GREAT LAKES FISHERY COMMISSION

1999 Project Completion Report[1]

Biological Impact of Low-head Barrier Dams

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Biological Impact of Low-head Barrier Dams

BILD

1999 FINAL COMPLETION REPORT

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Executive Summary

Several lines of evidence from our Project suggest that low-head barrier dams have impacts on stream fish communities around the Great Lakes. Barrier streams have more fish species overall than do Reference streams (without barrier dams), possibly because of differential “colonization” and “extinction” of species in Barrier and Reference streams. On average, the number of fish species present declines from downstream to upstream, but this decline is greater for Barrier streams than for Reference streams by an increment of two species on average. Similarity indices comparing the fish communities Above and Below barrier dams are lower than those for corresponding sections of Reference streams. In Barrier streams, species richness shows a distinct peak just downstream of the dam that then decreases toward the mouth. This may reflect a “bottleneck” on fish movements. Reference streams show a gradual increase in species richness downstream. Some species are more sensitive in terms of exhibiting changes in their relative abundance Above or Below barriers. The most significant of these sensitive species is the sea lamprey, *Petromyzon marinus*, which we never found above barrier dams. Movements of some fish species are restricted by barrier dams, and the effect is highly seasonal.

Analyses of historical data suggest that the time course of the impacts of barrier dams on species richness is on the order of decades. Comparisons of fish communities and habitat in streams with natural barriers (waterfalls),

streams with barrier dams, and Reference streams indicate that the ecological effects of barrier dams are comparable to those of having a natural barrier present.

Low - head barriers have relatively small effects on the size composition of fish species communities above barriers. Barrier streams are significantly wider and deeper than Reference streams, but these differences do not explain differences in fish communities between Barrier and Reference streams. These habitat differences appear to be inherent features of the streams that have been selected for barriers. Some fish species are affected by barriers in ways suggesting that barriers create suitable habitat immediately upstream or downstream of the barrier. In particular, native lampreys exhibit increased relative abundance in areas above low - head barrier dams, possibly due to reduced application of chemical lampricide, or to reduced competition from sea lamprey.

Allowing passage of nontarget fish species would likely reduce the impacts of barriers. This could be achieved by seasonal operation of barriers with adjustable crests to allow fish passage outside lamprey spawning season, or by greater use of fishways or bypass channels.

A. Review of Objectives and Deliverables

Project Objectives

This Project is a three (3) year research project to:

(i) assess the broad-scale impacts of low-head barriers on communities of stream fishes across the Great Lakes;

(ii) identify the species experiencing the greatest impact;

(iii) assess specific mechanisms of how low-head barriers impact these sensitive species; and,

(iv) recommend modifications in design and operation of low-head barriers, in consultation with control agencies and technical experts, to minimize their impact on non-target species while enhancing or retaining their efficiency at lamprey control.

Year 1 (1996) addressed objectives (i) and (ii) by:

(a) developing and analyzing a historical database for Great Lakes tributary stream fishes,

(b) developing a standardized protocol for sampling the composition, abundance, and size structure of stream fish communities, and

(c) using this standardized sampling protocol to carry out an extensive field survey of tributary streams in the Great Lakes basin.

Year 2 (1997) addressed objective (iii) by:

(a) intensive study of selected pairs of Barrier and Reference streams across the Great Lakes basin,

(b) repetition of intensive sampling on a seasonal basis in selected stream pairs,

(c) mark - recapture study of fishes in pairs of Barrier and Reference streams, and

(d) analysis of ecomorphological characters of fishes in selected pairs of Barrier and Reference streams.

Year 3 (1998) addressed objectives (iii) by:

(a) repetition of intensive sampling on a seasonal basis in selected pairs of Barrier and Reference streams across the Great Lakes basin

(b) mark -recapture study of fishes in pairs of Barrier and Reference streams across the Great Lakes basin

(c) detailed studies of age and growth of selected fish species from Barrier and Reference streams across the Great Lakes basin, and

(d) detailed comparisons of fish species from streams with natural barriers and low head barrier dams.

Synopsis of Deliverables

1. An integrated, easily accessible database summarizing relevant historical information on communities of stream fishes inhabiting stream tributaries of the Great Lakes. Information regarding the database is also be available through the World Wide Web site for the Axelrod Institute of Ichthyology, University of Guelph.

2. A standard protocol for sampling communities of stream fishes.

3. Impacts of Low-head Barriers - Planning Workshop:

- initial analyses of integrated database
- selection of study streams for extensive field survey
- prioritization of additional factors to be considered as blocking effects
- finalization of a scientifically defensible design for the field survey

4. Impacts of Low-head Barrier - Year 1 Workshop:

- written annual report of results from the compilation of existing data and the extensive field survey, including species lists for each tributary studied, a ranking of the impact of low-head barriers on each species and each life-stage within species
- development of specific predictions regarding the mechanisms behind the observed impacts
- finalization and coordination of scientifically defensible study designs for the intensive field investigations

5. Impacts of Low-head Barrier - Year 2 Workshop:

- written, annual report of findings for year 2
- identification of specific changes to be made for year 3 in light of findings for year 2

6. Impacts of Low-head Barriers - Closing Workshop:

- written, annual report of finding for year 2 and 3
- consultations with control agents and technical experts regarding potential

modifications in the design and use of low-head barriers

7. Final Project Report:

- accessible database summarizing data collected during our extensive, field survey and during the intensive, multi-year field investigations
- final synopsis of our findings regarding the magnitude of the impact of low-head barrier dams on communities of fishes in the tributary streams along the Great Lakes and the mechanisms behind these impacts,
- recommendations (i) specifying modifications in the design of low-head barriers, (ii) identifying environmental circumstances influencing design or operation of barriers,
- recommendations for modifications in operation of barriers.

8. Graduate Theses and Publications

A minimum of three (3) graduate theses and corresponding publications in scientific journals.

B. Progress on Deliverables

Deliverables **1**, **2** and **3** have been completed, as described in **July 1996 Progress Report**.

Completion of Deliverable **4** was described in detail in the **1997 Annual Report.**

Deliverable **5** was completed at a Workshop meetings held 3 - 5 October 1997 and 24 - 26 April 1998 at Michigan State University.

Deliverables **6** and **7** were completed during year 3 of this Project. Our Historical and Current Databases were discussed at the Closing Workshop and have been delivered to the Commission as part of the Closing Report (Appendices to this Report). Recommendations regarding design and operation of low-head barrier dams are proposed in this Report following discussions with Control Agents at the Closing Workshop.

Deliverable **8** is still in progress (but nearing completion!) with two (2) graduate students still working towards their theses (Jon Goldstein, University of Wisconsin; Marlene Ross, University of Guelph). Two graduate theses have already been completed (L. Porto, M. Sc., University of Guelph 1997; Hope Clem Dodd, M. Sc., 1999, Michigan State University). One paper from this study has recently been published (Porto et al., 1999). Several manuscripts, co-authored by various combinations of the Principal Investigators and collaborators in the BILD project are in various stages of preparation. As drafts of these manuscripts are completed they will be submitted to the Commission when submitted for publication in the primary literature. In particular, a draft outline of a manuscript solicited by the organizers of SLIS II has been submitted to the organizers of that meeting.

B.1 Deliverable 1 - Historical (electronic) Database

The Historical Database compiled in Microsoft Access was completed by Trevor Middel, under the terms of the additional support provided by the Commission. Details were given in our **1996 Annual Report** and in a separate covering document supplied by Trevor Middel with the copy of the Database submitted to the Commission.

B.2 Deliverable 2 - Standard Protocol for sampling fish communities

Planning Workshop, University of Guelph, April 1996; Training Workshop, Michigan State University , May 1996 - Appendix G.1 of **1996 Annual Report.**

B.3 Deliverable 3 - Planning Workshop - Impacts of Low-head Barrier Dams

Planning Workshop University of Guelph April 1996 - refer to **July 1996 Progress Report** for details.

B.4 Deliverable 4 - Impacts of Low-head Barriers - Year 1 Workshop

The Workshop for Year 1 was divided into two meetings, the first at Michigan State in November 1996 and the second at the University of Guelph in May 1997, as described below. Refer to **1996 Annual Report** for data summaries, methodology and protocols from this meeting.

1996 Reporting and Analysis Workshop

We held a Reporting and Analysis Workshop for Year 1 at the Michigan State University 15 - 17 November 1996. Details were given in our **1996 Annual Report.**

B.5 Deliverable 5 - Impacts of Low-head barriers - Year 2 Workshop

The Workshop for Year 2 (1997) was divided into two meetings, as for Year 1 (1996). We held a combined Field Season Planning and Methods Training Workshop at the University of Guelph 12 - 13 May 1997. We finalized detailed plans for selection of field sites and data collection for 1997 field season. Those present included Ellie Koon (US Fish & Wildlife Service); (Dan Hayes and Hope Clem Dodd (Michigan State); Jeff Baylis, Jon Goldstein and A. N. Other (University of Wisconsin); David Noakes, Rob McLaughlin, Louise Porto, Istvan Imre, Bill Beamish and Dominique Charron (University of Guelph); Leon Carl and Trevor Middel (Ontario Ministry of Natural Resources); Bob Randall and Ken Minns (Department of Fisheries and Oceans, Canada).

The Year 2 (1997) Reporting and Analysis Workshop was divided into two meetings, as in previous years. Both meetings were held at the Michigan State University, 24 - 26 April 1998 and 20 - 22 November 1998. Those present were Jeff Baylis and Jon Goldstein (University of Wisconsin - Madison), David Noakes, Rob McLaughlin and Marlene Ross (University of Guelph), Leon Carl

(Ontario Ministry of Natural Resources), and Dan Hayes and Hope Dodd (Michigan State University). The **1998 Final Report** provided data summaries, methodologies and protocols from those meetings.

B.6 Impacts of Low Head barrier Closing Workshop

The Closing Workshop was held during April 1999 in Ann Arbor, Michigan, in conjunction with the Great Lakes Fishery Commission and the Sea Lamprey Control Agents. We distributed written, annual report of finding for year 2 and 3 to those attending that Workshop, for discussion. At that Workshop we held consultations with control agents and technical experts regarding potential modifications in the design and use of low-head barriers

B.7 Final Completion Report

This document constitutes our Final Completion Report for this Project. We have repeated some sections from earlier Reports for continuity, but our earlier Reports should be consulted for complete details. This Final Completion Report includes:

an accessible database summarizing data collected during our extensive, field survey and during the intensive, multi-year field investigations (as an electronic Appendix),

the final synopsis of our findings regarding the magnitude of the impact of low-head barrier dams on communities of fishes in the tributary streams along the Great Lakes and the mechanisms behind these impacts, recommendations (i) specifying modifications in the design of low-head barriers, (ii) identifying environmental circumstances influencing design or operation of barriers,

recommendations for modifications in operation of barriers.

B.8 Deliverable 8 - Graduate Student Theses

The M. Sc. thesis of Louise Porto (Zoology, University of Guelph 1998) was submitted as an Appendix to our 1997 Final Report. The M. Sc. thesis of Hope Clem Dodd (Fisheries and Wildlife, Michigan State University 1999) is submitted as an Appendix to this Report. The outlines for the M. Sc. Theses of Jon Goldstein (Zoology, University of Wisconsin 2000) and of Marlene Ross (Zoology, University of Guelph 2000) are included as Appendices in this Report. Completion of the latter two thesis is expected by April 2000.

C. Evidence of an Impact

The sea lamprey, *Petromyzon marinus*, a native of the Atlantic Ocean, invaded the Great Lakes following the construction of the Welland Canal (Stewart et al. 1981). It first appeared in Lake Erie in 1921 and soon spread to the upper Great Lakes where significant populations became established by 1947 (Applegate 1950, 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, Stewart et al. 1981).

Since 1950, a variety of control methods have been instituted to reduce sea lamprey abundance in the Great Lakes. These efforts have centered around the prevention of successful reproduction. 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) began in 1958 and is the primary method used to control sea lamprey 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, Hunns and Young 1980). Although TFM has little apparent effect on fish species other than lampreys, public sentiment, along with high cost of chemical control, has lead the Great

Lakes Fishery Commission to look for alternative control methods to reduce the use of lampricides by 50% (Great Lakes Fishery Commission 1990).

To supplement the use of chemical control methods, the sterile male release program has been instituted on Lake Superior tributaries and in the Saint Mary's River. This control method 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. Scientists believe that by increasing the ratio of sterile males to normal males, spawning success will decline thereby decreasing sea lamprey numbers (Hanson 1981).

Another alternative to chemical treatment is the construction of low-head barrier dams. These dams are built to prevent adult sea lamprey from migrating to suitable spawning habitat upstream. Early attempts at blocking spawning migrations included installation of mechanical weirs and traps and the use of electrical barriers. These control methods were deemed as ineffective, costly, and caused mortality to nontarget species (Applegate and Smith 1951, Erkkila et al. 1956, McLain 1957, Dahl and McDonald 1980). Low-head barrier dams were constructed to be more effective at blocking sea lamprey while preventing mortality of nontarget species.

While low-head barrier dams do not appear to cause mortality of nontarget species, they can have negative impacts at several different levels within the stream community (Pringle 1997, Benstead et al. 1999). The most obvious is the blocking of fish movement during periods of spawning, low food abundance, and different life stages. Low-head barriers may also indirectly affect fish communities by changing habitat and water quality of the stream.

In this Report, we discuss the evidence for an impact of low-head lamprey barrier dams on stream habitat and fish populations. Our *a priori* hypothesis was that streams containing low-head dams will have a greater loss of species upstream of the barrier when compared to upstream sections of the Reference streams (those without a barrier). We also hypothesized that abundance of some nontarget species will decrease upstream of the dams due to habitat alteration or blocking of movement upstream and thereby altering community and population size composition.

We have presented and discussed the details of the evidence for an impact in our 1998 Final Report. Based on the general habitat characteristics we measured, low-head barrier dams showed relatively little habitat alteration when compared to Reference streams. Average width and maximum depth were found to be significantly higher in Barrier streams, but mean substrate size was similar between the two stream types. Based on the River Continuum Concept (Vannote et al. 1980), we expect to see 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 we find that sites directly above the impoundment (Above 1) are deeper on average compared to those sites in Reference streams. Although we excluded the impoundment from our sampling protocol, our sites closest to the dam may still have been in the impacted zone upstream of the small reservoir. Since dams often act as sediment traps, we would expect sites closest to the dam (Above 1 sites), where water flow is slowed, to consist mainly of fine substrate particles such as silt and sand and the site directly downstream to have coarser substrate. This was not evident in our analysis of mean substrate size where substrate size is consistent at sites above and below the barrier, suggesting these dams are not large enough to significantly change the substrate composition of the stream. Temperature, which is often affected by surface release dams, might be expected to increase directly below the barrier relative to that site in the Reference stream if these low-head barriers do in fact notably alter stream flow. However, we saw that temperature is not greatly increased directly below the dam, indicating that low-head barrier dams do not retain water long enough to severely change the temperature of the stream. Overall, barrier dams do not have substantial impacts on the physical habitat in streams beyond the small impoundment above the dam and the plunge pool just below.

Streams with barriers contained more species in upstream and downstream sections relative to Reference streams, with little variability in average species richness between summers for both stream types. This indicates that summer composition of these streams is relatively stable in terms of number of species caught, although the type of species present may change from year to year. Approximately 2.5 species were lost due to low-head barrier dams, suggesting that low-head barriers are indeed having an impact on species richness in these streams. Although the ANCOVA analyses indicated that width and depth explain some variation seen in species richness between Barrier and Reference streams, the trends in average species richness does not follow those of width or depth, nor do width or depth appear to be good predictors of species lost upstream of the barriers. This suggests that although Barrier streams may be somewhat 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 in Barrier streams. We believe that the trends seen in species richness within Barrier streams can be best explained by the blocking of fish movement upstream of the dam.

Using Reference streams as our guide to expected similarity between upstream and downstream sections, we find that Above and Below sections of Barrier streams are more similar than what would be expected if low-head dams were heavily impacting the stream community. Thus, we can conclude that although Barrier streams lose more species on average the species composition is nearly the same whether you are above or 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 reveal 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 affect movements of non-target species such as yellow perch and trout-perch. Logperch were negatively impacted by barriers in terms of frequency of occurrence, abundance, and average size, indicating that movement of this species is greatly affected by the dam. White suckers seem to be somewhat positively affected by barriers based on their higher abundance and mean length seen upstream of the barrier. Brown bullheads are also positively affect by the presence of a low-head barrier dam. American brook and northern brook lamprey were also favored by a barrier, possibly due to the fact that above stream sections act as a refuge from the lampricides used to treat the downstream sections in streams with barriers.

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, we conclude that the mechanism of impact on species richness is the blocking of fish movement upstream. Low-head barriers had a relatively small influence on the species composition or community size composition. Sea lamprey were successfully blocked by barrier dams, but movement of other nontarget species were also negatively affected. However, some fish species were positively affected by dams suggesting that these barriers may create habitat immediately upstream or downstream that favors some species or the barrier acts as a refuge from predators or chemical treatment (in the case of native lampreys). In this study, low-head barriers have been seen to be effective in blocking upstream sections from spawning adult sea lamprey, reducing the stream area that need to be treated by lampricides, with relatively little effect on stream habitat and fish communities. These results indicate that these types of barrier dams are a viable alternative to other sea lamprey control methods.

C.1 Demographics of Sensitive Species (other than sea lamprey)

For demographic analysis species were selected based on presence/absence, species richness, and length distributions from 1996 sampling (BILD 1996 Annual Report, 1997 Final Report, 1998 Final Report).

With the data collected from age structures, we evaluated the differences in population age structure, growth, and mortality between Barrier and Reference streams. Mean age was compared between above and below sections of Barrier and Reference stream to determine possible effects of barriers on age structure of sensitive species. Differences in mortality between stream types were evaluated using catch curves, and significant differences in growth were examined using an Analysis of Covariance (ANCOVA).

Age and Growth of Selected Species

In the 1997 and 1998 field seasons, rainbow trout scales and white sucker pectoral fin clips were collected for demographic analysis. Details are given in our 1998 Final Report.

Rainbow trout were significantly younger in Barrier streams, particularly downstream of barriers. They grew significantly faster in Barrier streams, and were less abundant in those streams, but instantaneous mortality rates were not different between Barrier and Reference streams. The lower density of rainbow trout in Barrier streams might lead to a density - dependent increase in growth (Dodd 1999).

White suckers were more abundant, and had lower instantaneous mortality rates in Barrier streams. However there was no difference in growth rates of suckers in Reference and Barrier streams. Suckers were older overall in Barrier streams, but were younger above the dams. This suggests that either there is higher mortality above dams or older suckers immediately downstream of the dams may be acting as source populations (Dodd 1999).

Overall, the effects of low - head barrier dams on the age and growth of these two species appear to be relatively minor (Dodd 1999).

C.2 Seasonal Movements and Species Composition

Abstract

In 1998, a mark-recapture study was conducted on several Barrier and Reference streams in an effort to determine seasonal movements and changes in species composition. Movement across the hypothetical Barrier was observed in Reference streams; however, it was limited to four species (Blacknose Dace, Creek Chub, Rainbow Trout, and White Sucker). In contrast, only one fish was observed to traverse an actual Barrier. In this instance, a Rainbow Trout was tagged above the Barrier and was later recaptured below the Barrier. Although limited seasonal movement was observed, substantial variability in species composition was documented in Barrier, Reference and Natural Barrier streams (more complete details of analysis of data from Natural Barrier streams are given in the Appendix of Jon Goldstein's Thesis Outline). Natural barriers are known to have impacts on stream fishes and their habitat (Hågglund and Sjoberg 1999), so comparison to our Barrier and Reference streams provides an calibration to those natural ecological impacts.

Methods

Two stream pairs (consisting of one Barrier and one Reference stream) were selected from the 24 matched pairs selected by Noakes et al. (1997). One pair of streams is on the Wisconsin side of Lake Superior (the Middle

(Barrier) and Poplar (Reference) Rivers) and was sampled by a field crew from University of Wisconsin. Another pair of streams is on the Michigan side of Lake Huron (the East Branch Au Gres (Barrier) and West Branch Rifle (Reference) Rivers) and was sampled by a field crew from Michigan State University. These streams were chosen based on similarity of habitat characteristics and accessibility for mark-recapture. The mark-recapture protocol utilized by Porto (1996) was applied in the 1998 surveys. Each of the four streams was sampled during the spring, summer and fall. For comparison, stream segments were located at the same locations as the 1996-1997 surveys by Noakes et al. (1997). Two sampling events were conducted within each season. The 1988 sampling dates for the East Branch Au Gres and the West Branch of the Rifle were as follows: Spring (May 18, June 15), Summer (July 7, August 5), Fall (September 26, October 24). The sampling dates for the Middle River were as follows: Spring (June 27, July 4), Summer (August 15, August 22), and Fall (October 18, October 25). The sampling dates for the Poplar River were as follows: Spring (June 27, July 4, and July 11), Summer (August 15, August 22), and Fall (October 17, October 24).

The standardized sampling protocol of Noakes et al. (1997) was followed. In addition to this protocol, all fish captured were marked. Fish were marked using a (Panjet) dye injector with Alcian Blue dye (6g per 100 ml distilled water) following the procedure of Porto (1996) and Clarkson and

Jones (1996, unpublished). Fish captured by the Michigan State field crew were anesthetized using the procedure of Porto (1996). Fish captured by the University of Wisconsin field crew were not anesthetized (due to high ambient temperatures and low recovery in pilot sampling efforts). In replicate samplings, recaptured fish were recorded and measured, unmarked fish were also measured and marked at this time. A key to mark placement for each stream has been included for review (Appendix 1 in Section **H** of this Report). The University of Wisconsin field crew utilized fin clips in addition to dye marks in an effort to measure mark retention.

Results

The 1998 mark-recapture data show some distinct differences with respect to Barrier and Reference streams. In addition, several differences were observed between watersheds. The mark-recapture data have been broken down below to illustrate these differences (note: all Tables are in Section **H**).

Middle (Barrier) and Poplar (Reference) Rivers

The ratio of fish marked between Reference and Barrier Streams was 1.51:1. The ratio of mark-recaptures between Reference and Barrier streams was 2.89:1. Not only were a disproportionately greater number of individuals caught in the Reference Stream, but a disproportionately greater number of individuals were recaptured in the Reference stream as well (4.9% in the Reference stream versus 2.6% in the Barrier Stream).

In the Poplar River (Reference stream), the majority of marked fish were recaptured within the same season and at the same site they were originally marked (Table 1, Table 3 a, Table 3 b). However, 24% of the marked fish remained in the stream for longer than one season and 6.7% of the marked fish remained in the stream throughout the term of the study. As expected, some movement across the hypothetical Barrier was observed.

Four fish (three white suckers and one creek chub) might have moved from the Poplar River (Reference) to the Middle River (Barrier). The mouths of these streams are located within a kilometer of each other, so movement between streams is possible, but human error cannot be completely ruled out (i.e., errors in marking fish).

In the Middle River (Barrier stream), as with the Reference stream, the majority of marked fish were recaptured within the same season and at the same site they were originally marked (Table 1, Table 4.A, Table 4.B). In contrast to the Reference stream, 14% of the marked fish remained in the stream for longer than one season and no marked fish remained in the stream throughout the term of the study. In addition, in contrast to the Reference stream, no movement across the Barrier was observed.

With regard to mark-retention, Alcian blue dye mark-retention varied significantly depending on the species and mark placement. Overall, about 22% of these marks were lost. However, most of these do not represent lost data since all fish were marked with both fin clips and Alcian blue dye. In general, dye marks on the ventral body surfaces were retained the best.

The greatest incidence of dye mark loss occurred on fins, although this was dependent somewhat on species and size.

The mark-recapture data for both the Reference and Barrier streams has been broken down to the species level. Species that were not recaptured have not been included.

East Branch Au Gres (Barrier) and West Branch Rifle (Reference) Rivers

The ratio of fish marked between Reference and Barrier Streams was 1.04:1. The ratio of mark-recaptures between Reference and Barrier streams was 0.57:1. In addition, a smaller proportion of individuals was recaptured in the Reference stream (1.9%) as opposed to the Barrier stream (3.6%). Both of these relationships contrast with the results from the Wisconsin pair where a disproportionately large number of individuals were caught and recaptured in the Reference Stream.

In the West Branch Rifle all of the marked fish were recaptured at the same site they were originally marked (Table 2, Table 5.A, and Table 5.B). However, only 46.1% of the marked fish occurred within the same season they were originally marked. In addition, 53.8% remained in the stream for longer than one season. None of the marked fish remained in the stream throughout the term of the study and no movement across the hypothetical Barrier was observed. With the exception of seasonal recaptures and duration of stream use, these results are consistent with the findings from the Wisconsin stream pair.

In the East Branch Au Gres (Barrier stream), as with the Reference stream, the majority (81.8%) of marked fish were recaptured at the same site they were originally marked, but they were not typically caught in the same season (Table 2, Table 6 a, Table 6b). Sixty percent of the marked fish remained in the stream for longer than one season. As was the case with the Reference stream, no marked fish remained in the stream throughout the term of the study. Only one fish, a Rainbow Trout, was observed to traverse the barrier. It moved from an above barrier site to a below barrier site. No fish were found to breach the Barrier. These results are similar to the Reference stream, but seasonal mark-recapture and duration of stream use were not congruent with the findings from the Wisconsin stream pair.

Species-specific mark-recapture data are summarized in Appendix H for each river sampled in 1998. For the Poplar and Middle Rivers, data on all species with any recaptures are presented. Data from the West Branch Rifle and East Branch Au Gres are limited to the following species or families: (Creek Chub, Longnose Dace, Mottled Sculpin, Northern Hogsucker, Salmon, Trout, and White Sucker). Alcian blue dye mark-retention was not assessed on the Michigan stream pair.

Our interpretations of these results are given in the Discussion of Jon Goldstein's M. Sc. Thesis Outline (next section of this Report).

C.2. Seasonal Movements

Jon Goldstein, M. Sc. Thesis

pp. 28-39

Has been moved to the end of the report, in the Appendices, after the published paper of Porto et al.

C.3 Analysis of Historical Database

We have extended the analyses we have conducted on our extensive and intensive (BILD Protocol) sampling to our Historical Database to investigate the effects of barrier dams on fish species on a temporal basis. Our hypothesis states that Barrier streams will suffer a loss of species above the barrier over time due to direct and indirect effects of barriers. Furthermore, the specific prediction is that the same species we judge as "sensitive" from our extensive and intensive field sampling, should be most significantly affected over time in the historical data collected after installation of barriers.

To investigate barrier impact on a temporal scale, this analysis focuses on the historical data gathered on the Barrier streams prior to the installation of barriers. This will provide the "before" data; the extensive and intensive data collected by BILD researchers during 1996-1998 will be included in the "after" comparison. A comparison of Barrier stream community data will show whether there has been a loss of species over time and how the community composition has changed. By using the historical data and BILD data for the Reference streams, a similar comparison can be made and used to filter out the loss of species which could be expected to have naturally occurred in the Barrier streams over time regardless of the barrier. Changes in the community will be investigated at both the species and the family level. The comparison of the results from our analyses at species and family level of fishes is important because not all datasets (especially historical data) can be taken beyond the family level. This comparison is also important because it is much easier to conduct fish surveys to family level, whereas confirmation of identification to the species level is much more demanding, time-consuming and dependent upon expert taxonomic resources.

We predict that the restriction of movement of one species into the upstream reaches of a Barrier stream will have splinter effects on both the upstream and downstream communities. For example, the removal of a predator species may induce an increase in a forage species or a competitor species upstream. For this reason, the species eliminated in Barrier streams will be reviewed and analyzed in terms of possible indirect barrier effects. A review of the literature regarding relationships within and between species will be used to explain possible indirect causes of species loss not observed in the Reference streams.

Database contents

- historical stream data has been collected from Michigan, Ontario, and Wisconsin
- data has received initial quality control (check for reliability and duplication) by Trevor Middel, and subsequently by Marlene Ross (collaboration with John Kelso and his Project)
- data available for a total of 184 streams (Figure D.5 - 1, Table D.5 - 1)
- most of the streams are within Ontario: Ontario data tends to be the shortest time frame (usually between 1970's and 1990's)

- fewer streams from Michigan and Wisconsin, but the data time frame tends to be much longer (as early as 1900 to 1990's)
- data from the American streams will be most useful in analyzing long term trends, before/after effects of barriers

historical data for BILD paired streams is incomplete; some streams do not have historical data in the database.

Analysis in Progress

1. Use the best data sets (i.e. paired streams with sufficient before/after data to look at changes in fish communities
2. Use the best, non-paired data sets to augment comparisons made in 1).
3. Analyze stream data with insufficient "before" data, in terms of finding similar trends observed in 1) and 2).

Use both species level and family level in the review of community changes.

Marlene Ross

M. Sc. Thesis Outline

Zoology Department, University of Guelph

Trends in Fish Community Diversity, Sensitive Species, and Extinction Rates in Streams within the Laurentian Great Lakes Basin: An Analysis of Historical Data

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D. Additional Contributions in Progress

A number of additional activities are currently underway and will continue after the formal completion of this Project, directed towards analyses of historical data, intensive study of possible mechanisms of barrier impacts, correlates and calibration of low-head barrier dam impacts, and dissemination of our results. These are listed individually below.

D.1 Additional Measures of Similarity

D.2 Correlates of Impact (dam history, type, etc.)

D.3 M. Sc. Students Projects

D.3.1 Louise Porto, University of Guelph - copy of completed M. Sc. thesis submitted with 1997 Final Report

D.3.2 Hope Clem Dodd, Michigan State University - The effects of low-head lamprey barrier dams on stream habitat and fish communities in tributaries of the Great Lakes - copy of completed M. Sc. Thesis included as Appendix to this Report

D.3.3 Jon Goldstein, University of Wisconsin, Madison - Natural barriers and low-head dams: a comparison of habitat and species diversity of 61 streams in the Great Lakes Basin- outline of M. Sc. thesis proposal included as an Appendix in this Report

D.3.4 Marlene Ross, University of Guelph - Trends in fish community diversity, sensitive species, and extinction rates in streams within the

Laurentian Great Lakes Basin: an analysis of historical data - outline of M. Sc. thesis proposal included with this Report

D.3.5 Rob McLaughlin, University of Guelph - odds ratio as a technique for assessing sensitivity of fish species to impacts of barriers

D.4 Dissemination of Information (Web site, FTP site)

D.4.1 Home Pages - Axelrod Institute of Ichthyology, including links to Project page <http://www.axelfish.uoguelph.ca> and to pages for the Great Lakes Fishery Commission

D.4.2 FTP site on network server computer located in Axelrod Institute of Ichthyology

D.4.3 Oral paper - Rob McLaughlin, David Noakes, Louise Porto, Leon Carl & Bob Randall - Canadian Conference for Fishery Research, Queens University, Kingston, Ontario January 1998

D.4.4 Oral presentation at Sea Lamprey Barrier Task Meeting by David Noakes and Dan Hayes - Michigan State University March 1998.

D.4.5 Poster paper - Louise Porto, David Noakes, Rob McLaughlin - Ontario Ecology and Ethology Colloquium, Queen's University, Kingston, Ontario April 1998

D.4.6 Invited seminar - Rob McLaughlin - York University, Biology Department, December 1998

D.4.7 Poster paper - David L. G. Noakes, Robert L. McLaughlin, Jeffrey R. Baylis, Leon M. Carl , Daniel B. Hayes, Robert G. Randall Ontario Ecology & Ethology Colloquium, University of Guelph, May 1999

D.4.8 Porto, L. M., R. L. McLaughlin & D. L. G. Noakes. 1999. Low - head barrier dams restrict the movements of fishes in two Lake Ontario streams. North American Journal of Fisheries Management 19: 1028 - 1036.

D.4.9 Poster paper - David L. G. Noakes, Robert L. McLaughlin, Jeffrey R. Baylis, Leon M. Carl , Daniel B. Hayes, Robert G. Randall, Louise Porto, Hope Dodd, Jon Goldstein & Marlene Ross - Canadian Conference for Fisheries Research, University of New Brunswick, January 2000

E. Recommendations

This section of the Report includes recommendations:

(i) specifying modifications in the design of low-head barriers,

(ii) identifying environmental circumstances influencing design or operation of barriers, and

(iii) for modifications in operation of barriers as related to the impact on nontarget fish species.

These recommendations have been developed as result of our various Workshops, syntheses and analyses of our current and historical data, and especially discussions during our Closing Workshop in 1999.

Our conclusions are simple and consistent, considering the wealth of information we have considered. We can summarize our recommendations on these five points as follows:

(i) From our results and analyses we do not see any general patterns relating barrier placement and operation to local fish habitat features of Great Lakes tributary streams. This statement must be tempered by the understanding that we did not sample all barrier types equally in our study. In particular, variable crest dams should be investigated in any future study.

(ii) The impact of a low - head barrier dam on any specific stream will always require study and consideration of local features and conditions. The presence of particular sensitive nontarget fish species, or some local environmental feature, would be examples of special concern. Regional or biogeographical aspects of fish species distributions would also merit consideration. Our Project was designed to evaluate the general consequences and mechanisms of impacts of low - head barrier dams across the Great Lakes basin. We have shown variations among both Barrier and Reference streams in our extensive, intensive and historical data. Environmental impact assessment of individual streams remains an important criterion.

(iii) We recommend that, if possible, low head sea lamprey barrier dams be operated as variable crest barriers. It is clear from our results that one mechanism of impact for low - head barrier dams is the direct blocking of the seasonal movements of nontarget fishes. Fishways and bypass channels could be alternatives to permit movement of nontarget fish species past barriers, but they seem likely to involve more complex engineering and operating costs. They would also likely involve more handling of fishes. In addition, the effectiveness of such fishways and bypass channels would have to be established on a case - by - case basis. It is not just a matter of whether fishes pass the barrier, but what numbers are involved relative to Reference streams, and whether the passage of the fishes has population - and community level consequences (e.g., spawning and recruitment).

(iv) Barriers should be operated as much as possible on a seasonal basis. Our results that low - head barriers currently in place successfully block upstream movement of migratory sea lamprey. If the operation of barriers can be adjusted on a seasonal basis, their effects could be optimized to restrict the upstream movement of sea lamprey at the time of their spawning migration. At other times the direct blocking effects of the barriers could be minimized by allowing free movements of nontarget species.

(v) The effects of barriers on certain nontarget species deserves further attention as related to conservation or restoration of nontarget species (i.e., other than sea lamprey). For example, some of the native lamprey species are of increasing concern for conservation. The increased abundance of these species in stream sections above low - head barrier dams suggest that these barriers could provide a refuge for these species.

F. Collaboration

F.1 Department of Fisheries and Oceans - Dr. J. R. Kelso & Lisa O'Connor - historical database, sampling protocols, assessing impacts of barrier dams, participation in joint workshops and reporting meetings

F.2 Royal Ontario Museum - Dr. E. J. Crossman, Becky Cudmore, Erling Holm - historical database, fish identification, extensive survey

F.3 Ontario Ministry of Natural Resources - District Biologists - extensive survey, reports of results of extensive fish sampling from Barrier and Reference streams

F.4 New York State - Les Wedge - historical database, extensive survey; sharing results from 1996 extensive survey and his earlier surveys for stocked salmonids in New York streams

F.5 Watershed Project - Guelph, Madison, Guadalajara - watershed ecology, fish communities, database management, graduate student exchanges

F.6 Sea Lamprey Low-head Barrier Dam Project - sampling protocols, historical database, impacts of barrier dams; workshops; meetings; mailing lists

F.7 Department of Fisheries and Oceans, Canada - contribution to Workshop review of field sampling procedures and protocols - Bob Randall - April 1998

G. Appendices

G.1 Comparison of fish species and numbers of individuals captured in successive yearly samples in Reference, Barrier and Natural Barrier streams (Jon Goldstein & Jeff Baylis).

G.2 Printed copy of M. Sc. thesis, Hope Dodd (Fisheries Biology, Michigan State University)

G.3 Printed copy of manuscript (McLaughlin et al., Potential and pitfalls...) in review

G.4 Copy of published paper (Porto et al., Low-head barrier dams...)

G.5 Electronic copy (DOS diskette, RTF format) of the text and tables of this Report

G.6 Electronic copy (MS Access) of extensive survey and intensive field sampling database.

The following comparison of the spring, summer and fall Wisconsin sampling (1998) with the Noakes et al. (1997) historical data is the first attempt to assess the variability in the species composition and results from seasonal mark-recaptures. A similar comparison for the data from the Michigan State University has not been compiled since their mark-recapture data was collected from a selected list of species. A comparison for the Mosquito River, Michigan, a Natural Barrier Stream sampled in 1996-1997 using the Noakes et al. (1997) protocol has also been included.

Middle River, WI Whole Stream Summary: (Barrier)

Cumulative Total # of Species 1996-1997 = 28
Cumulative Total # of Species Above the Barrier 1996-1997 = 13
Cumulative Total # of Species Below the Barrier 1996-1997 = 26

1998 Sampling Comparison:
(A) = Above the Barrier
(B) = Below the Barrier

New Species in Sample

(A, B) Brassy Minnow
(B) Brook Trout
(A, B) Mimic Shiner
(A) Misc.*
(A) Northern Redbelly Dace
(B) Rainbow Trout*

Previously Sampled Species Absent

(A, B) Black Bullhead
(B) Brown Trout
(B) Lake Chub
(B) Northern Brook Lamprey
(B) Northern Pike
(B) Redtail Chub
(B) River Darter
(B) Ruffe
(A, B) Sea Lamprey
(B) Stonecat
(B) Walleye

* These species are new to either the above or below segment of the stream, but not to the river as a whole.

Cumulative Species List 1996-1998:

(A, B) Black Bullhead
(A, B) Blacknose Dace
(A, B) Brassy Minnow
(A, B) Brook Stickleback
(B) Brook Trout
(B) Brown Trout
(B) Burbot
(A, B) Common Shiner
(A, B) Creek Chub
(A, B) Horneyhead Chub
(A, B) Johnny Darter
(B) Lake Chub
(B) Log Perch
(A, B) Longnose Dace
(A, B) Mimic Shiner
(A, B) Misc.
(A, B) Mottled Sculpin
(A, B) Mud Minnow
(B) Northern Brook Lamprey
(B) Northern Pike
(A) Northern Redbelly Dace
(A, B) Rainbow Trout
(B) Redtail Chub
(B) River Darter
(B) Rock Bass
(B) Ruffe
(B) Sauger
(A, B) Sea Lamprey
(B) Stonecat
(B) Trout Perch
(B) Walleye
(A, B) White Sucker

REFERENCE STREAM COMPARISON

Poplar River, WI Whole Stream Summary: (Reference)

Cumulative Total # of Species 1996-1997 = 23

Cumulative Total # of Species Above the Barrier 1996-1997 = 15

Cumulative Total # of Species Below the Barrier 1996-1997 = 21

1998 Sampling Comparison:

(A) = Above the Barrier
(B) = Below the Barrier

New Species in Sample

(A) Bluntnose Minnow
(B) Green Sunfish
(A) Horneyhead Chub*
(B) Mimic Shiner
(A) Misc.*
(A) Pearl Dace
(A) Pumpkinseed*
(B) Trout Perch

Previously Sampled Species Absent

(A, B) Golden Shiner
(B) Lake Chub
(B) Sauger
(B) Stonecat

* These species are new to either the above or below segment of the stream, but not to the river as a whole.

