.71
TROUT-PERCH	0.00	79.75	61.00	66.91	-73.84
WALLEYE	0.00	177.50	0.00	0.00	-177.50
WHITE BASS	0.00	185.00	0.00	178.00	-7.00
WHITE SUCKER	140.52	133.08	131.56	115.45	-8.68
YELLOW BULLHEAD	66.00	0.00	0.00	0.00	66.00
YELLOW PERCH	0.00	88.35	89.34	89.28	-88.42

Table 9. Number at age and mean age of rainbow trout for each stream (top table) and for above and below sections (bottom table).

Stream	Age				Mean
Name	0	1	2	3	Age
East Branch AuGres	39	35	6	2	0.65
West Branch Rifle	6	9	4	1	1.00
Miners	13	1	1	0	0.20
Harlow	6	28	3	0	0.92

Stream		Age				Mean
Name		0	1	2	3	Age
East Branch AuGres	Above	23	27	6	2	0.78
	Below	16	8	0	0	0.33
West Branch Rifle	Above	3	1	3	1	1.25
	Below	3	8	1	0	0.83
Miners	Above	0	0	0	0	0.00
	Below	13	1	1	0	0.20
Harlow	Above	5	7	0	0	0.58
	Below	1	21	3	0	1.08

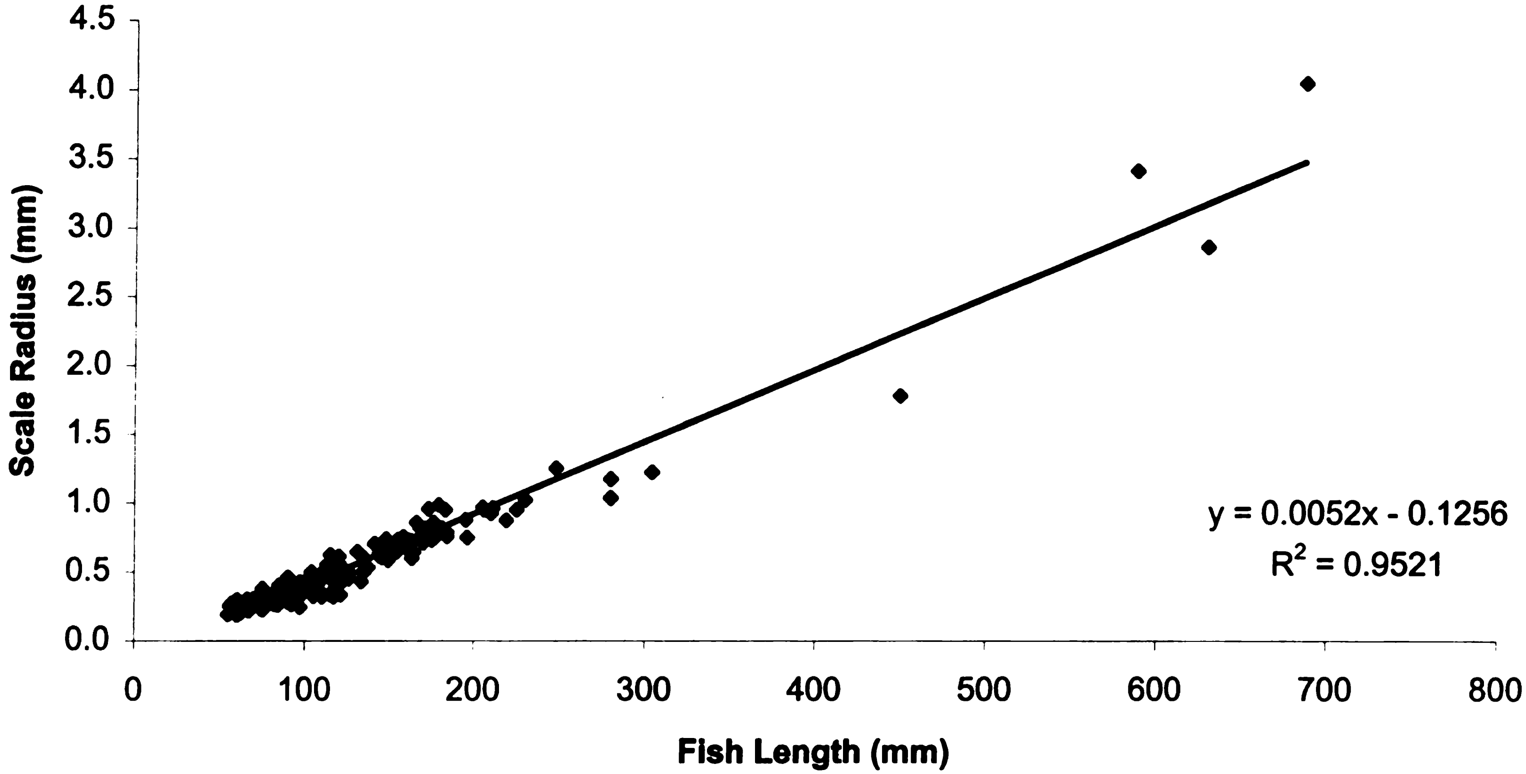
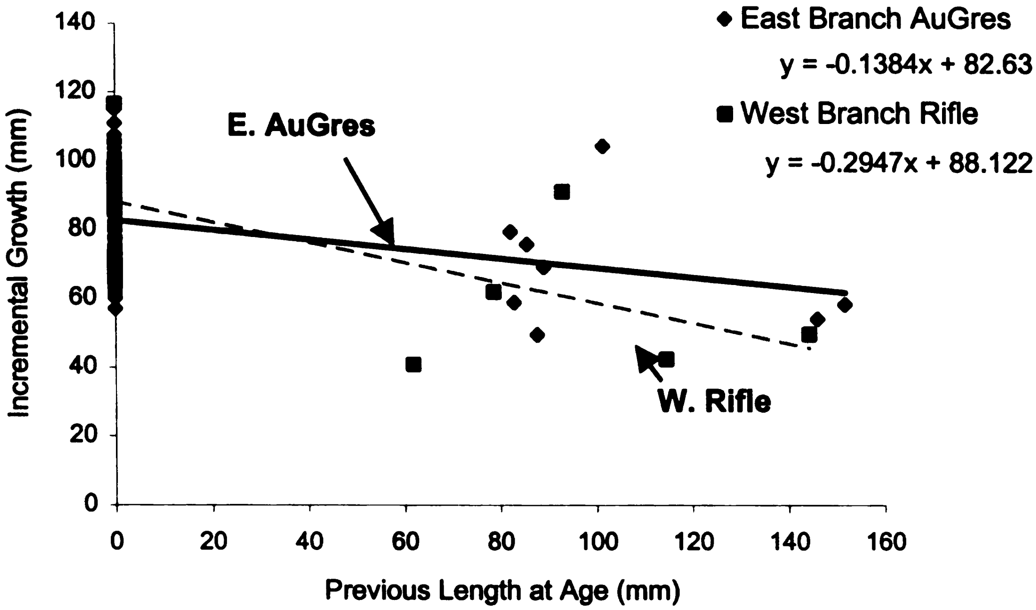


Figure 14. Regression of fish length on scale radius for back-calculations of length at age for rainbow trout.

intercept value was then used to back-calculate the length at annulus formation for the year in which the fish was caught and the previous year. Incremental growth for that year was then computed by taking the difference between the two back-calculated lengths to find the growth of the individual fish for the previous year. An ANCOVA was performed on the regressions of previous length at age and incremental growth to examine differences in growth for the previous year between stream types (Figure 15). Based on the analysis, rainbow trout in barrier streams demonstrated significantly higher growth (approximately 10 mm) than in reference streams (P=0.0017).