Cumulative Species List 1996-1998:

(A, B) Blacknose Dace
(A) Bluntnose Minnow
(A, B) Brassy Minnow
(B) Brook Stickleback
(A) Brown Trout
(A, B) Common Shiner
(A, B) Creek Chub
(A, B) Golden Shiner
(B) Green Sunfish
(A ,B) Horneyhead Chub
(A ,B) Johnny Darter
(B) Lake Chub
(B) Log Perch
(A, B) Longnose Dace
(B) Mimic Shiner
(A, B) Misc.
(A, B) Mottled Sculpin
(A, B) Mud Minnow
(A, B) Northern Redbelly Dace
(A ,B) Pearl Dace
(A ,B) Pumpkinseed
(A, B) Rainbow Trout
(A, B) Rock Bass
(B) Sauger
(B) Stonecat
(B) Trout Perch
(A, B) White Sucker

NATURAL BARRIER STREAM COMPARISON

Mosquito River, WI Whole Stream Summary: (Natural Barrier)

Cumulative Total # of Species 1996 = 6

Cumulative Total # of Species Above the Barrier 1996 = 6
Cumulative Total # of Species Below the Barrier 1996 = N/A*

1997 Sampling Comparison:
(A) = Above the Barrier
(B) = Below the Barrier

New Species in Sample	Previously Sampled Species Absent
(B) Blacknose Dace*	(A) Blacknose Dace
(B) Brook Trout*	(A) Brook Stickleback
(B) Mottled Sculpin*	(A) Misc.
(B) Rainbow Trout*	(A) Mud Minnow
	(A) Northern Redbelly Dace

*** This river was not sampled below the Barrier in 1996, however six above stream segments were sampled in 1996. Six segments were sampled in 1997; three segments were above the Barrier and three segments were below the Barrier.**

Cumulative Species List 1996-1997:

(A, B) Blacknose Dace
(A,B) Brook Trout
(A) Brook Stickleback
(A) Misc.
(B) Mottled Sculpin
(A) Mud Minnow
(A) Northern Redbelly Dace
(B) Rainbow Trout

H. Tables

Seasonal movements, species composition and recapture data (from section C.4)

APPENDIX 1.

Middle River* (Barrier)		SPRING	SUMMER	FALL
		PANJET™ MARK		
	Relative Barrier Position	Caudal	Dorsal	Ventral
FIN CLIP OR PANJET™ MARK	Above 3	Ventral	Ventral	Ventral
	Above 2	Right Pelvic	Right Pelvic	Right Pelvic
	Above 1	Right Pectoral	Right Pectoral	Right Pectoral
	Below 1	Left Pectoral	Left Pectoral	Left Pectoral
	Below 2	Left Pelvic	Left Pelvic	Left Pelvic
	Below 3	Anal	Anal	Anal

* All fish ≥ 40mm TL were marked and clipped. Fish < 40mm TL were not marked.

Poplar River* (Reference)		SPRING	SUMMER	FALL
		PANJET™ MARK		
	Relative Barrier Position	Caudal	Dorsal	Double Ventral
FIN CLIP OR PANJET™ MARK	Above 3	Caudal	Caudal	Caudal
	Above 2	Right Pectoral	Right Pectoral	Right Pectoral
	Above 1	Right Pelvic	Right Pelvic	Right Pelvic
	Below 1	Left Pectoral	Left Pectoral	Left Pectoral
	Below 2	Dorsal	Dorsal	Dorsal
	Below 3	Double Pelvic	Double Pelvic	Double Pelvic

* All fish ≥ 40mm TL were marked and clipped. Fish < 40mm TL were not marked.

East Branch AuGres* (Barrier)		SPRING	SUMMER	FALL **	FIN MARK IF < 80mm, but > 40mm
		VENTRAL PANJET™ MARK			
	Relative Barrier Position	Pectoral	Anal	Pelvic	
FIN PANJET™ MARK	Above 3	Right Pectoral	Right Pectoral	Right Pectoral	Caudal
	Above 2	Left Pectoral	Left Pectoral	Left Pectoral	Caudal
	Above 1	Caudal	Caudal	Caudal	Caudal
	Below 1	Anal	Anal	Anal	Dorsal
	Below 2	Right Pelvic	Right Pelvic	Right Pelvic	Dorsal
	Below 3	Dorsal	Dorsal	Dorsal	Dorsal

* Mark-recapture and identification were limited to the following species or families for this stream:

White Sucker
Northern Hogsucker
Trout
Salmon
Longnose Dace
Mottled Sculpin
Creek Chub

Fish < 40mm TL were not marked.

** No data were recorded for the last fall sampling except recapture of marked fish.

APPENDIX 1. (CONT.)

West Branch Rifle* (Reference)		SPRING	SUMMER	FALL **	FIN MARK IF < 80mm, but > 40mm
		VENTRAL PANJET™ MARK			
	Relative Barrier Position	Pectoral	Anal	Pelvic	
FIN PANJET™ MARK	Above 3	Right Pectoral	Right Pectoral	Right Pectoral	Caudal
	Above 2	Caudal	Caudal	Caudal	Caudal
	Above 1	Left Pectoral	Left Pectoral	Left Pectoral	Caudal
	Below 1	Anal	Anal	Anal	Dorsal
	Below 2	Right Pelvic	Right Pelvic	Right Pelvic	Dorsal
	Below 3	Dorsal	Dorsal	Dorsal	Dorsal

* Mark-recapture and identification were limited to the following species or families for this stream:

White Sucker
Northern Hogsucker
Trout
Salmon
Longnose Dace
Mottled Sculpin
Creek Chub

Fish < 40mm TL were not marked.

** No data were recorded for the last fall sampling except recapture of marked fish.

APPENDIX 2.

STREAM: POPLAR, WI (REFERENCE)
SPECIES: WHITE SUCKER

Of Individuals Caught Above the Barrier: 163 # MARKED: 358
Of Individuals Caught Below the Barrier: 195 # RECAPTURED: 31

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	8					
	Above 2	2	4				
	Above 3						
	Below 1	2			2		
	Below 2		1				
	Below 3	2	1	3			3

Of Unknowns (not included in table): 3*

* Three fish either were marked incorrectly or moved from the reference stream to the barrier stream.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	4	4	
	SUMMER	▨	7	1
	FALL	▨	▨	4

Of Unknowns (not included in table): 11*

* Three fish either were marked incorrectly or moved from the reference stream to the barrier stream.

Of Panjet™ Marks Lost: 9 Observed Mark Loss: 29.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: ROCK BASS

\# Of Individuals Caught Above the Barrier: 37 # MARKED: 42
\# Of Individuals Caught Below the Barrier: 5 # RECAPTURED: 5

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		4				
	Above 3						
	Below 1						
	Below 2						
	Below 3						1

\# Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1		
	SUMMER	▨	2	
	FALL	▨	▨	

\# Of Unknowns (not included in table): 2

\# Of Panjet™ Marks Lost: 1 Observed Mark Loss: 20.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: RAINBOW TROUT

Of Individuals Caught Above the Barrier: 34 # MARKED: 35
Of Individuals Caught Below the Barrier: 1 # RECAPTURED: 2

		SITE RECAPTURED					
	Relative Barrier Position	Above 1	Above 2	Above 3	Below 1	Below 2	Below 3
SITE TAGGED	Above 1		1				
	Above 2						
	Above 3			1			
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	1

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 50.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: PUMPKINSEED

Of Individuals Caught Above the Barrier: 2 # MARKED: 4
Of Individuals Caught Below the Barrier: 2 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1		
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 100.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: MUD MINNOW

Of Individuals Caught Above the Barrier: 19 # MARKED: 19
Of Individuals Caught Below the Barrier: 0 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	1					
	Above 2						
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1		
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: MOTTLED SCULPIN

Of Individuals Caught Above the Barrier: 15 # MARKED: 91
Of Individuals Caught Below the Barrier: 76 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 1

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1		
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: Misc. #1

Of Individuals Caught Above the Barrier: 2 # MARKED: 2
Of Individuals Caught Below the Barrier: 0 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			1
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: River Shiner

Of Individuals Caught Above the Barrier: 61 # MARKED: 61
Of Individuals Caught Below the Barrier: 0 # RECAPTURED: 6

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	4					
	Above 2		1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 1

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			1
	SUMMER	▨	1	
	FALL	▨	▨	3

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 16.7%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: LONGNOSE DACE

Of Individuals Caught Above the Barrier: 90 # MARKED: 328
Of Individuals Caught Below the Barrier: 238 # RECAPTURED: 4

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	1					
	Above 2		1				
	Above 3						
	Below 1				1		
	Below 2						1
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	2		
	SUMMER	▨	1	
	FALL	▨	▨	1

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 25.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: JOHNNY DARTER

Of Individuals Caught Above the Barrier: 96 # MARKED: 183
Of Individuals Caught Below the Barrier: 87 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 100.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: CREEK CHUB

Of Individuals Caught Above the Barrier: 528 # MARKED: 963
Of Individuals Caught Below the Barrier: 435 # RECAPTURED: 108

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	25					
	Above 2	6	28				
	Above 3	2		12			3
	Below 1				8		
	Below 2					3	
	Below 3					1	15

Of Unknowns (not included in table): 5*

* One fish either was marked incorrectly or moved from the reference stream to the barrier stream

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	13	9	8
	SUMMER		25	11
	FALL			16

Of Unknowns (not included in table): *26

* One of these fish either was marked incorrectly or moved from the reference stream to the barrier stream

Of Panjet™ Marks Lost: 23 Observed Mark Loss: 21.2%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: COMMON SHINER

\# Of Individuals Caught Above the Barrier: 444 # MARKED: 1460
\# Of Individuals Caught Below the Barrier: 1016 # RECAPTURED: 14

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	5					
	Above 2	3	1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						1

\# Of Unknowns (not included in table): 4

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	3		
	SUMMER	▨		1
	FALL	▨	▨	9

\# Of Unknowns (not included in table): 1

\# Of Panjet™ Marks Lost: 1 Observed Mark Loss: 7.1%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: BRASSY MINNOW

# Of Individuals Caught Above the Barrier: 23	# MARKED: 23
# Of Individuals Caught Below the Barrier: 0	# RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			1
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: POPLAR, WI (REFERENCE)
SPECIES: BLACKNOSE DACE

Of Individuals Caught Above the Barrier: 194 # MARKED: 733
Of Individuals Caught Below the Barrier: 539 # RECAPTURED: 35

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	5					4
	Above 2		2				1
	Above 3						
	Below 1				4		
	Below 2						
	Below 3	1					8

Of Unknowns (not included in table): 10

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	17	3	
	SUMMER	▨	10	
	FALL	▨	▨	2

Of Unknowns (not included in table): 3

Of Panjet™ Marks Lost: 7 Observed Mark Loss: 20.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: WHITE SUCKER

Of Individuals Caught Above the Barrier: 88 # MARKED: 244
Of Individuals Caught Below the Barrier: 156 # RECAPTURED: 24

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		8	1			
	Above 3			1			
	Below 1				2		1
	Below 2					9	
	Below 3						2

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	12	1
	FALL	▨	▨	3

Of Unknowns (not included in table): 8

Of Panjet™ Marks Lost: 8 Observed Mark Loss: 33.3%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: SAUGER

Of Individuals Caught Above the Barrier: 0 # MARKED: 5
Of Individuals Caught Below the Barrier: 5 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	Above 1	Above 2	Above 3	Below 1	Below 2	Below 3
SITE TAGGED	Above 1						
	Above 2						
	Above 3						
	Below 1						
	Below 2					1	
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: ROCK BASS

Of Individuals Caught Above the Barrier: 0 # MARKED: 5
Of Individuals Caught Below the Barrier: 5 # RECAPTURED: 2

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2					2	
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 20.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: RAINBOW TROUT

Of Individuals Caught Above the Barrier: 15 # MARKED: 20
Of Individuals Caught Below the Barrier: 5 # RECAPTURED: 3

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		3				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	2	
	FALL	▨	▨	1

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: MUD MINNOW

Of Individuals Caught Above the Barrier: 12 # MARKED: 17
Of Individuals Caught Below the Barrier: 5 # RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2					1	
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	1

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: LONGNOSE DACE

Of Individuals Caught Above the Barrier: 91 # MARKED: 234
Of Individuals Caught Below the Barrier: 143 # RECAPTURED: 2

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		2				
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	2

Of Unknowns (not included in table): 0

Of Panjet™ Marks Lost: 0 Observed Mark Loss: 0.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: HORNEYHEAD CHUB

Of Individuals Caught Above the Barrier: 4 # MARKED: 61
Of Individuals Caught Below the Barrier: 57 # RECAPTURED: 3

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1				2		
	Below 2					1	
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	1

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 33.3%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: CREEK CHUB

Of Individuals Caught Above the Barrier: 270 # MARKED: 644
Of Individuals Caught Below the Barrier: 374 # RECAPTURED: 26

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	3					
	Above 2		7				
	Above 3			2			
	Below 1				5		
	Below 2					3	
	Below 3						4

Of Unknowns (not included in table): 2

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1	5	
	SUMMER	▨	9	2
	FALL	▨	▨	6

Of Unknowns (not included in table): 3

Of Panjet™ Marks Lost: 5 Observed Mark Loss: 19.2%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: COMMON SHINER

Of Individuals Caught Above the Barrier: 345 # MARKED: 1160
Of Individuals Caught Below the Barrier: 815 # RECAPTURED: 5

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		4				
	Above 3						
	Below 1				1		
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	3

Of Unknowns (not included in table): 1

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 20.0%

STREAM: MIDDLE, WI (BARRIER)
SPECIES: BLACKNOSE DACE

Of Individuals Caught Above the Barrier: 226 # MARKED: 444
Of Individuals Caught Below the Barrier: 218 # RECAPTURED: 6

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		5				
	Above 3						
	Below 1						
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1		
	SUMMER	▨	3	
	FALL	▨	▨	

Of Unknowns (not included in table): 2

Of Panjet™ Marks Lost: 1 Observed Mark Loss: 16.7%

STREAM: EAST BRANCH AUGRES, MI (BARRIER)
SPECIES: CREEK CHUB

Of Individuals Caught Above the Barrier: 34 # MARKED: 102
Of Individuals Caught Below the Barrier: 68 # RECAPTURED: 8

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	1					
	Above 2						
	Above 3						
	Below 1				1	2	
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 3

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	1	4	
	SUMMER	▨		
	FALL	▨	▨	1

Of Unknowns (not included in table): 2

STREAM: EAST BRANCH AUGRES, MI (BARRIER)
SPECIES: MOTTLED SCULPIN

Of Individuals Caught Above the Barrier: 243 # MARKED: 414
Of Individuals Caught Below the Barrier: 171 # RECAPTURED: 2

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 1

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	1

Of Unknowns (not included in table): 1

STREAM: EAST BRANCH AUGRES, MI (BARRIER)
SPECIES: NORTHERN HOGSUCKER

Of Individuals Caught Above the Barrier: 2
Of Individuals Caught Below the Barrier: 8

MARKED: 10
RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨		
	FALL	▨	▨	1

Of Unknowns (not included in table): 0

STREAM: EAST BRANCH AUGRES, MI (BARRIER)
SPECIES: RAINBOW TROUT

# Of Individuals Caught Above the Barrier: 96	# MARKED: 135
# Of Individuals Caught Below the Barrier: 41	# RECAPTURED: 17

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	3					
	Above 2	1	1				
	Above 3			7			1
	Below 1				1		
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 2*

* One fish was tagged above the Barrier and recaptured above the Barrier.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING		3	2
	SUMMER	▨	4	6
	FALL	▨	▨	1

Of Unknowns (not included in table): 1

STREAM: WEST BRANCH RIFLE, MI (REFERENCE)
SPECIES: BROOK TROUT

\# Of Individuals Caught Above the Barrier: 0
\# Of Individuals Caught Below the Barrier: 12

\# MARKED: 12
\# RECAPTURED: 1

		SITE RECAPTURED					
	1998	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2					1	
	Below 3						

\# Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	

\# Of Unknowns (not included in table): 1

STREAM: WEST BRANCH RIFLE, MI (REFERENCE)
SPECIES: BROWN TROUT

Of Individuals Caught Above the Barrier: 29
Of Individuals Caught Below the Barrier: 0

MARKED: 29
RECAPTURED: 6

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3			5			
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING		4	
	SUMMER	▨	1	1
	FALL	▨	▨	

Of Unknowns (not included in table): 0

STREAM: WEST BRANCH RIFLE, MI (REFERENCE)
SPECIES: CREEK CHUB

Of Individuals Caught Above the Barrier: 70 # MARKED: 202
Of Individuals Caught Below the Barrier: 132 # RECAPTURED: 2

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		1				
	Above 3						
	Below 1						
	Below 2					1	
	Below 3						

Of Unknowns (not included in table): 0

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	1

Of Unknowns (not included in table): 0

STREAM: WEST BRANCH RIFLE, MI (REFERENCE)
SPECIES: LONGNOSE DACE

# Of Individuals Caught Above the Barrier:	69	# MARKED:	206
# Of Individuals Caught Below the Barrier:	137	# RECAPTURED:	4

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1				1		
	Below 2						
	Below 3						1

Of Unknowns (not included in table): 2

* Two fish were tagged below the barrier and recaptured at site Below 1.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING		1	
	SUMMER	▨		
	FALL	▨	▨	

Of Unknowns (not included in table): 3

STREAM: WEST BRANCH RIFLE, MI (REFERENCE)
SPECIES: WHITE SUCKER

# Of Individuals Caught Above the Barrier: 94	# MARKED: 186
# Of Individuals Caught Below the Barrier: 92	# RECAPTURED: 1

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2						
	Above 3						
	Below 1						
	Below 2						
	Below 3						

Of Unknowns (not included in table): 1

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING			
	SUMMER	▨	1	
	FALL	▨	▨	

Of Unknowns (not included in table): 0

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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

A THESIS

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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.

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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

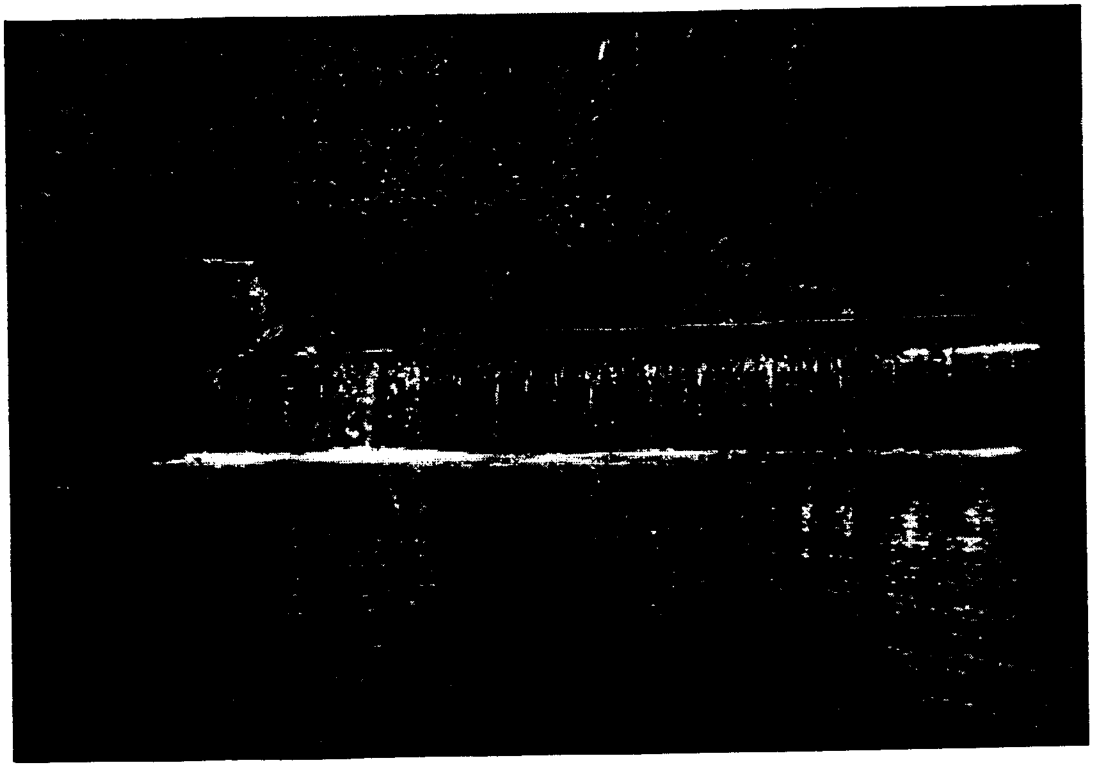


Figure 1. Photographs of low-head barriers in this study showing the "V" shape design (top photograph) and the straight line design (bottom photograph).

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.

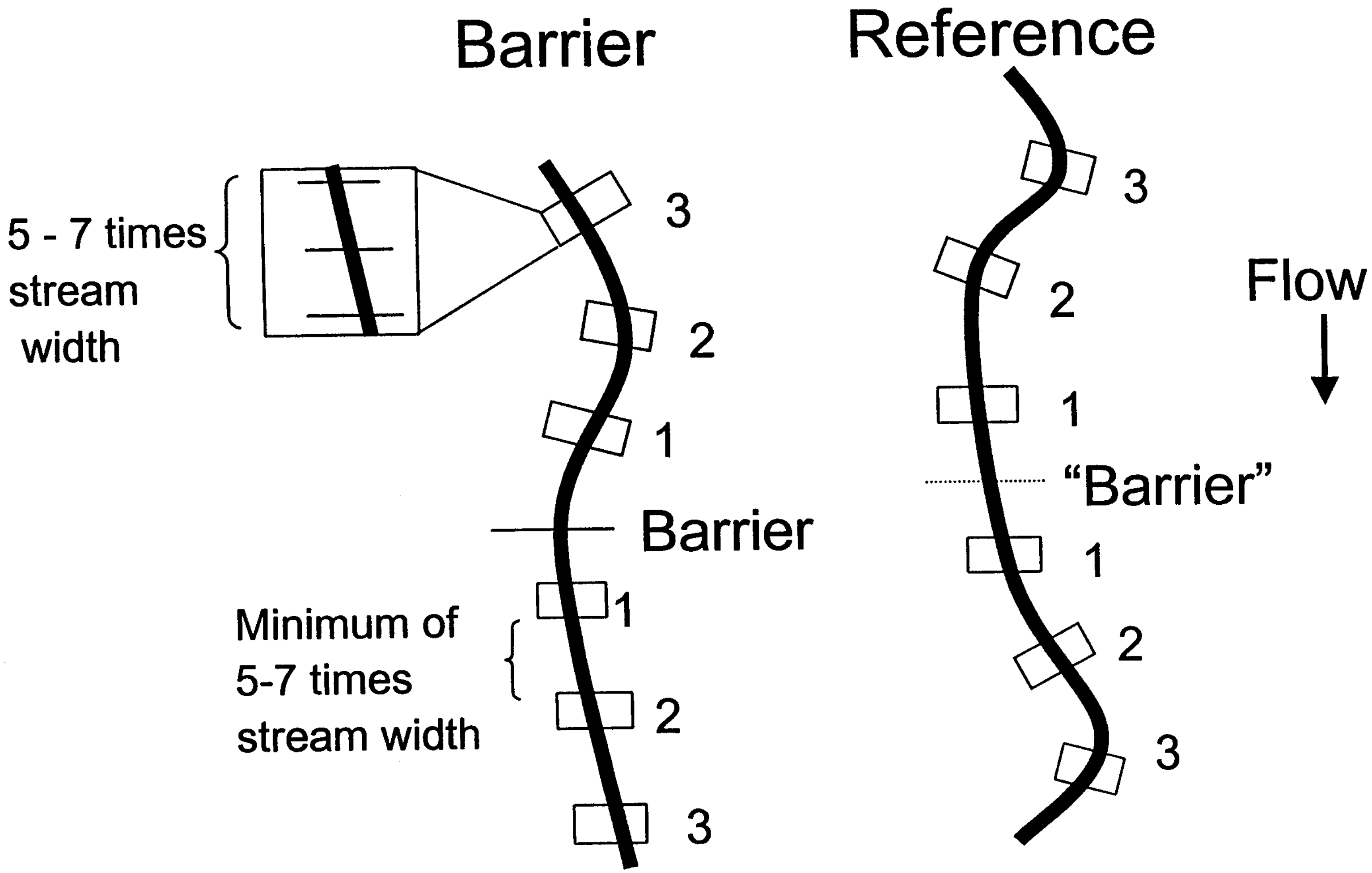


Figure 3. Location of sites within a stream pair with a enlarged view of site 3 showing the three transects.

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.

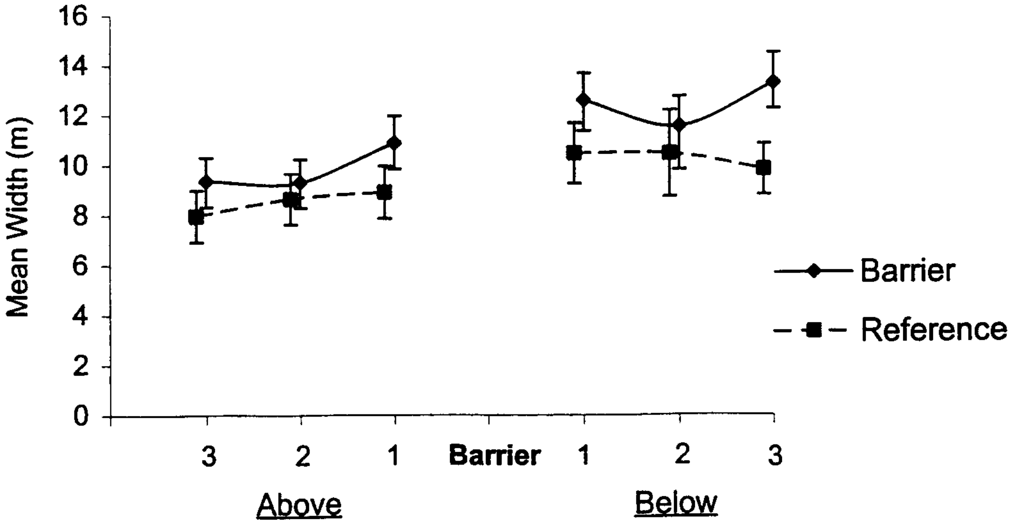
Differences in age between stream types and stream positions were determined by performing a mixed model ANOVA on mean age for both rainbow trout and white sucker. For growth analysis of rainbow trout and white sucker, the Hile method (a modified version of the Fraser-Lee method) of linear regression 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.



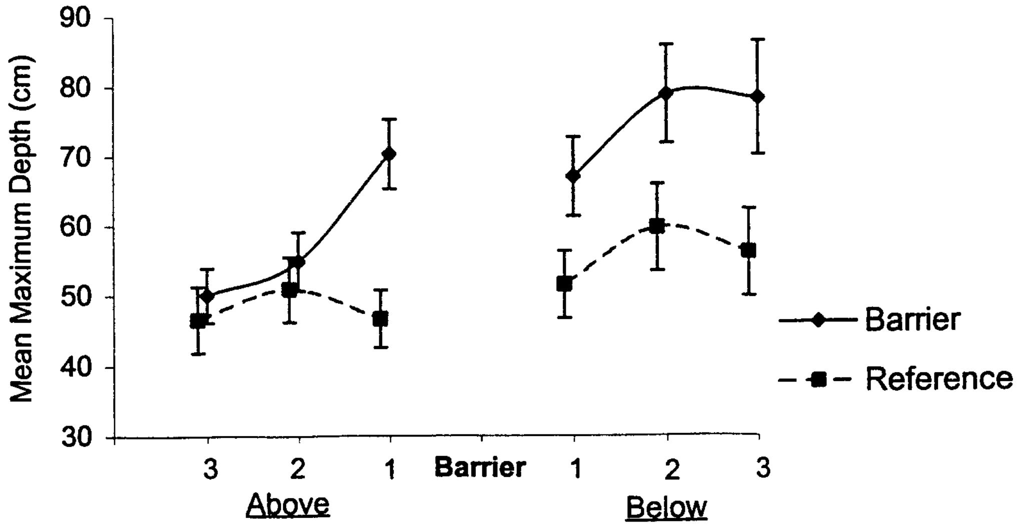
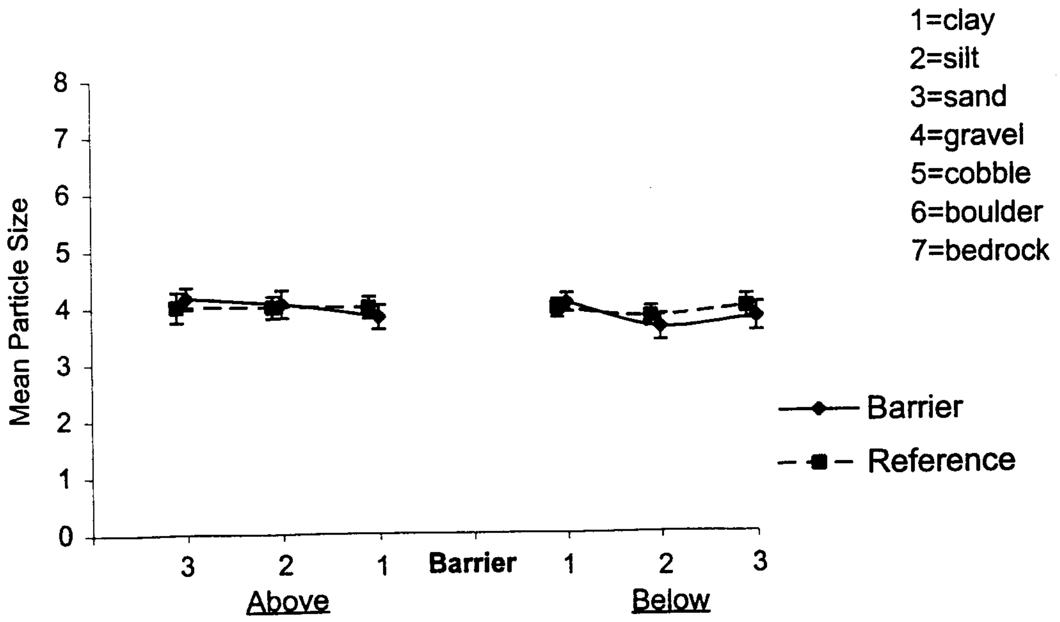


Figure 4. Trends in mean width (top) and mean maximum depth (bottom) (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.



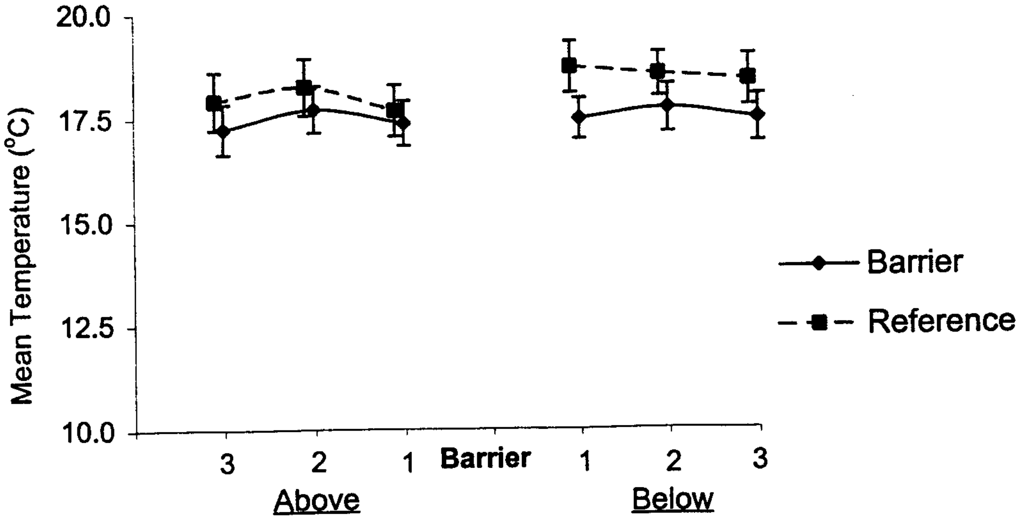


Figure 5. Trends in mean particle size (top) and mean temperature (bottom) (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.

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)

Stream Pair	Summer 1996				Summer 1997				Mean Impact
	Barrier Above	Barrier Below	Reference Above	Reference Below	Barrier Above	Barrier Below	Reference Above	Reference Below	(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

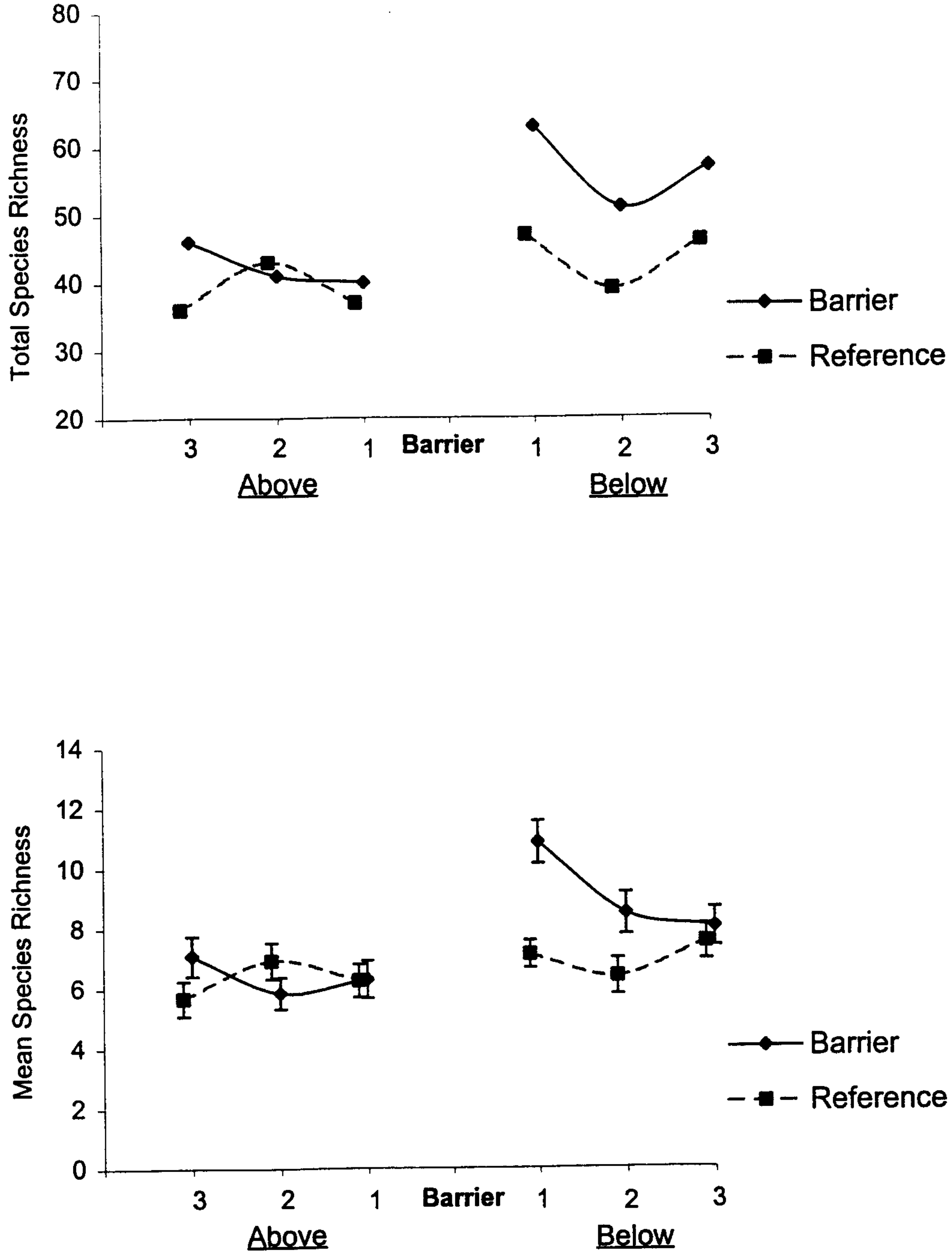


Figure 6. Trends in total (top) and mean (bottom) species richness (+- one standard error) for barrier and reference streams at the six sites sampled for all streams and years combined.