Catch curves were constructed for all four streams to examine differences in mortality of rainbow trout among stream types. Based on the catch curves, rainbow trout appeared to be fully selected by the backpack electroshocker at age one, therefore, age zero fish were dropped from the analysis (Figure 16, Figure 17). Since I caught only two fish in Miners River that were older than age zero, I excluded the Miners/Harlow pair from this analysis. The catch curves were log transformed such that I could test for differences in instantaneous mortality rate (i.e. slope of the line). Results from the ANCOVA, indicate there was no significant difference in mortality between the barrier and reference stream (P=0.3205).

White suckers showed a much broader age range from age zero to twelve for all streams sampled with most fish being age one (Table 10, Table 11). Mean age ranged from 1.00 to 3.90 years with white suckers being significantly older in barrier streams by approximately 0.4 years (P=0.0480). Within each reference stream, mean age of white sucker was similar between above and below sections except for the Poplar River in which mean age was higher in the above section. Mean age for barrier streams was



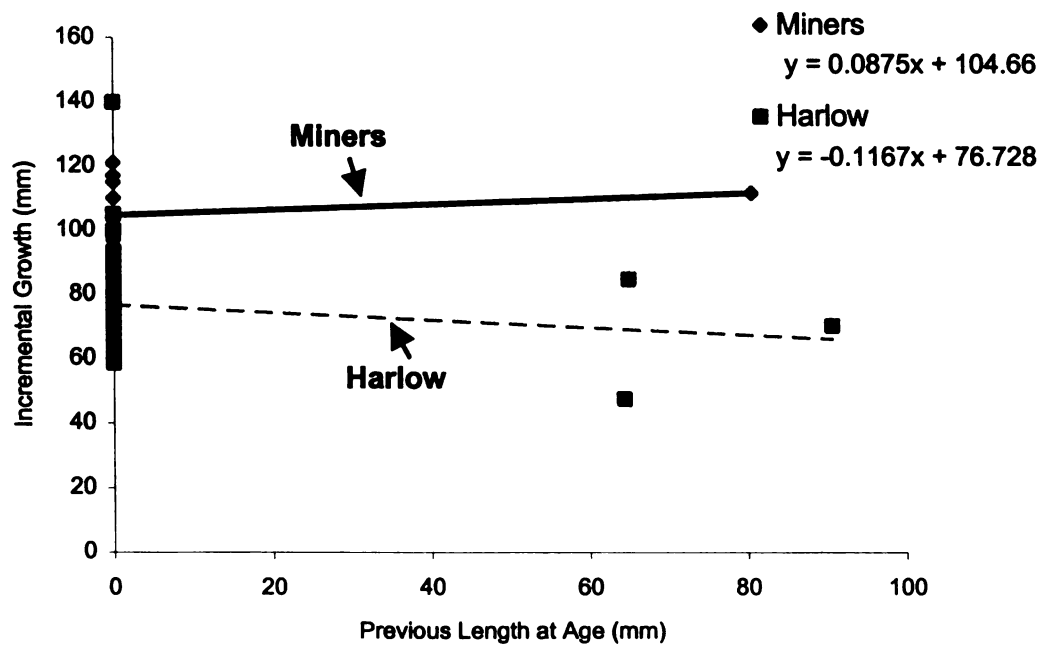


Figure 15. Growth of rainbow trout for East Branch AuGres/ West Branch Rifle pair (top) and Miners/Harlow pair (bottom).

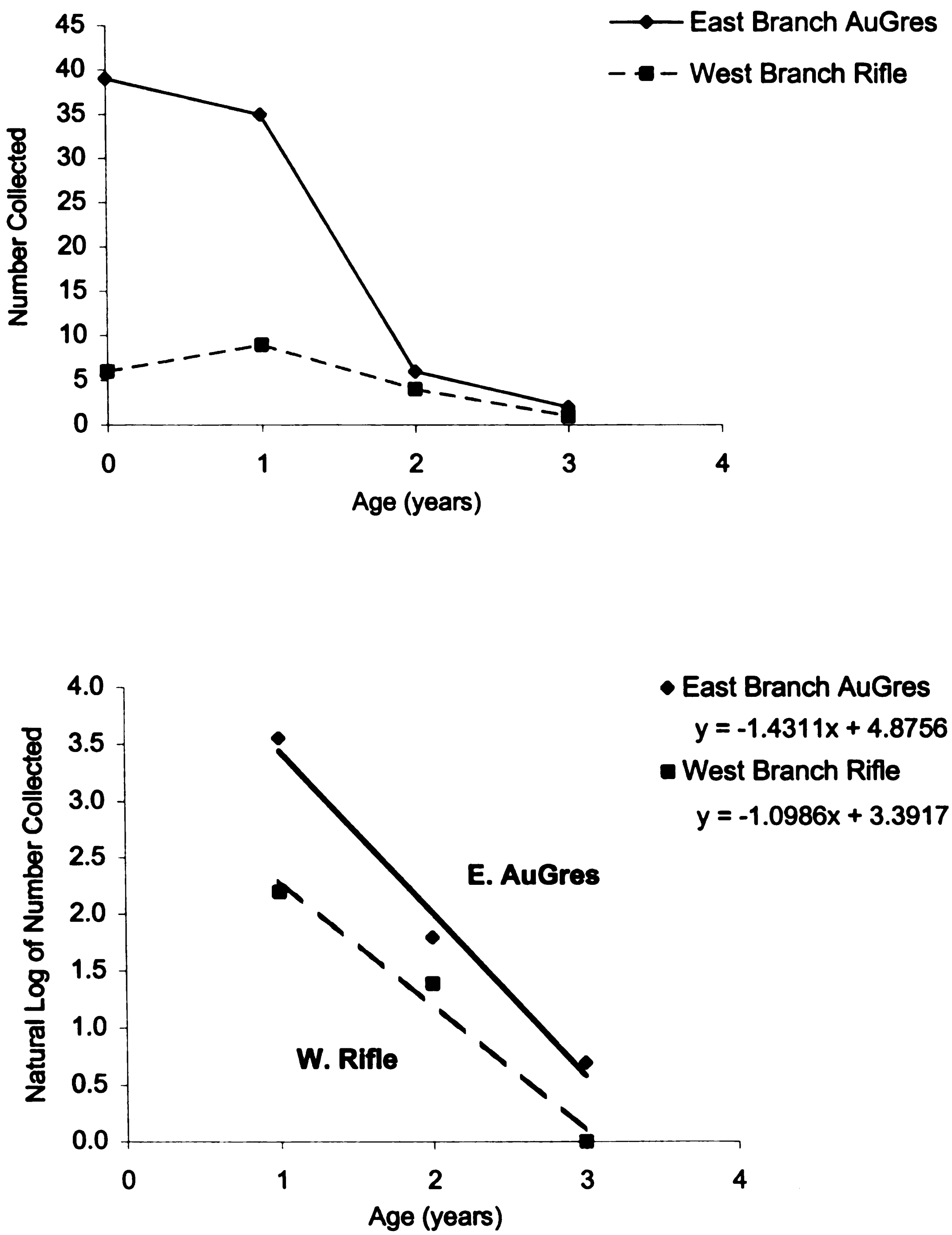


Figure 16. Catch curve and natural log transformed catch curve for rainbow trout for East Branch AuGres/West Branch Rifle stream pair.