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

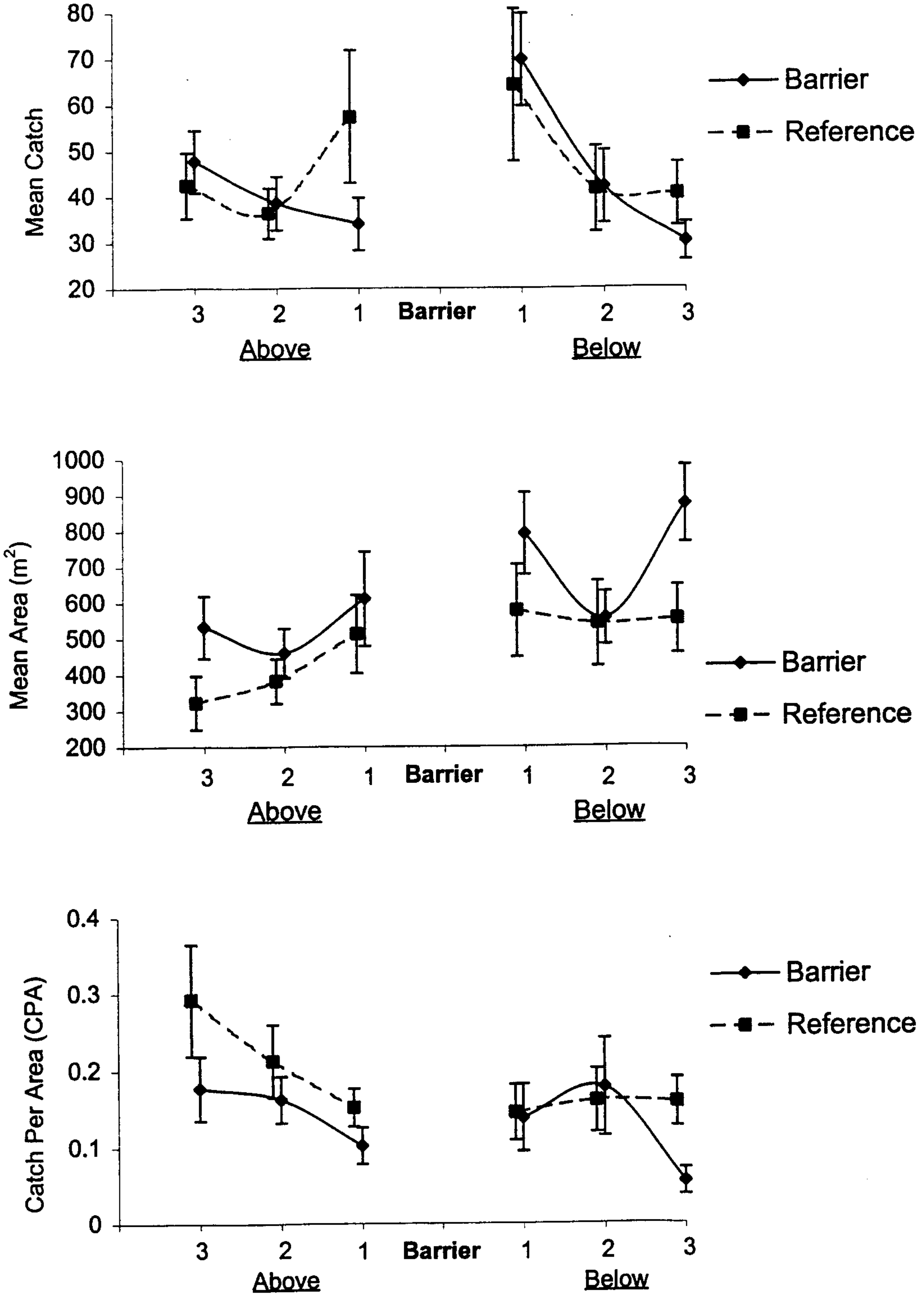
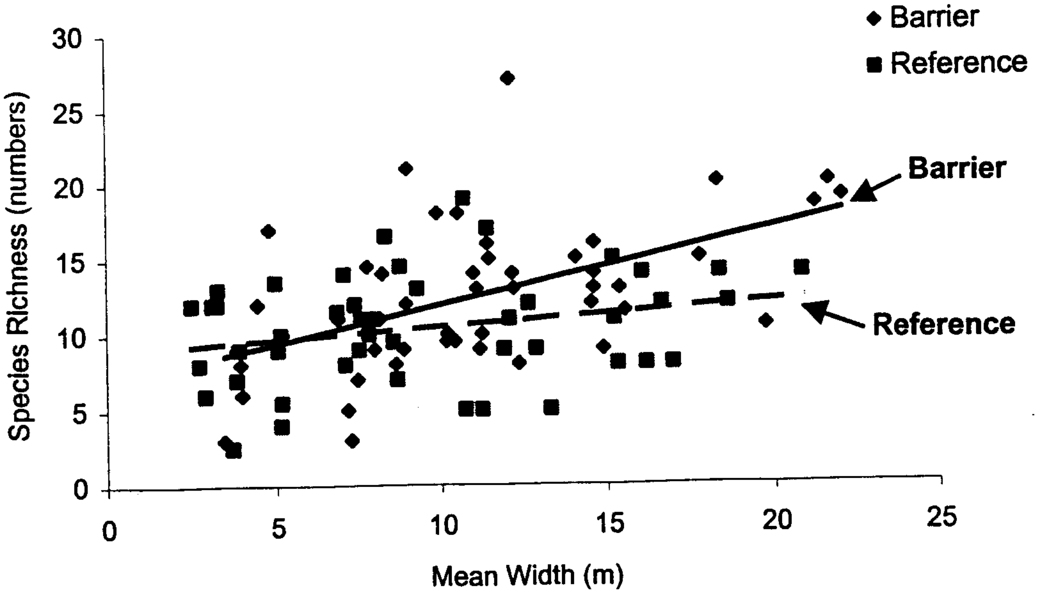


Figure 7. Trends in mean catch (top), mean area (middle), and mean catch per area (bottom) (+- one standard error) in barrier and reference streams at the six sites sampled for all streams and years combined.

(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



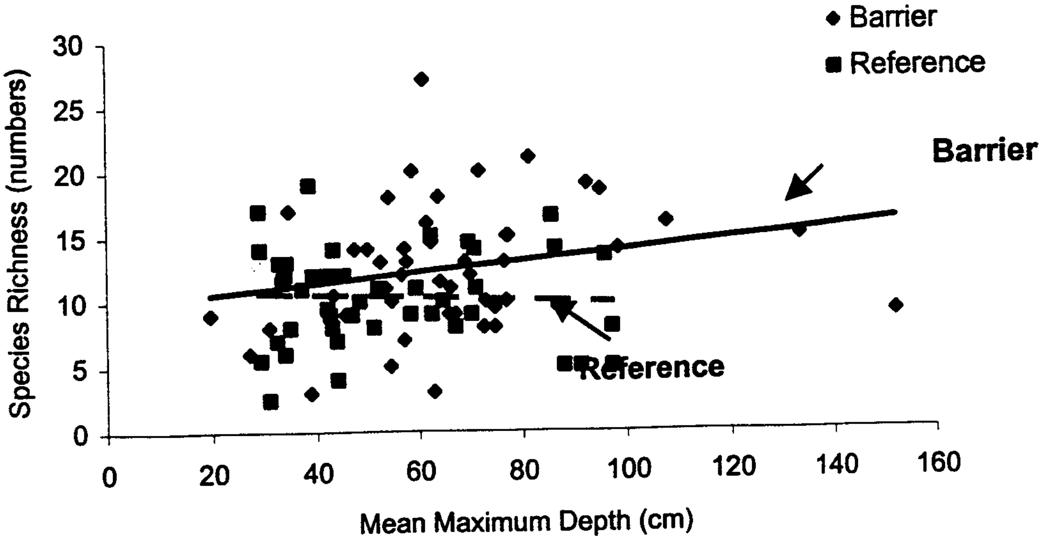
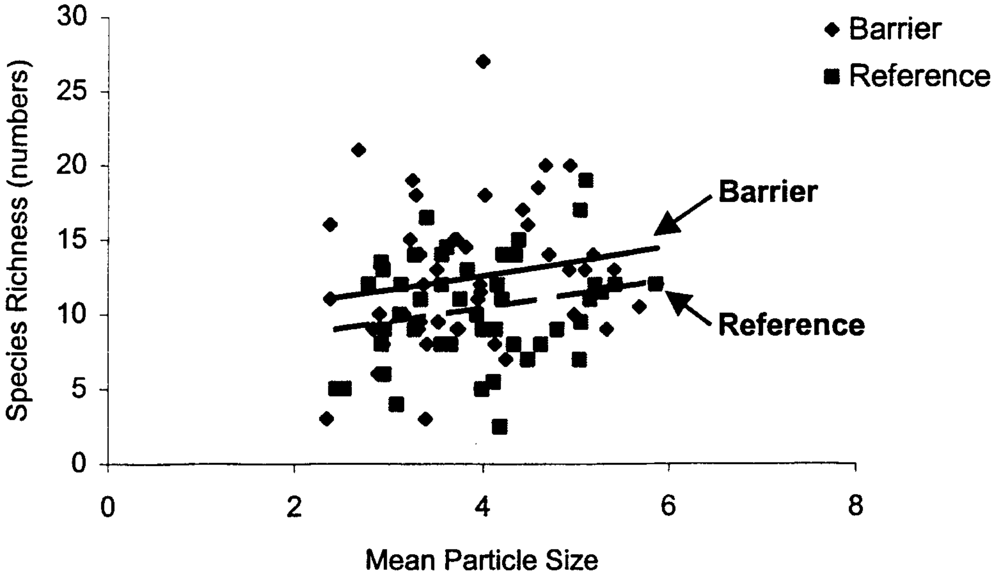


Figure 8. Influence of mean width (top) and mean maximum depth (bottom) on species richness in barrier and reference streams combining summer 1996 and 1997.

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



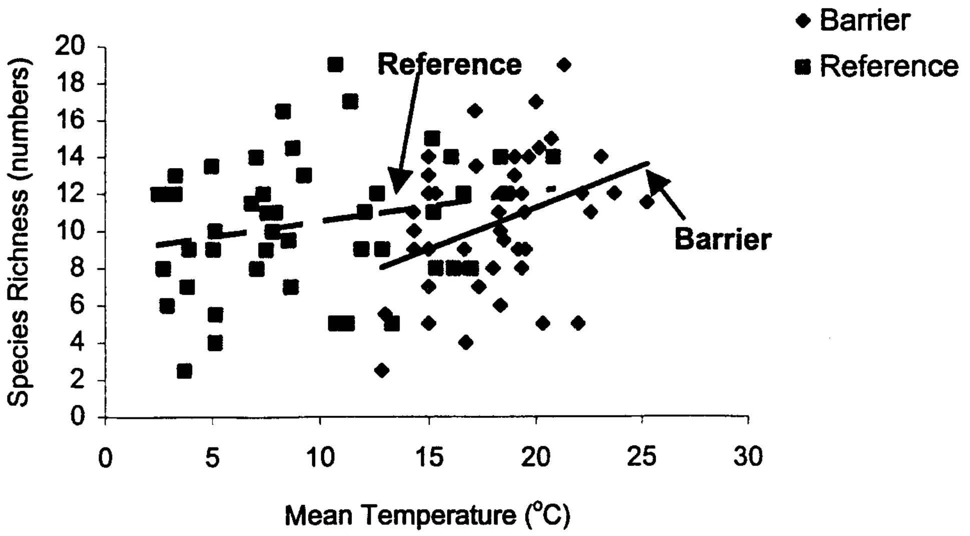
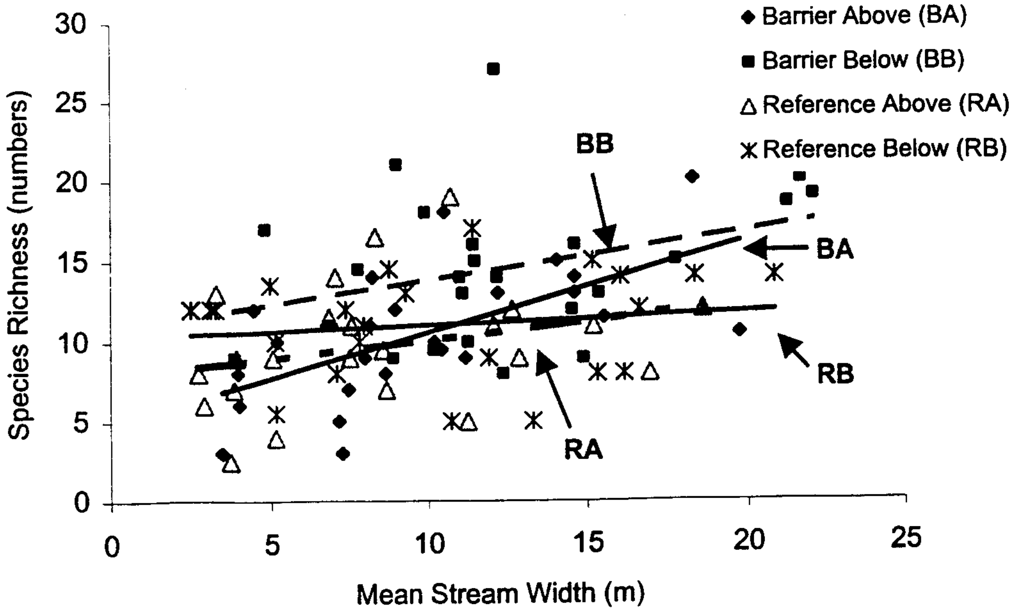


Figure 9. Influence of mean particle size (top) and mean temperautre (bottom) on species richness in barrier and reference streams combining summer 1996 and 1997.



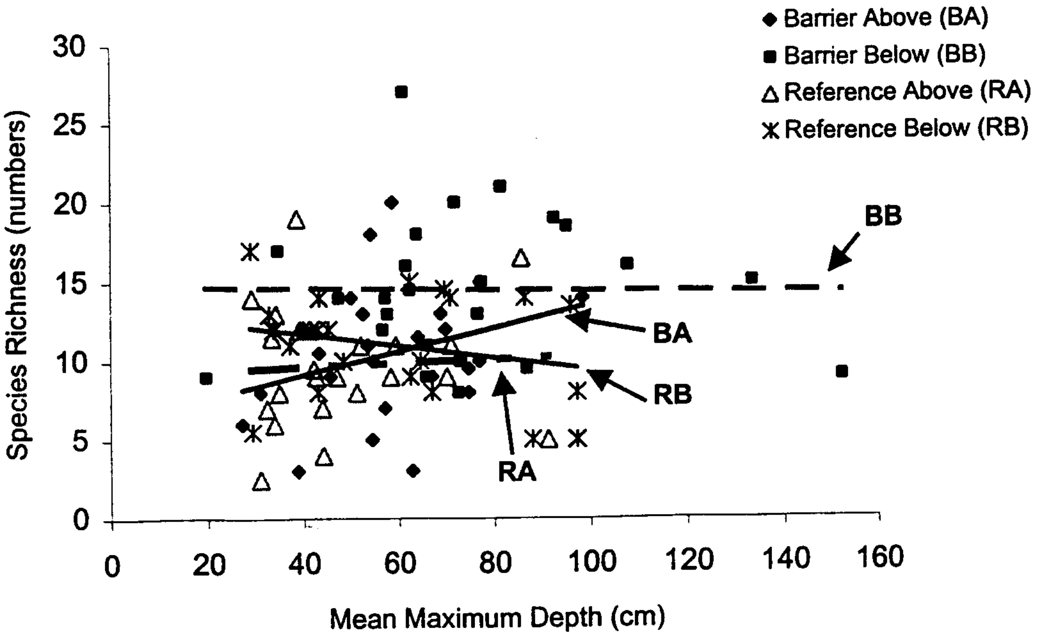
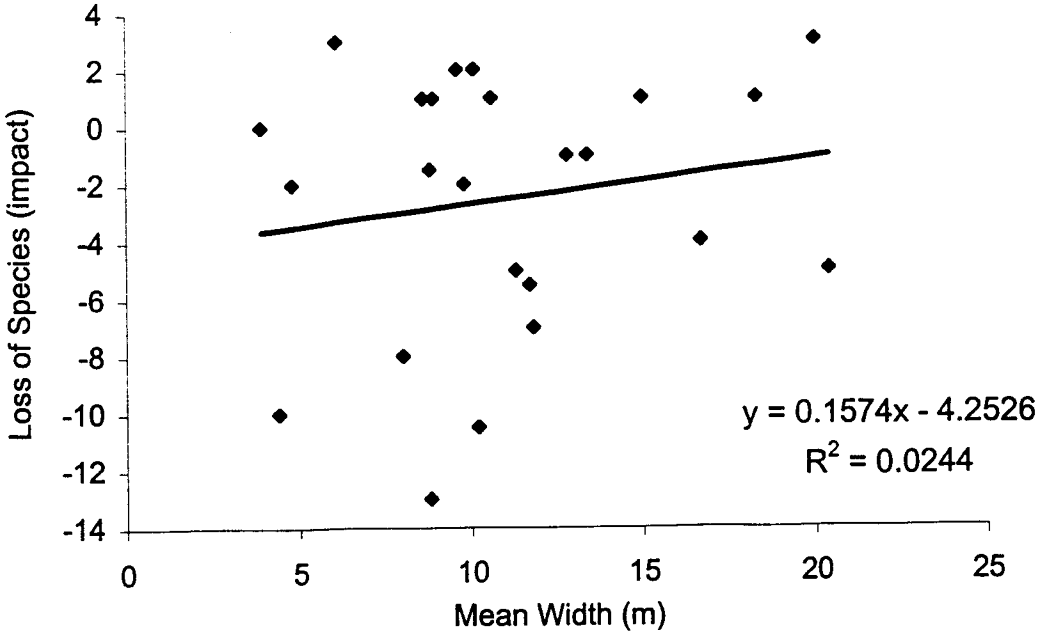


Figure 10. Influence of mean width (top) and mean maximum depth (bottom) on species richness in each stream position combining summer 1996 and 1997.

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



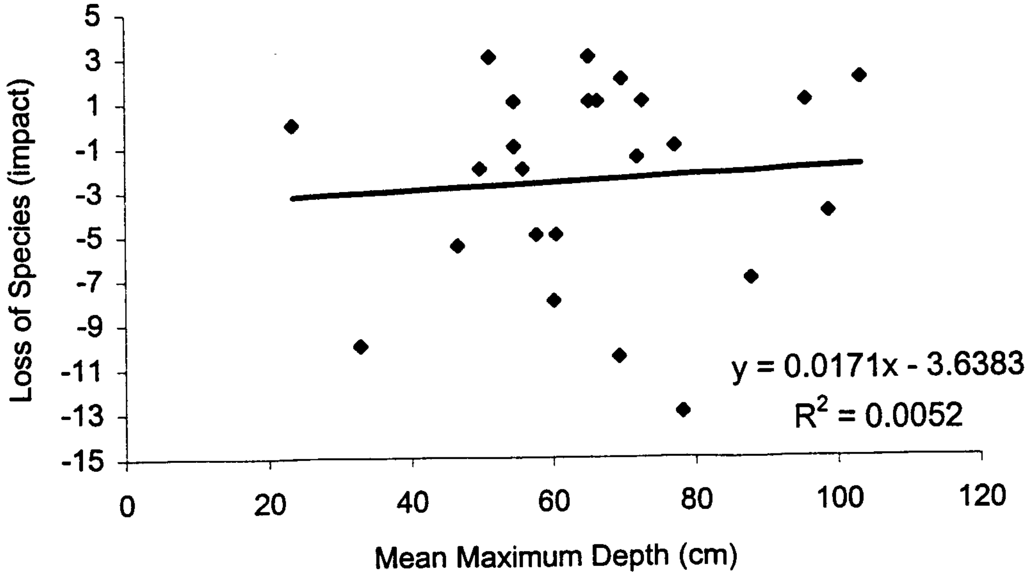


Figure 11. Influence of mean width (top) and mean maximum depth (bottom) on loss of species above the barrier (Impact) for 1996 and 1997 combined.

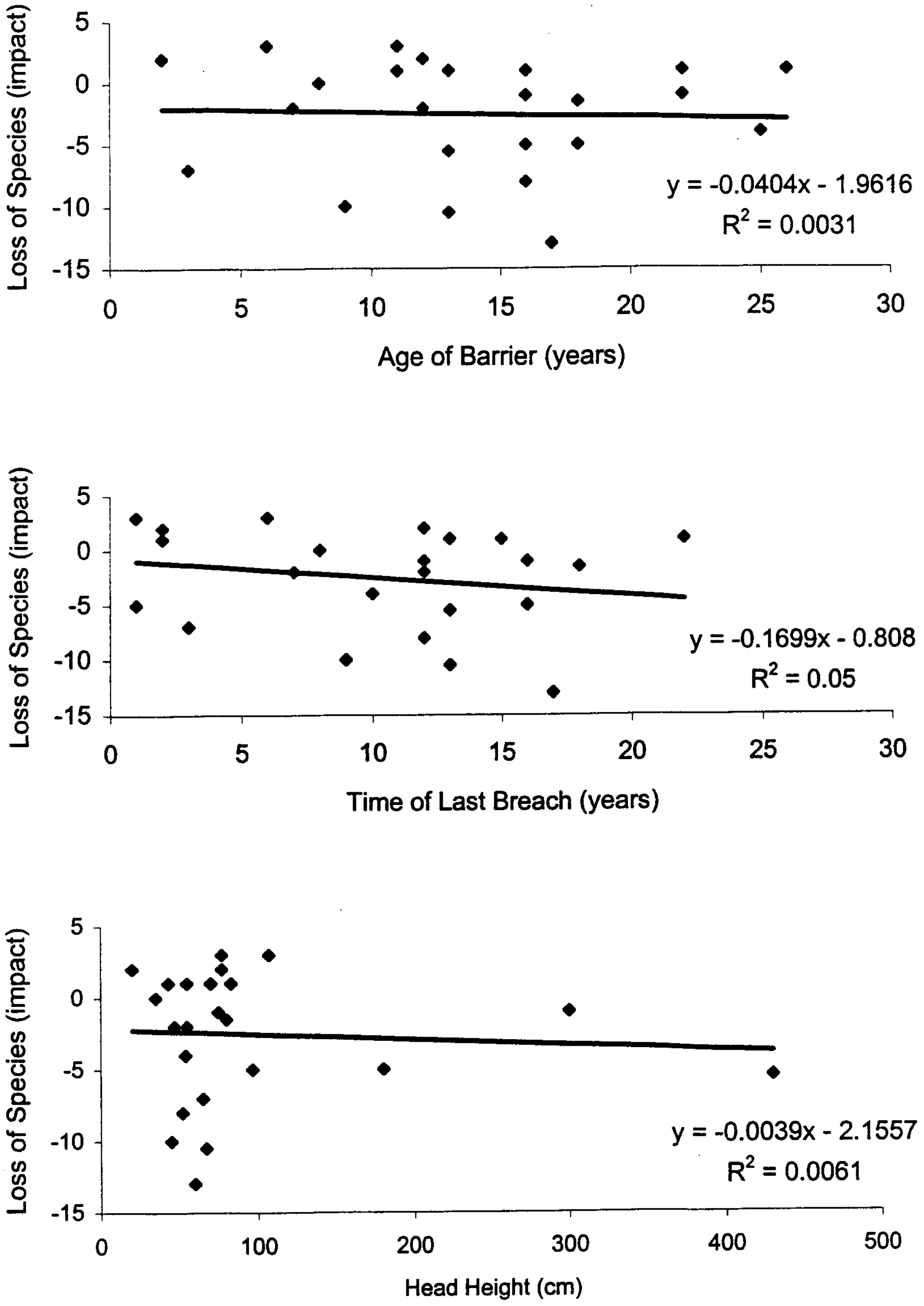


Figure 12. Influence of barrier age (top), time of last breach (middle) and head height (bottom) on loss of species above the barrier (Impact) for 1996 and 1997 combined.

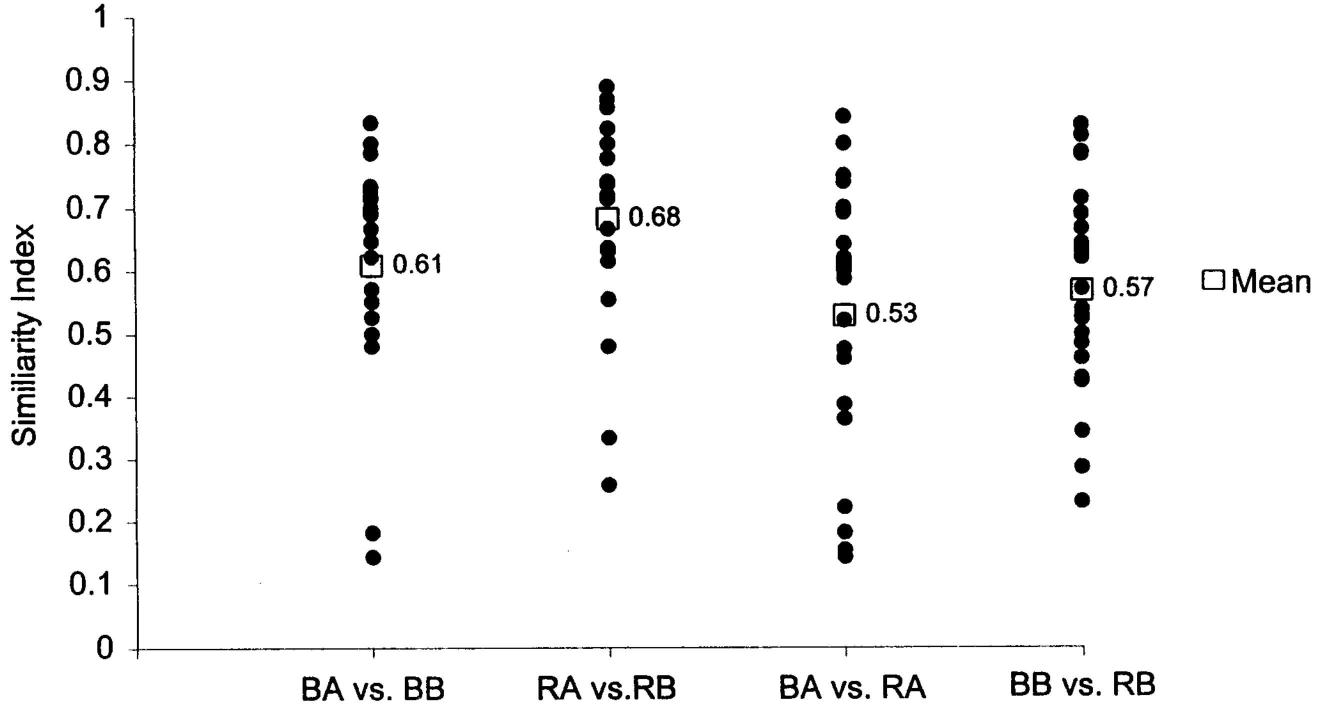


Figure 13. Distribution of Sϕrensen's Similarity Index comparing species composition between the four stream positions (BA=Barrier Above, BB=Barrier Below, RA=Reference Above, RB=Reference Below).

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	Barrier Above	Number of Streams 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)

			Number of Streams		
Common Name	Scientific Name	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 Impact	Overall Impact
	Barrier Above	Barrier Below	Reference Above	Reference Below		
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)

	Number of Sites					
Common 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 Name	Age 0	Age 1	Age 2	Age 3	Mean 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 Name		Age 0	Age 1	Age 2	Age 3	Mean 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

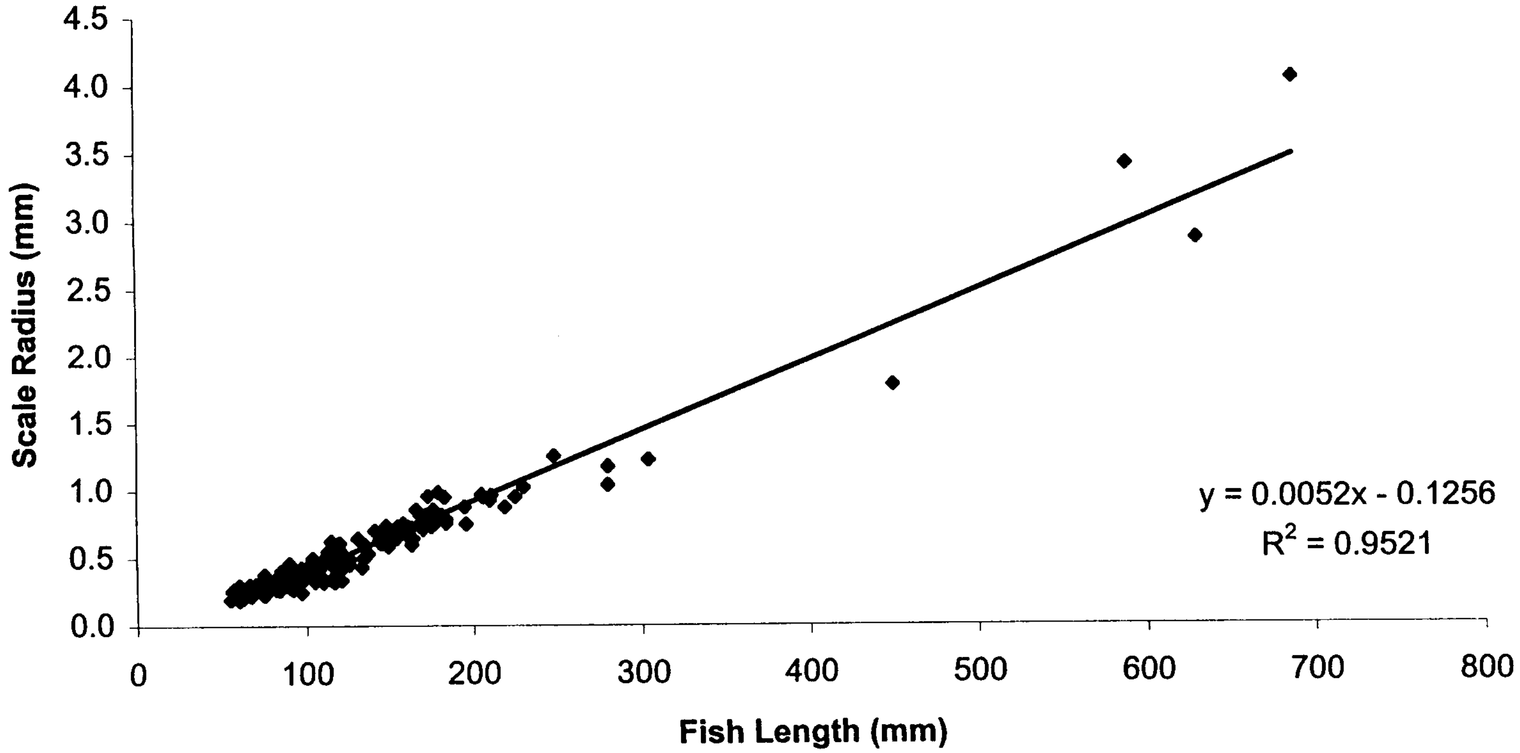


Figure 14. Regression of fish length on scale radius for back-calculations of length at age for rainbow trout.

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

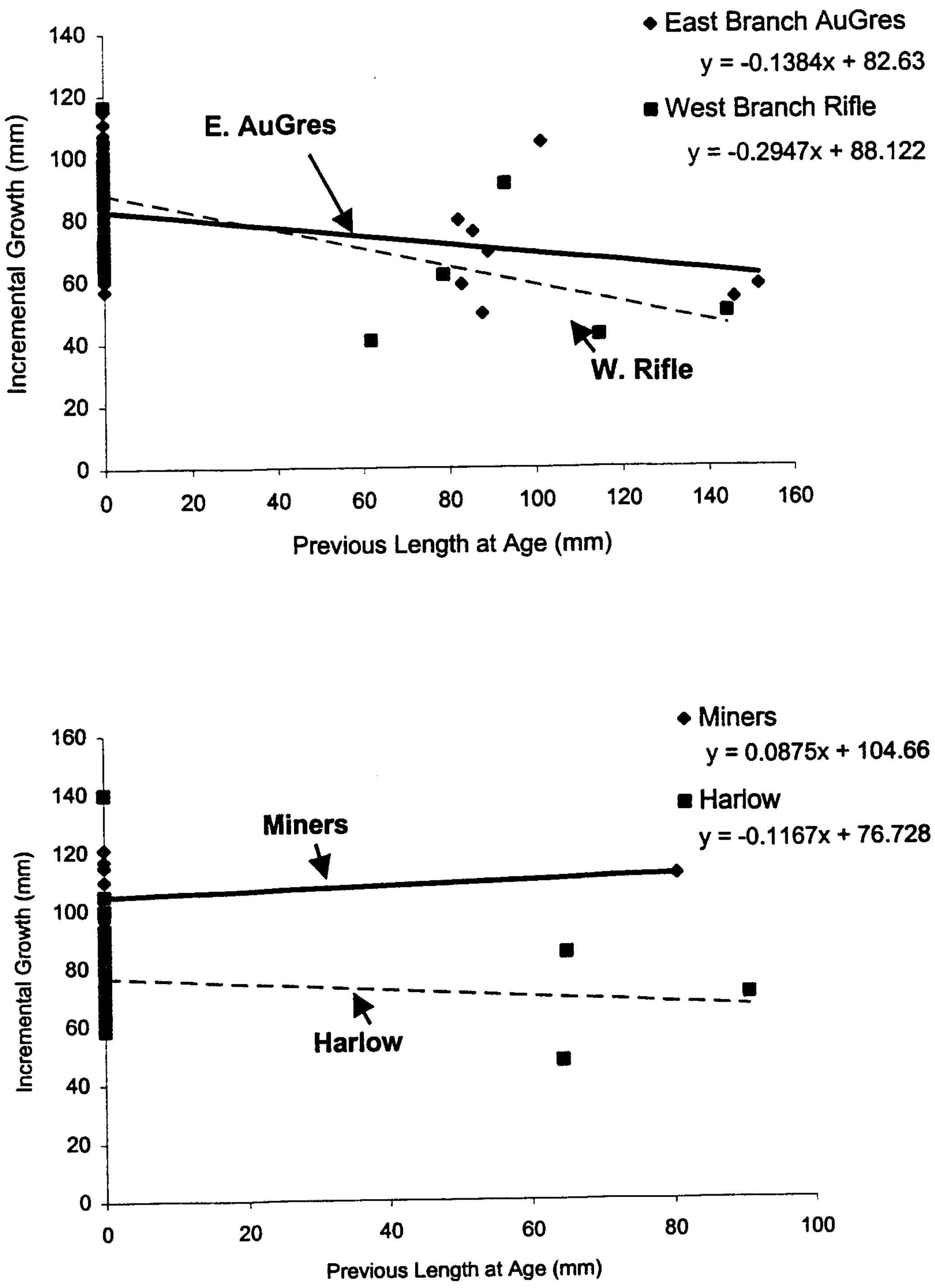
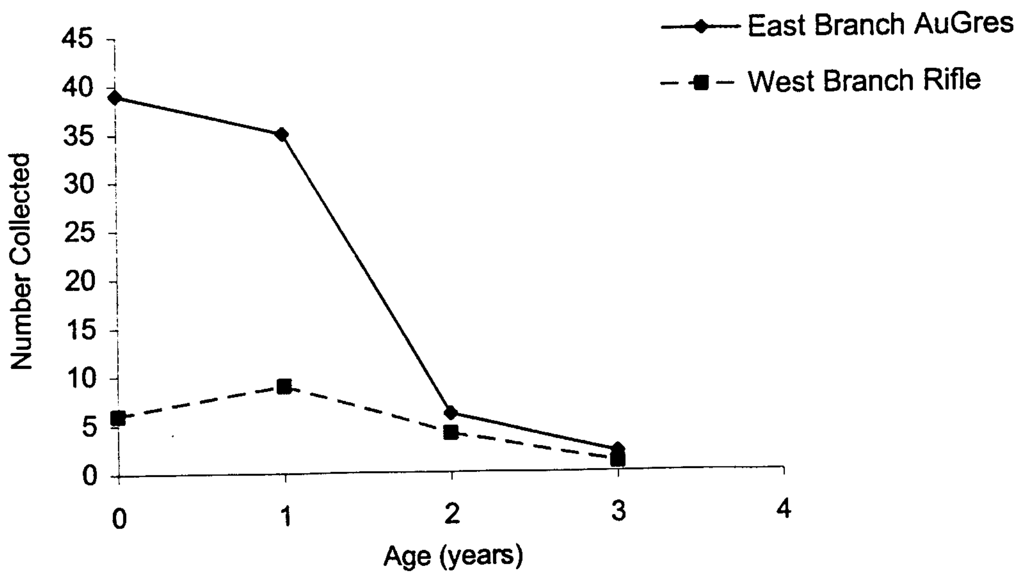


Figure 15. Growth of rainbow trout for East Branch AuGres/ West Branch Rifle pair (top) and Miners/Harlow pair (bottom).



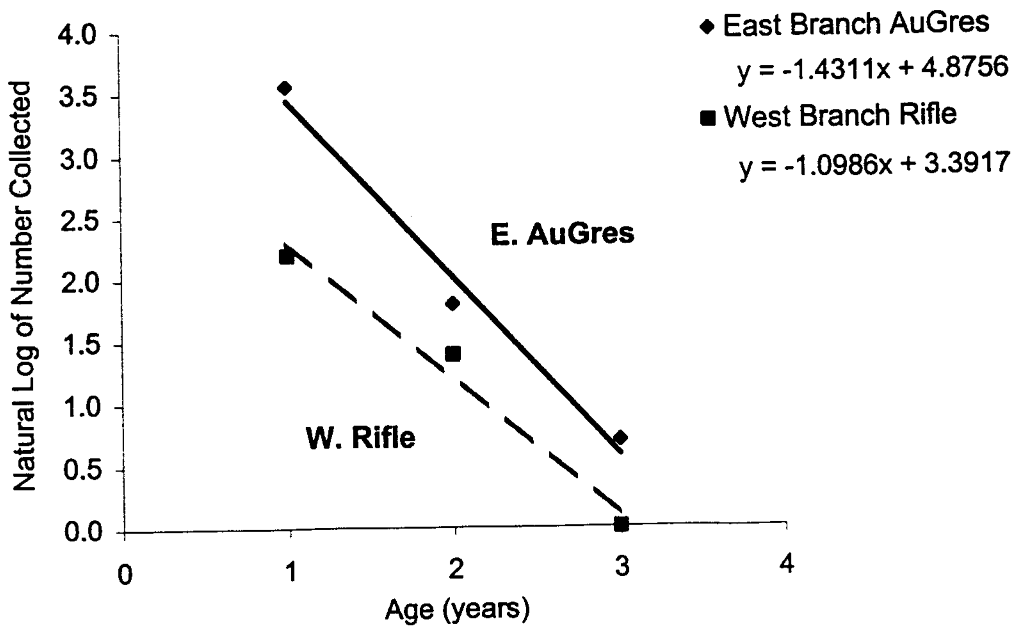


Figure 16. Catch curve and natural log transformed catch curve for rainbow trout for East Branch AuGres/West Branch Rifle stream pair.

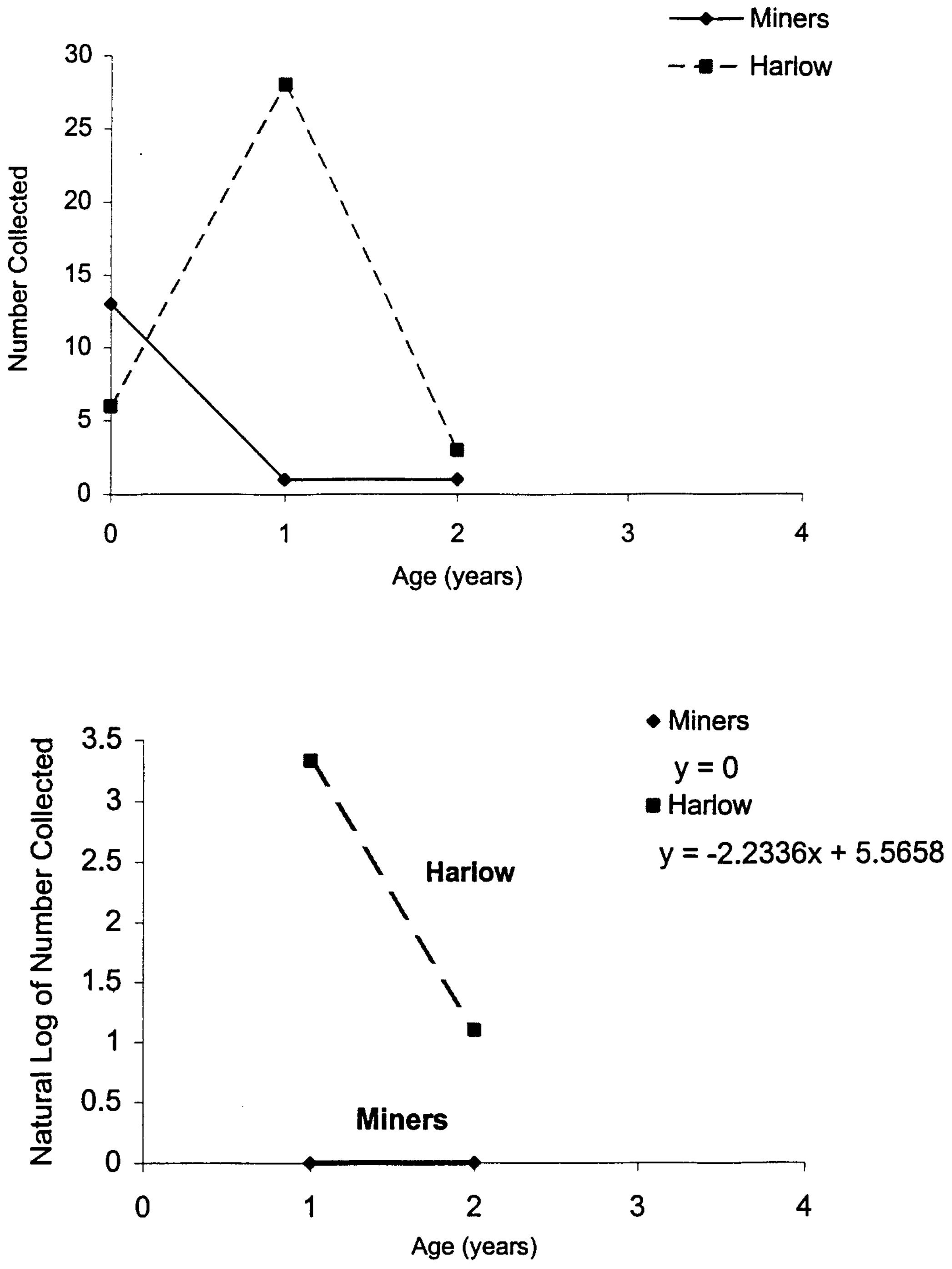


Figure 17. Catch curve and natural log transformed catch curve for rainbow trout for Miners/Harlow stream pair.

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 ($P_{\text{stream type} \cdot \text{age}}=0.0128$).

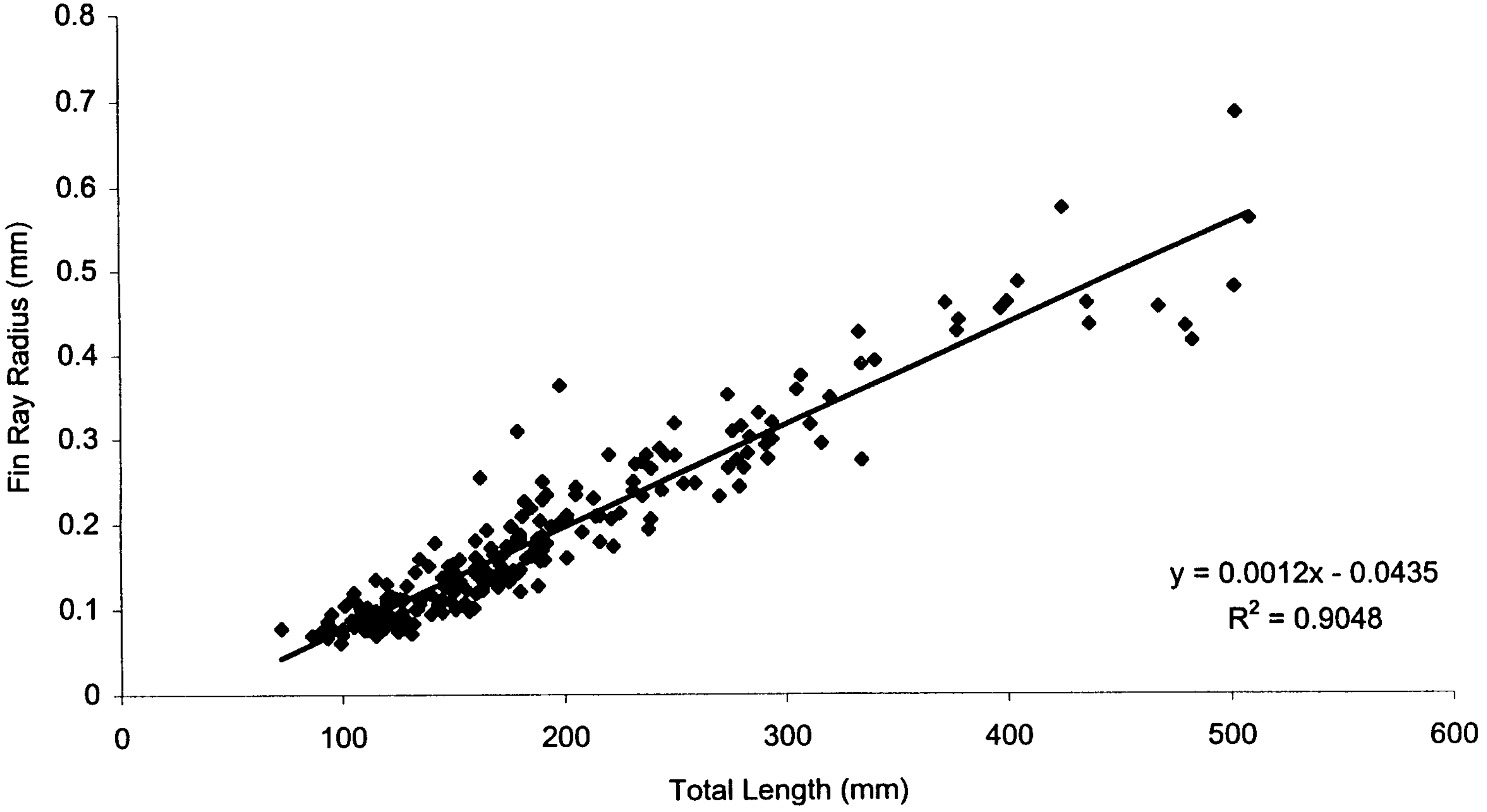
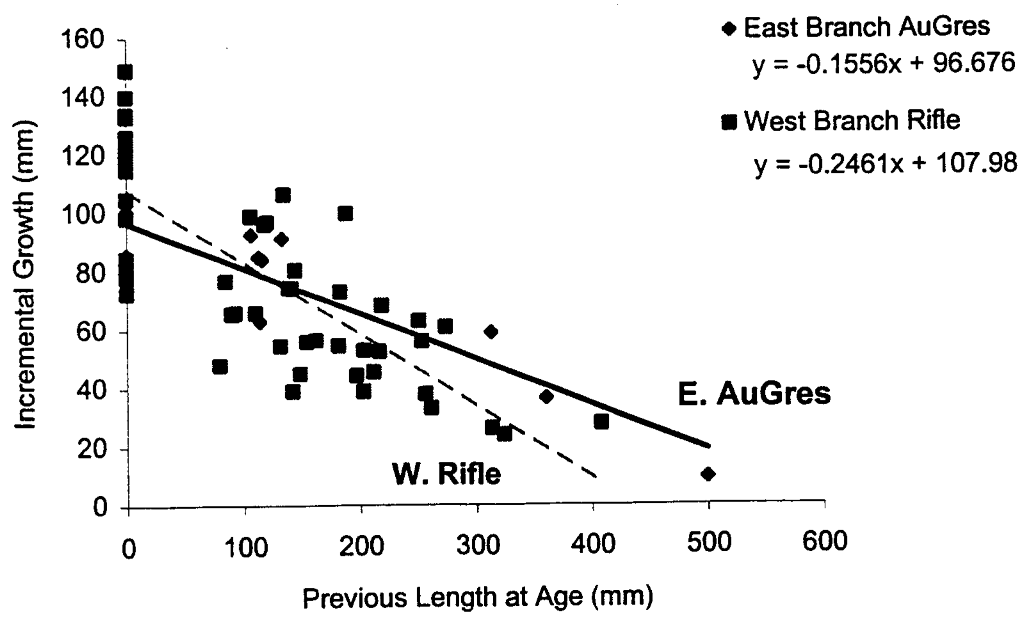


Figure 18. Regression of fish length on fin ray radius for back-calculations of length at age for white sucker.



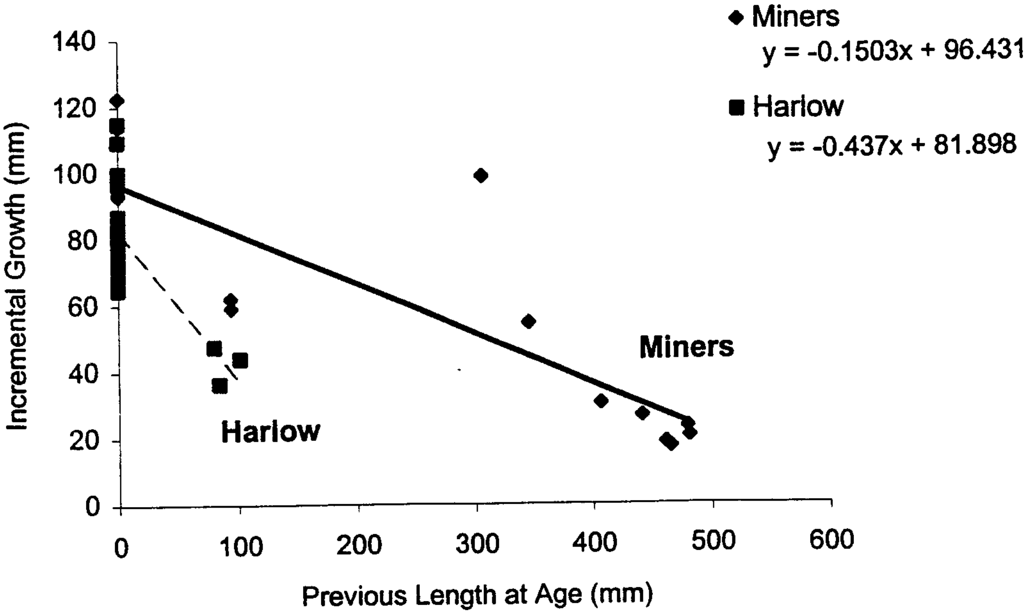
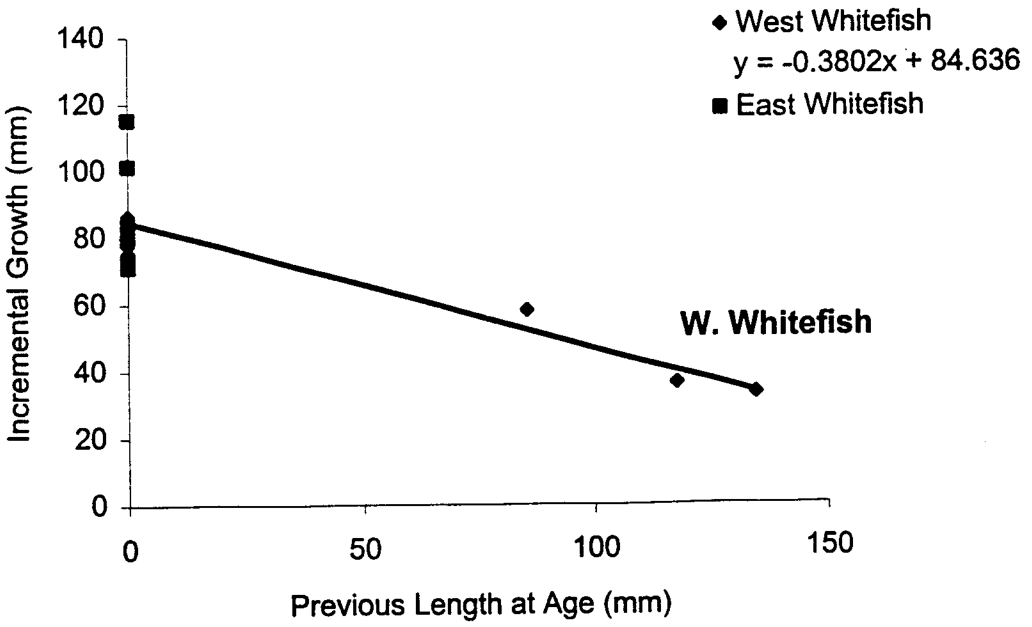


Figure 19. Growth of white sucker for East Branch AuGres/ West Branch Rifle pair (top) and Miners/Harlow pair (bottom).



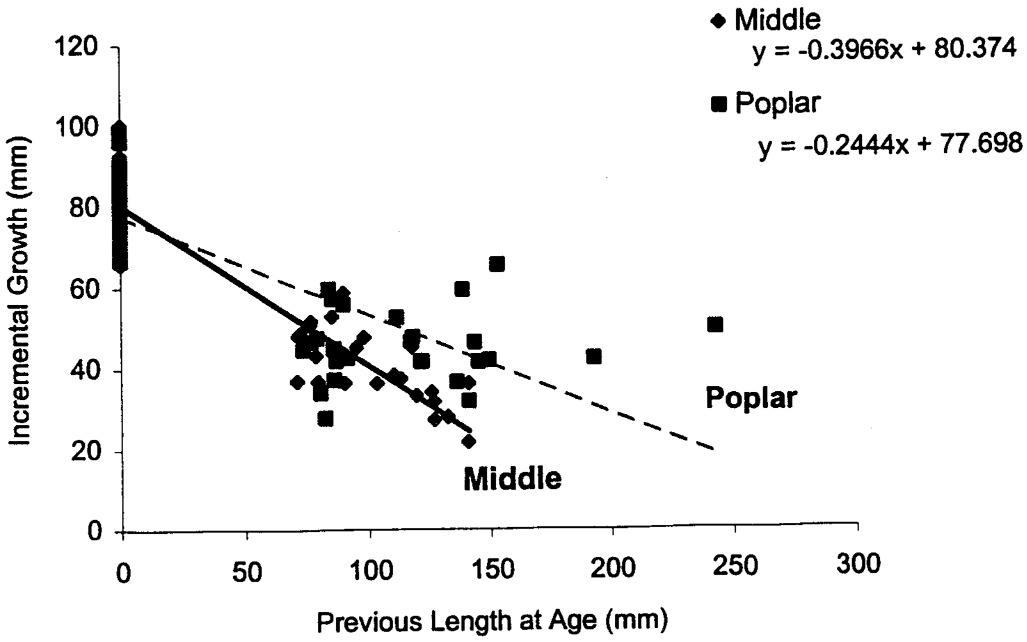


Figure 20. Growth of white sucker for West Whitefish/East Whitefish pair (top) and Middle/Poplar pair (bottom).

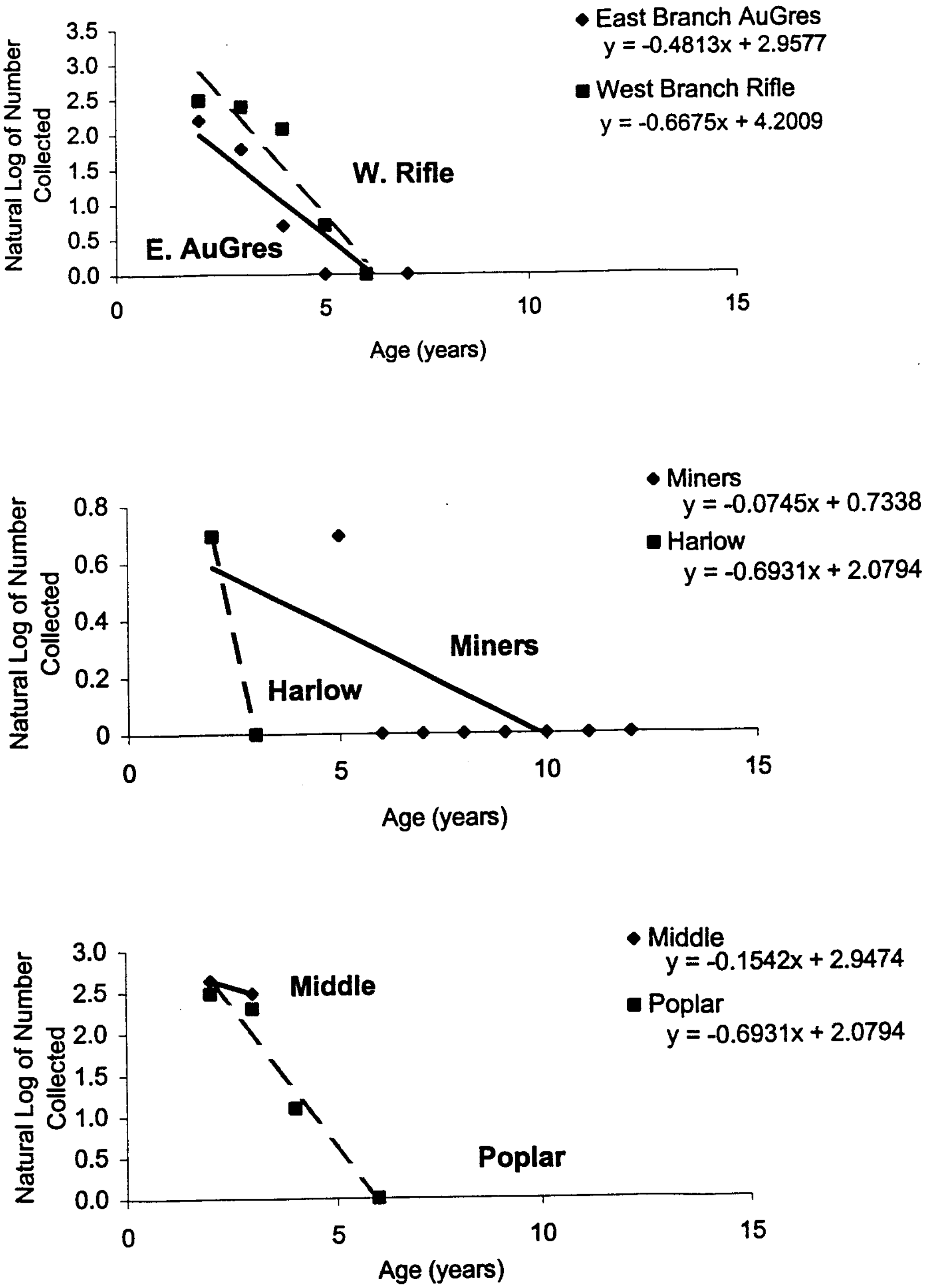


Figure 21. Natural log transformed catch curves for white suckers for East Branch AuGres/West Branch Rifle pair (top), Miners/Harlow pair (middle), and Middle/Poplar pair (bottom).

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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Potentials and Pitfalls of Database Design: Lessons from a Historical Database for Great Lakes' Stream Fishes

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ABSTRACT

There is considerable enthusiasm for and value in the development and analysis of large databases that integrate physical and biological data from diverse sources and over broad spatial, temporal, and taxonomic scales. There also are special challenges associated with such ventures. We introduce the Biological Impacts of Low-head Dams (BILD) historical database. The database was developed as part of a project assessing the impacts that small barriers used in sea lamprey control have on assemblages of stream fishes throughout the Great Lakes Drainage Basin. We also highlight the challenges encountered in developing the database. Our review is intended to assist the decision making of fisheries scientists, managers, and funding agencies asked either to develop an historical database, or to provide data or funding for one.

There is considerable enthusiasm, if not demand, for the development of databases bringing together scientific information from diverse sources. The enthusiasm has arisen for at least three reasons. First, scientists and resource managers, and their employers, have recognized that such databases are valuable for making scientifically-defensible decisions regarding fish stocks and their environment. For example, the data may be used to document initial conditions of a fish population or its environment, to identify spatial or temporal trends, to calibrate mathematical models, or to avoid or support litigation. Second, the incredible advancements in desktop computing and networking now allow more users to access greater amounts of information. Database approaches in particular can increase the integrity and consistency of the data by providing a single repository, can encourage data sharing among researchers with different areas of expertise, and can facilitate the transfer of data among different application programs used for analysis (Harvey and Press 1996). Third, developments in statistics, such as meta-analysis, are improving greatly our ability to summarize what has been done, to examine questions at broader spatial, temporal, and taxonomic scales, and to plan future research (Osenberg et al. 1999).

These developments mean that scientists and resource managers whose primary training may emphasize skills pertaining to fisheries management, fish ecology, and environmental issues and policy making, will be asked more frequently to be involved in the construction or management of large databases, or to contribute data or funds to them. On one hand, this is desirable because fish and fisheries scientists are likely to be 'closer' to the data, and methods of collection, and therefore can improve the quality of the design and analysis of the database (Van Alstyne et al. 1995). On the other hand, this can be problematic if the scientists are unfamiliar with database design and management. Indeed, in some areas of biology there is growing risk that scientists collecting large amounts of data may have to turn it over to outsiders specializing in the design and analysis of large databases (Reichhardt 1999; but see Campbell 1999). Further, despite software advances encouraging greater involvement by less experienced end-users, developing databases remains a complex task. Such issues necessitate greater discussion of the potentials and pitfalls of databases in fisheries research. In addition, while recent sources from other disciplines have sought to address these issues to varying degrees (Michael 1991; ESA 1995; NRC 1995; Harvey and Press 1996), it is unclear whether they are widely known and their examples may be exceptional in terms of project size and funding. We therefore highlight some of the challenges we encountered while developing and analyzing the Biological Impacts of Low-head Barriers (BILD) Historical Database. First we describe the database and what it was developed to do. Then we describe the challenges encountered during its development. Our intention is to assist other scientists, resource managers, and funding agencies asked to be involved in projects of a similar nature.

The BILD Database

The BILD historical database was developed as part of a project assessing the impact low-head barriers (0.4 - 2.0 m in height) have on assemblages of stream fishes found throughout the Great Lakes drainage basin. The Great Lakes Fishery Commission (GLFC) is considering expanded use of low-head barriers as an alternative method of controlling parasitic sea lamprey (*Petromyzon marinus*). During the early 1900's, sea lamprey invaded the upper Great Lakes through shipping passages and were responsible, in part, for population crashes of large fishes such as lake trout

(*Salvelinus namaycush*). Since 1958, sea lampreys in the Great Lakes have been controlled by periodic treatment of rearing streams with the larval lampricide, 3-trifluoromethyl-4-nitrophenol (TFM). In 1992, the GLFC pledged to reduce its reliance on TFM by 50% because of public concern regarding the use of chemicals (GLFC 1992). Low-head barriers represent one alternative method of control being considered. These barriers deny adult sea lamprey access to their spawning grounds in streams, thereby restricting TFM treatment to the section of stream below the barrier, reducing the amount of TFM used, and the number of nontarget fishes exposed to the chemical. Unfortunately, the impact of these small barriers on other taxa of stream fishes has not been assessed.

The database combines data from five sources: Department of Fisheries and Oceans Canada, Michigan Department of Natural Resources, Ontario Ministry of Natural Resources (OMNR), Wisconsin Fish Distribution Survey Database, and US Fish and Wildlife Service Sea Lamprey Management Program. It contains information on (i) the structure of stream fish assemblages throughout that portion of the Great Lakes Drainage Basin where sea lamprey are likely to breed, (ii) the physical characteristics of the sample streams, as well as specific sample sites and times, and (iii) the specifications for any barriers (Table 1). The information on stream fishes is based on over 26,000 sample surveys for 183 streams across the Great Lakes (Figure 1). Fifty nine of the streams have man-made barriers on them, while 14 have natural barriers. For some streams, the sample surveys date back to the early 1900's although such examples are exceptional (Figure 2).

The BILD historical database is being used to assess whether low-head barriers have a consistent, basin-wide impact on stream fish assemblages and to identify those species impacted most by barriers. It is intended to complement a extensive field survey conducted in the summer of 1996 which examined the species composition of 24 matched pairs of barrier (with barrier) and reference (without barrier) streams across the Great Lakes Basin (Hayes et al. MS, Porto et al. 1999). Strengths of the field survey include its paired design and standardized sampling protocol. A weakness of the field survey is the absence of time-series data, because the magnitude of any impacts could be time dependent (e.g. Tilman et al. 1994). Given that considerable time would be required to carry out a proper Before-After-Control-Impact Paired Series Design (e.g. Bence et al. 1996), it was hoped that the historical data would provide useful time series to augment our field survey.

Analysis of the historical data is still underway and has been challenging for reasons described below. A first step has been identifying the limitations with the available data and these are considerable. For example, historical records suitable for comparison of pre- and post-construction periods were available for only five of the 47 streams used in our extensive field survey (one reference stream had to be used twice in our pairings): four barrier streams and only one corresponding reference stream. An additional 17 barrier streams and 17 reference streams had some historical data, but the time series were short and restricted to the period of post-barrier construction. More broadly, in only 15 of the 73 barrier streams in the historical database are geographical references adequate to distinguish surveys made below versus above the barrier location, and only three of the 15 streams had surveys conducted above the barrier, the fragmented habitat where impacts such as local extinctions are most likely to be observed.

For those streams where reasonable times series are available (regardless of sample location relative to the barrier), we are now examining whether there are consistent changes in the species composition before versus after construction of a barrier. These changes will be compared with any temporal changes observed in streams without barriers, which could reflect impacts due to factors other than barriers such as changing water levels in the Great Lakes. The changes also will be compared with differences observed in the species composition of barrier and reference streams from our extensive field survey. In addition, the time series are being used to estimate probabilities of local extinction and colonization for individual species in barrier and reference streams (e.g. Clark and Rosenzweig 1994).

The Challenges

The first significant challenge we encountered was drafting a project plan that (i) identified the specific goals and objectives of the database, (ii) identified who the end users (beyond ourselves) likely would be, (iii) identified potential sources of data, (iv) selected the software package with which to develop the database, and (v) laid out the schedule for the project's completion. While the need for planning is a truism, experts agree that inadequate planning and failure to adhere to a plan can waste time and resources and lead to an inferior database (Michael 1991; NRC 1995; Harvey and Press 1996).

Our plan reduced the openendedness of the data compilation process which could have been a formidable problem with an area the size of the Great Lakes drainage basin and with sources ranging from federal government agencies to Ontario conservation authorities and from research scientists in universities to professional consultants. For example, our plan helped us avoid spending extra time to acquire data that were not directly relevant to the impacts of small barriers on stream fishes. In addition, it also led us to focus on the main federal, state, and provincial agencies for sources of data because they could provide large volumes of data with the least effort. Smaller data sources, such as those from Ontario conservation authorities, journal publications, and graduate theses were not pursued because of the added effort required to obtain fewer data and because of the increased possibility of data duplication if the sources had shared their data with federal, state, or provincial agencies. When contacting the agencies, our plan helped us articulate clearly the type of data we were looking for and how we intended to use it.

Our plan also exposed the uncertainty surrounding the time needed to complete the database project. We had relatively limited resources and did not know how much data were available. In addition, we could not use methods designed for estimating the extent of data from literature searches (Harvey and Press 1996). We ambitiously planned to complete the project in six months. It actually took 17, and some decisions are still outstanding (see below).

Finally, our plan also helped us begin designing the database with the end users in mind. The first step was our choice of database management system. We selected Microsoft Access because it has simplified relational database design greatly, is easy to use, and is Windows and Macintosh compliant and therefore widely available. Its query-by-example feature provides a flexible, effective method for data retrieval and, for more sophisticated users, Access also offers structured query language. It also was powerful enough to handle the volume of data we compiled in the end. In general, selecting a database management system requires careful consideration given the number of database packages available, their limitations, and continual software developments. As a rule, it is key that the management system be adequate to handle the amount and types of data collected and to meet the project goals both immediately and into the future.

The second, and perhaps greatest, challenge we faced was accommodating the differences inherent among the various data sets. This is a common problem for databases integrating data from diverse sources (NRC 1995). We realized that inherent differences were likely, that their careful consideration would be important at the analysis stage, and that the database needed to be developed with these issues in mind.

The differences existed at a variety of levels. One was the different house preferences in the form and format of the information we were provided. Data from the Michigan Department of Natural Resources, for example, had to be entered manually from original data collection sheets, while data from the other agencies were provided electronically. Manual entry is more time consuming and error prone than electronic processing, but easier for backchecking specific entries. Electronic files acquired from different agencies also differed in the software used to create them and translation of these files was not as seamless as one might expect. Lastly, we had to accommodate different house preferences in the organization of data. For instance, the various agencies used different codes to identify fish species and none of the individual coding systems was adequate to accommodate all of the species present in the combined datasets. We therefore devised our own coding system. In addition, the source databases differed in how they formatted (e.g. dates), classified (e.g. gear types, weather), and reported their data (e.g. measurement and geographical referencing systems). They also varied in the thoroughness of documentation (metadata) (ESA 1995; NRC 1995) provided.

There also were inherent differences among the surveys contained within each of the agency databases. The Wisconsin Fish Distribution Survey, for example, comprised collections made from over 50 sources including Fish Distribution Survey personnel, university scientists and students, power corporations, and commercial and recreational fishers. Even within sampling programs, such as Sea Lamprey Control, the sampling protocols have changed over time. It therefore must be recognized that the individual sample surveys varied in their design and original purpose, the expertise of the personnel carrying them out, and the field collection methods. In addition, they likely varied in the methods used to audit and verify the data and to document important decisions.

Such inherent differences affect the quality of the data, where quality is rigorously defined as "the totality of features and characteristics of a product or service that bears on its abilities to meet the stated or implied needs and expectation of the user" (ANSI/ASQC 1994). For our purposes, we distinguish between the quality of the data at the time we received it (primary quality) and the quality of the data after any manipulation required to incorporate it into the BILD Historical Database (secondary quality).

In terms of primary quality, we assumed that the data we received from contributors was free of errors. Although this is often not recommended (e.g. NRC 1995), it was necessary in our case given the resources available and it was considered reasonable given that the data had already passed the agencies' own quality control procedures. We took three steps to ensure the secondary quality of the database and its interface. First, we verified record by record all imported and manually-entered data with the original datasets. Second, the database was beta tested by graduate students and upper-level undergraduate students, some trained in computer sciences and others trained in ichthyology, and data were checked and the database design modified in light of their comments. Third, we solicited feedback from control experts and potential end users at two workshops.

Owing to the variation in data quality, analysis and interpretation of the BILD database will be challenging. For example, a time series of surveys for any given stream may have gaps and the individual surveys may differ in the (i) seasonal timing of the collection, (ii) location of the collection relative to the barrier, (iii) effort, method, and therefore efficiency of the collection, and (iv) precision of taxonomic identifications. Such differences can seriously confound attempts to detect changes in the fish community following the construction of a barrier. Nevertheless, there also is considerable interest in and development of statistical methods used to synthesize research findings across studies (meta-analysis) and these methods can help accommodate the heterogeneity in data quality due to among survey differences in methodology and design (Osenberg et al. 1999). One pertinent recommendation is that to avoid unconscious biases, suppositions regarding data quality need to be tested empirically as part of the meta-analysis rather than applied *a priori* to devise criteria for the selection data sets (Osenberg et al. 1999).

A final and, in some respects, unresolved challenge concerns the administration of the database. Administration includes issues such as how the information is disseminated to users, who maintains the database and the documentation, and who grants access to users. Ideally, these issues should be addressed at the beginning of the project because there need to be adequate mechanisms and resources available for administrative tasks following construction of the database. With the BILD historical database, the responsibility and potential costs of administering it rest with the GLFC.

One of the easier administrative tasks is deciding the best format in which to make the database available to potential users. If the database is large and updated regularly, then on-line dissemination may be favored particularly if broad data sharing is desirable. This option may be technically challenging, however (e.g. Beard et al. 1998). Alternatively, if the database is large and relatively static, then compact disks may be a better alternative. If the database is small enough, zip disks may be sufficient. Presently, the BILD database is available on zip disk, although it may be made available on the GLFC website at a later date (G. Christie, GLFC, personal communication).

To what extent the BILD database will be updated is unclear. While there is considerable momentum within the scientific community to keep databases "alive" (Reichhardt 1999), reflection regarding the BILD database is needed for a three reasons. First, some databases are developed and used for synoptic purposes rather than for ongoing research or assessment (Michael 1991). Second, the decision to keep the database alive should depend on useful criteria, such as the quality of metadata (documentation) regarding the component surveys; the rarity, time length, and analyzability of the data; and the scale across which sites have been sampled and their relocatability (ESA 1995). In this respect, it is reasonable for the GLFC to consider the results of the BILD project and the prospects for its barrier program, before committing to a long-term database project. Finally, should the GLFC barrier program proceed, any future research or assessment data may be better stored in a separate, linked databases for reasons of logistics and ownership (Van Alstyne et al. 1995; Hale et al. 1998).

Probably the most onerous administrative task is determining who owns the database or, at least, who will be responsible for granting access to it. The management of intellectual property in digital environments is an area of much ethical and legal uncertainty and contention in both Canada and the United States (e.g. Fishbein 1991; Reichhardt 1998; Fortier et al. 1999). Issues related to ownership and access are most likely to arise if the project has involved multiple collaborators from different institutions, if the project was funded by a granting council, and if there have been multiple contributors to the database (Hilgartner and Brandt-Rauf 1994; Harvey and Press 1996). The BILD database was no exception. Indeed, database administrators from some of the contributing agencies we contacted had concerns about allowing us access to their data. There are no easy solutions here, but we make three recommendations. First, potential contributors of data need to weigh their enthusiasm to manage and analyze their data further against the time and resources available for doing so and against the broader interest served by creating a larger database for analysis by a larger community of users. Second, database developers need to be clear about project objectives and to acknowledge more strongly the contributions made by individual sources. Third, to avoid conflict after the fact, database administrators need to adhere to the project objectives and, when changes are needed, communicate these changes to the contributors. Furthermore, if the database is made available to a wide set of users, contributors should be included in this set.

Conclusion

Considerable enthusiasm remains for the BILD historical database. At this time, it represents the best historical information available for detecting changes in the composition of stream fish assemblages following the construction of low-head lamprey barriers. At the very least, evaluation of the limitations and uncertainties of the data should assist with assessment protocols developed for any future barrier construction projects.

We expect the same enthusiasm exists for other database projects. Such enthusiasm needs to be balanced by greater recognition and appreciation of what a database project entails and the potential limitations of the product. Two considerations, in particular, are worth bearing in mind. One is that integrating data from diverse sources is a conceptually sophisticated, resource-intensive task (Batra and Sein 1994; NRC 1995; Harvey and Press 1996), a fact that can get overlooked. This consideration, as well as the issues raised above, may be viewed as mundane by those experienced with database design, however, software advances are encouraging greater participation by less-experienced end users and novices are more likely to make significant errors than experts (e.g. Batra and Davis 1992). Moreover, current database software cannot guarantee a well-developed database anymore than current wordprocessing software can guarantee a well-written essay. The other consideration is that compiling volumes of related information does not necessarily translate into lots of data suitable for answering a specific research question, owing to issues of data quality and analyzability. We recognize that historical databases can have an important role in fisheries research and management (e.g. Moyle 1997). But based on the considerations above, we also stress the need for careful consideration of any suggestion that compilation of existing data will provide a suitable, less expensive alternative to a new, properly designed study.

Databases promise to become an increasingly important part of fisheries research and management (Schnute and Richards 1994). Greater discussion of the potentials and pitfalls of databases is therefore in the interest of project proposers, granting agencies, and end-users, to ensure that the database projects are planned carefully and completed successfully.

Acknowledgments

We thank Gavin Christie, Randy Eshenroder, and Chris Goddard (Great Lakes Fishery Commission) for their assistance at various stages during this project's development; the Department of Fisheries and Oceans Canada (Sea Lamprey Control Centre), Michigan Department of Natural Resources, Ontario Ministry of Natural Resources, Wisconsin Department of Natural Resources, and US Fish and Wildlife Service (Sea Lamprey Management Program) for granting us access to their data; and, Ellie Koon (US Fish and Wildlife Service, Sea Lamprey Management Program) and Bob Randall (Department of Fisheries and Oceans Canada) for providing helpful comments on the manuscript. This project was supported financially by the Great Lakes Fishery Commission.

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Table 1. A synopsis of information contained in the Biological Impacts of Low-head Barrier Dams (BILD) Historical Database.

Descriptors of Fish Assemblage Structure

- fish taxa present
- number of fish caught from each taxa
- population estimates (Leslie, Zippin, Carle and Strub methods)

Sampling Activity

- sampling location (e.g. latitude/longitude, relation to barrier)
- sampling gear (weir, trapnet, electrofisher, etc.)
- collection method (single versus triple pass)
- sampling effort (time, sample area)
- sampling conditions (temperature, cloud cover, etc.)
- source agency

Stream Characterization

- stream name
- geographical reference (latitude, longitude, lake)
- spring discharge

Barrier Characterization

- presence/absence of barrier
- geographical location
- age of barrier
- specific features (e.g. fixed vs. inflatable crest, natural vs. fabricated)
- presence of jumping pool

Figure captions

Figure 1. Geographical distribution of streams included in the BILD historical database.

Figure 2. Years of the oldest and most recent surveys made for streams included in the BILD historical database. Each vertical bar represents a stream.