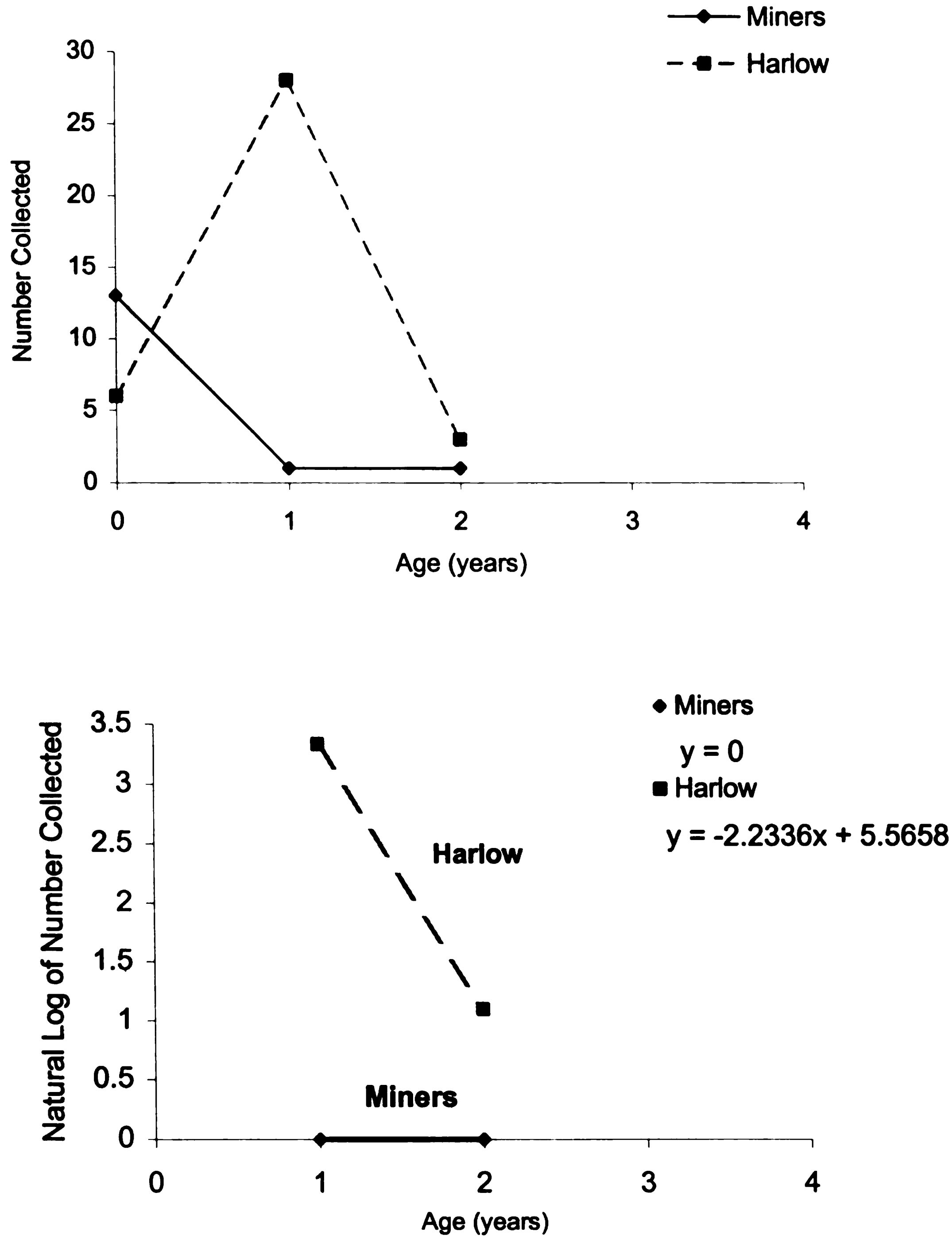


Figure 17. Catch curve and natural log transformed catch curve for rainbow trout for Miners/Harlow stream pair.

Table 10. Number at age and mean age of white sucker for each stream.

	Age													Mean
Stream	0	1	2	3	4	5	6	7	8	9	10	11	12	Age
East Branch AuGres	3	13	9	6	2	1	0	1	0	0	0	0	0	1.97
West Branch Rifle	0	19	12	11	8	2	1	0	0	0	0	0	0	2.34
Miners	0	10	2	0	0	2	1	1	1	1	1	1	1	3.90
Harlow	0	21	2	1	0	0	0	0	0	0	0	0	0	1.17
West Whitefish	0	6	1	2	0	0	0	0	0	0	0	0	0	1.56
East Whitefish	0	6	0	0	0	0	0	0	0	0	0	0	0	1.00
Middle	0	17	14	12	0	0	0	0	0	0	0	0	0	1.88
Poplar	0	24	12	10	3	0	1	0	0	0	0	0	0	1.92

Table 11. Number at age and mean age of white sucker for above and below sections.

		Age													Mean
Stream	Position	0	1	2	3	4	5	6	7	8	9	10	11	12	Age
East Branch AuGres	Above	0	3	5	5	0	1	0	0	0	0	0	0	0	2.36
	Below	3	10	4	1	2	0	0	1	0	0	0	0	0	1.71
West Branch Rifle	Above	0	10	7	7	4	0	1	0	0	0	0	0	0	2.31
	Below	0	9	5	4	4	2	0	0	0	0	0	0	0	2.38
Miners	Above	0	3	1	0	0	0	0	0	0	0	0	0	0	1.25
	Below	0	7	1	0	0	2	1	1	1	1	1	1	1	4.56
Harlow	Above	0	4	1	0	0	0	0	0	0	0	0	0	0	1.20
	Below	0	17	1	1	0	0	0	0	0	0	0	0	0	1.16
West Whitefish	Above	0	5	1	2	0	0	0	0	0	0	0	0	0	1.63
	Below	0	1	0	0	0	0	0	0	0	0	0	0	0	1.00
East Whitefish	Above	0	2	0	0	0	0	0	0	0	0	0	0	0	1.00
	Below	0	4	0	0	0	0	0	0	0	0	0	0	0	1.00
Middle	Above	0	9	6	3	0	0	0	0	0	0	0	0	0	1.67
	Below	0	8	8	9	0	0	0	0	0	0	0	0	0	2.04
Poplar	Above	0	8	8	10	3	0	1	0	0	0	0	0	0	2.40
	Below	0	16	4	0	0	0	0	0	0	0	0	0	0	1.20

highest in above sections of the East Branch AuGres and West Whitefish, while the other two barrier streams (Miners and Middle) showed older white suckers in the below sections. Taking into account all stream pairs, I found a significant difference in mean age among the four stream positions (P=0.0017). White suckers above barrier dams were significantly younger than those in the below section by approximately 0.7 years (P=0.0005). Within reference streams, mean age was significantly higher in upstream sections (by 0.7 years) compared to downstream sections (P=0.0157). There was also a significant difference between the below sections of barrier and reference streams with the barrier below section consisting of older white suckers (P=0.0002).

As with rainbow trout, a regression of white sucker fish length on fin ray radius was used to back-calculate previous lengths at age (Figure 18). The regressions of previous length at age on incremental growth was analyzed for each stream pair to examine differences in growth between stream types (Figure 19, Figure 20). Based on the ANCOVA, stream type showed a significant interaction with previous length at age (P=0.0046) and growth was not found to be significantly different between barrier and reference streams (P=0.7707).

For all streams, catch curves were created to detect differences in white sucker mortality. White suckers were fully selected by the backpack electroshocker at age two, therefore, age zero and age one fish were excluded (Figure 21). Since fish older than age one were not caught in the East Whitefish River, I excluded this pair from this analysis. An ANCOVA performed on the slopes of the regressions showed a significant difference in instantaneous mortality rate between the barrier and reference stream ($P_{stream\ type\ *\ age}$=0.0128).

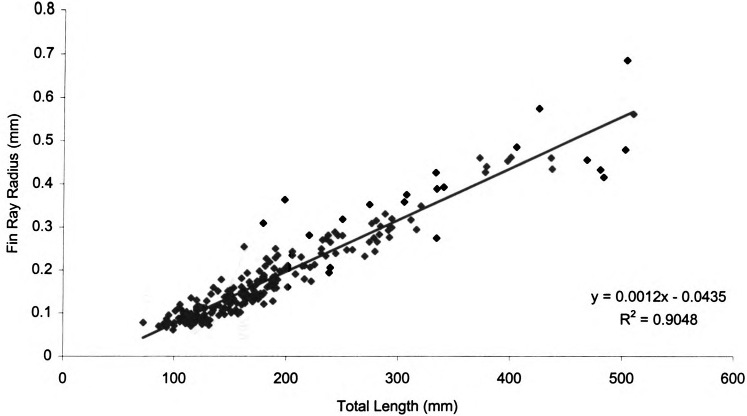
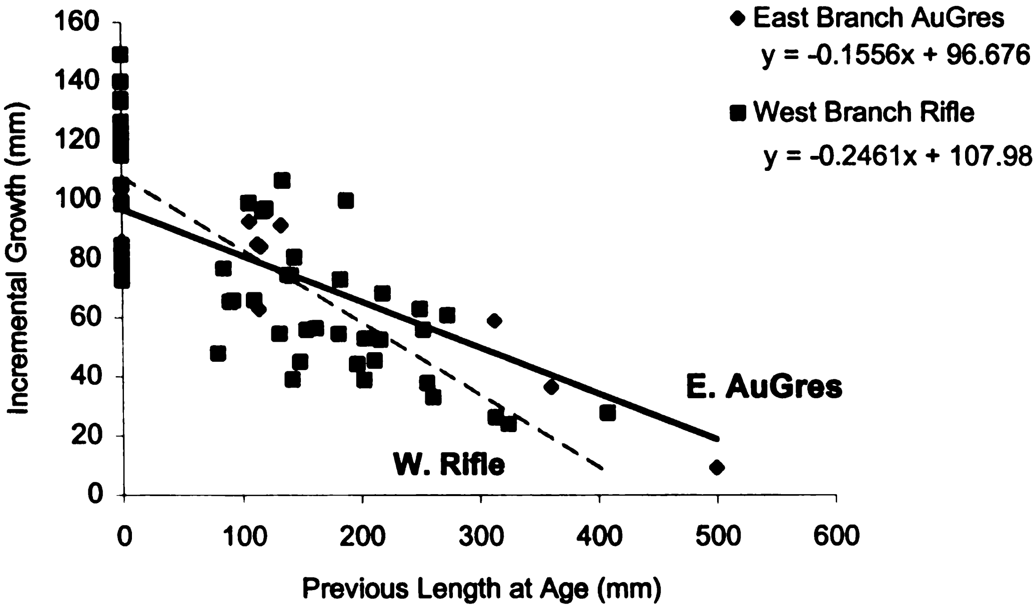


Figure 18. Regression of fish length on fin ray radius for back-calculations of length at age for white sucker.



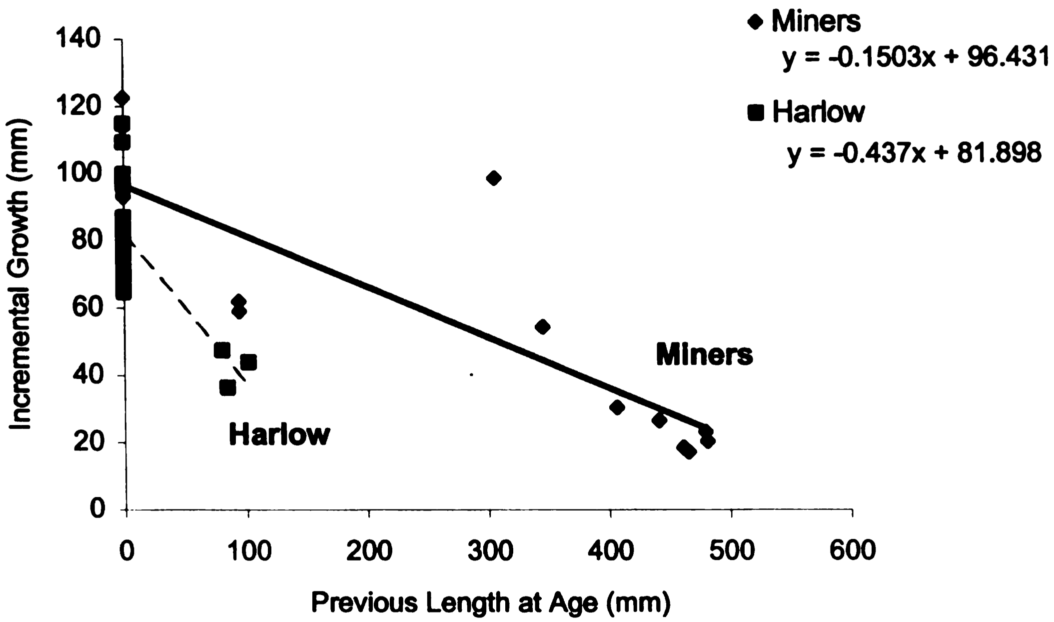


Figure 19. Growth of white sucker for East Branch AuGres/ West Branch Rifle pair (top) and Miners/Harlow pair (bottom).