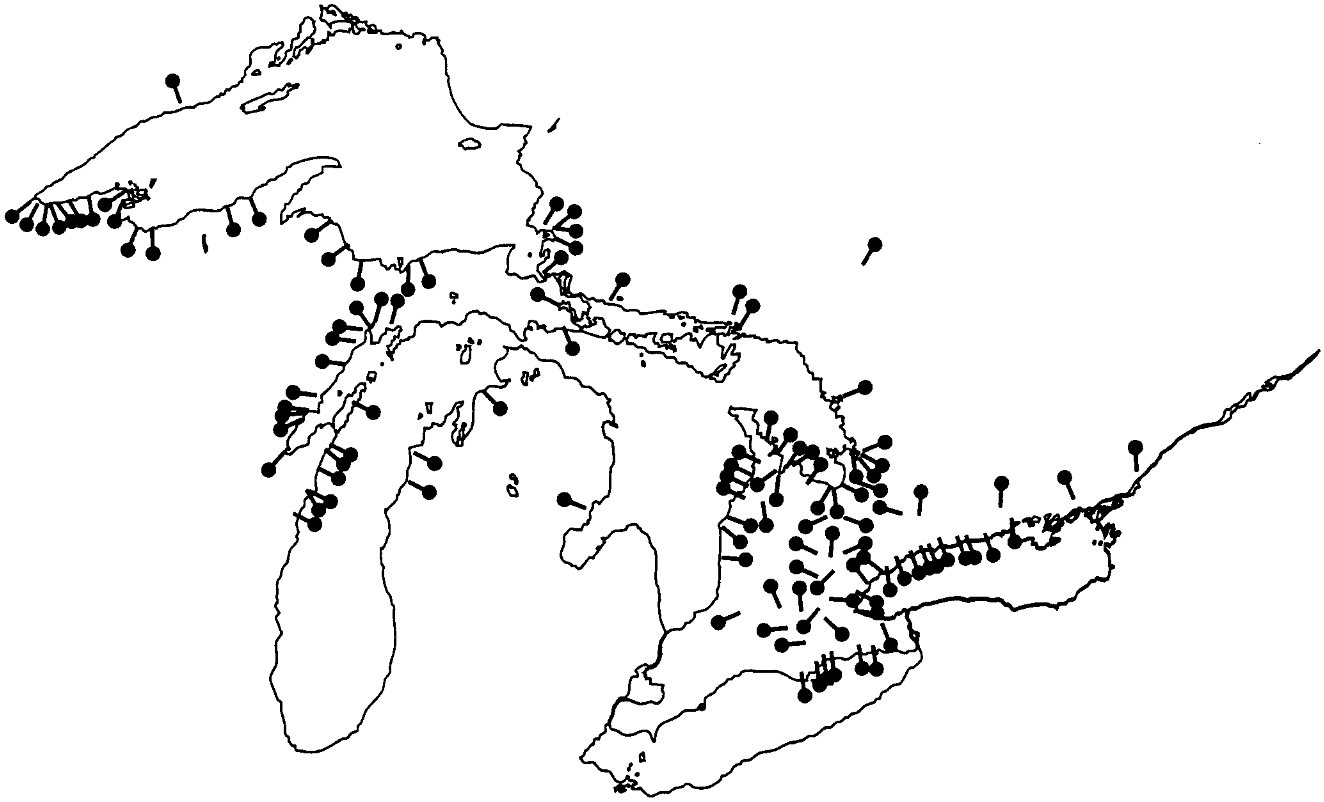

Fig. 1

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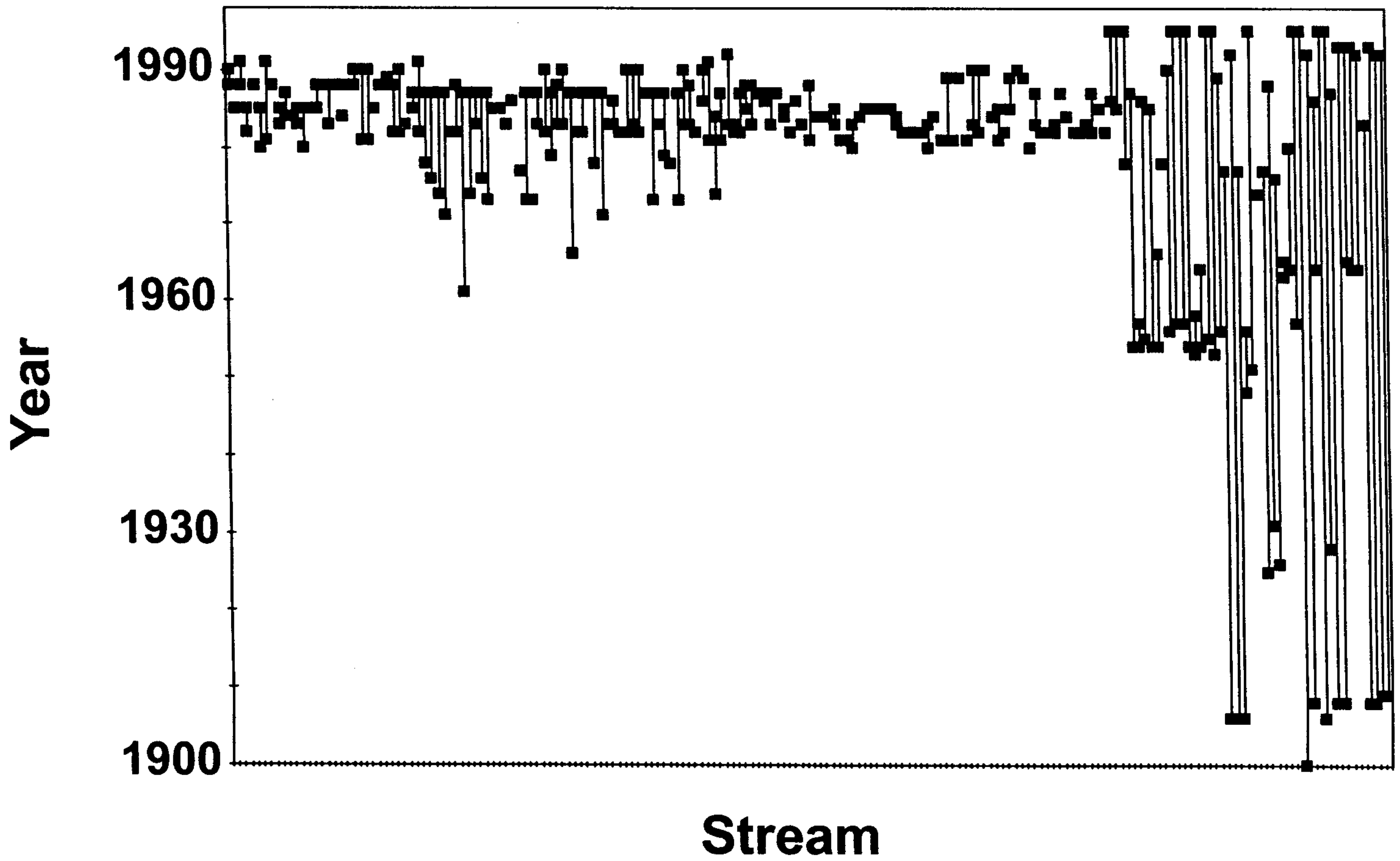

Fig. 2
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Low-Head Barrier Dams Restrict the Movements of Fishes in Two Lake Ontario Streams

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Abstract.—The Great Lakes Fishery Commission (GLFC) is considering greater use of low-head barrier dams on stream tributaries of the Laurentian Great Lakes to control populations of sea lampreys *Petromyzon marinus*. The impact of these barriers on nontarget fishes is not known. A mark–recapture study on four Lake Ontario streams examined movements of fishes in streams with (barrier) and without (reference) low-head barriers. A significantly lower proportion of fishes moved across a real barrier on barrier streams than across a hypothetical barrier on reference streams (0.15 versus 0.50, respectively). The impact of the barriers on movement was more pronounced in spring and fall than in summer. However, the likelihood of fishes moving versus not moving between sample segments on either side of a barrier location (but not across the barrier) did not differ significantly between barrier and reference streams. The upstream (longitudinal) decline in species richness was greater for barrier streams than for reference streams in each season. At both interspecific and intraspecific levels, mean total lengths of fish traversing real barriers were significantly greater than the mean total lengths of fish traversing hypothetical barriers. Our findings demonstrate that low-head barriers restrict the movements of some fishes and suggest this restriction affects assemblage structure above the barrier.

Control of parasitic sea lamprey *Petromyzon marinus*, within the Laurentian Great Lakes is one of the principal responsibilities of the Great Lakes Fishery Commission (GLFC; Anonymous 1992). Sea lampreys entered the upper Great Lakes through shipping passages in the early 1900s and were responsible, in part, for population crashes of lake trout *Salvelinus namaycush* and other important fishes (Smith and Tibbles 1980).

Since 1958, the main method of control has been application of the larval lampricide 3-trifluoromethyl-4-nitrophenol (TFM) to streams used by adult sea lampreys for spawning and for larval lamprey rearing prior to transformation and migration into the Great Lakes (Sawyer 1980). Most streams are treated every four or more years. In spite of the success of the TFM program, by the year 2000 the GLFC intends to reduce the amount of TFM used annually by 50% because of public concern regarding the introduction of chemicals into the environment, concerns that lamprey may be adapting to the chemical treatment, and increases in the cost of purchasing TFM (GLFC, unpublished).

Low-head barrier dams are small structures, 0.4–2 m in height, that the GLFC is considering as an alternative method of sea lamprey control. These dams block the upstream spawning migrations of adult or maturing sea lampreys (Hunn and Youngs 1980), thereby reducing the stream area treated with TFM to that below the dam. Currently, up to 171 dams are planned for construction on 164 streams now treated with TFM (GLFC, unpublished data). Construction of these dams would reduce the GLFC's reliance on TFM by the targeted 50%, and the money saved on the purchase of TFM would offset the cost of the dams (GLFC, unpublished data).

Although the use of dams and barriers of various designs for lamprey control predates the use of TFM, the impact of small dams on other stream fishes is not known satisfactorily (Hunn and Youngs 1980; Smith and Tibbles 1980). A collaborative, extensive field survey of 24 matched pairs of barrier (barrier present) and reference (barrier absent) streams across the Laurentian Great Lakes was, therefore, conducted (Noakes et al. 1998). The results of this survey demonstrated that low-head barrier dams have a consistent impact on stream-fish assemblages, and the longitudinal decline in species richness from below to above a real barrier was greater than that for a hypothetical barrier. In addition, the similarity between the fish assemblages below and above a barrier location was lower for barrier streams than for reference streams.

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The survey did not examine mechanisms responsible for the impact, but restriction of fish movements is an obvious possibility. The life histories of many lake and stream fishes include seasonal periods of movement or migration (Hall 1972; Matheney and Rabeni 1995; Matthews 1998). Low-head barriers could impede these movements thereby altering population dynamics and ultimately assemblage structure (e.g. Pringle 1997). In the only earlier study of low-head barriers, Kelso and Noltie (1990) concluded that a barrier on the Carp River, Lake Superior, precluded the passage of pink salmon *Oncorhynchus gorbuscha* but not coho salmon *O. kisutch* and chinook salmon *O. tshawytscha*. Chase (1996) examined the impacts of a current velocity barrier on white suckers *Catostomus commersoni* and found that large, gravid individuals could not pass upstream. These studies focused only on the spawning migrations of selected lake fishes, however, and not instream movements of the assemblage of resident and migratory stream fishes. A more comprehensive study was needed to test whether and when low-head barriers affect the movements of fishes, which in turn would help technical experts adjust the types of barriers constructed (e.g., fixed- versus adjustable-crest designs) and develop policy regarding seasonal barrier usage during the year, presumably in ways that would control sea lampreys effectively while minimizing impacts on nontarget fishes.

We therefore conducted a seasonal mark–recapture study to determine if and when low-head barrier dams restrict the movements of fishes in streams. Four predictions were tested. First, if low-head barriers restrict movement, then the proportion of fishes traversing a real barrier would be lower than the proportion traversing a hypothetical barrier. Second, if the amount of movement within barrier and reference streams is similar, then the likelihood of fishes moving among different sample segments on either side of the barrier location, but not across it, would not differ between barrier and reference streams. Third, if barriers prevent fishes from recolonizing upstream, then the upstream (longitudinal) decline in species richness would be consistently greater for barrier streams than for reference streams. Fourth, if low-head barrier dams impede movement, then smaller fishes, which generally have poorer swimming abilities (Webb 1975; Motta et al. 1995), would be less likely to traverse a barrier than larger fishes. Therefore, the mean length of fish traversing real barriers would be greater than the mean length of fish traversing hypothetical barriers.

Methods

Two pairs of tributary streams on the Canadian side of Lake Ontario (Duffins and Lynde Creeks, Grafton and Salem Creeks) were selected for study. The pairs were selected from the original 24 stream pairs sampled during our extensive survey. Selection of the pairs was based on their proximity to the University of Guelph and their accessibility for a mark–recapture study of the fish assemblage. Duffins Creek (barrier present; 43°50′ 900″N, 079°03′340″W) and Lynde Creek (reference; 43°52′465″N, 78°78′632″W) are located near Ajax and Whitby, Ontario, Canada, respectively. Grafton Creek (barrier present; 43°58′215″N, 078°03′341″W) and Salem Creek (reference; 44°00′055″N, 77°50′048″W) are smaller streams located further east. Head heights for the barriers at Duffins and Lynde Creeks were 0.75 and 0.45 m, respectively. All four streams are inhabited by sea lamprey and are treated periodically with TFM, but no TFM treatments occurred during our study (J. Weiss, Department of Fisheries and Oceans, Sea Lamprey Control Centre, personal communication).

Our sampling protocol was the same as that used in our extensive survey and was developed in consultation with technical experts from Sea Lamprey Control Centre, Canada, and the U.S. Fish and Wildlife Service. A hypothetical barrier location on reference streams was selected to correspond to the location (distance from the stream mouth) of the real low-head barriers on the barrier streams. For each stream, six stream segments were sampled: three above and three below the real or hypothetical barrier location. Sample segment lengths were 5–7 times the wetted stream width, which corresponds to one riffle–pool sequence (Leopold et al. 1964; Lyons 1992), and were separated by stream segments whose lengths were also 5–7 times the wetted width.

Sampling of fishes was conducted twice in each of three seasons: summer (June 17–28, 1996), fall (October 18–21 and November 22–25, 1996), and spring (April 24–27 and May 14–23, 1997). Sampling episodes within each season were separated by 3–4 weeks to allow for movement of the fishes.

Fishes were sampled in each segment using single-pass backpack electrofishing (Smith-Root Inc. Model 12-B; pulsed DC; 60 Hz at 6ms [200–300 V]; Jones and Stockwell 1995; Simonson and Lyons 1995). Electrofishing with pulsed current is one of the least selective of all active fishing methods (Lagler 1978) but is biased against small fishes (Reynolds 1983; Zalewski and Cowx 1990). Consequently, we captured no fishes smaller than 10 mm total length (TL). Captured fishes were anesthetized with tricane methanesulfonate (MS-222; Summerfelt and Smith 1990), identified to species, and measured (TL in mm). Voucher specimens of species not identifiable in the field were preserved in 10% formalin and later identified by us or by E. Holm (Royal Ontario Museum, Canada). During our initial sampling effort, fishes 40 mm TL or greater were marked (see below), and during subsequent resampling efforts fishes were screened for marked individuals, and any unmarked individuals were marked. Following capture and handling, fishes were allowed to recuperate for 20 min in flow-through bins (45 × 40 × 35 cm) located within the stream; they were then released.

Fishes were marked with Alcian Blue and a fin clip, and the combination of these varied according to the sample segment and season of capture. Alcian Blue (6 g per 100 mL distilled water) was applied using a Panjet inoculator (Hart and Pitcher 1969; Starkie 1975). Fishes less than 40 mm TL were too small to mark. Fishes 40–69 mm TL could only be marked in a manner suitable for identifying whether they were captured initially above or below the barrier and the season of capture, but not the segment of capture. Field experiments indicated that short-term mark retention was high and handling mortality low (Porto 1997).

Within each sample segment, four habitat variables were measured along transects placed at the ends and midpoint of the segment. The variables were water temperature (°C), wetted width (m), maximum water depth (m), and substrate composition. Water temperature was measured with an alcohol thermometer, wetted width with a measuring tape, maximum water depth with a meter stick, and substrate composition with a modified Wentworth scale (i.e., clay, silt, sand = 0.06–2 mm; gravel = 3–64 mm; cobble = 65–256 mm; boulder = 257–4,096 mm; bedrock > 4,096 mm; Leopold et al. 1964). These habitat variables were measured during each sampling effort upon completion of fish sampling.

Statistical analyses.—Fish movements were categorized in three ways.

No movement: This describes fish that were recaptured in the same segment in which they were marked.

Movement among segments: This describes fish that were recaptured in a segment other than the segment in which marked, but a real or hypothetical barrier was not traversed. If large (>250 mm TL) migrant fishes were present in segments downstream of the barrier, they were included in this movement category; i.e., they were not previously marked or observed during summer sampling and had moved from Lake Ontario into one of the downstream segments. They included rainbow trout *O. mykiss*, white sucker, longnose sucker *C. catostomus*, chinook salmon, coho salmon, and brown trout *Salmo trutta*.

Movements across a barrier: This included fish recaptured in a segment on the opposite side of the barrier from the segment where it was marked. If large migrant fishes were found upstream of the barrier location, they were included in this category. Only movements in the upstream direction were considered in our analyses because of the very low percentage (<1%) of downstream movements crossing the barriers.

Our recapture rate for marked fishes was similar between stream pairs but was low overall (336 of 6,930 individuals = 5%). It therefore was necessary to aggregate the data between stream pairs for our analyses. Data from sampling episodes within a season also were aggregated.

We tested our first two predictions using logistic regression to fit the following equations:

$$\log_e(p_3/p_1) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2$$

for prediction 1 and

$$\log_e(p_2/p_1) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2$$

for prediction 2; p_1 is the probability of a category 1 movement, p_2 is the probability of a category 2 movement, p_3 is the probability of a category 3 movement, x_1 represents the barrier type (real or hypothetical), and x_2 represents the season (spring, summer, or fall); b_0 is an intercept, and b_1 and b_2 are regression coefficients for barrier type and season. This is the approach typically taken with polytomous data (Feinberg 1977). Tests of significance and confidence intervals were calculated using type III analyses and likelihood ratio (G) statistics. The statistical interactions between barrier type and season were considered in an initial model, but later removed because they did not improve the overall fit significantly ($G = 2.7$, df = 2, $P > 0.20$ and $G = 2.5$, df = 2, $P > 0.20$, respectively).

We tested our third prediction using analysis of variance (ANOVA) to examine how the longitudinal change in species richness from below to above the barrier varied with barrier type and sea-

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TABLE 1.—Habitat measurements made for sample segments above and below the barrier locations on barrier (B) and reference (R) streams within each stream pair. Values are means for summer 1996.

	Stream pair		Stream pair	
Habitat measurement	Duffins (B)	Lynde (R)	Grafton (B)	Salem (R)
Above barrier				
Water temperature (°C)	17	19	14	15
Wetted width (m)	14.9	8.1	4.1	3.6
Maximum depth (m)	0.79	0.35	0.35	0.38
Substrate size[a]	3.7	4.2	4.2	2.9
Below barrier				
Water temperature (°C)	18	19	16	15
Wetted width (m)	12.7	10.3	6.3	3.5
Maximum depth (m)	0.81	0.44	0.60	0.45
Substrate size[a]	3.9	3.9	4.2	2.9

[a] Substrate was ranked on the following scale: 1 = clay, 2 = silt, 3 = sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock.

son. For this analysis, a mean change in species richness was calculated based on the sampling episodes conducted within each season. We then examined the effects of barrier type and season after blocking for stream pair.

We tested our fourth prediction at the interspecific and intraspecific levels with a two-way ANOVA. Mean total length ($\log_{10}$ transformed) was the dependent variable, and barrier type and whether the species traversed the barrier location (yes or no) were the independent variables. Planned contrasts were used to test whether fish(es) traversing a real barrier were larger, on average, than those traversing a hypothetical barrier—as predicted—and whether fish(es) that traversed a real barrier were larger, on average, than those that did not, as assumed. The analysis at the interspecific level was conducted using mean total lengths for each species. The analysis at the intraspecific level was conducted using total lengths of individual rainbow trout. Sample sizes were too small to extend the intraspecific analysis to other species.

Results

Statistical summaries of the habitat variables are provided in Table 1 for the sections above and below the barrier locations on each stream.

The likelihood of fishes traversing a barrier location varied with both barrier type and season. For each season, the proportion of fishes crossing a barrier relative to the proportion not crossing was significantly lower for barrier streams than for reference streams ($G = 92.0$, df = 1, $P < 0.001$; Figure 1). Further, for both barrier and reference streams, the proportion of fishes moving across the barrier was greatest during the spring and fall and lowest in summer ($G = 163.8$, df = 2, $P < 0.001$; Figure 1).

Three of 42 total species sampled for all streams traversed the low-head barriers: rainbow trout, chinook salmon, and white sucker. Seven of the 42 species traversed the hypothetical barrier: rainbow trout, white sucker, bluntnose minnow *Pimphales notatus*, brown trout, creek chub *Semotilus atromaculatus*, longnose dace *Rhinichthys cataractae*, and mottled sculpin *Cottus bairdi*. For the seven species common to both barrier and reference streams that traversed either barrier type, significantly less movement was observed on barrier streams than on reference streams (paired *t*-test: one-tailed, $t = -3.26$, $P < 0.05$, df = 6; Table 2), in spite of the low sample sizes and greater sampling variability for some of the species.

The proportion of fishes that moved among the sample segments above or below the barrier, but not across the barrier, did not differ significantly between barrier and reference streams ($G = 2.5$, df = 1, $P = 0.12$). Movement did vary significantly with season ($G = 259.2$, df = 2, $P < 0.001$); regardless of barrier type, the probability of fishes moving among sample segments was highest in spring and lower in fall and summer (Figure 2).

Across all seasons, the reduction in species richness above versus below the barrier was significantly greater for barrier streams than for reference streams ($F = 24.9$, df = 1, 5, $P < 0.005$; Figure 3). Overall, the magnitude of these longitudinal declines did not differ significantly across seasons (season effect: $F = 0.19$, df = 2,5, $P > 0.80$.), nor did the difference in changes observed between barrier and reference streams vary significantly across seasons, as indicated by the nonsignificant statistical interaction (barrier × season interaction: $F = 1.49$, df = 2,5, $P > 0.30$). Species that were observed only below the real barriers but below

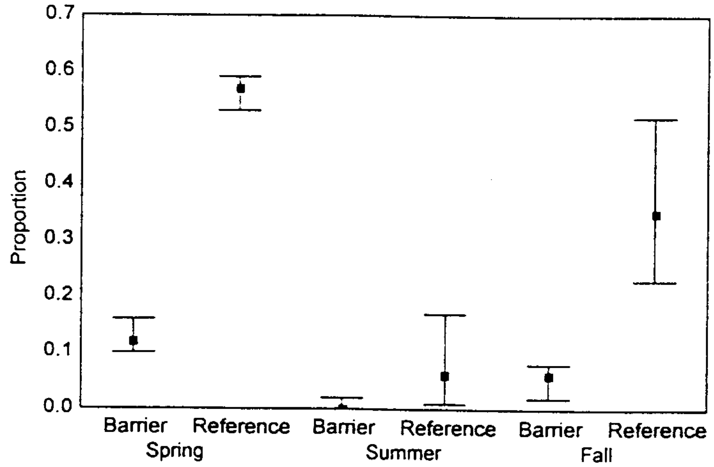

FIGURE 1.—Proportions of fishes traversing a low-head barrier on barrier streams and a hypothetical barrier on reference streams during the three seasons. Solid squares indicate observed proportions and horizontal bars indicate the 95% confidence limits predicted from a logistic regression analysis.

and above the hypothetical barriers included mottled sculpin, longnose dace, logperch *Percina caprodes*, rock bass *Ambloplites rupestris*, and rosyface shiner *Notropis rubellus*.

Fish(es) traversing a real barrier were larger, on average, than fish(es) traversing a hypothetical barrier. At the interspecific level, the geometric mean length was 427 mm (95% confidence limits: 173–1,054 mm) for the three species traversing a real barrier and 125 mm (95% confidence limits: 66–237 mm) for the seven species traversing a hypothetical barrier (planned contrast: t = 2.28; one-tailed; df = 1, 24; $P < 0.02$). Our assumption that larger fishes would be more likely to traverse a barrier than smaller fishes also was supported (planned contrast: t = 3.09; one-tailed; df = 1, 24; $P < 0.005$). At the intraspecific level, mean length was 539 mm (95% confidence limits: 455–638 mm) for rainbow trout that traversed a low-head barrier and 374 mm (95% confidence limits: 276–509 mm) for the rainbow trout that traversed a hypothetical barrier (planned contrast: t = 2.05; one-tailed; df = 1, 244; $P < 0.03$). Our assumption that larger fish would be more likely to traverse a real barrier than smaller fish also was supported for rainbow trout (planned contrast: t = 13.7; one-tailed; df = 1, 244; $P < 0.0001$).

TABLE 2.—Proportions of the seven fishes common to both barrier and reference streams that were observed traversing a real (barrier stream) or a hypothetical (reference stream) barrier in the seasonal mark–recapture study. Numbers of individuals marked are provided in parentheses.

Species	Barrier stream	Reference stream	Difference in proportion
Rainbow trout	0.26 (180)	0.18 (68)	0.08
White sucker	0.01 (181)	0.63 (170)	−0.62
Brown trout	0 (2)	0.6 (5)	−0.6
Longnose dace	0 (1)	0.2 (5)	−0.2
Creek chub	0 (17)	0.33 (3)	−0.33
Bluntnose minnow	0 (1)	1.0 (1)	−1.0
Mottled sculpin	0 (4)	0.33 (3)	−0.33

Discussion

Our findings demonstrate that low-head barriers restrict the movements of at least some fishes and suggest that such restrictions on movement are responsible, in part, for the differences in fish assemblages observed above and below barriers in this study, as well as in our previous extensive survey of Great Lakes streams. This conclusion is based on four predictions that were supported by our study. Fishes were less likely to traverse a real barrier than a hypothetical barrier (prediction 1); however, the likelihood of fishes moving between sample segments on either side of the barrier locations, relative to not moving, was similar between barrier and reference streams (prediction 2). In addition, the longitudinal decline in species richness above versus below the barrier was greater for barrier streams than for reference streams (Prediction 3). Finally, fish(es) traversing a real barrier were larger, on average, than those traversing a hypothetical barrier (Prediction 4).

Our conclusion that restrictions on movement are partly responsible for the impacts on fish assemblage structure is based on the differences in

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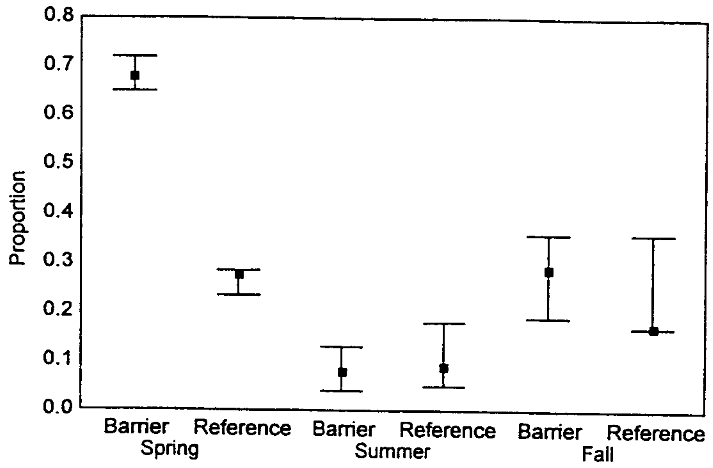

FIGURE 2.—Proportions of fishes moving among segments above or below, but not across, a low-head barrier on barrier streams and a hypothetical barrier on reference streams. Solid squares indicate observed proportions and horizontal bars indicate the 95% confidence limits predicted from a logistic regression analysis.

the longitudinal change in species richness observed between barrier and reference streams. Reduced species richness is expected in the isolated habitat following fragmentation (e.g. Wilson and Willis 1975). Accordingly, two species (mottled sculpin and longnose dace) of the five expected but not found above the low-head barriers, based on their distributions in reference streams, were listed as species impeded by low-head barriers. The remaining three species expected but not found above the low-head barriers (logperch, rosyface shiner, and rock bass) were not listed as species impeded by low-head barriers because their movements across the hypothetical barriers were not observed. Movements for these three species were difficult to ascertain. This evidence may seem incongruous, but it is plausible considering how habitat fragmentation models are expected to affect assemblage structure (Nee and May 1992; Tilman et al. 1994). These models predict that poorly dispersing species, which are also assumed to be the best competitors, will be the most susceptible to habitat fragmentation, thus presenting the conundrum that species most susceptible to restric-

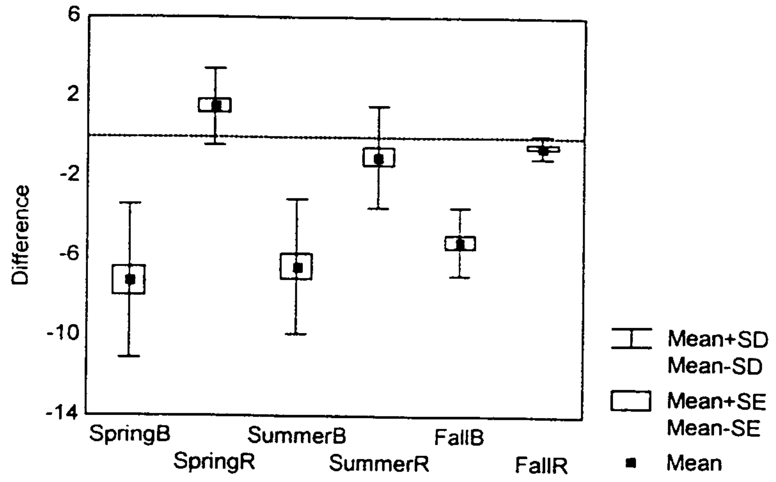

FIGURE 3.—The change in number of species (species richness) above compared with below a low-head barrier on barrier streams (B) and a hypothetical barrier on reference streams (R). Means (solid squares) are for each stream pair within a season. Negative values indicate that fewer species were found upstream of the barrier location than down stream, positive values indicate the opposite, and zero indicates no change.

tions on movement may be those with movements that are the most challenging to detect in the absence of any restrictions.

We have attributed the differences observed between barrier and reference streams to the physical presence of a low-head barrier. Our matched pairs do not represent a true experiment where a barrier was assigned at random to a stream within a pair, however. Therefore, the differences observed between barrier and reference streams could correspond to other intrinsic differences between the streams (e.g. physical habitat) or between the fish assemblages inhabiting them. We believe this is not the case for three reasons. First, our stream pairs were selected to match general habitat features (e.g., width, depth, water flow, geographical proximity) as closely as possible, although some differences were evident (Table 1). Second, we found subsequently that the fish assemblages in the matched pairs were reasonably similar; i.e., Sorensen's indices exceeded 0.62 when comparing sections below the barrier between streams within a pair and exceeded 0.47 when comparing sections above. Third, for fishes not traversing the barriers, the proportions of individuals moving between sample segments and individuals not moving were similar among barrier and reference streams, suggesting levels of movement in stream sections away from the barrier locations were similar between the stream types.

Our study has two noteworthy limitations. One is that it was restricted to two matched pairs of Lake Ontario streams. Examinations of stream pairs on other Great Lakes will be needed to assess the generality of our findings. Another limitation is that the sample sizes for some of our analyses were small because of the low recapture rate; sample sizes were generally too small to examine most species individually. Nevertheless, the whole assemblage orientation of our study remains a unique feature relative to earlier studies and our analysis comparing species was able to detect a consistent reduction in movement across barriers despite limited sample sizes for some species (Table 2). It is not unusual for recapture rates to be low for stream fishes (Hill and Grossman 1987; Cunjak 1992). The reasons for the low recapture rate in our study are unclear, although we believe it is due to the movement of fishes to areas outside our sample segments. Field experiments indicated that mortality due to handling and marking was less than 1% and that dye marks were retained (Porto 1997). Furthermore, independent sampling of one of our study streams (Grafton Creek) suggested that triple pass techniques would not improve our abundance estimates nor, therefore, markedly increase number of recaptures (J. Weise, Department of Fisheries and Oceans, Sea Lamprey Control Centre, personal communication).

The impacts of large, high dams are well known. They appreciably impede the movement of fishes and alter habitat (e.g., water flow and temperature) both above and below the dam (e.g. Li et al. 1987; Bayley and Li 1992; Nicola et al. 1996; Holmquist et al. 1998). These changes typically lead to local extinctions of some species and population growth for others (e.g. Li et al. 1987; Winston et al. 1991; Nicola et al. 1996; Pringle 1997; Holmquist et al. 1998). These changes also may favor invasions or introductions (planned or unplanned) of exotic species, which can further impact the native fish assemblage (Li et al. 1987; Bayley and Li 1992). The impacts of low-head dams are expected to be less substantial. It is thought that the lower crest height will at least allow the passage of fishes with good jumping abilities and that flow and habitat alterations to the stream will be minor, as reported by Kelso and Noltie (1990). Yet, no studies have been conducted to explicitly test these perceptions, even though low-head barriers have been used in lamprey control for some time (Hunn and Youngs 1980; Smith and Tibbles 1980). Our study complements a diffuse but growing literature that suggests low-head barriers in particular, and small impoundments in general, restrict movements of fishes and affect local fish assemblages in ways similar to, but smaller in magnitude than, those reported for larger dams (Griswold et al. 1982; Chase 1996; Kelso and Noltie 1990).

As the impacts of small impoundments are quantified further it will become important to place the magnitude of the impacts in context. On one hand, there could be a tendency to dismiss the impacts because they are smaller in magnitude than those observed for larger dams and because the fishes of smaller streams may not have the same recreational (e.g. fishing) appeal or conservation concerns that fishes of larger systems do. On the other hand, populations of stream fishes can become extinction-prone following habitat fragmentation (Pringle 1997) and recolonization is delayed or prevented when there are obstacles to movement (Griswold et al. 1982; Detenbeck et al. 1992). One useful step to help place the magnitude of the impacts in context would be to consider how any impacts measured for low-head barriers compare with similar measurements made for natural instream barriers, such as small waterfalls, beaver

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The seasonal variation in movement we quantified may provide a means for minimizing the impacts that low-head barriers have on nontarget fishes while still retaining their effectiveness at controlling sea lamprey. There are various modifications that can be made to a basic fixed-crest design, including adjustable crests, temporary small openings (traps), and possibly fishways. These could be used in ways that restrict the movement of fishes only during the period when sea lampreys are migrating upstream. The success of such an adaptive seasonal policy of deployment would be enhanced by a comparison of fish movements across different types of barriers, as well as additional detailed information on the timing of sea lamprey migrations and the instream movements made by other fishes. Information on how fishes respond behaviorally to the presence of a physical barrier also would be useful.

There is wide recognition that instream movements probably represent an important aspect of the life history of many stream fishes (Matthews 1998), yet detailed quantitative studies are relatively sparse and focused on species of economic interest (e.g., salmonids). Moreover, even our preconceptions regarding well-studied species have been found to be incorrect in some stream systems (e.g., Gowan et al. 1994). The paucity of research focused directly upon the movements of stream fishes is surprising for at least two reasons. First, because of the largely one-dimensional nature of streams, stream fishes could be appealing study systems for testing models of population redistribution (e.g., Endler 1977; Turchin 1998). Second, because there is growing concern regarding the impact of small stream alterations (e.g. dams, culverts), stronger quantification of the movements of stream fishes could be extremely valuable to resource managers and planners.

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Abstract

Sea Lamprey (*Petromyzon marinus*) have had significant and wide-ranging effects on the fauna of the streams and lakes of the Great Lakes Basin. While many of the direct effects of sea lamprey predation have been well documented, many of the more subtle secondary effects caused by sea lamprey control measures have yet to be explored in detail. Stream barriers have been one of the predominant methods utilized in controlling sea lamprey reproduction since the early 1930's. In an effort to determine the nature and strength of these secondary effects, a fine-scaled study of stream characteristics and fish species richness was conducted on 61 streams throughout the Great Lakes from 1996-1998. This study is part of a basin-wide study to evaluate and document the extent to which barriers have altered the species and population characteristics and has separated low-head barrier-induced habitat alterations from the myriad of other factors that have been implicated in causing these changes.

Methods

In 1996, a habitat assessment was conducted on each of the paired Barrier and Reference streams. In 1997, the habitat assessment was repeated on the Middle and Polar Rivers, WI and on the East and West Branch of the Whitefish Rivers, MI. This habitat assessment was also conducted on all of the Natural Barrier streams.

The habitat assessment was conducted on all sites sampled in the broad-scale study and the natural barrier study. In both studies, site selection was not randomized. Site selection was determined primarily by accessibility. Establishing where to begin a site was controlled by proximity to a thalweg. Determining where to end a site, however, was controlled by the wetted width of the downstream transect (Transect 1). Each site consists of three transects which extend in a straight line running perpendicular to the flow of the stream beginning and ending at the point at which standing water is or is no longer present. Transect 1 was established as close to a thalweg as possible. The wetted width of this transect was measured and multiplied by a factor of 5-7 to determine the location of the upstream transect (Transect 3). The multiplier was a minimum of 5X, but may have been as large as 7X to allow the site to begin and end at a thalweg. The distance between Transect 1 and Transect 3 was recorded (in m) as the length of the site. An additional transect (Transect 2) was also established at a point approximately half the distance between Transect 1 and Transect 3. Wetted width, pebble counts, maximum depth were recorded at each transect. Water temperature and water conductivity were measured and recorded only at Transect 1.

The wetted width, for the purposes of this study, is defined as the distance between the starting and ending point of a transect. Three estimates of wetted width were measured at each site, one at each transect. The mean stream width per site was comprised of an average of the wetted widths from each of the three transects.

Pebble counts were taken at one foot intervals across each of the three transects in an effort to determine substrate composition. The University of Guelph field crew and the Michigan State field crew recorded 50 pebble counts per transect regardless of stream width. The University of Wisconsin field crew recorded pebble counts for the entire wetted width of each transect. Substrate Composition was classified by category based on modified Wentworth scale (Stanfield et al. 1997 per Porto 1996). Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand (0.062 mm), 4 = gravel (>2-64 mm), 5 = cobble (>64-256mm), 6 = boulder (>256-4096mm), 7 = bedrock (>4096 mm). For the statistical analysis, substrate ranks were averaged per transect and an average of the three transects was used to determine the mean substrate per site.

While crossing the stream to determine wetted width and/or pebble counts, the maximum depth (in cm) of each transect was measured. The mean depth per site was comprised of an average of the maximum depths from each of the three transects.

Water temperature and Conductivity were measured once per site at Transect 1. Water temperature (in degrees Celsius) was measured with a Hannan (Model 9010) Temperature Probe. Conductivity (in μmhos) was measured using an Oakley Dissolved Particle and Conductivity Probe. Readings for both variables were taken by submersing the respective probe at the maximum depth of Transect 1.

Additional notes regarding cloud cover (0-25%, 25-50%, 50-75%, >75%), precipitation (none, light, moderate), water color (clear, yellow/brown/, blue/green, other) and relevant water conditions (.i.e. flow, turbidity, etc.) were collected immediately proceeding the electroshock sampling of the site. Data collection for the habitat assessment, other than measuring the first transect, were collected after electroshocking (see section on Species Richness) of the site was completed to limit disturbances.

Results

When barrier and reference stream pairings were evaluated to determine differences in mean width (Table 1, Table 6), 10 of 25 streams showed a significant difference in whole stream mean width (2-tailed paired t-test ($p<.05$)). Three additional stream pairings showed significant differences between specific segments (above or below relative barrier positions) of the stream (2-tailed paired t-test ($p<.05$)), but were not significant when variability within the entire stream was taken into account. Of the streams that showed a significant difference in whole stream mean width, in 8 of 10 cases barrier streams were significantly wider than their associated reference stream.

When barrier and reference stream pairings were evaluated to determine differences in mean depth (Table 2, Table 6), 8 of 25 streams showed a significant difference in whole stream mean depth (2-tailed paired t-test ($p<.05$)). Four additional stream pairings showed significant differences between specific segments (above or below relative barrier positions) of the stream (2-tailed paired t-test ($p<.05$)), but were not significant when variability within the entire stream was taken into account. Of the streams that showed a significant difference in whole stream mean depth, in 7 of 8 cases barrier streams were significantly deeper than their associated reference stream.

When barrier and reference stream pairings were evaluated to determine differences in mean temperature (Table 3, Table 6), 7 of 25 streams showed a significant difference in whole stream mean temperature (2-tailed paired t-test ($p<. 05$)). Five additional stream pairings showed significant differences between specific segments (above or below relative barrier positions) of the stream (2-tailed paired t-test ($p<. 05$)), but were not significant when variability within the entire stream was taken into account. Of the streams that showed a significant difference in whole stream mean temperature, in 4 of 7 cases barrier streams were significantly cooler than their associated reference stream.

When barrier and reference stream pairings were evaluated to determine differences in mean substrate size (Table 4, Table 6), 9 of 25 streams showed a significant difference in whole stream mean substrate size (2-tailed paired t-test ($p<. 08$)). Two additional stream pairings showed significant differences between specific segments (above or below relative barrier positions) of the stream (2-tailed paired t-test ($p<. 05$)), but were not significant when variability within the entire stream was taken into account. Of the streams that showed a significant difference in whole stream mean substrate size, in 4 of 9 cases barrier streams had significantly larger substrate than their associated reference stream.

When barrier and reference streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean width (Table 5, Table 5.1, Table 6), 1 of 25 reference streams showed a significant difference in within stream mean width (2-tailed paired t-test ($p<. 05$)). In comparison, 5 of 25 barrier streams showed a significant difference in within stream mean width (2-tailed paired t-test ($p<. 08$)). All of the streams that showed a significant difference in within stream mean width (both reference and barrier) were significantly narrower above the relative barrier position.

When barrier and reference streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean depth (Table 5, Table 5.1, Table 6), 3 of 25 reference streams showed a significant difference in within stream mean depth (2-tailed paired t-test ($p<. 05$)). In comparison, 3 of 25 barrier streams showed a significant difference in within stream mean depth (2-tailed paired t-test ($p<. 05$)). Of the three reference streams that showed a significant difference in within stream mean depth, all were significantly shallower above the relative barrier position. Of the barrier streams that showed a significant difference in within stream mean depth, two were significantly shallower above the relative barrier position.

When barrier and reference streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean temperature (Table 5, Table 5.1, Table 6), 7 of 25 reference streams showed a significant difference in within stream mean temperature (2-tailed paired t-test (p<. 08)). In comparison, five of 25 barrier streams showed a significant difference in within stream mean temperature (2-tailed paired t-test (p<.05)). Of the reference streams that showed a significant difference in within stream mean temperature, three were significantly warmer above the relative barrier position. Of the barrier streams that showed a significant difference in within stream mean temperature, three were significantly warmer above the relative barrier position.

When barrier and reference streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean substrate (Table 5, Table 5.1, Table 6), 2 of 25 reference streams showed a significant difference in within stream mean substrate (2-tailed paired t-test (p<. 05)). In comparison, 4 of 25 barrier streams showed a significant difference in within stream mean substrate (2-tailed paired t-test (p<. 08)). Of the reference streams that showed a significant difference in within stream mean substrate, three had significantly larger substrate above the relative barrier position. Of the barrier streams that showed a significant difference in within stream mean substrate, three had significantly larger substrate above the relative barrier position.

When natural barrier streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean width (Table 7), 2 of 10 streams showed a significant difference in within stream mean width (2-tailed paired t-test (p<. 05)). All of the natural barrier streams that showed a significant difference in within stream mean width were significantly narrower above the relative barrier position.

When natural barrier streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean depth (Table 7), 2 of 10 streams showed a significant difference in within stream mean depth (2-tailed paired t-test (p<. 08)). All of the natural barrier streams that showed a significant difference in within stream mean depth were significantly shallower above the relative barrier position.

When natural barrier streams were evaluated to determine within stream differences (above verse below relative barrier position) in mean temperature and mean substrate size (Table 7), there were no significant differences (2-tailed paired t-test (p>. 05)).

Correlated variables were evaluated via standard linear regression (Figures 1-12, Table 8) is an effort to determine relative trends within and between stream types.

The relationship between mean temperature and mean width, while not strongly correlated (r2 values ranged from .040 to .173) (Table 8) had a similar slope within and between each category of stream type. There were no significant differences in the slopes of these regressions in respect to this correlation (Figure 1, Figure 2).

The relationship between mean substrate and mean width, while not strongly correlated (r2 values ranged from .051 to .320) (Table 8) had a similar slope within and between each category of stream type. There were no significant differences in the slopes of these regressions in respect to this correlation (Figure 3, Figure 4). The linear fit for the section below the barrier (on barrier streams) is potentially a point of concern. Depending on whether or not all data points are utilized (allowing for extreme values) a Kolmogorov-Schmirnov test for differentiation may result in a significant difference between the Below Barrier linear fit and any other linear fit.

The relationship between mean substrate and mean temperature, while not strongly correlated (r2 values ranged from .031 to .099) (Table 8) had a similar slope within and between each category of stream type. There were no significant differences in the slopes of these regressions in respect to this correlation (Figure 5, Figure 6).

The relationship between mean substrate and mean depth, while not strongly correlated (r2 values ranged from .001 to .173) (Table 8) had a similar slope within and between each category of stream type. There were no significant differences in the slopes of these regressions in respect to this correlation (Figure 7, Figure 8).

The relationship between mean temperature and mean depth, while not strongly correlated (r2 values ranged from .008 to .081) (Table 8) had a similar slope within each category of stream type, but not between stream types (Barrier verses Reference). There were no significant differences in the slopes of these regressions within stream types in respect to this correlation (Figure 9, Figure 10). Between stream types (Barrier verses Reference) there was a significant difference between the linear fit of these variables. It should be noted that the linear fit models differ directionally. The linear fit for Reference streams is negative while the slope for Barrier streams is positive.

The relationship between mean depth and mean width, while not strongly correlated (r2 values ranged from .132 to .267) (Table 8) had a similar slope within and between each category of stream type. There were no significant differences in the slopes of these regressions in respect to this correlation (Figure 11, Figure 12).

Comparing the 1996 and 1997 habitat assessments yielded, regardless of barrier type, no significant changes between sites, between above or below barrier stream sections, or on a whole stream basis.

The relationships between the variables correlated above with respect to natural barrier streams were not significantly different from the slopes predicted by the linear fits as presented previously. The exception to this is the relationship between mean temperature and mean depth. In this case, natural barrier reflected only the relationship depicted in the reference stream linear fits.

Discussion

The main take home message of the analysis presented above does not focus so much on what was significantly different, although this area does have some implications, but in the predominant lack of significance. With few exceptions, regardless of barrier type, habitat characteristics were static across the sampling regime. This fact, in and of itself, would suggest a relatively small secondary impact on habitat characteristics as a result of utilizing barriers (low-head or natural) for sea lamprey control.

Where significant differences occur between stream types, there are some important trends. In general, when evaluating the entire stream, barriers result in wider, deeper and cooler streams with larger substrates. This trend changes slightly when evaluating changes within a given stream.

In streams with significant changes as a result of barrier utilization, sections of the streams above the barrier are narrower, shallower, and warmer and have larger substrates than the corresponding below barrier portions of the stream.

Barrier (low-head) are affecting habitat characteristics, but at very low levels. This becomes noticeable only after a comparison with the effects of natural barrier streams. These streams had even fewer significant differences in habitat characteristics and are relatively uniform throughout their range. Where there were significant differences, though, the trend did not differ from that seen in either reference or barrier streams suggesting that if there is a slightly enhanced impact it is representative of what would occur in a natural setting.

Two other concerns were also addressed, first, that yearly or seasonal variation in habitat characteristics biased our analysis and second, that multi-variate statistics would elucidate additional relationships that could be used to explain differences in species richness. The 1997 habitat assessment provided no evidence to support either yearly or seasonal variation in habitat characteristics. In addition, the multi-variate analysis (ANOVA and ANCOVA) conducted by Michigan State University in 1998 did not reveal any additional interactions between habitat characteristics and could not explain trends in species richness (Baylis et al. 1996).

Species Richness

Abstract

Methods

In an effort to determine disparities in species richness between barrier and reference streams, a single upstream pass with a Smith-Root™ Backpack Electroshocker (model 12B with programmable output wave (POW)) equipped with a rattail cathode and eighteen-inch circular anode was conducted at each site. The Smith-Root™ Backpack Electroshocker used by the University of Wisconsin field crew was set to emit a pulsed DC current of 400 Volts, 60 Hz at 6ms (setting I5). The University of Guelph and Michigan State field crews utilized 200-300 Volts, at 60 Hz at 6ms (setting I5). These settings were modified based on conductivity and temperature (Smith-Root™ Manual 1996). Real and electroshocker times (in seconds) were recorded to at each site as a control and to assess variations in catch per unit effort (CPUE).

Fish captured by the University of Guelph and Michigan State field crews were anesthetized per Porto (1996). Fish captured by the University of Wisconsin field crew were not anesthetized (due to high ambient temperatures and low recovery in pilot sampling efforts). Captured fish were identified to species, measured (total length in mm). Ancillary notes regarding breeding coloration, the presence of ecto-parasites, or any other identifying marks were also noted. Fish were either allowed to recuperate in a flow-through holding tank or returned directly to the stream at the site at which they were collected.

Representative voucher and unidentified specimens, were fixed in 10% formalin and preserved in 70% isopropyl alcohol for later identification. Species identifications were confirmed by Ehrling Holmes at the Royal Ontario Museum. Voucher specimens are currently on reserve at the Royal Ontario Museum under accession number 6532.

This sampling protocol was used by the University of Guelph, Michigan State University, and the University of Wisconsin field crews in 1996 and 1997. The 1998 survey by the University of Wisconsin field crew utilized the 1996 protocol, but the 1998 sampling conducted by the Michigan State University was limited to a select species complex.

Results

Tables 9-11 provide a broad scale view of the abundance of species and their distributions. In natural barrier streams, an average of 5.6 more species were found below the barrier in comparison to 4.72 and 2.08 in reference and barrier (low-head) streams respectively.

Discussion

The greatest species richness within stream types (barrier, reference, and natural barrier) was found to occur below the relative barrier position. There is little evidence to support a barrier induced habitat alteration, nor were differences in habitat significant enough to explain trends in species richness (Baylis et al. 1996). This aside, barrier streams are not a good indicator of what would be called a "natural barrier" effect. Natural barrier streams have on average 5.6 more species below the barrier than above. Reference streams (which have no barriers) seem to be a better reflection of a natural situation than low-head streams, with 4.72 species excluded, than the barrier stream with 2.08.

There are at least three plausible explanations of these results. First, low-head dams may provide refugia that would otherwise not be present. Plunge pool (areas of deep water found directly below low-head dams that were specifically excluded from the sampling protocol, Noakes et al. 1996) effects and the fact that barrier streams are on average deeper, colder, wider and have larger substrates could allow more species of fish to persist for longer periods, and decrease the mean difference in species richness between above and below barrier stream segments. Random sampling of plunge pools by the University of Wisconsin field crew in 1998 does not support this hypothesis.

A second hypothesis that could explain the disparity in species composition between barrier and reference streams is predation and/or predator avoidance. Barriers, in blocking access to upstream habitat, may concentrate predators and prey both above and below barriers. The resulting interactions may create additional turnover in the demographics of streams affected by barriers.

A third hypothesis is that changes in species composition are so plastic that a three-year study is not sufficient to determine barrier-induced changes in stream demographics. If the main mode of stream tenure is transience, the effect of "weedy species" may not be adequately accounted for in a simple presence/absence analysis. Barriers have been shown to have strong implications in both increasing and decreasing extinction events depending on the particular nature of the watershed and the species involved (Pringle, C.M., 1997.) If barriers limit successful colonization events as well, alternative models such as those based on island biogeography, may prove to be more suitable in determining relative barrier impacts.

Seasonal Movements and Species Composition

Abstract

In 1998, a mark-recapture study was conducted on several Barrier and Reference streams in an effort to determine seasonal movements and changes in species composition. Movement across the hypothetical Barrier was observed in Reference streams; however, it was limited to four species (Blacknose Dace, Creek Chub, Rainbow Trout, and White Sucker). In contrast, only one fish was observed to traverse an actual Barrier. In this instance, a Rainbow Trout was tagged above the Barrier and was later recaptured below the Barrier. Although limited seasonal movement was observed, substantial variability in species composition was documented in Barrier, Reference and Natural Barrier streams.

Methods

Two stream pairs (consisting of one Barrier and one Reference stream) were selected from the 24 matched pairs selected by Noakes et al. (1997). One pair of streams is on the Wisconsin side of Lake Superior (the Middle (Barrier) and Poplar (Reference) Rivers) and was sampled by a field crew from University of Wisconsin. Another pair of streams is on the Michigan side of Lake Huron (the East Branch AuGres (Barrier) and West Branch Rifle (Reference) Rivers) and was sampled by a field crew from Michigan State University. These streams were chosen based on similarity of habitat characteristics and accessibility for mark-recapture. The mark-recapture protocol utilized by Porto (1996) was applied in the 1998 surveys. Each of the four streams was sampled during the spring, summer and fall. For comparison, stream segments were located at the same locations as the 1996-1997 surveys by Noakes et al. (1997). Two sampling events were conducted within each season. The 1988 sampling dates for the East Branch AuGres and the West Branch of the Rifle were as follows: Spring (May 18, June 15), Summer (July 7, August 5), Fall (September 26, October 24). The sampling dates for the Middle River were as follows: Spring (June 27, July 4), Summer (August 15, August 22), and Fall (October 18, October 25). The sampling dates for the Poplar River were as follows: Spring (June 27, July 4, and July 11), Summer (August 15, August 22), and Fall (October 17, October 24).

The standardized sampling protocol of Noakes et al. (1997) was followed. In addition to this protocol, all fish captured were marked. Fish were marked using a Panjet™ dye inoculator with Alcian Blue dye (6g per 100ml distilled water) following the procedure of Porto (1996) and Clarkson and Jones (1996, unpublished). Fish captured by the Michigan State field crew were anesthetized per Porto (1996). Fish captured by the University of Wisconsin field crew were not anesthetized (due to high ambient temperatures and low recovery in pilot sampling efforts). In replicate samplings, recaptured fish were recorded and measured; unmarked fish were also measured and marked at this time. A key to mark placement for each stream has been included for review (APPENDIX 1). As per Porto (1996), fish were also given a fin clip to denote the fall season and above/below segment of capture.

Results

The 1998 mark-recapture data show some distinct differences with respect to Barrier and Reference streams. In addition, several differences were observed between watersheds. The mark-recapture data have been broken down below to illustrate these differences.

Middle (Barrier) and Poplar (Reference) Rivers

The ratio of fish marked between Reference and Barrier Streams was 1.51:1. The ratio of mark-recaptures between Reference and Barrier streams was 2.89:1. Not only were a disproportionately greater number of individuals caught in the Reference Stream, but a disproportionately greater number of individuals were recaptured in the Reference stream as well, (4.9% in the Reference stream versus 2.6% in the Barrier Stream).

In the Poplar River (Reference stream), the majority of marked fish were recaptured within the same season and at the same site they were originally marked (TABLE 12, TABLE 14.A, TABLE 14.B). However, 24% of the marked fish remained in the stream for longer than one season and 6.7% of the marked fish remained in the stream throughout the term of the study. As expected, some movement across the hypothetical Barrier was observed.

Four fish (three white suckers and a creek chub) might have moved from the Poplar River (Reference) to the Middle River (Barrier). The mouths of these streams are located within a mile of each other, so movement between streams is possible, but human error cannot be completely ruled out (i.e., errors in marking fish).

In the Middle River (Barrier stream), as with the Reference stream, the majority of marked fish were recaptured within the same season and at the same site they were originally marked (TABLE 12, TABLE 15.A, TABLE 15.B). In contrast to the Reference stream, 14% of the marked fish remained in the stream for longer than one season and no marked fish remained in the stream throughout the term of the study. In addition, in contrast to the Reference stream, no movement across the Barrier was observed.

The mark-recapture data for both the Reference and Barrier streams has been broken down to the species level. Species-specific mark-recapture data are summarized in APPENDIX 1-34 for each river sampled in 1998. For the Poplar and Middle Rivers, data on all species with any recaptures are presented. Species that were not recaptured have not been included.

East Branch AuGres (Barrier) and West Branch Rifle (Reference) Rivers

The ratio of fish marked between Reference and Barrier Streams was 1.04:1. The ratio of mark-recaptures between Reference and Barrier streams was .57:1. In addition, a smaller proportion of individuals was recaptured in the Reference stream (1.9%) as opposed to the Barrier stream (3.6%). Both of these relationships contrast with the results from the Wisconsin pair where a disproportionately large number of individuals were caught and recaptured in the Reference Stream.

In the West Branch Rifle all of the marked fish were recaptured at the same site they were originally marked (TABLE 13, TABLE 16.A, and TABLE 16.B). However, only 46.1% of the marked fish occurred within the same season they were originally marked. In addition, 53.8% remained in the stream for longer than one season. None of the marked fish remained in the stream throughout the term of the study and no movement across the hypothetical Barrier was observed. With the exception of seasonal recaptures and duration of stream use, these results are consistent with the findings from the Wisconsin stream pair.

In the East Branch AuGres (Barrier stream), as with the Reference stream, the majority (81.8%) of marked fish were recaptured at the same site they were originally marked, but they were not typically caught in the same season (TABLE 13, TABLE 17.A, TABLE 17.B). Sixty percent of the marked fish remained in the stream for longer than one season. As was the case with the Reference stream, no marked fish remained in the stream throughout the term of the study. Only one fish, a Rainbow Trout, was observed to traverse the barrier. It moved from an above barrier site to a below barrier site. No fish were found to breach the Barrier. These results are similar to the Reference stream, but seasonal mark-recapture and duration of stream use were not congruent with the findings from the Wisconsin stream pair.

Species-specific mark-recapture data are summarized in APPENDIX 1-34 for each river sampled in 1998. Data from the West Branch Rifle and East Branch AuGres are limited to the following species or families: (Creek Chub, Longnose Dace, Mottled Sculpin, Northern Hogsucker, Salmon, Trout, and White Sucker).

Discussion

Mark Retention

Abstract

Barrier Impacts of Lowhead Dams - Great Lakes Fisheries Commission
University of Wisconsin - Madison

In 1998, a mark retention experiment was conducted on four Wisconsin streams to determine if the high mark retention observed by Porto (1996) could be replicated on a larger sample size over an extended time frame. Panjet™ mark-retention varied significantly depending on the species and mark placement. Overall, 22.2% of Panjet™ marks were lost over the term of the study. In general, dye marks on the ventral body surfaces were retained the best. The greatest incidence of dye mark loss occurred on fins, although this was dependent somewhat on species and size.

Methods

In an effort to measure Panjet™ mark retention, the 1998 mark-recapture protocol utilized by the University of Wisconsin field crew on the Middle (Barrier) and Poplar (Reference) Rivers, WI was modified to incorporate a combination of time-dependent site-specific fin clips. A key to mark placement for each stream has been included for review (APPENDIX 1).

Results

In all, 77.8% of the 284 fish recaptured between May and October of 1998 retained their Panjet™ mark. Mark retention was not significantly different between barrier (76.7% mark-retention) and reference streams (78.2% mark retention) (Table 12). Mark retention rates are broken down by stream and species in Appendix 2.

Discussion

Mark retention in the 1998 sampling was lower than that reported by Porto 1996, 77.8% versus 97.80% respectively. This is likely due to the size of the fish and the location of the mark. In general, dye marks on the ventral body surfaces were retained the best. The greatest incidence of dye mark loss occurred on fins, although this was dependent somewhat on species and size. Utilizing a Panjet™ offered substantial savings in terms of handling time, however, conducting pilot studies of optimal mark placement and determining a lower limit on the size of the fish marked is recommended. High Panjet™ mark retention rates and the tendency for fins to regenerate over time may point to injection marking techniques as an alternative to fin clips for long-term mark recapture studies.

Turnover

Abstract

The following comparison of the 1998 seasonal mark-recapture study with the Noakes et al. (1996-1997) historical data is an attempt to assess the variability in the species composition over time. The comparison is limited to a three years of research by the University of Wisconsin and two years of research by Michigan State University and the University of Geulph. A multi-year comparison for the Mosquito River, Michigan, a Natural Barrier Stream sampled in 1996-1997 using the Noakes et al. (1997) protocol has also been included. Variability was significant in both barrier and reference streams. Barrier streams displayed prior-year turnover rates ranging from 17.24% to 54.16%. In contrast, Reference streams displayed prior-year turnover rates ranging from 10.00% to 50.00%. The Mosquito River, Michigan, had a 42.85% prior-year above barrier turnover rate.

Results

Tables 18-19 illustrate three-year (1996-1998) assessments on the Middle and Poplar Rivers.

In addition Tables 20-25 depict five two-year comparisons for the following Barrier streams: East Branch AuGres River, Grafton Creek, Echo River, West Branch of the Whitefish River, Miners Creek and Albany Creek. Tables 26-31 illustrate two-year comparisons for the following Reference streams: Lynde Creek, West Branch of the Rifle River, East Branch of the Whitefish River, Root River, Harlows Creek, and Beavertrail Creek. Table 32 highlights turnover in Natural Barriers.

Discussion

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Thanks everyone…!

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Table 1 A Comparison of Reference and Barrier Stream Widths.

Stream Pair	Barrier Stream			Reference Stream			Significant Differences		
	Mean Width			Mean Width			Mean Width		
Position Relative to Barrier	Above	Below	Whole	Above	Below	Whole	Above	Below	Whole
1	10.70	10.20	10.45	8.47	8.85	8.66			
2	4.47	7.78	6.13	2.74	4.99	3.87			
3	16.78	18.70	17.74	10.16	13.02	11.59	+		+
4	10.21	11.01	10.61	3.84	3.28	3.56	(+)	+	+
5	14.61	15.39	15.00	6.68	15.33	11.01	(+)	(+)	+
6	8.65	9.00	8.83	11.26	10.75	11.01			
7	14.62	22.04	18.33	16.89	18.36	17.63			
8	18.29	21.65	19.97	12.08	16.06	14.07			
9	10.54	12.11	11.33	5.15	7.11	6.13	+	+	+
10	17.91	18.31	18.11	18.34	15.35	16.85			
12	7.52	10.73	9.13	4.17	8.11	6.14			+
13	5.21	14.90	10.06	5.07	5.16	5.12		+	
14	7.18	8.89	8.04	12.88	13.31	13.10		(-)	-
15	8.23	11.43	9.83	12.65	16.64	14.65			
16	7.99	10.84	9.42	7.58	20.84	14.21			
17	10.71	11.76	11.24	7.19	7.78	7.49	+	+	+
18	8.96	14.63	11.80	15.23	16.17	15.70	-		-
19	3.47	6.89	5.18	2.91	2.51	2.71			
20	4.00	3.85	3.93	3.72	5.17	4.45	+		
21	7.28	12.37	9.83	2.91	2.51	2.71	+		
22	14.86	12.68	13.77	8.08	10.30	9.19	+	(+)	+
23	4.10	6.28	5.19	3.61	3.48	3.55		(+)	+
24	12.21	14.55	13.38	10.72	11.42	11.07			
25	8.15	11.10	9.63	7.53	7.40	7.47			

The stream pairings were tested for similarity using a 2-tailed paired t-test. Pairing were comprised of barrier stream (streams with low-head dams) and reference streams (streams with no barriers, low-head or natural). The data-points used for width (in m) were comprised of averages from the three transects run at each site. There are three sites above and below the barrier or hypothetical barrier. A "+" =significantly different ($p \leq .05$) and greater than the mean reference stream value. A "-" =significantly different ($p \leq .05$) and less than the mean reference stream value. Values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant.

Table 2 A Comparison of Reference and Barrier Stream Depths.

Stream Pair	**Barrier Stream**			**Reference Stream**			**Significant Differences**		
	Mean Depth			**Mean Depth**			**Mean Depth**		
Position Relative to Barrier	**Above**	**Below**	**Whole**	**Above**	**Below**	**Whole**	**Above**	**Below**	**Whole**
1	77.26	71.44	74.35	92.30	70.81	81.56			-
2	39.96	62.41	51.19	34.93	96.00	65.47			
3	74.07	134.86	104.47	51.73	67.85	59.79			+
4	77.00	57.22	67.11	32.33	33.63	32.98	+	+	+
5	69.00	76.67	72.84	44.00	97.33	70.67	(+)		
6	74.78	81.56	78.17	91.33	97.33	94.33			
7	98.56	92.67	95.62	51.22	70.89	61.06			+
8	58.78	71.94	65.36	52.00	43.33	47.67			
9	54.22	61.11	57.67	44.11	43.11	43.61			
10	46.10	53.55	49.83	39.30	40.80	40.05		(-)	
12	59.70	88.04	73.87	61.15	68.19	64.67			
13	54.67	152.22	103.45	42.67	48.44	45.56		+	+
14	54.44	65.89	60.17	70.22	88.11	79.17			
15	50.00	61.67	55.84	41.25	45.43	43.34			
16	67.13	73.00	70.07	59.44	78.86	69.15			
17	42.10	45.82	43.96	32.78	36.71	34.75	(+)		+
18	70.00	102.57	86.29	62.50	67.11	64.81			
19	38.89	66.17	52.53	33.89	33.89	33.89			
20	27.11	19.67	23.39	30.89	29.22	30.06		-	
21	62.89	72.67	67.78	33.89	33.89	33.89	+		
22	79.17	80.67	79.92	35.39	43.89	39.64	(+)	+	+
23	34.61	59.64	47.13	37.94	45.00	41.47			
24	52.56	56.67	54.62	38.67	28.89	33.78		+	+
25	53.56	57.67	55.62	47.00	43.00	45.00			

The stream pairings were tested for similarity using a 2-tailed paired t-test. Pairing were comprised of barrier stream (streams with low-head dams) and reference streams (streams with no barriers, low-head or natural). The data-points used for depth (in cm) were comprised of averages from the three transects run at each site. There are three sites above and below the barrier or hypothetical barrier. A "+" =significantly different ($p \leq .05$) and greater than the mean reference stream value. A "-" =significantly different ($p \leq .05$) and less than the mean reference stream value. Values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant.

Table 3 A Comparison of Reference and Barrier Stream Temperatures.

Stream Pair	Barrier Stream			Reference Stream			Significant Differences		
	Mean Temperature			Mean Temperature			Mean Temperature		
Position Relative to Barrier	Above	Below	Whole	Above	Below	Whole	Above	Below	Whole
1	15.00	14.78	14.89	13.33	15.78	14.56			
2	13.88	14.00	13.94	16.22	17.22	16.72			
3	16.00	15.71	15.86	14.67	15.33	15.00			
4	16.00	14.67	15.34	17.33	19.33	18.33	(-)	-	-
5	20.67	21.17	20.92	17.00	17.00	17.00	(+)	+	+
6	19.33	17.33	18.33	20.33	22.00	21.17	-		
7	19.67	21.67	20.67	19.33	19.67	19.50			
8	18.47	18.87	18.67	18.27	23.10	20.69			
9	19.87	19.23	19.55	16.73	18.00	17.37	+		
10	14.40	12.85	13.63	14.90	17.43	16.17	(-)		
12	14.22	13.44	13.83	13.00	16.22	14.61		-	
13	18.33	16.67	17.50	16.67	14.33	15.50		+	+
14	13.33	13.33	13.33	15.00	15.00	15.00		-	-
15	19.50	19.03	19.27	23.73	22.2	22.97		-	-
16	13.80	13.83	13.82	14.30	15.00	14.65			
17	20.03	18.27	19.15	21.30	19.39	20.35			
18	17.17	19.20	18.19	19.47	16.70	18.09		+	
19	12.17	17.25	14.71	18.33	18.83	18.58	-		-
20	16.00	16.00	16.00	12.83	13.00	12.92	+	+	+
21	17.67	17.00	17.34	18.33	18.83	18.58			
22	17.00	18.33	17.67	19.00	19.00	19.00			
23	14.33	15.67	15.00	15.00	15.00	15.00			
24	19.83	20.67	20.25	21.33	20.00	20.67			
25	17.00	16.00	16.50	19.50	15.33	17.42	-		

The stream pairings were tested for similarity using a 2-tailed paired t-test. Pairing were comprised of barrier stream (streams with low-head dams) and reference streams (streams with no barriers, low-head or natural). The data-points for temperature (in Celsius) were taken once per site. There are three sites above and below the barrier or hypothetical barrier. A "+" =significantly different ($p \leq .05$) and greater the mean reference stream value. A "-" =significantly different ($p \leq .05$) and less than the mean reference stream value. Values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant.

Table 4 A Comparison of Reference and Barrier Stream Substrates.

Stream Pair	Barrier Stream			Reference Stream			Significant Differences		
	Mean Substrate			Mean Substrate			Mean Substrate		
Position Relative to Barrier	Above	Below	Whole	Above	Below	Whole	Above	Below	Whole
1	3.48	3.27	3.38	3.37	3.58	3.48			
2	3.37	3.81	3.59	2.93	2.92	2.93			
3	4.05	3.19	3.62	4.94	3.91	4.43			-
4	4.98	5.18	5.08	4.48	3.56	4.02		+	+
5	4.92	5.10	5.01	5.04	4.33	4.69			
6	2.95	2.68	2.82	2.53	2.45	2.49	+		
7	3.33	3.25	3.29	3.66	3.56	3.61			
8	4.93	4.66	4.80	3.33	4.21	3.77	+		+
9	4.02	3.99	4.01	3.08	3.55	3.32			
10	5.42	4.69	5.06	5.83	4.53	5.18			
12	4.23	3.31	3.77	2.97	3.87	3.42			
13	2.90	3.31	3.11	3.27	3.12	3.20			
14	3.98	3.74	3.86	4.79	3.99	4.39			(-)
15	4.71	4.47	4.59	5.43	5.86	5.65		-	
16	3.72	3.16	3.44	3.76	3.27	3.52			
17	5.39	4.74	5.07	5.29	5.01	5.15			
18	3.97	2.38	3.18	4.20	4.62	4.41		(-)	(-)
19	2.35	2.39	2.37	2.95	2.79	2.87			
20	2.89	2.84	2.87	4.18	4.11	4.15	-		-
21	3.39	3.40	3.40	2.95	2.79	2.87			
22	3.70	3.85	3.78	4.17	3.89	4.03	-		-
23	4.23	4.17	4.20	2.86	2.89	2.88	+	+	+
24	5.42	5.88	5.65	5.10	5.04	5.07		(+)	+
25	3.94	3.51	3.73	4.13	4.15	4.14			

The stream pairings were tested for similarity using a 2-tailed paired t-test. Pairing were comprised of barrier stream (streams with low-head dams) and reference streams (streams with no barriers, low-head or natural). Substrate counts were averaged per transect with a mean of 50, and an average of the three transects was used. Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock. There are three sites above and below the barrier or hypothetical barrier. A "+" =significantly different ($p \leq .05$) and greater than the mean reference stream value. A "-" =significantly different ($p \leq .05$) and less than the mean reference stream value. Values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant.

Table 5 Barrier & Reference Streams: A Comparison of In-Stream (Above vs. Below Barrier) Characteristics.

Stream Pair	Stream Type	Stream	Characteristics			
			W	D	T	S
E20	R	Fishers Creek				
E20	B	Forestville Creek				
E19	R	South Otter Creek		-		
E19	B	Clear Creek				
H2	R	Beaver Trail River			-	
H2	B	Albany River				
H1	R	Riffle River West Branch				
H1	B	Au Gres River East Branch				
H5	B	Manitou River				
H5	R	Blue Jay River				
H21	B	Youngs Creek				
H3	B	Echo River		-		+
H3	R	Root River		-		+
H4	B	Kaskawong Creek		+		
H4	R	Brown Creek			(-)	+
H6	B	Sturgeon River			(+)	(+)
H6	R	Mad River				
M10	B	Whitefish River West Branch			-	
M10	R	Whitefish River East Branch				
M15	B	Days River	(-)			
M15	R	Rapid River			(+)	
M9	B	East Twin River	_			
M9	R	Hibbard's Creek				

The stream pairings were tested for similarity using a 2-tailed paired t-test. The data-points used for depth (in cm) and width (in m) were comprised of averages from the three transects run at each site, temperature (in Celsius) was taken once per site. Substrate counts were averaged per transect with a mean of 50, and an average of the three transects was used. Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock. There are three sites above and below the barrier or hypothetical barrier. The following characteristics, listed by their stream pairings, were used: W=Width, D=Depth, T=Temperature, S=Average Substrate, +=significantly different ($p \leq .05$) and greater than the mean above-barrier stream value, -=significantly different ($p \leq .05$) and less than the mean above-barrier reference value, values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant. * The Ahnapee River is a barrier stream. It was treated as a reference stream for comparisons with the Kewaunee River, but was included in the compilation for barrier stream comparisons. * South Otter Creek was used as a reference stream in two pairs, but was only sampled once. ***The Poplar River is a barrier stream, but it is treated as a reference stream for comparisons with the Middle River. ****Salem Creek is a barrier stream, but it is treated as a reference stream for comparisons with Grafton Creek. Stream pair #11 was not sampled. In regards to the stream pair number, the capitol letter refers to the first letter of the respective Great Lake watershed into which the stream drains, for example, E=Lake Erie. Stream Types are as follows: R = Reference, B = Barrier.

Table 5.1 Barrier & Reference Streams: A Comparison of In-Stream (Above vs. Below Barrier) Characteristics (cont.)

Stream Pair	Stream Type	Stream	Characteristics			
			W	D	T	S
M7	B	Betsie River				
M7	R	Upper Platte River				
M8	B	Kewaunee River				
M8	B	Ahnapee River			-	
O22	B	Duffins Creek				
O22	R	Lynde Creek				
O23	B	Grafton Creek	-			
O23	R	Salem Creek		-		
O25	B	Shelter Valley Creek				
O25	R	Wilmot Creek			+	
O24	B	Little Salmon River				
O24	R	Grindstone Creek			(+)	
S12	B	Miners Creek				
S12	R	Harlows Creek	-		-	
S16	B	Misery River				
S16	R	Firesteel River				
S17	B	Middle River				
S17	R	Poplar River				
S14	B	Stokely River				
S14	R	Pancake River				
S18	B	Neebing River	-		-	+
S18	R	Whitefish River				
S13	B	Big Carp River	-	-	+	-
S13	R	Little Carp River			(+)	

The stream pairings were tested for similarity using a 2-tailed paired t-test. The data-points used for depth (in cm) and width (in m) were comprised of averages from the three transects run at each site, temperature (in Celsius) was taken once per site. Substrate counts were averaged per transect with a mean of 50, and an average of the three transects was used. Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock. There are three sites above and below the barrier or hypothetical barrier. The following characteristics, listed by their stream pairings, were used: W=Width, D=Depth, T=Temperature, S=Average Substrate, +=significantly different ($p \leq .05$) and greater than the mean above-barrier stream value, -=significantly different ($p \leq .05$) and less than the mean above-barrier reference value, values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant. * The Ahnapee River is a barrier stream. It was treated as a reference stream for comparisons with the Kewaunee River, but was included in the compilation for barrier stream comparisons. * South Otter Creek was used as a reference stream in two pairs, but was only sampled once. ***The Poplar River is a barrier stream, but it is treated as a reference stream for comparisons with the Middle River. ****Salem Creek is a barrier stream, but it is treated as a reference stream for comparisons with Grafton Creek. Stream pair #11 was not sampled. In regards to the stream pair number, the capitol letter refers to the first letter of the respective Great Lake watershed into which the stream drains, for example, E=Lake Erie. Stream Types are as follows: R = Reference, B = Barrier.

Table 6 A Summary of Reference and Barrier Stream Characteristics.

Pair	Reference	Barrier	Above Barrier				Below Barrier				Whole Stream			
			W	D	T	S	W	D	T	S	W	D	T	S
1	Riffle River West Branch	Au Gres River East Branch										-		
2	Beaver Trail River	Albany River												
3	Root River	Echo River	+								+	+		-
4	Brown Creek	Kaskawong Creek	(+)	+	(-)		+	+	-	+	+	+	-	+
5	Blue Jay River	Manitou River	(+)	(+)	(+)		(+)		+		+		+	
6	Mad River	Sturgeon River			-	+								
7	Upper Platte River	Betsie River										+		
8	Ahnapee River**	Kewaunee River				+								+
9	Hibbard's Creek	East Twin River	+		+		+				+			
10	Whitefish River East Branch	Whitefish River West Branch			(-)			(-)						
12	Harlows Creek	Miners Creek							-		+			
13	Little Carp River	Big Carp River					+	+	+			+	+	
14	Pancake River	Stokely River					(-)		-		-		-	(-)
15	Rapid River	Days River							-	-			-	
16	Firesteel River	Misery River												
17	Poplar River***	Middle River	+	(+)			+				+	+		
18	Whitefish River	Neebing River	-						+	(-)	-			(-)
19	South Otter Creek	Clear Creek			-								-	
20	Fishers Creek	Forestville Creek	+		+	-		-	+				+	-
21	South Otter Creek*	Youngs Creek	+	+										
22	Lynde Creek	Duffins Creek	+	(+)		-	(+)	+			+	+		-
23	Salem Creek****	Grafton Creek				+	(+)			+	+			+
24	Grindstone Creek	Little Salmon River						+		(+)		+		+
25	Wilmot Creek	Shelter Valley Creek			-									

The stream pairings were tested for similarity using a 2-tailed paired t-test. Pairing were comprised of barrier stream (streams with low-head dams) and reference streams (streams with no barriers, low-head or natural). The data-points used for depth (in cm) and width (in m) were comprised of averages from the three transects run at each site, temperature (in Celsius) was taken once per site. Substrate counts were averaged per transect with a mean of 50, and an average of the three transects was used. Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock. There are three sites above and below the barrier or hypothetical barrier. The following characteristics, listed by their stream pairings, were used: W=Width, D=Depth, T=Temperature, S=Average Substrate, +=significantly different ($p \leq .05$) and greater than the mean reference stream value, -=significantly different ($p \leq .05$) and less than the mean reference stream value, values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant. * The Ahnapee River is a barrier stream. It was treated as a reference stream for comparisons with the Kewaunee River, but was included in the compilation for barrier stream comparisons. * South Otter Creek was used as a reference stream in two pairs, but was only sampled once. ***The Poplar River is a barrier stream, but it is treated as a reference stream for comparisons with the Middle River. ****Salem Creek is a barrier stream, but it is treated as a reference stream for comparisons with Grafton Creek. Stream pair #11 was not sampled.

Table 7 Natural Barriers: A Comparison of In-Stream (Above vs. Below Barrier) Characteristics.

Pair	STREAM	Characteristics			
		W	D	T	S
S26	Mosquito				
S27	Onion	na	na	na	na
S28	Lost Creek #1	na	na	na	na
M29	Root				
S30	Amnicon		-		
S31	Siskiwit				
S32	Baltimore				
S33	Black	na	na	na	na
M34	Chocolay East	-			
M35	Chocolay West				
S36	Huron				
S37	Laughing Whitefish		(-)		
S38	Silver	-			
S39	Montreal	na	na	na	na

The stream pairings were tested for similarity using a 2-tailed paired t-test. The data-points used for depth (in cm) and width (in m) were comprised of averages from the three transects run at each site, temperature (in Celsius) was taken once per site. Substrate counts were averaged per transect with a mean of 50, and an average of the three transects was used. Substrates were given a numerical rank according to the following scale: 1 = clay, 2 = silt, 3= sand, 4 = gravel, 5 = cobble, 6 = boulder, 7 = bedrock. There are three sites above and below the barrier or hypothetical barrier. The following characteristics, listed by their stream pairings, were used: W=Width, D=Depth, T=Temperature, S=Average Substrate, +=significantly different ($p \leq .05$) and greater than the mean above-barrier stream value, -=significantly different ($p \leq .05$) and less than the mean above-barrier reference value, values in parenthesis are not significant at ($p \leq .05$), but are within .03 of this criteria. Shaded areas are not significant. Stream pair #11 was not sampled. Characteristics signified by an (na) did not have below barrier sites for comparison. In regards to the stream pair number, the capitol letter refers to the first letter of the respective Great Lake watershed into which the stream drains, for example, E=Lake Erie.

Table 8 **r^2 values for Linear Fit Figures**

r^2 values	**BA**	**BB**	**BW**	**RA**	**RB**	**RW**
Mean Temperature x Mean Width	.151	.173	.160	.079	.040	.067
Mean Substrate x Mean Width	.320	.072	.051	.240	.216	.264
Mean Substrate x Mean Temperature	.099	.043	.034	.031	.039	.053
Mean Substrate x Mean Depth	.001	.108	.173	.065	.067	.061
Mean Temperature x Mean Depth	.081	.008	.005	.033	.016	.029
Mean Depth x Mean Width	.267	.228	.233	.132	.164	.147

These r^2 values correspond to the linear fit Figures ( ) presented earlier. BA = barrier streams above the dam; BB = barrier streams below the dam; BW = barrier streams as a whole. RA = reference streams above the hypothetical barrier; RB = reference streams below the hypothetical barrier; RW = reference streams as a whole. Each r^2 value was determined utilizing 22 degrees of freedom

Table 9 Natural Barriers: A Comparison of In-Stream Species Richness

Stream Number	Stream Name	Species Richness		Difference (Above-Below)
		# of Species Above	# of Species Below	
26	Mosquito**	5	4	1
27	Onion***	1	*na	na
28	Lost Creek #1	0	na	na
29	Root (Wisconsin)	13	32	-19
30	Amnicon	7	19	-12
31	Siskiwit	6	10	-4
32	Baltimore	9	11	-2
33	Black	12	na	na
34	Chocolay East	6	11	-5
35	Chocolay West	4	6	-2
36	Huron	4	8	-4
37	Laughing Whitefish	7	13	-6
38	Silver	4	7	-3
39	Montreal	9	na	na

*Segments designated by an (na) were not sampled. **Data for the Mosquito River are comprised of a cumulative total of species from 1996 and 1997. ***The Onion River has no below barrier segments as the barrier on this stream has been removed for greater than 15 years.