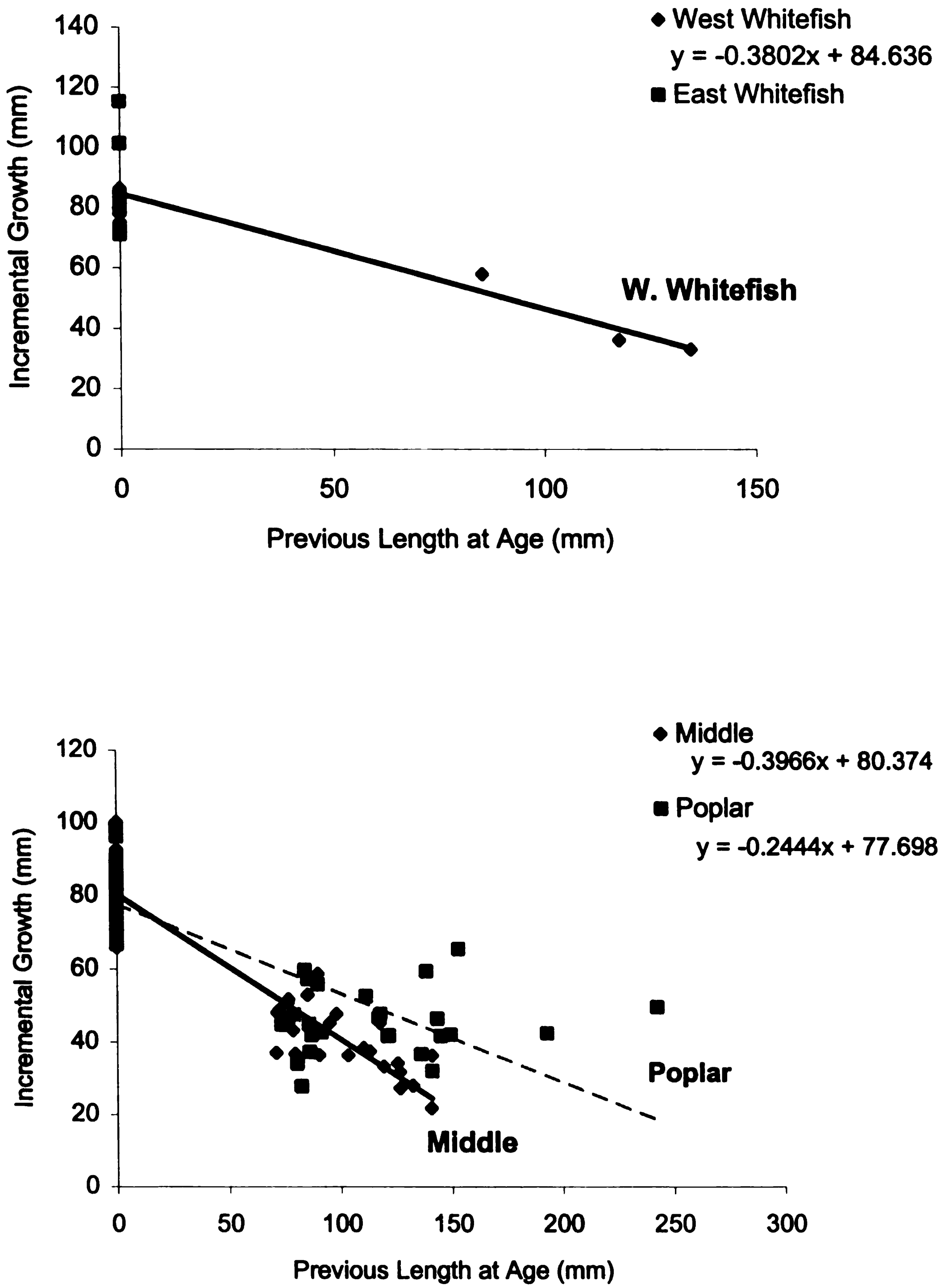


Figure 20. Growth of white sucker for West Whitefish/East Whitefish pair (top) and Middle/Poplar pair (bottom).

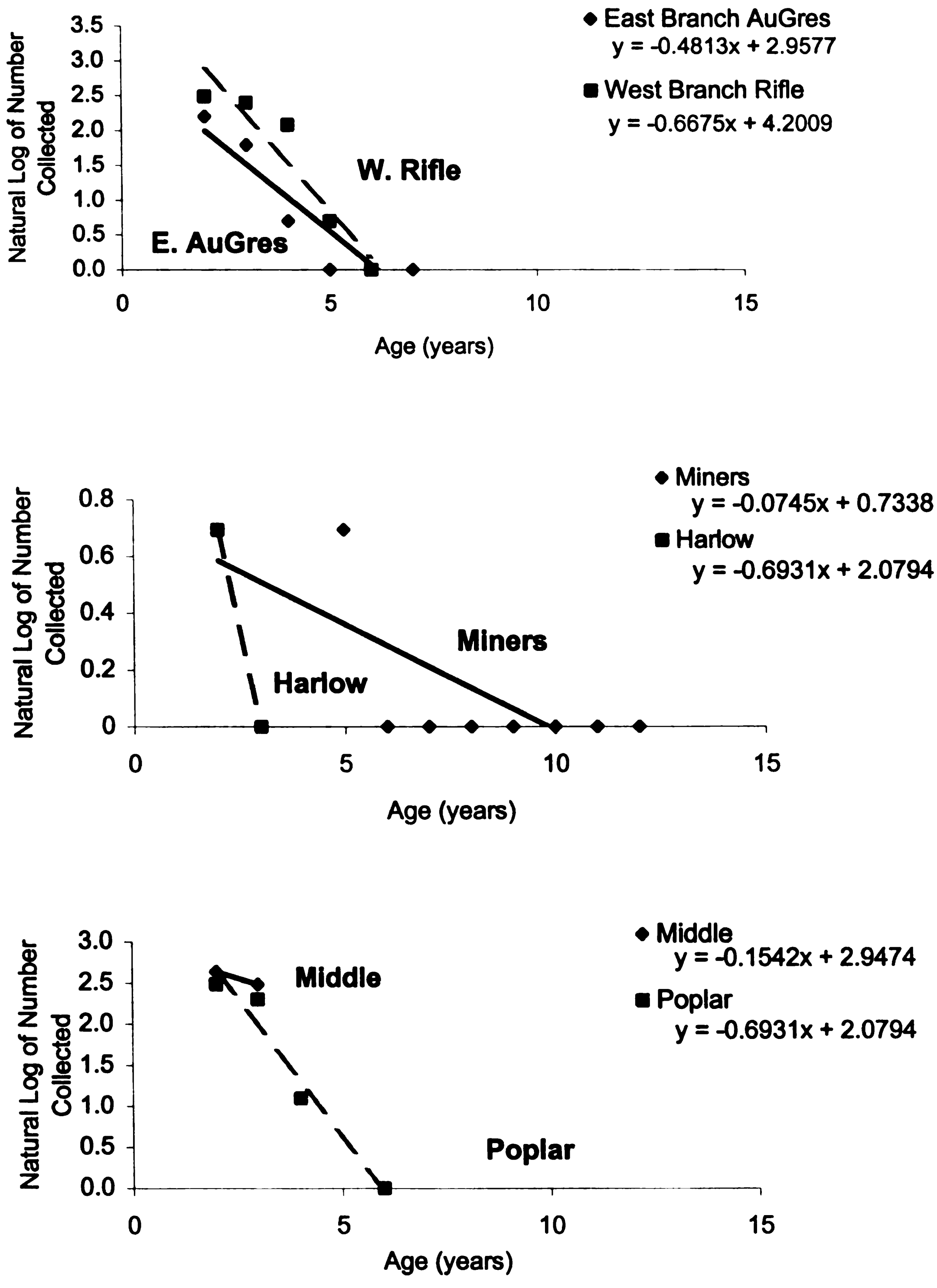


Figure 21. Natural log transformed catch curves for white suckers for East Branch AuGres/West Branch Rifle pair (top), Miners/Harlow pair (middle), and Middle/Poplar pair (bottom).

DISCUSSION

Based on the general habitat characteristics we measured, streams with low-head barriers showed relatively little habitat alteration when compared to reference streams. Average width and average maximum depth were found to be significantly higher in barrier streams, but mean substrate size and mean water temperature was similar between the two stream types. Based on the River Continuum Concept (Vannote et al. 1980), I anticipated seeing a gradual increase in width, depth, and temperature and a decrease in substrate size moving in a downstream direction. Both barrier and reference streams follow this trend of increased width and depth downstream, but sites directly above the impoundment (Above 1site) are deeper on average compared to those sites in reference streams (Figure 4). Although we tried to exclude the impoundment from our sampling protocol, our sites closest to the dam may have been within the impacted zone upstream of the small reservoir were the stream began to deepen.

According to Ward and Stanford (1983), dams slow the flow of water creating a reservoir and often act as sediment traps. From this knowledge, sites closest to the dam (Above 1 sites) would be expected to have a greater portion of fine substrate particles such as silt and sand and the site directly downstream to have coarser substrate. This was not evident in our graph of mean substrate size where substrate size is consistent at sites above and below the barrier (Figure 5). This suggests that these dams are not large enough to significantly change the substrate composition of the stream. Temperature, which is often affected by surface release dams such as these, might be expected to increase directly below the barrier relative to that site in the reference stream (Fraley

1979). However, we see that average temperature is not appreciably greater directly below the dam compared to above sites within barrier streams and that the Below 1 sites in barrier streams are actually cooler on average than the Below 1 sites in reference streams. This indicates that low-head barrier dams do not retain water long enough to noticeably increase the temperature of the stream and that the higher temperatures in reference streams may be due to them being somewhat shallower and narrower, allowing light to penetrate further down the water column. Beyond the small impoundment above the dam and the plunge pool just below, barrier dams did not have substantial impacts on the physical habitat in the study streams.

For community composition between stream positions, species richness was found to be higher in both upstream and downstream sections of barrier streams relative to reference streams. This may be due to barrier streams being wider and deeper on average allowing for more species to be sustained in these streams. Examining temporal variation of the fish community, little variability in average species richness was evident between summers for both stream types, indicating that barriers are not impacting the stability of these streams in terms of number of species caught, although the actual species present may change from year to year.

Comparing the trends in average width and maximum depth (Figure 4) with those of average richness and relative abundance (Figure 6, Figure 7), I found that the habitat characteristics we measured had very little explanatory power on the differences among stream types. For reference streams, trends in habitat seem to be more closely linked to trends in average richness and mean abundance. In streams without barriers, average width, maximum depth, and species richness generally increased in a downstream direction, while catch per area declined from upstream to downstream. With width and depth increasing in a downstream direction, I anticipated seeing higher numbers of fish moving downstream. This prediction was not supported in my study for reasons that are unclear at this time. For streams with low-head barriers, mean width, maximum depth, and average richness also showed a general increase downstream, but there is a distinct peak in richness directly below the dam which is not seen for width or depth. Mean catch for barrier streams also showed a distinct peak below the dams that then declined, but, unlike species richness, mean catch in above sites declined towards the barriers. The ANCOVA analyses suggested that width and/or depth do explain some variation seen in species richness and mean abundance, however, the trends between habitat and mean richness or abundance within barrier streams are not as closely linked as they appear to be in reference streams, indicating these dams are not influencing the richness and abundance of the fish community by habitat alteration. A significant number of species, approximately 2.5 species, were lost upstream due to low-head barrier dams, suggesting that these barriers are indeed having an impact on species richness in these streams. When I excluded sea lamprey from the analysis on species lost upstream of the dam, I found the average loss of species declined slightly to approximately 2.3 species lost above the barrier. Although barrier streams were significantly different than reference streams in terms of width and depth, these differences in habitat do not account for the greater species richness seen in barrier streams, the high number of species found directly below the dam, nor the greater loss of species within barrier streams.

Characteristics of the barriers were also found to have no explanatory power on number of species lost above the dam, indicating that the impact of the dam did not increase with the size of the dams in this study. It is important to note, however, that all of the dams in this study were quite small and that this conclusion does not extend to dams larger than I examined. From the analyses of habitat and barrier characteristics on species richness along with the high peak in richness and abundance found directly below the dam, I conclude that the trends seen in mean species richness and mean relative abundance within barrier streams can best be explained by the blocking of fish movement by the dam regardless of its size, resulting in an aggregation of species downstream. An additive result of the dam may also be an increase in macroinvertebrate drift over the barrier, thus, increasing the food resource and resulting in continual aggregation of fish downstream of the dam. Since I did not investigate macroinvertebrate drift over the dam, I can only speculate as to this being a possible effect of the barrier on the stream community.

Using reference streams as a guide to expected similarity between upstream and downstream fish communities, above and below sections of barrier streams are relatively similar when compared to the Sϕrensen's index for reference streams. If barrier dams were severely impacting the fish community, the community similarity within barrier streams would be much lower compared to reference streams. Thus, despite the greater loss of species above barriers, I concluded that the species composition is quite similar above and below the barrier. Community size composition was also shown to be similar between above and below stream sections of barrier and reference streams with no significant impact of barrier dams on community size. Therefore, at the community level, barriers produce no substantial impact on species composition or size of the fish community.

As seen from our frequency of occurrence data, low-head barrier dams are successful in preventing sea lamprey from migrating upstream, however they also appear to affect movements of some non-target species. Non-jumping species such as yellow perch, trout-perch, and logperch were negatively impacted by barriers in terms of frequency of occurrence and mean abundance, indicating that movement of these species upstream is greatly affected by the dam. Black bullheads were positively affected by the presence of a low-head barrier dam, which may be due to utilization of the small impoundment by this species. For native lampreys, such as american brook lamprey, I suspect the barrier creates a refuge from lampricides due to the fact that only downstream sections are treated. In this study, low-head barrier dams were shown to affect individual sensitive species with some species being negatively impacted while others showed a positive impact in occurrence or abundance.

Since I suspected that low-head dams may block fish from migrating upstream, I examined the effects of barriers on age and growth of two migrating species: rainbow trout, a jumping species, and white sucker, a non-jumping species. Because low-head barrier dams are designed and constructed to allow salmonids to pass, I predicted barriers would have no significant impact on the age and growth of this species. However, from my analysis, I found that rainbow trout were significantly younger in barrier streams particularly downstream of the dam, grew significantly faster, and were less abundant overall in barrier streams, but showed no differences in instantaneous mortality rate (Table 12). One possible explanation for faster growth in barrier streams may be due to

Table 12. Comparisons between barrier and reference streams for age, growth, mortality, and abundance of rainbow trout (top) and white suckers (bottom).

Rainbow trout	BARRIER	REFERENCE
MEAN AGE	Younger Below Younger Overall	Younger Above Older Overall
GROWTH	Faster	Slower
MORTALITY	No Difference	No Difference
MEAN ABUNDANCE	Less Abundant	More Abundant

White sucker	BARRIER	REFERENCE
MEAN AGE	Younger Above Older Overall	Younger Below Younger Overall
GROWTH	No Difference	No Difference
MORTALITY	Lower	Higher
MEAN ABUNDANCE	More Abundant	Less Abundant

density dependent factors. With rainbow trout less abundant in barrier streams, the prey-to-predator ratio is higher, allowing individual rainbow trout to have access to a higher number of macroinvertebrates. TFM treatments increases drift of macroinvertebrates severely (Dermott and Spence 1984; Kolton et al. 1986). Thus, the stream section above the dam, where TFM is not used, may act as a refuge creating relatively large populations of macroinvertebrates. This may also explain the slightly older population of rainbow trout above the dams where older rainbow trout are traversing the barrier to utilize the abundant prey resource upstream. A related explanation of faster rainbow trout growth could be higher drift of macroinvertebrates over the dam from the populations upstream increasing the prey resource for trout in this area allowing rainbow trout to attain smolt size (size at time of migration to the Great Lakes) at an earlier age shifting the population age structure to a younger mean age.