Table 10 **Reference Streams: A Comparison of In-Stream Species Richness**

Stream Number	Stream Name	Species Richness		Difference (Above-Below)
		# of Species Above	# of Species Below	
1	Riffle River West Branch	17	16	1
2	Beaver Trail River	9	15	-6
3	Root River	10	9	1
4	Brown Creek	7	12	-5
5	Blue Jay River	7	8	-1
6	Mad River	5	5	0
7	Upper Platte River	8	13	-5
8	Ahnapee River**	12	15	-3
9	Hibbard's Creek	4	8	-4
10	Whitefish River East Branch	14	20	-6
12	Harlows Creek	8	11	-3
13	Little Carp River	9	10	-1
14	Pancake River	9	5	4
15	Rapid River	14	13	1
16	Firesteel River	13	18	-5
17	Poplar River***	10	13	-3
18	Whitefish River	12	10	2
19	South Otter Creek*	6	12	-6
20	Fishers Creek	3	5	-2
21	South Otter Creek*	6	12	-6
22	Lynde Creek	16	15	1
23	Salem Creek****	17	18	-1
24	Grindstone Creek	18	18	0
25	Wilmot Creek	8	12	-4

Stream pair #11 was not sampled. *South Otter Creek is used as a reference stream in two pairs, but was only sampled once. **The Ahnapee River is a barrier stream, but it is treated as a reference stream for comparisons with the Kewaunee River. ***The Poplar River is a barrier stream, but it is treated as a reference stream for comparisons with the Middle River. ****Salem Creek is a barrier stream, but it is treated as a reference stream for comparisons with Grafton Creek.

Table 11 Barrier Streams (low-head): A Comparison of In-Stream Species Richness

Stream Number	Stream Name	Species Richness		Difference (Above-Below)
		# of Species Above	# of Species Below	
1	Au Gres River East Branch	9	18	-9
2	Albany River	10	12	-2
3	Echo River	14	21	-7
4	Kaskawong Creek	10	14	-4
5	Manitou River	13	14	-1
6	Sturgeon River	8	21	-13
7	Betsie River	12	19	-7
8	Kewaunee River	20	21	-1
9	East Twin River	18	28	-10
10	Whitefish River West Branch	14	25	-11
12	Miners Creek	10	11	-1
13	Big Carp River	10	10	0
14	Stokely River	5	9	-4
15	Days River	16	16	0
16	Misery River	9	10	-1
17	Middle River	8	12	-4
18	Neebing River	13	17	-4
19	Clear Creek	4	11	-7
20	Forestville Creek	6	11	-5
21	Youngs Creek	4	8	-4
22	Duffins Creek	17	29	-12
23	Grafton Creek	11	21	-10
24	Little Salmon River	13	12	1
25	Shelter Valley	11	13	-2

Stream pair # 11 was not sampled.

TABLE 12. UNIVERSITY OF WISCONSIN - 1998 MARK – RECAPTURE SUMMARY – ALL SPECIES

(See TABLES 2-6 and APPENDIX 1-34 for a breakdown of TABLE 1 and TABLE 2 by stream and species)

1998	# OF INDIVIDUALS MARKED	# OF INDIVIDUALS RECAPTURED	% RECAPTURED	% OF RECAPTURES THAT RETAINED PANJET™ MARK
MIDDLE RIVER (BARRIER)	2834	73	2.6%	76.7%
POPLAR RIVER (REFERENCE)	4302	211	4.9%	78.2%
TOTALS	7136	284	3.9%	77.8%

TABLE 13. MICHIGAN STATE UNIVERSITY 1998 MARK-RECAPTURE SUMMARY – ALL SPECIES

(See TABLES 1-4 and APPENDIX 1-34 for a breakdown of TABLE 1 and TABLE 2 by stream and species)

1998	# OF INDIVIDUALS MARKED	# OF INDIVIDUALS RECAPTURED	% RECAPTURED
EAST BRANCH AUGRES RIVER (BARRIER)	779	28	3.6%
WEST BRANCH RIFLE RIVER (REFERENCE)	809	16	1.9%
TOTALS	1588	44	2.8%

TABLE 14.A. MARK-RECAPTURE SUMMARY POPLAR RIVER, WI (REFERENCE)

Of Individuals Caught Above the Barrier: 1708 # MARKED: 4302
Of Individuals Caught Below the Barrier: 2594 # RECAPTURED: 211

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	49	1				4
	Above 2	11	45				1
	Above 3	2		13			3
	Below 1	2			15		
	Below 2		1			3	1
	Below 3	3	1	3		1	28

Of Unknowns (not included in table): 24*

* Four fish either were marked incorrectly or moved from the reference stream to the barrier stream

TABLE 14.B.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	43	16	11
	SUMMER	▨	46	13
	FALL	▨	▨	36

Of Unknowns (not included in table): 46*

* Four fish either were marked incorrectly or moved from the reference stream to the barrier stream

Of Panjet^{TM} Marks Lost: 46 Observed Mark Loss: 21.8%

TABLE 15.A. MARK-RECAPTURE SUMMARY MIDDLE RIVER, WI (BARRIER)

Of Individuals Caught Above the Barrier: 1051 # MARKED: 2834
Of Individuals Caught Below the Barrier: 1783 # RECAPTURED: 73

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	3					
	Above 2		29	1			
	Above 3			3			
	Below 1				10		1
	Below 2					17	
	Below 3						7

Of Unknowns (not included in table): 2

TABLE 15.B.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	2	5	
	SUMMER	▨	30	3
	FALL	▨	▨	17

Of Unknowns (not included in table): 16

Of Panjet™ Marks Lost: 17 Observed Mark Loss: 23.9%

TABLE 16.A. MARK-RECAPTURE SUMMARY EAST BRANCH AUGRES, MI (BARRIER)

# Of Individuals Caught Above the Barrier: 392	# MARKED: 779
# Of Individuals Caught Below the Barrier: 387	# RECAPTURED: 28

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**	4					
	Above 2	1	1				
	Above 3			7			1
	Below 1				2	1	
	Below 2					1	
	Below 3						4

Of Unknowns (not included in table): 6*

* One fish was tagged above the Barrier and recaptured above the Barrier.

TABLE 16.B.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING	2	7	2
	SUMMER	▨	5	6
	FALL	▨	▨	3

Of Unknowns (not included in table): 3

TABLE 17.A. MARK-RECAPTURE SUMMARY WEST BRANCH RIFLE, MI (REFERENCE)

Of Individuals Caught Above the Barrier: 341
Of Individuals Caught Below the Barrier: 468

MARKED: 809
RECAPTURED: 16

		SITE RECAPTURED					
	Relative Barrier Position	**Above 1**	**Above 2**	**Above 3**	**Below 1**	**Below 2**	**Below 3**
SITE TAGGED	**Above 1**						
	Above 2		2				
	Above 3			5			
	Below 1				1		
	Below 2					2	
	Below 3						3

Of Unknowns (not included in table): 3*

* Two fish were tagged below the Barrier and recaptured at site Below 1.

TABLE 17.B.

		SEASON RECAPTURED		
	1998	SPRING	SUMMER	FALL
SEASON TAGGED	SPRING		5	1
	SUMMER	▨	5	1
	FALL	▨	▨	1

Of Unknowns (not included in table): 3

Table 18

MIDDLE RIVER (BARRIER) LAKE SUPERIOR WATERSHED	# OF INDIV. SAMPLED IN 1996		# OF INDIV. SAMPLED IN 1997		# OF INDIV. SAMPLED IN 1998	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Black Bullhead	1	1				
Blacknose Dace	53	86	125	210	231	213
Brassy Minnow					4	11
Brook Stickleback			5	1	4	1
Brook Trout						2
Brown Trout				1		
Burbot		5		2		2
Common Shiner	7	30	43	1	341	817
Creek Chub	10	58	121	125	270	375
Horneyhead Chub		16	2	32	4	57
Johnny Darter	4	5	11	18	56	70
Lake Chub				1		
Log Perch		5		11		21
Longnose Dace	51	36	51	81	91	143
Mimic Shiner					4	1
Mottled Sculpin	18		12	15	49	12
Mud Minnow		2	6	1	12	5
Northern Pike				1		
Northern Redbelly Dace					1	
Redtail Chub				105		
Rainbow Trout			4		15	5
River Darter				1		
Rock Bass				3		5
Ruffe		1				
Sauger		3		2		5
Sea Lamprey				2		1
Stonecat				1		
Trout Perch				1		4
Walleye				2		
White Sucker	2	6	28	133	88	156
Number of Species Above/Below	8	11	11	23	14	20
Number of Species in Stream	14		24		21	
Cum. # of Species Above/Below			11	25	15	29
Cumulative # of Species in Stream			26		30	
Turnover Above/Below/Year Prior			5/11	14/25	3/14	10/26
Turnover Stream/Year Prior			14/26		11/28	
% Turnover Above/Below/Yr. Prior			45.45%	56%	21.42%	38.46%
% Turnover Stream/Year Prior			53.84%		39.28%	

Table 19

POPLAR RIVER (REFERENCE) LAKE SUPERIOR WATERSHED	# OF INDIV. SAMPLED IN 1996		# OF INDIV. SAMPLED IN 1997		# OF INDIV. SAMPLED IN 1998	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blacknose Dace	43	41	66	153	196	539
Bluntnose Minnow					1	
Brassy Minnow			2	4	23	
Brook Stickleback			1	1		1
Brown Trout	1		5		5	
Common Shiner	5	26	49	131	445	1016
Creek Chub	20	12	123	138	528	435
Golden Shiner			4	2		
Green Sunfish						1
Horneyhead Chub		1			3	6
Johnny Darter		5	15	17	96	87
Lake Chub				1		
Log Perch		4		4		1
Longnose Dace	59	70	56	60	90	238
Mimic Shiner						1
Mottled Sculpin	2	23	13	26	15	76
Mud Minnow	4	1	15	6	19	
Northern Brook Lamprey				2		
Northern Redbelly Dace			2	1	1	
Pearl Dace				1	8	1
Pumpkinseed	1		2		2	2
Rainbow Trout			18	3	34	1
Rock Bass	1	1	2		37	5
Trout Perch						5
Sauger		1				
Sea Lamprey			1			
Stonecat		1				
Unknown				2	64	
White Sucker	3	6	17	36	163	195
Number of Species Above/Below	10	13	17	17	17	17
Number of Species in Stream	15		21		22	
Cum. # of Species Above/Below			17	21	20	23
Cumulative # of Species in Stream			24		28	
Turnover Above/Below/Year Prior			7/17	12/21	6/20	12/23
Turnover Stream/Year Prior			12/24		9/26	
% Turnover Above/Below/Yr. Prior			41.17%	57.14%	30%	52.17%
% Turnover Stream/Year Prior			50%		34.61%	

1 unknown

Table 20

EAST BRANCH AUGRES (BARRIER) LAKE HURON WATERSHED	# OF INDIV. SAMPLED IN 1996		# OF INDIV. SAMPLED IN 1997		# OF INDIV. SAMPLED IN 1998	
SPECIES	ABOVE	BELOW	ABOVE	BELOW	ABOVE	BELOW
Blacknose Dace	11	60	76	18		
Black Bullhead		1				
Brassy Minnow		1		5		
Brook Stickleback	2				5	1
Brook Trout			1			
Brown Trout	3			1		
Coho Salmon	6	1	3			
Common Carp		1		2		
Common Shiner		4				
Creek Chub	29	48	34	23	34	68
Fathead Minnow		1		1		
Finescale Dace			4	1		
Green Sunfish		1		1		
Johnny Darter	13	5	3	3		
Largemouth Bass				1		
Longnose Dace		50	1	13		73
Mottled Sculpin	52	53	63	27	243	171
Mud Minnow	11	16	7	9		
Northern Hogsucker		1	1	3	2	8
Pearl Dace		17				
Pugnose Minnow				1		
Rainbow Trout	51	6	35	12	96	41
Redside Dace				5		
Sea Lamprey		3				1
Striped Shiner				1		
White Sucker		7	10	5	12	24
Number of Species Above/Below	9	18	12	19	6*	8*
Number of Species in Stream	20		21		8*	
Cum. # of Species Above/Below			14	24	14	25
Cumulative # of Species in Stream			26		26	
Turnover Above/Below/Year Prior			6/14	11/24	2/8*	2/8*
Turnover Stream/Year Prior			11/26		2/8*	
% Turnover Above/Below/Yr. Prior			42.85%	45.83%	25%	25%
% Turnover Stream/Year Prior			42.30%		25%	

Table 21

GRAFTON CREEK (BARRIER) LAKE ONTARIO WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
American Brook Lamprey		2	1	
Blacknose Dace	23	33	2	5
Blacknose Shiner	6			
Bluntnose Minnow		28		
Brassy Minnow	1			
Brook Stickleback	16	20	13	28
Brook Trout	10	3	1	1
Brown Bullhead	1			
Chinook Salmon	2			
Common Shiner		7		
Creek Chub	5	141		1
Fantail Darter		9		
Fathead Minnow		4		
Johnny Darter	15	153	1	16
Log Perch		1		1
Longnose Dace		159		8
Mottled Sculpin		178		2
Northern Redbelly Dace		3	2	1
Pumpkinseed		1		
Rainbow Trout	244	194	121	44
Redbelly Dace		15		
Rock Bass		1		
Sea Lamprey		3		
Spotfin Shiner		3		
White Sucker	1	17		46
Number of Species Above/Below	11	21	7	11
Number of Species in Stream	25		12	
Cum. # of Species Above/Below			13	21
Cumulative # of Species in Stream			25	
Turnover Above/Below/Year Prior			8/13	10/21
Turnover Stream/Year Prior			13/25	
% Turnover Above/Below/Yr. Prior			61.53%	47.61%
% Turnover Stream/Year Prior			52%	

Table 22

ECHO RIVER (BARRIER) LAKE HURON WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blacknose Dace	23	40	25	1
Bluntnose Minnow	3	10		
Brassy Minnow	11			
Brook Stickleback	1			
Central Mudminnow	2		2	
Common Shiner		3		1
Creek Chub	10	5	3	2
Emerald Shiner		1		
Finescale Dace			1	
Iowa Darter			1	
Johnny Darter	14	27	6	12
Largemouth Bass		8		1
Logperch		6		
Longnose Dace	70	6	55	1
Mimic Shiner		2		
Mottled Sculpin	23	19	46	3
Northern Pike		1		
Pearl Dace		1		
Rainbow Trout	3		2	
Rock Bass	2	16	1	3
Sand Shiner				1
Sea Lamprey	1	3	2	1
Silver Redhorse		1		1
Slimy Sculpin	25		1	
Smallmouth Bass		1		
Trout Perch		1		1
Walleye		1		
White Sucker	53	3	1	1
Yellow Perch		8		2
Number of Species Above/Below	14	21	13	14
Number of Species in Stream	26		19	
Cum. # of Species Above/Below			16	22
Cumulative # of Species in Stream			29	
Turnover Above/Below/Year Prior			5/16	9/22
Turnover Stream/Year Prior			13/29	
% Turnover Above/Below/Yr. Prior			31.25%	40.90%
% Turnover Stream/Year Prior			44.82%	

3 unknowns

Table 23

WHITEFISH WEST (BARRRIER) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	ABOVE	BELOW	ABOVE	BELOW
Blacknose Dace	287	85	159	40
Blacknose Shiner	▨	2	▨	1
Blackside Darter	▨	23	▨	7
Bluntnose Minnow	▨	8	▨	▨
Brassy Minnow	▨	1	3	1
Brook Stickleback	8	7	8	4
Brook Trout	6	11	6	10
Burbot	▨	9	▨	8
Common Shiner	24	10	17	8
Creek Chub	37	42	24	16
Fantail Darter	13	4	5	1
Fathead Minnow	▨	4	▨	1
Finescale Dace	▨	3	7	▨
Greater Redhorse	▨	▨	▨	2
Horneyhead Chub	▨	10	▨	▨
Iowa Darter	▨	▨	1	▨
Johnny Darter	7	19	1	8
Log Perch	▨	17	▨	10
Longnose Dace	113	46	78	10
Mottled Sculpin	78	37	43	6
Mud Minnow	18	13	15	1
Northern Redbelly Dace	8	▨	9	1
Pearl Dace	▨	3	▨	2
Rainbow Trout	16	13	15	12
River Darter	1	▨	1	▨
River Redhorse	▨	2	▨	▨
Rock Bass	▨	5	▨	2
Smallmouth Bass	▨	2	▨	1
White Sucker	22	34	18	27
Number of Species Above/Below	14	25	17	23
Number of Species in Stream	27		26	
Cum. # of Species Above/Below			17	27
Cumulative # of Species in Stream			29	
Turnover Above/Below/Year Prior			3/17	6/27
Turnover Stream/Year Prior			5/29	
% Turnover Above/Below/Yr. Prior			17.64%	22.22%
% Turnover Stream/Year Prior			17.24%	

1 unknown

Table 24

MINERS CREEK (BARRIER) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	ABOVE	BELOW	ABOVE	BELOW
American Brook Lamprey	▨	3	▨	▨
Blacknose Dace	10	119	6	14
Brook Stickleback	1	▨	▨	▨
Brook Trout	39	▨	40	1
Lake Trout	▨	2	▨	▨
Lamprey	1	1	▨	7
Longnose Dace	1	6	▨	27
Mottled Sculpin	17	32	5	38
Mudminnow	1	▨	▨	▨
Northern Pike	▨	2	▨	▨
Northern Redbelly Dace	4	1	▨	▨
Pearl Dace	▨	▨	21	1
Rainbow Trout	▨	2	▨	2
Slimy Sculpin	19	▨	13	4
White Sucker	8	32	3	10
Yellow Perch	▨	2	▨	▨
Number of Species Above/Below	10	11	6	9
Number of Species in Stream	15		9	
Cum. # of Species Above/Below			11	14
Cumulative # of Species in Stream			16	
Turnover Above/Below/Year Prior			6/11	8/14
Turnover Stream/Year Prior			8/16	
% Turnover Above/Below/Yr. Prior			54.54%	57.14%
% Turnover Stream/Year Prior			50%	

Table 25

ALBANY (BARRIER) LAKE HURON WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	ABOVE	BELOW	ABOVE	BELOW
Blacknose Shiner	3	▨	35	1
Bluntnose Minnow	▨	1	▨	1
Brassy Minnow	▨	▨	4	1
Brook Stickleback	28	▨	58	5
Brook Trout	6	1	6	4
Coho Salmon	▨	2	1	10
Common Shiner	▨	▨	12	▨
Creek Chub	▨	1	1	▨
Fathead Minnow	2	6	▨	▨
Finescale Dace	▨	▨	7	2
Iowa Darter	▨	▨	20	1
Johnny Darter	▨	14	▨	▨
Longnose Dace	▨	176	1	108
Mottled Sculpin	17	7	34	26
Mud Minnow	25	▨	90	▨
Ninespine Stickleback	▨	▨	▨	1
Northern Redbelly Dace	14	6	▨	▨
Pearl Dace	7	▨	▨	▨
Rainbow Trout	12	20	39	69
Rock Bass	▨	▨	▨	3
Sand Shiner	▨	▨	▨	1
Sea Lamprey	10	2	10	1
Slimy Sculpin	▨	3	▨	▨
White Sucker	▨	▨	▨	3
Number of Species Above/Below	10	12	14	16
Number of Species in Stream	16		19	
Cum. # of Species Above/Below			17	21
Cumulative # of Species in Stream			24	
Turnover Above/Below/Year Prior			10/17	14/21
Turnover Stream/Year Prior			13/24	
% Turnover Above/Below/Yr. Prior			58.82%	66.66%
% Turnover Stream/Year Prior			54.16%	

Table 26

LYNDE CREEK (REFERENCE) LAKE ONTARIO WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blackside Darter	3	2	▨	▨
Bluntnose Minnow	11	9	8	7
Common Shiner	14	15	31	▨
Creek Chub	7	25	2	▨
Fathead Minnow	▨	▨	▨	1
Johnny Darter	130	123	20	33
Log Perch	3	7	4	5
Longnose Dace	137	70	57	31
Northern Pike	2	▨	▨	▨
Pumpkinseed	4	4	▨	▨
Rainbow Darter	170	163	31	20
Rainbow Trout	2	4	▨	5
Rock Bass	19	22	2	▨
Rosyface Shiner	21	66	4	▨
Smallmouth Bass	3	1	▨	▨
Spotfin Shiner	1	4	▨	▨
White Sucker	5	6	111	59
Number of Species Above/Below	16	15	10	8
Number of Species in Stream	16		12	
Cum. # of Species Above/Below			16	16
Cumulative # of Species in Stream			17	
Turnover Above/Below/Year Prior			7/16	9/16
Turnover Stream/Year Prior			6/17	
% Turnover Above/Below/Yr. Prior			43.75%	56.25%
% Turnover Stream/Year Prior			35.29%	

1 unknown

Table 27

WEST BRANCH RIFLE (REFERENCE) LAKE HURON WATERSHED	# OF INDIV. SAMPLED IN 1996		# OF INDIV. SAMPLED IN 1997		# OF INDIV. SAMPLED IN 1998	
SPECIES	ABOVE	BELOW	ABOVE	BELOW	ABOVE	BELOW
Blacknose Dace	163	84	63	72	▓	▓
Bluegill	▥	1	1	▥	▓	▓
Brassy Minnow	1	4	▥	1	▓	▓
Brook Stickleback	1	▥	▥	▥	▓	▓
Brook Trout	▥	3	▥	2	▥	12
Brown Trout	2	▥	12	3	29	▥
Common Carp	5	1	▥	▥	▓	▓
Common Shiner	6	4	2	1	▓	▓
Creek Chub	83	67	21	44	70	132
Fathead Minnow	13	1	▥	▥	▓	▓
Finescale Dace	▥	▥	1	▥	▓	▓
Golden Redhorse	▥	1	▥	▥	▓	▓
Horneyhead Chub	2	▥	3	▥	▓	▓
Johnny Darter	9	27	11	21	▓	▓
Longnose Dace	1	2	4	3	69	137
Mottled Sculpin	12	6	7	11	49	68
Mud Minnow	5	1	9	▥	▓	▓
Northern Hogsucker	63	10	2	2	22	21
Pumpkinseed	▥	▥	1	▥	▓	▓
Rainbow Trout	▥	3	1	2	6	6
River Chub	1	▥	1	▥	▓	▓
Sea Lamprey	2	▥	▥	1	2	▥
White Sucker	15	24	28	20	94	92
Number of Species Above/Below	17	16	16	13	8*	7*
Number of Species in Stream	21		19		9*	
Cum. # of Species Above/Below			21	18	21	18
Cumulative # of Species in Stream			23		23	
Turnover Above/Below/Year Prior			9/21	7/18	1/9*	2/9*
Turnover Stream/Year Prior			5/23		0/9*	
% Turnover Above/Below/Yr. Prior			48.85%	38.88%	11.11%	22.22%
% Turnover Stream/Year Prior			21.73%		0%*	

3 unknowns

Table 28

WHITEFISH EAST (REFERENCE) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blacknose Dace	67	97	29	24
Blackside Darter	2	4	▨	▨
Bluntnose Minnow	2	5	1	1
Brook Trout	9	10	8	8
Burbot	▨	1	▨	1
Common Shiner	2	8	▨	8
Creek Chub	5	34	1	10
Fantail Darter	3	5	1	▨
Horneyhead Chub	▨	4	▨	▨
Johnny Darter	4	7	1	2
Log Perch	15	3	5	2
Longnose Dace	26	30	14	9
Mottled Sculpin	36	29	11	16
Mud Minnow	4	13	2	7
Northern Redbelly Dace	▨	1	▨	1
Pearl Dace	▨	1	▨	1
Rainbow Trout	65	3	62	3
Rock Bass	1	5	1	3
White Sucker	▨	28	1	13
Yellow Perch	▨	1	▨	1
Number of Species Above/Below	14	20	13	17
Number of Species in Stream	20		18	
Cum. # of Species Above/Below			15	20
Cumulative # of Species in Stream			20	
Turnover Above/Below/Year Prior			3/15	3/20
Turnover Stream/Year Prior			2/20	
% Turnover Above/Below/Yr. Prior			20%	15%
% Turnover Stream/Year Prior			10%	

1 unknown

Table 29

ROOT RIVER (REFERENCE) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blacknose Dace	37	35	21	29
Brook Trout	▨	▨	1	1
Common Carp	▨	▨	1	▨
Creek Chub	1	2	5	16
Johnny Darter	▨	2	▨	▨
Log Perch	1	3	▨	▨
Longnose Dace	90	37	58	29
Mottled Sculpin	41	33	18	26
Mud Minnow	1	1	1	3
Rainbow Trout	51	8	41	12
Rock Bass	6	6	8	9
White Sucker	3	▨	170	161
Yellow Perch	2	▨	▨	▨
Number of Species Above/Below	10	9	10	9
Number of Species in Stream	11		10	
Cum. # of Species Above/Below			12	11
Cumulative # of Species in Stream			13	
Turnover Above/Below/Year Prior			4/12	4/11
Turnover Stream/Year Prior			5/13	
% Turnover Above/Below/Yr. Prior			33.33%	36.36%
% Turnover Stream/Year Prior			38.46%	

1 unknown

Table 30

HARLOWS CREEK (REFERENCE) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Blacknose Dace	▨	▨	▨	4
Bluegill	1	20	▨	1
Brook Stickleback	2	▨	16	▨
Brook Trout	11	▨	38	4
Brown Trout	▨	▨	2	▨
Burbot	▨	4	▨	2
Central Mudminnow	▨	▨	5	1
Coho salmon	▨	1	8	2
Finescale Dace	▨	▨	▨	1
Johnny Darter	▨	▨	▨	1
Longnose Dace	3	50	1	25
Longnose Sucker	▨	▨	▨	27
Mottled Sculpin	12	13	24	16
Pumpkinseed	▨	3	▨	▨
Rainbow Trout	7	4	3	15
Rock Bass	▨	7	▨	4
Sea Lamprey	1	1	▨	1
Slimy Sculpin	▨	▨	3	1
White Sucker	▨	14	6	17
Yellow Perch	1	3	1	▨
Number of Species Above/Below	8	11	11	16
Number of Species in Stream	13		19	
Cum. # of Species Above/Below			13	18
Cumulative # of Species in Stream			20	
Turnover Above/Below/Year Prior			7/13	9/18
Turnover Stream/Year Prior			8/20	
% Turnover Above/Below/Yr. Prior			53.84%	50%
% Turnover Stream/Year Prior			40%	

Table 31

BEAVERTAIL (REFERENCE) LAKE HURON WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	ABOVE	BELOW	ABOVE	BELOW
Blackchin Shiner		5		
Blacknose Dace	33	1		16
Blackside Darter		2		
Bluntnose Minnow		1		
Brook Stickleback	1			
Central Mudminnow	9	13	4	1
Chinook Salmon			1	
Creek Chub	2			4
Fathead Minnow	3	1		
Finescale Dace				1
Grass Pickerel			3	
Iowa Darter		2	1	
Johnny Darter		1	1	
Longnose Dace		2	1	
Mottled Sculpin	3	3	2	5
Ninespine Stickleback		2		
Northern Pike				2
Northern Redbelly Dace	22			
Pearl Dace	4			
Pugnose Minnow			1	
Rainbow Trout	8			9
Rock bass		4	4	
Silver Shiner		4		
Slimy Sculpin			1	
Threespine Stickleback	1			
White Sucker		7	1	
Number of Species Above/Below	10	14	11	7
Number of Species in Stream	20		16	
Cum. # of Species Above/Below			19	18
Cumulative # of Species in Stream			26	
Turnover Above/Below/Year Prior			17/19	15/18
Turnover Stream/Year Prior			12/26	
% Turnover Above/Below/Yr. Prior			89.47%	83.33%
% Turnover Stream/Year Prior			46.15%	

Table 32

MOSQUITO RIVER (NATURAL BARRIER) LAKE SUPERIOR WATERSHED	NUMBER OF INDIVIDUALS SAMPLED IN 1996		NUMBER OF INDIVIDUALS SAMPLED IN 1997	
SPECIES	**ABOVE**	**BELOW**	**ABOVE**	**BELOW**
Brook Trout	37		11	37
Blacknose Dace	58			2
Brook Stickleback	20			
Mottled Sculpin				7
Mud Minnow	1			
Northern Redbelly Dace	67			
Rainbow Trout				9
Number of Species Above/Below	5		1	4
Number of Species in Stream	5		4	
Cum. # of Species Above/Below			5	5
Cumulative # of Species in Stream			7	
Turnover Above/Below/Year Prior			4/5	
Turnover Stream/Year Prior			3/7	
% Turnover Above/Below/Yr. Prior			80%	
% Turnover Stream/Year Prior			42.85%	

1 unknown

FIGURE 1

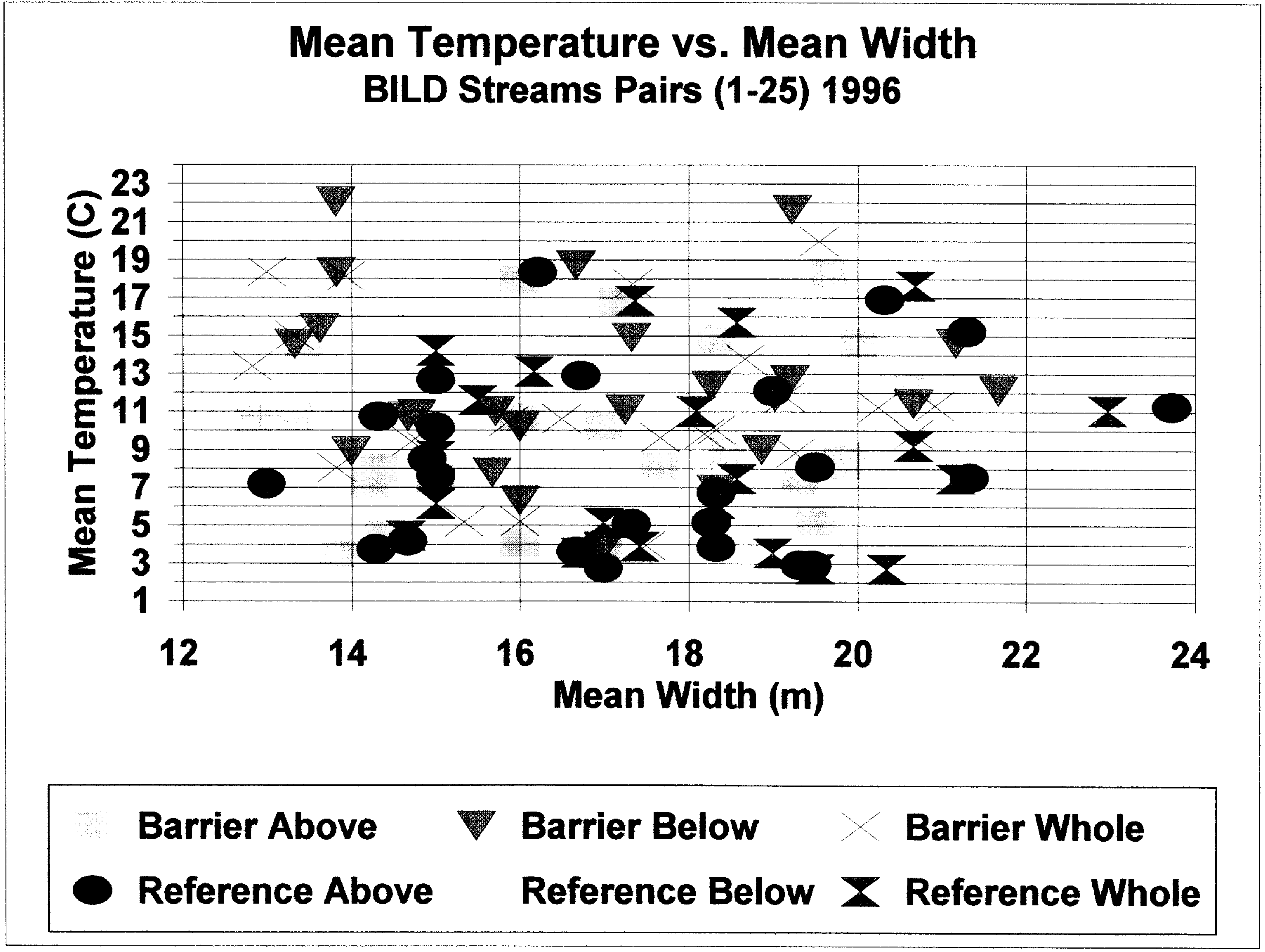

Mean Temperature vs. Mean Width
BILD Streams Pairs (1-25) 1996
Mean Temperature (C)
23
21
19
17
15
13
11
9
7
5
3
1
12
14
16
18
20
22
24
Mean Width (m)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 2

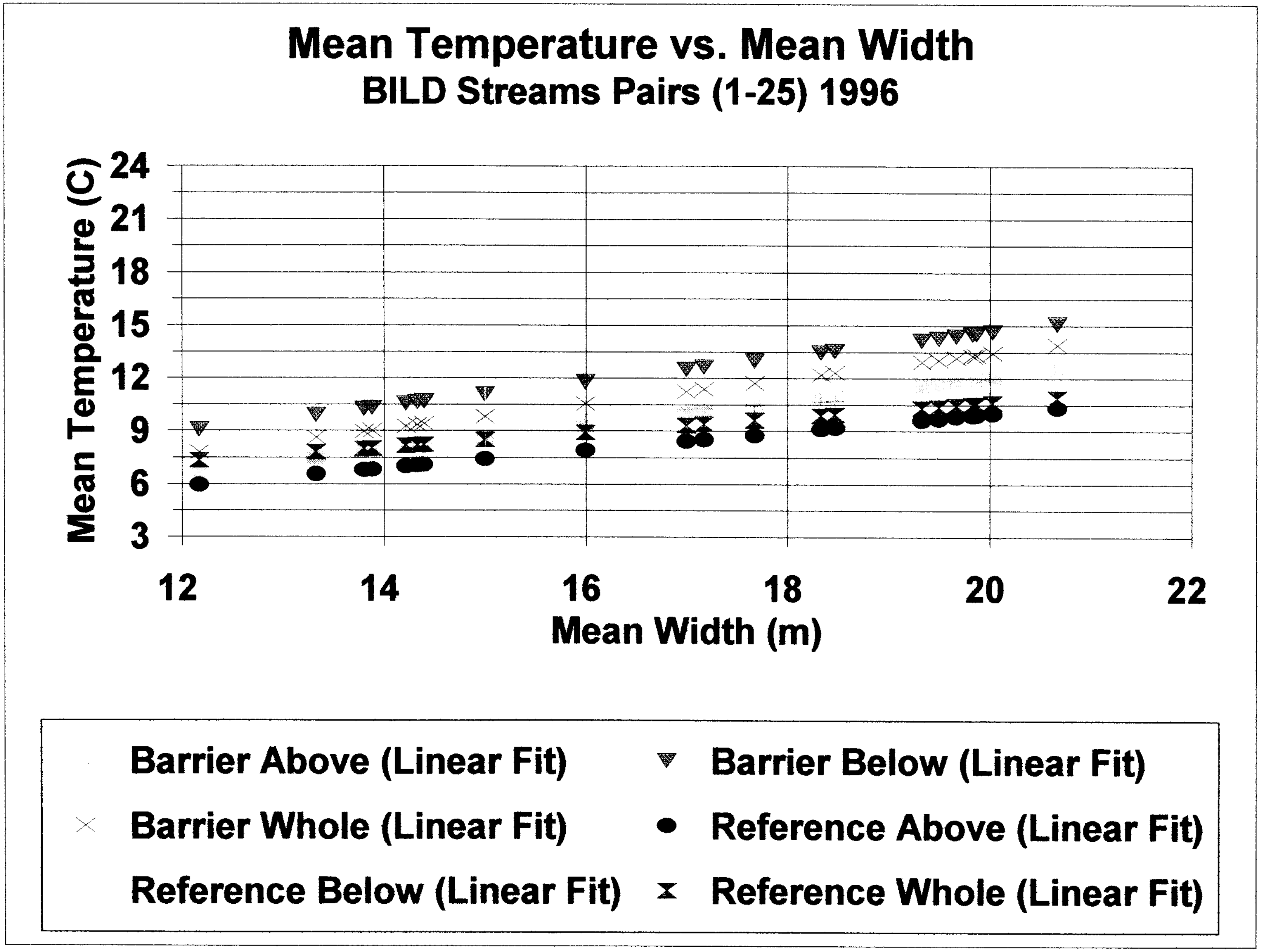

Mean Temperature vs. Mean Width
BILD Streams Pairs (1-25) 1996
Mean Temperature (C)
24
21
18
15
12
9
6
3
12
14
16
18
20
22
Mean Width (m)
Barrier Above (Linear Fit)
Barrier Below (Linear Fit)
Barrier Whole (Linear Fit)
Reference Above (Linear Fit)
Reference Below (Linear Fit)
Reference Whole (Linear Fit)