Another explanation for faster rainbow trout growth might be higher productivity in streams with dams. Streams with low-head barriers were chosen for dam construction based on the fact that these streams had high production of sea lamprey. Since larval sea lamprey are filter-feeders, they thrive better in streams with higher course (CPOM) and fine particulate organic matter (FPOM) (Moore and Mallatt 1980). This nutrient source is also a major diet component of many aquatic macroinvertebrates (Merritt and Cummins 1996), thus, streams with more CPOM and FPOM, should produce higher biomass of macroinvertebrates, a major prey source for rainbow trout (Scott and Crossman 1973) allowing rainbow trout to grow faster in streams with barrier dams. Because I did not measure productivity or macroinvertebrate composition/numbers, I can only speculate as to the mechanisms affecting the growth and age structure of rainbow trout in barrier streams.

Since adult white suckers also feed on aquatic insects (Trembly and Magnan 1991; Hayes et. al. 1992), I would expect a higher macroinvertebrate fauna to also produce an increase in growth of white sucker. However, this was not observed in the data (Table 12). One plausible reason to explain a lack of difference in growth between stream types assuming barrier streams are more productive may be due to intraspecific and interspecific competition. White suckers are more abundant in barrier streams possibly increasing competition among the population and, due to white suckers also feeding on invertebrates, they might be out competed by other species such as the territorial rainbow trout for similar food resources (Scott and Crossman 1973). Trembly and Magnan (1991) found evidence of competition of food resources between white sucker and brook trout, but, in their study, white sucker out competed brook trout shifting the diet of brook trout from zoobethos to zooplankton. Because trout in the stream feed in the water column whereas juvenile and adult white sucker feed on the bottom (including macroinvertebrates), the possibility of higher macroinvertebrate drift across the barrier (which was speculated to increase rainbow trout growth in barrier streams) would not benefit the white sucker. Therefore, the availability of macroinvertebrates to this species may be similar between stream types regardless of a possibly higher prey source in barrier streams.

Like macroinvertebrates and native lamprey, white suckers are also adversely affected by TFM treatments especially during times of stress (Dahl and McDonald 1980), thus, barrier dams may act as a refuge upstream lowering mortality in barrier streams overall.

According to the literature (Dahl and McDonald 1980; Hunn and Youngs 1980), white suckers are unable to move across the barrier and therefore unable to migrate upstream to spawn. From the information in the literature, I anticipated a perched population of white suckers upstream which were younger on average than the population downstream due to the inability for spawning adults to traverse the barrier moving upstream but able to traverse moving downstream during feeding migration. From my analysis, I found white suckers to be older overall in barrier streams but significantly younger above dams, suggesting that low-head dams may be impacting the age structure of the upstream population by acting as a source of mortality for above sections. Another possible explanation might be that older larger white suckers utilize the impoundment, acting as a population source, but went undetected in the study because the reservoir was not sampled. According to Erman (1973), white suckers increased in abundance and were smaller upstream of the reservoir after dam construction, with larger fish being caught in the impoundment. He attributed this to utilization of the reservoir by larger white suckers while smaller suckers remained in the stream. As such, I conclude that although some non-jumping species may not be able to maintain their populations above barriers (i.e. yellow perch or trout-perch), white suckers are either able to traverse the barrier when water levels are high during the spring or to maintain their population despite an impairment to movement (i.e. use of reservoir for protection or food by lager fish).

CONCLUSIONS

Although barrier streams were found to be significantly wider and deeper than reference streams, there was relatively little effect of the barrier on the general habitat measurements we examined. An impact on number of species seen above the barrier dam was evident, but width and maximum depth could not explain the trend of high species richness below the dam nor the greater loss of species upstream of the barrier. Therefore, I conclude that the major mechanism of impact on species richness is the blocking of fish movement upstream, although at the community level, low-head barriers had a relatively small influence on species composition or community size composition between upstream and downstream sections.

In this study, low-head barriers were found to be effective in blocking sea lamprey, reducing the amount of stream needing treatment by lampricides, but had relatively little effect on stream habitat and fish communities. Although I found an average loss of 2.5 species upstream, a portion of that loss can be attributed to the loss of sea lamprey above the dam. Other fish species that were completely blocked by the barriers were yellow perch and trout-perch. Although yellow perch is a game species in the Great Lakes, this fish is primarily a lentic species that may use calm rivers during certain life stages such as spawning or feeding (Scott and Crossman 1973). The trout-perch, both a lentic and lotic species, mature at age one with most dying after spawning only once (Kinney 1950; Scott and Crossman 1973). Although barriers affect the distribution of trout-perch within the stream, the residence time of this species in streams is low such that barriers may not have a severe impact on the population age structure or growth. Therefore, the average loss of 2.5 species due to the dams can be considered to be a biologically minor impact on the stream community.

In some cases, barrier dams appeared to have a positive effect possibly through creation of habitat immediately upstream or downstream of the dam or creation of a refuge from chemical treatments (particularly for native lampreys). Further study is needed to determine the specific mechanisms of impact on potentially sensitive species.

Rainbow trout age and growth showed to be impacted within barrier streams by a mechanism(s) that is unclear and which may become apparent with further study of the productivity and macroinvertebrate fauna of barrier streams. Contrary to the literature, white suckers did not appear to be negatively affected by the presence of a barrier in terms of overall abundance, growth, or mortality. As stated previously, this may be due to white suckers traversing the barrier during times of breach or the ability of white suckers to sustain a population despite blockage to movement.

In conclusion, our results show low-head barrier dams have relatively little impact on the fish community and are a viable alternative to other sea lamprey control methods. By building these low-head barrier dams the amount of TFM applied to the stream ecosystem can be reduced benefiting fish species sensitive to chemical treatments (i.e. native lampreys and white suckers) as well as their prey sources (i.e. macroinvertebrates). As such, the low-head barrier dam control program should be continued as a supplemental method to reduce the use of lampricides in Great Lakes tributaries while maintaining sea lamprey abundance at target levels.

APPENDICES

APPENDIX A. Average differences in mean width, maximum depth, and particle size (1=clay 2=silt 3=sand 4=gravel 5=cobble 6=boulder 7=bedrock) between barrier and reference streams for each stream pair for 1996 and 1997 combined.

Stream Pair	Barrier Width (m)	Reference Width (m)	Difference Width (m)	Barrier Depth (cm)	Reference Depth (cm)	Difference Depth (cm)	Barrier Part. Size	Reference Part. Size	Difference Part. Size
1	10.2	8.6	1.6	69.3	77.8	-8.5	3.4	3.5	-0.1
2	6.1	3.9	2.2	51.2	65.5	-14.3	3.6	2.9	0.7
3	16.7	10.2	6.5	98.8	52.4	46.4	3.6	4.5	-0.9
4	10.6	3.6	7.0	66.5	32.9	33.6	5.1	4.0	1.1
5	15.0	10.3	4.7	72.8	57.3	15.5	5.0	4.8	0.2
6	8.8	11.1	-2.3	78.2	93.7	-15.5	2.8	2.5	0.3
7	18.3	17.7	0.6	95.6	61.1	34.5	3.3	3.6	-0.3
8	20.0	14.1	5.9	65.3	47.7	17.6	4.8	3.8	1.0
9	11.3	6.1	5.2	57.7	43.6	14.1	4.0	3.3	0.7
10	20.4	17.0	3.4	60.6	49.8	10.8	5.3	4.8	0.5
12	8.8	5.9	2.9	72.0	61.6	10.4	3.8	3.4	0.4
13	10.1	5.1	5.0	103.4	45.6	57.8	3.1	3.2	-0.1
14	8.0	13.1	-5.1	60.2	79.2	-19.0	3.9	4.4	-0.5
15	9.8	14.6	-4.8	55.8	43.3	12.5	4.6	5.6	-1.0
16	9.6	14.2	-4.6	69.9	72.2	-2.3	3.4	3.5	-0.1
17	11.7	7.4	4.3	46.6	35.2	11.4	5.0	5.2	-0.2
18	11.8	15.7	-3.9	87.8	69.1	18.7	3.2	4.4	-1.2
19	4.8	2.7	2.1	49.8	33.9	15.9	2.4	2.9	-0.5
20	3.9	4.4	-0.5	23.4	30.1	-6.7	2.9	4.1	-1.2

APPENDIX A. (cont'd)

Stream Pair	Barrier Width (m)	Reference Width (m)	Difference Width (m)	Barrier Depth (cm)	Reference Depth (cm)	Difference Depth (cm)	Barrier Part. Size	Reference Part. Size	Difference Part. Size
21	8.6	2.7	5.9	65.3	33.9	31.4	3.4	2.9	0.5
22	12.8	8.2	4.6	77.3	30.9	46.4	3.7	4.1	-0.4
23	4.4	3.2	1.2	32.8	37.9	-5.1	4.3	3.0	1.3
24	13.4	11.1	2.3	54.6	33.8	20.8	5.6	5.1	0.5
25	8.9	7.5	1.4	54.6	45.0	9.6	3.8	4.1	-0.3
Mean	11.0	9.1	1.9	65.4	51.4	13.9	3.9	3.9	0.0

APPENDIX B. Percentage of stream bed particles for each stream sampled combining summer 1996 and 1997.

Stream Pair No.	Stream Name	Stream Type	Percent Clay	Percent Silt	Percent Sand	Percent Gravel	Percent Cobble	Percent Boulder	Percent Bedrock
1	East Branch AuGres	Barrier	6.76	9.05	36.37	37.76	5.08	4.97	0.00
1	West Branch Rifle	Reference	0.67	10.78	41.17	34.44	10.67	2.28	0.00
2	Albany	Barrier	0.11	11.78	44.85	21.30	16.03	5.92	0.00
2	Beavertail	Reference	5.11	26.85	46.96	12.96	7.89	0.22	0.00
3	Echo	Barrier	6.17	0.89	49.44	18.56	20.33	4.61	0.00
3	Root	Reference	3.72	0.33	5.22	37.11	37.67	15.94	0.00
4	Kuskawong	Barrier	0.78	2.00	3.89	17.00	34.33	42.00	0.00
4	Brown	Reference	3.89	1.33	23.89	38.22	25.33	7.33	0.00
5	Manitou	Barrier	1.11	4.89	6.56	12.33	38.67	27.44	9.00
5	Blue Jay	Reference	3.56	8.31	13.90	13.39	21.86	11.86	27.12
6	Sturgeon	Barrier	5.80	21.81	63.30	5.23	2.16	1.70	0.00
6	Mad	Reference	19.07	12.00	68.93	0.00	0.00	0.00	0.00
7	Betsie	Barrier	0.00	7.67	63.56	22.33	5.22	1.22	0.00
7	Upper Platte	Reference	0.00	17.44	19.67	50.00	10.33	2.56	0.00
8	Kewaunee	Barrier	0.30	5.53	7.24	29.98	32.39	10.66	13.88
8	Ahnapee	Reference	0.00	29.01	13.79	20.81	31.39	4.99	0.00
9	East Twin	Barrier	0.45	9.05	8.90	57.86	19.73	3.41	0.59
9	Hibbards	Reference	1.11	29.83	14.64	40.88	11.60	1.93	0.00
10	West Branch of the Whitefish	Barrier	0.00	6.42	6.01	11.54	44.26	9.36	29.44
10	East Branch of the Whitefish	Reference	2.56	19.58	2.88	14.85	23.06	1.69	35.40
12	Miners	Barrier	0.00	5.72	54.39	10.11	17.44	10.00	2.33
12	Harlow	Reference	0.00	8.67	58.09	16.56	13.51	3.16	0.00

APPENDIX B. (con't)

Stream Pair No.	Stream Name	Stream Type	Percent Clay	Percent Silt	Percent Sand	Percent Gravel	Percent Cobble	Percent Boulder	Percent Bedrock
13	Big Carp	Barrier	8.04	8.70	67.17	5.32	3.15	7.61	0.00
13	Little Carp	Reference	0.78	4.78	72.78	19.33	0.56	1.78	0.00
14	Stokely	Barrier	0.00	3.22	33.67	40.44	19.44	3.22	0.00
14	Pancake	Reference	1.11	0.00	20.22	34.78	29.67	9.56	4.67
15	Days	Barrier	0.00	5.87	19.75	27.22	25.80	2.49	18.86
15	Rapid	Reference	0.00	5.83	6.32	17.87	17.37	4.09	48.51
16	Misery	Barrier	0.00	6.62	77.81	4.14	6.13	0.50	4.80
16	Firesteel	Reference	0.00	9.93	43.27	39.39	4.04	1.18	2.19
17	Middle	Barrier	0.00	0.24	12.34	20.99	34.36	15.25	16.82
17	Poplar	Reference	0.00	2.63	6.13	22.28	33.17	15.89	19.90
18	Neebing	Barrier	0.00	66.62	0.00	16.14	5.61	11.63	0.00
18	Whitefish	Reference	0.00	6.08	3.78	50.41	31.08	5.00	3.65
19	Clear	Barrier	29.73	28.67	30.00	2.80	4.67	4.13	0.00
19	South Otter	Reference	0.00	23.89	70.22	2.22	2.33	1.33	0.00
20	Forestville	Barrier	10.89	0.00	83.33	4.89	0.22	0.11	0.56
20	Fishers	Reference	1.11	2.56	30.33	23.78	31.22	10.78	0.22
21	Youngs	Barrier	8.13	9.29	45.44	16.75	13.27	7.13	0.00
21	South Otter	Reference	0.00	23.89	70.22	2.22	2.33	1.33	0.00
22	Duffins	Barrier	9.19	5.32	27.35	27.80	24.47	5.87	0.00
22	Lynde	Reference	3.44	9.89	12.33	33.11	31.22	10.00	0.00
23	Grafton	Barrier	1.78	9.67	13.78	27.22	31.00	15.10	1.44
23	Salem	Reference	18.93	19.27	19.93	24.27	16.37	1.22	0.00

APPENDIX B. (cont'd)

Stream Pair No.	Stream Name	Stream Type	Percent Clay	Percent Silt	Percent Sand	Percent Gravel	Percent Cobble	Percent Boulder	Percent Bedrock
24	Little Salmon	Barrier	0.78	1.44	1.44	9.33	27.77	34.22	25.00
24	Grindstone	Reference	0.67	2.79	7.36	10.83	34.15	44.19	0.00
25	Shelter Valley	Barrier	2.00	10.83	39.00	8.50	29.17	10.50	0.00
25	Wilmot	Reference	6.11	7.89	6.78	28.67	46.11	4.44	0.00

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