FIGURE 3

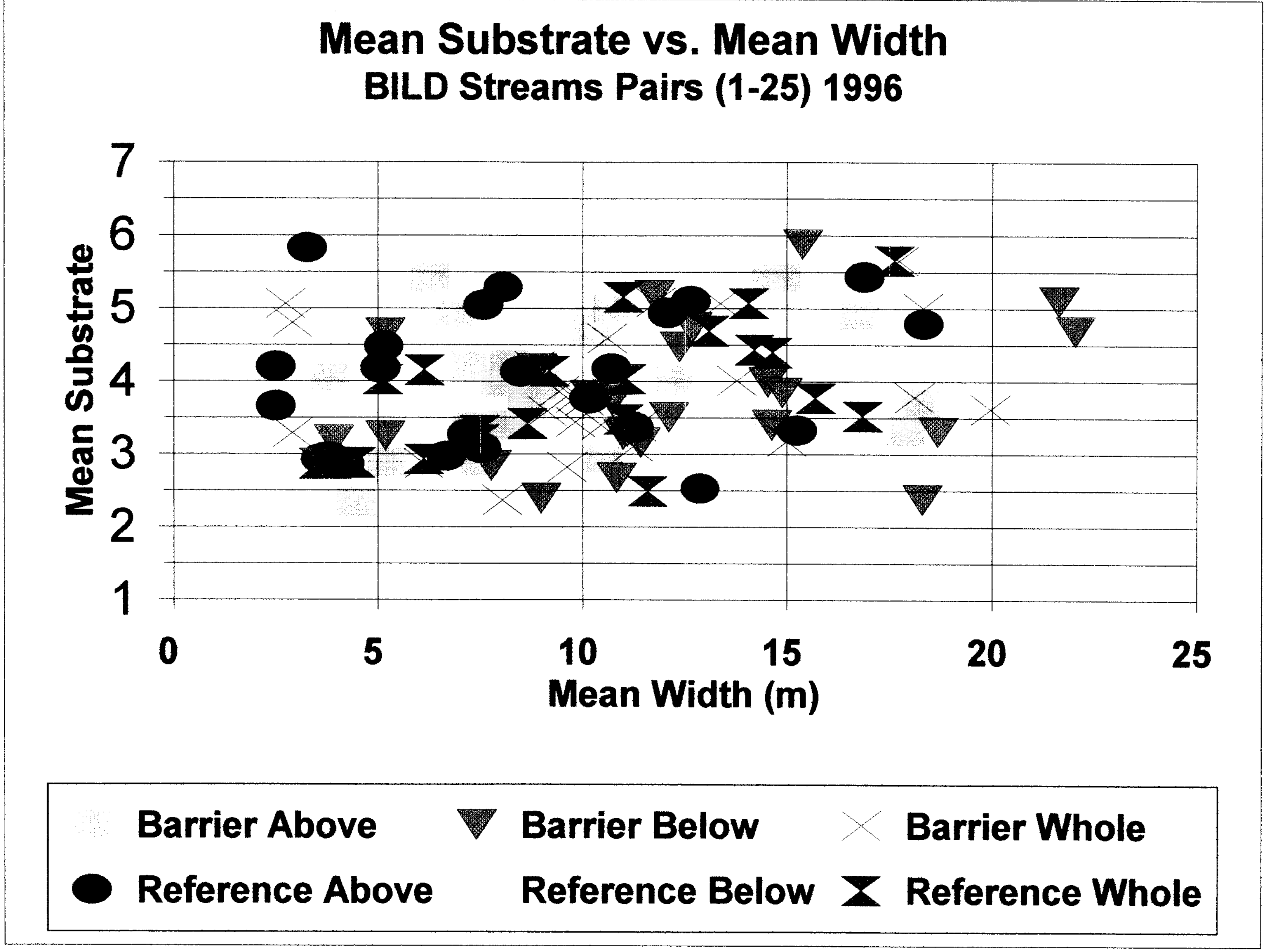
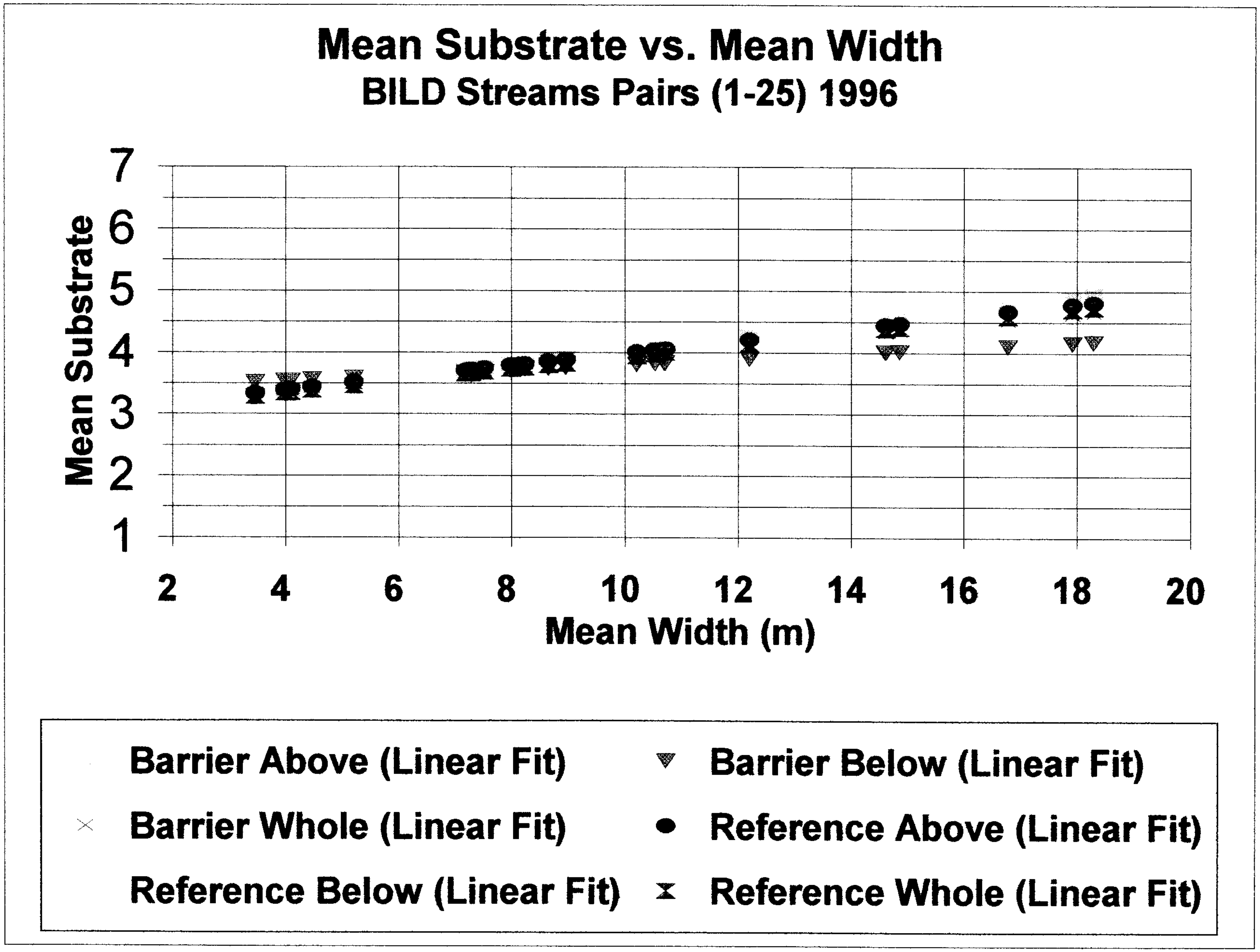

Mean Substrate vs. Mean Width
BILD Streams Pairs (1-25) 1996
Mean Substrate
7
6
5
4
3
2
1
0
5
10
15
20
25
Mean Width (m)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 4



Mean Substrate vs. Mean Width
BILD Streams Pairs (1-25) 1996

FIGURE 5

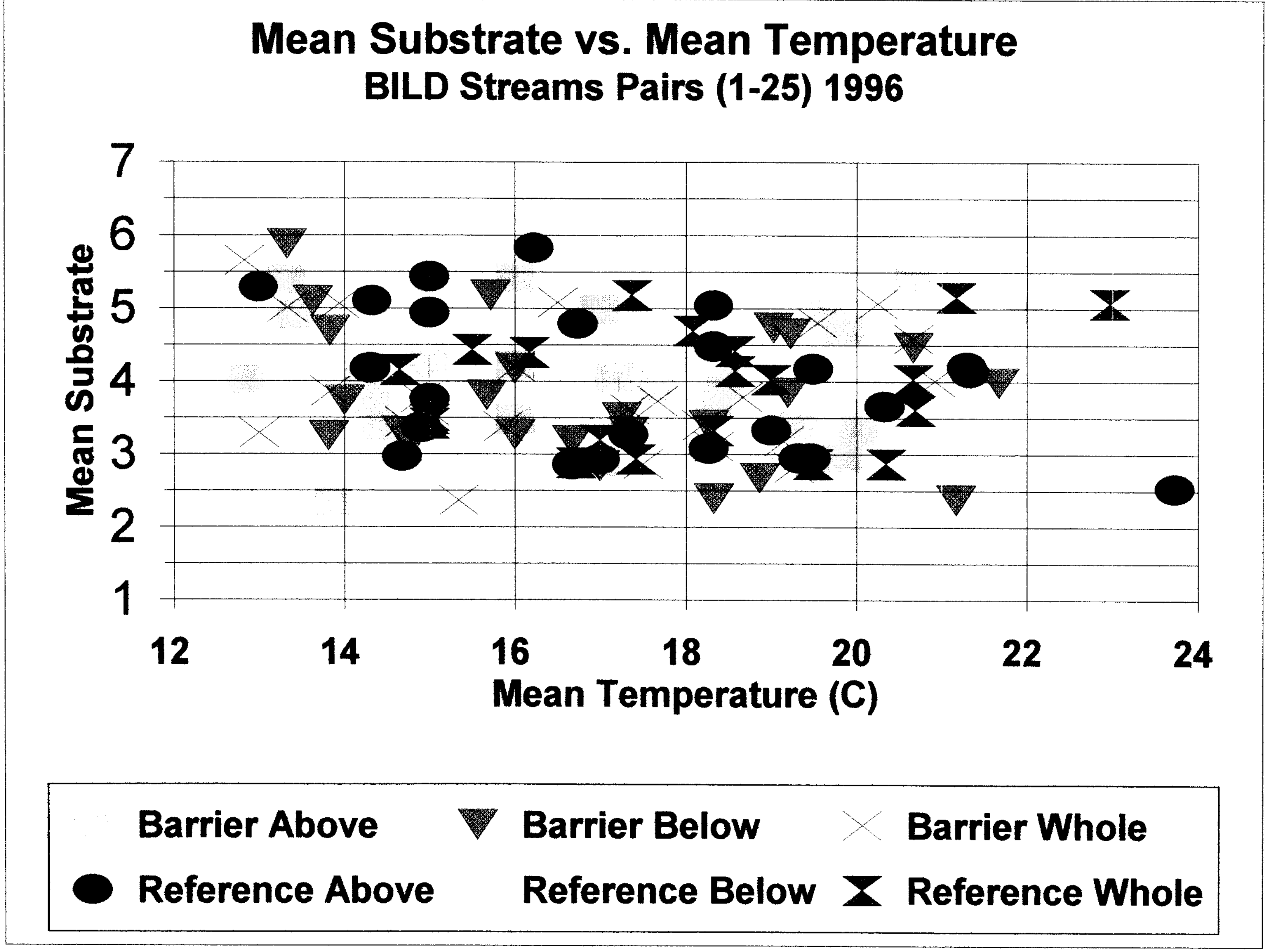

Mean Substrate vs. Mean Temperature
BILD Streams Pairs (1-25) 1996
Mean Substrate
7
6
5
4
3
2
1
12
14
16
18
20
22
24
Mean Temperature (C)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 6

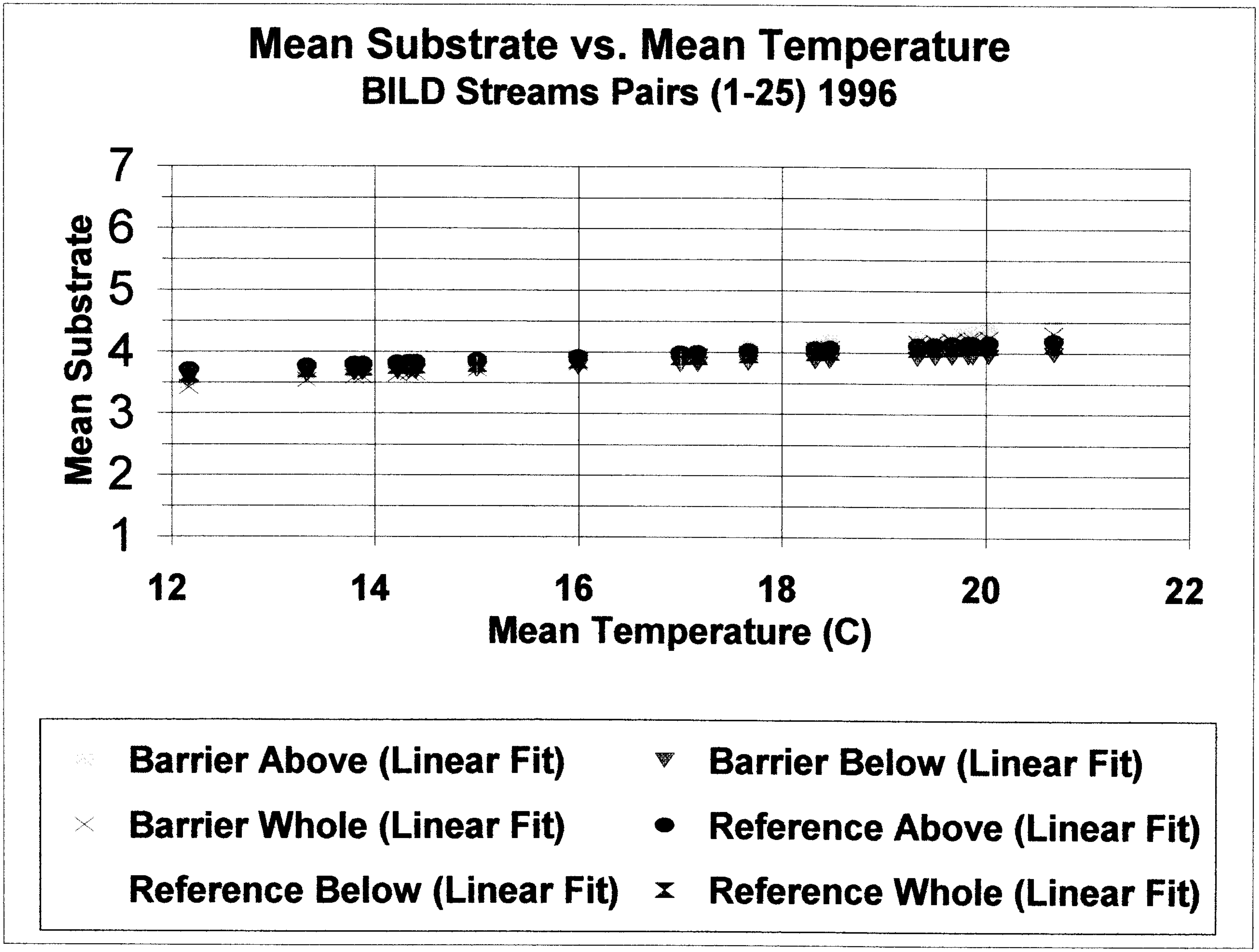

Mean Substrate vs. Mean Temperature
BILD Streams Pairs (1-25) 1996
Mean Substrate
7
6
5
4
3
2
1
12
14
16
18
20
22
Mean Temperature (C)
Barrier Above (Linear Fit)
Barrier Below (Linear Fit)
Barrier Whole (Linear Fit)
Reference Above (Linear Fit)
Reference Below (Linear Fit)
Reference Whole (Linear Fit)

FIGURE 7

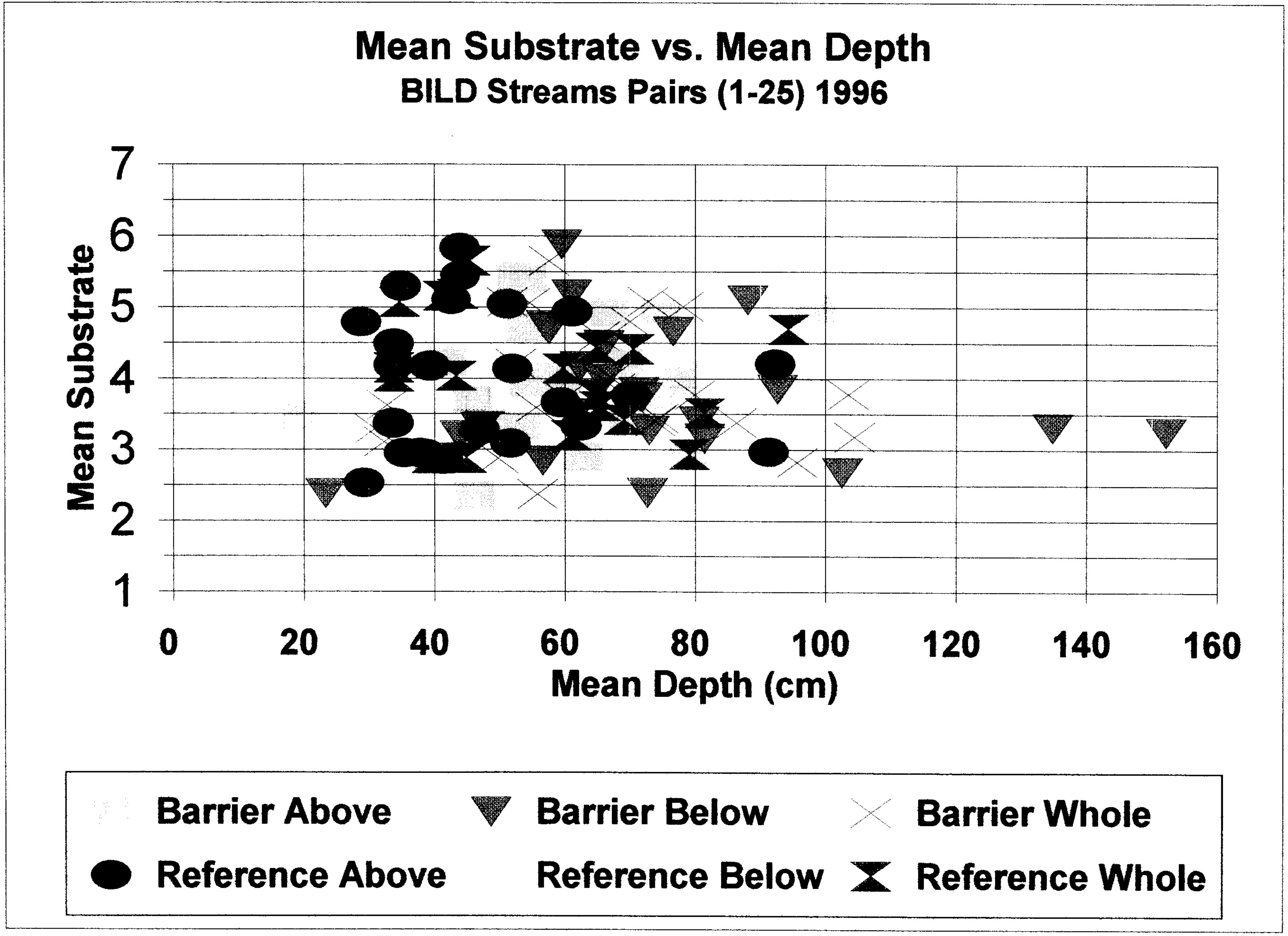

Mean Substrate vs. Mean Depth
BILD Streams Pairs (1-25) 1996
Mean Substrate
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
Mean Depth (cm)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 8

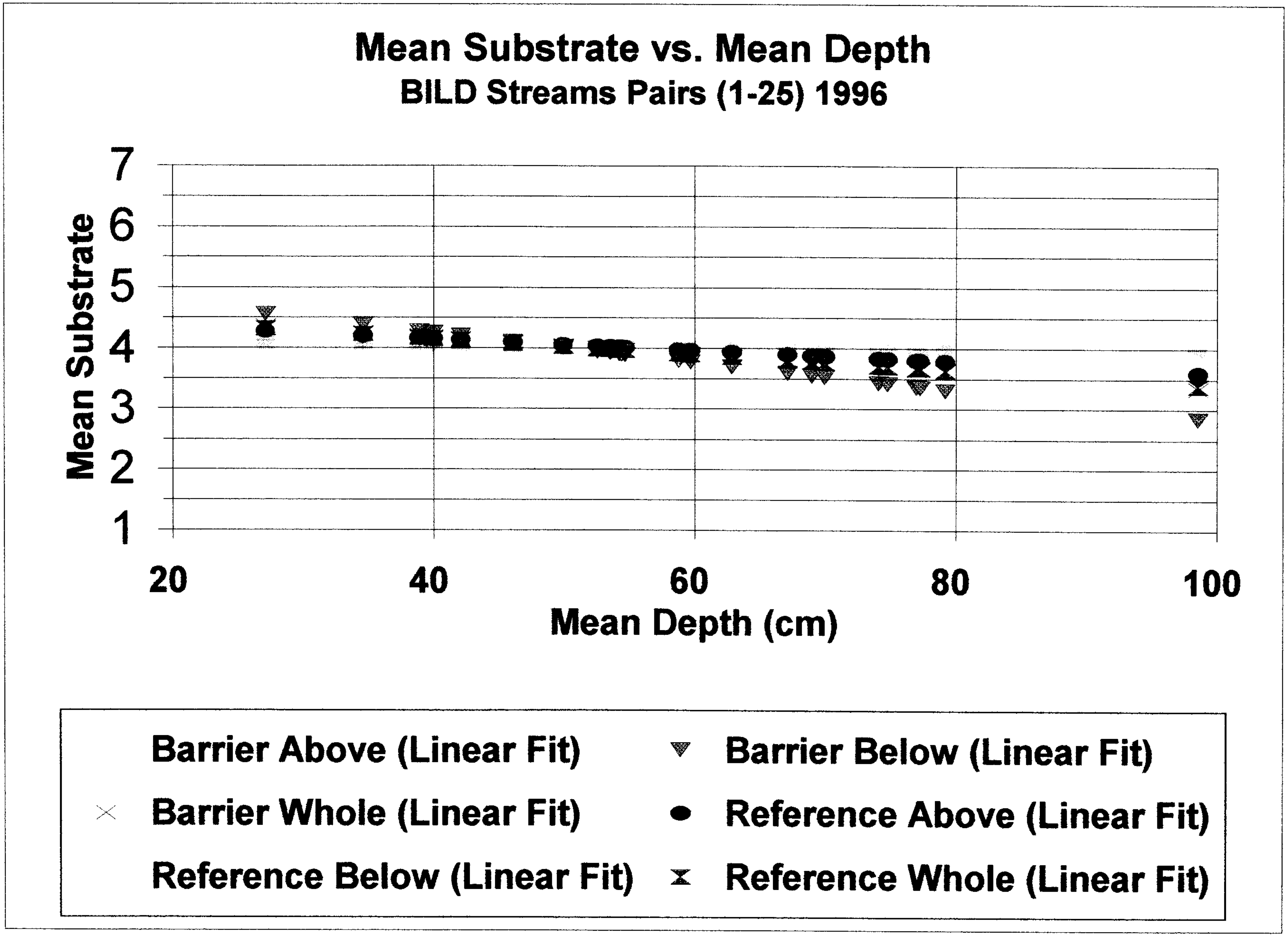

Mean Substrate vs. Mean Depth
BILD Streams Pairs (1-25) 1996
Mean Substrate
7
6
5
4
3
2
1
20
40
60
80
100
Mean Depth (cm)
Barrier Above (Linear Fit)
▼ Barrier Below (Linear Fit)
× Barrier Whole (Linear Fit)
● Reference Above (Linear Fit)
Reference Below (Linear Fit)
⧗ Reference Whole (Linear Fit)

FIGURE 9

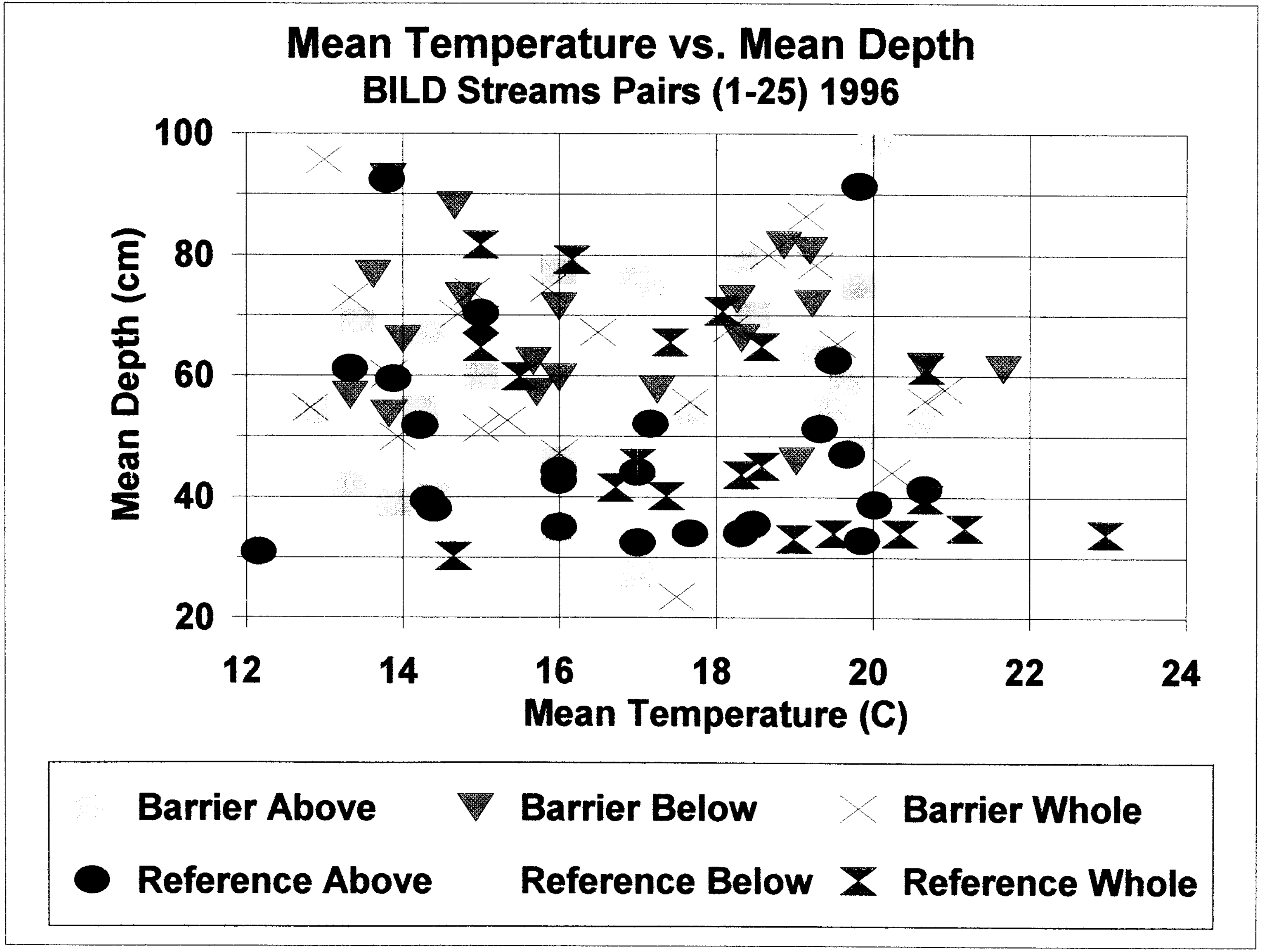

Mean Temperature vs. Mean Depth
BILD Streams Pairs (1-25) 1996
Mean Depth (cm)
100
80
60
40
20
12
14
16
18
20
22
24
Mean Temperature (C)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 10

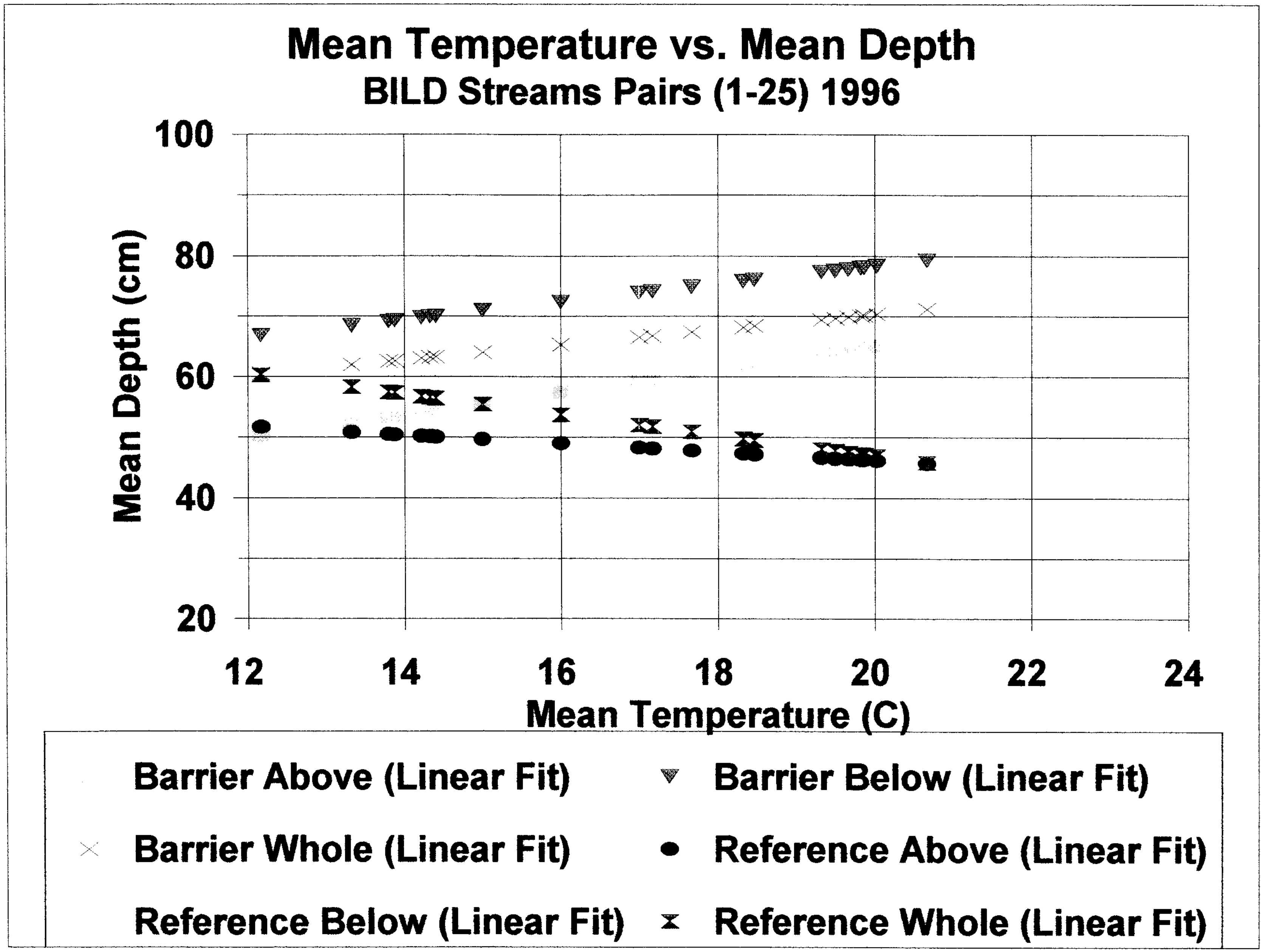

Mean Temperature vs. Mean Depth
BILD Streams Pairs (1-25) 1996
Mean Depth (cm)
100
80
60
40
20
12
14
16
18
20
22
24
Mean Temperature (C)
Barrier Above (Linear Fit)
▼ Barrier Below (Linear Fit)
× Barrier Whole (Linear Fit)
● Reference Above (Linear Fit)
Reference Below (Linear Fit)
⧗ Reference Whole (Linear Fit)

FIGURE 11

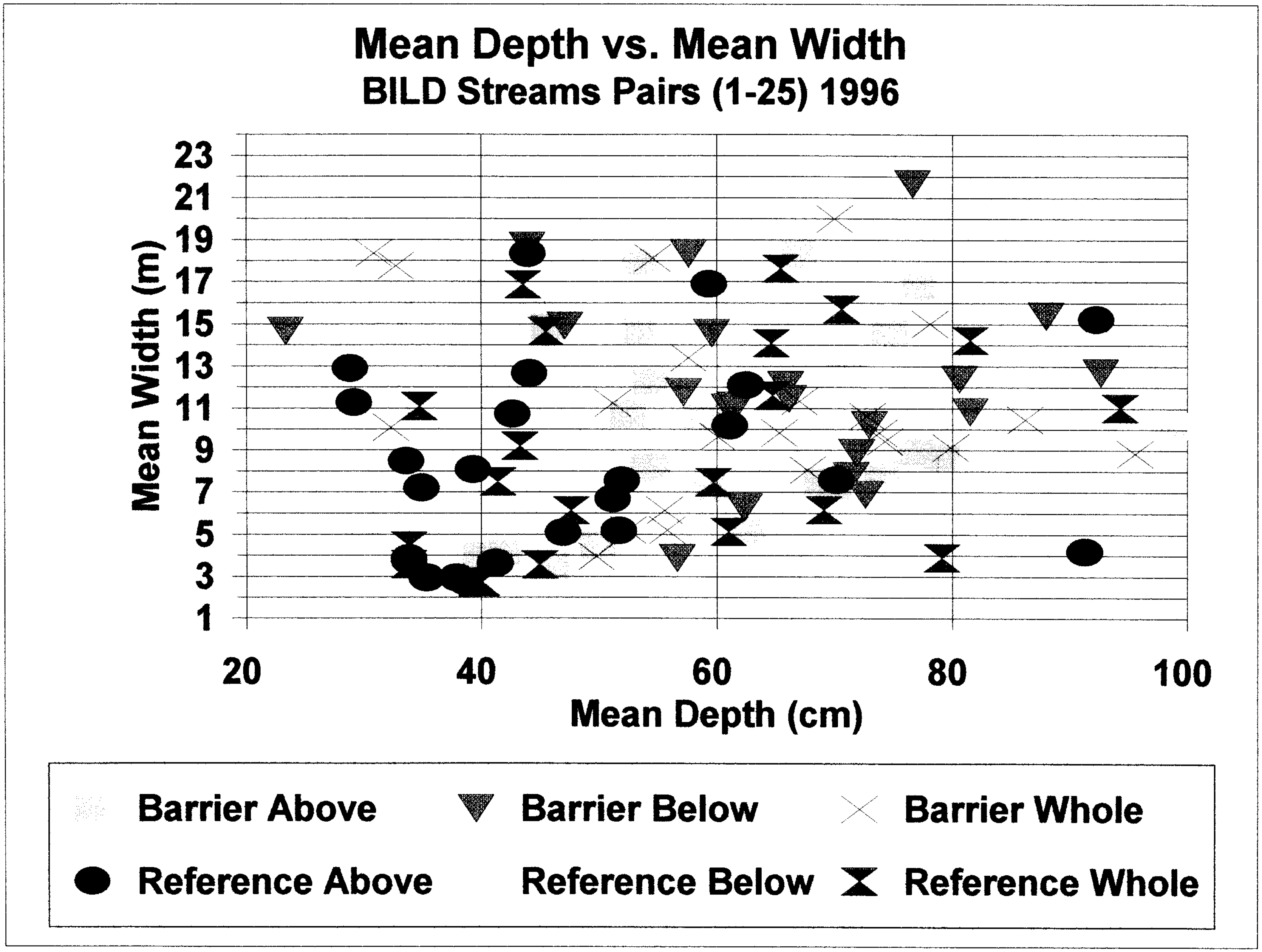
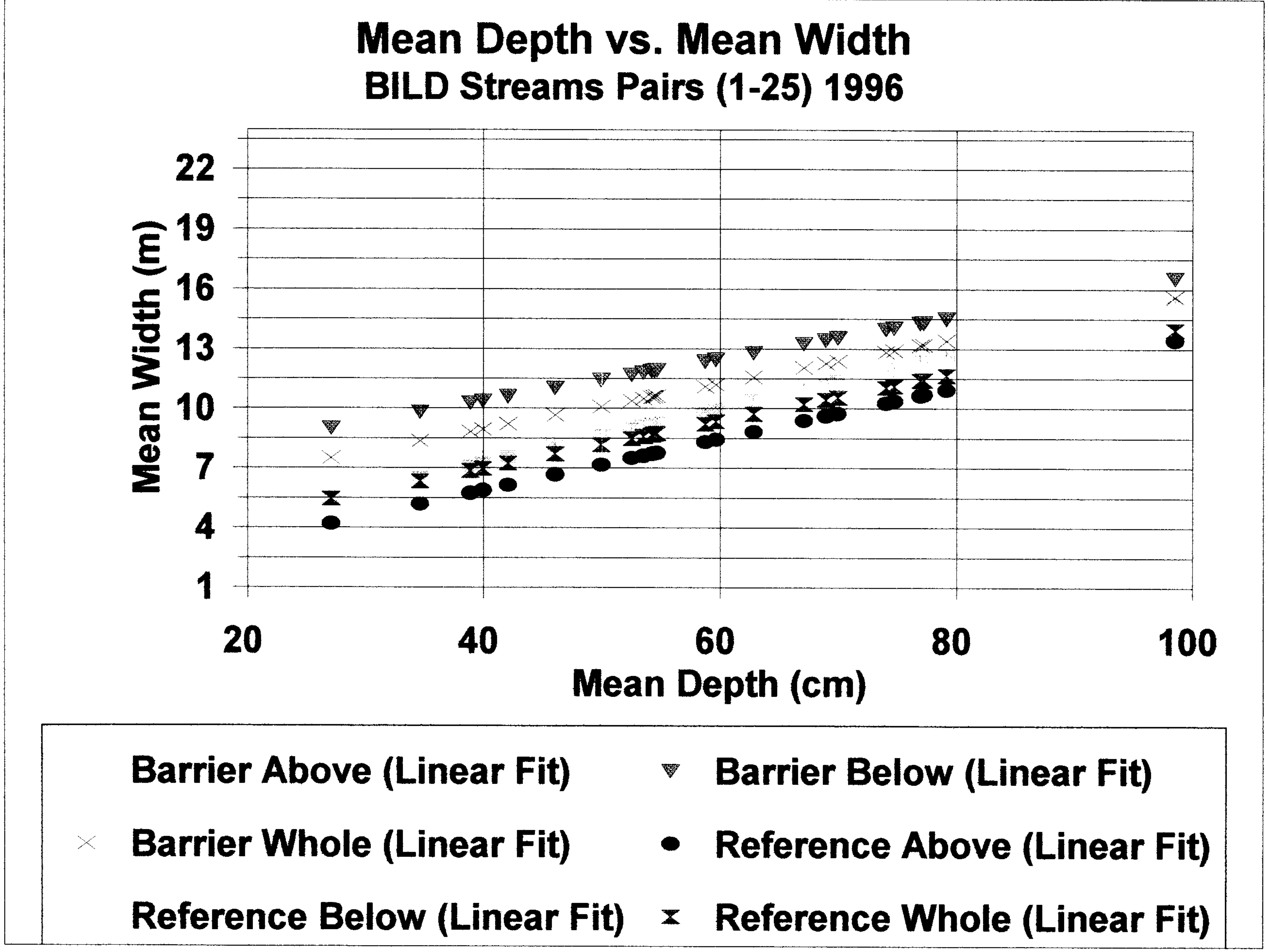

Mean Depth vs. Mean Width
BILD Streams Pairs (1-25) 1996
Mean Width (m)
23
21
19
17
15
13
11
9
7
5
3
1
20
40
60
80
100
Mean Depth (cm)
Barrier Above
Barrier Below
Barrier Whole
Reference Above
Reference Below
Reference Whole

FIGURE 12


Mean Depth vs. Mean Width
BILD Streams Pairs (1-25) 1996
Mean Width (m)
22
19
16
13
10
7
4
1
20
40
60
80
100
Mean Depth (cm)
Barrier Above (Linear Fit)
▼ Barrier Below (Linear Fit)
× Barrier Whole (Linear Fit)
● Reference Above (Linear Fit)
Reference Below (Linear Fit)
⧗ Reference Whole (Linear Fit)