EFFECTS OF THE STRONACH DAM REMOVAL ON FISH IN THE PINE RIVER, MANISTEE COUNTY, MICHIGAN

Chapter Two of a 2007 Dissertation entitled:
Effects of Dam Removal on Fluvial Geomorphology and Fish

By Bryan A. Burroughs
Professor Daniel B. Hayes

Department of Fisheries & Wildlife
Michigan State University
13 Natural Resources, East Lansing, MI 48824-1222
www.fw.msu.edu
517-353-6697

INTRODUCTION

Dams affect river systems in a myriad of direct and indirect ways including disrupting the flow of water, energy, sediment, nutrients, and biota (e.g., Hammad 1972, Petts 1980, Williams and Wolman 1984, Cushman 1985, Bain et al. 1988, Ward and Stanford 1989, Benke 1990, Ligon et al. 1995). These changes impact lotic fish communities both through habitat alteration and fragmentation (Hayes et al. in press). Habitat alteration occurs upstream and downstream of dams, but in fundamentally different ways. Upstream from dams, the flow of water, sediment, and nutrients is slowed, creating impoundments and converting lotic habitat to lentic habitat (Petts 1980, Ward and Stanford 1989). This decreases habitat suitability for lotic species, and often leads to the juxtaposition of lentic fish communities in impoundments with upstream resident lotic species. Downstream of dams, habitat is altered through the reduction of sediment supply, subsequent erosion, water temperature changes and flow variability (Williams and Wolman 1984, Cushman 1985, Ligon et al. 1995, Collier et al. 1996). This often leads to the displacement of resident fish species and the colonization of other invasive or non-native fish species (Martinez et al. 1994, Quinn and Kwak 2003). From a fisheries management perspective, changes in resident fish communities can be seen as either detrimental or beneficial depending on conservation status and fishery values of the fish species being lost or gained.

Dams also impact fish communities through habitat fragmentation. All fish species need access to habitats essential for reproduction, feeding and survival. The placement of dams on rivers prevents or impedes movements for many fish species. For diadromous fishes, dams can block essential fish reproductive migrations, and the migration of juveniles to feeding habitats, often with severe consequences for these fish populations (Benke 1990, Pringle et al. 2000). Many non-diadromous riverine fish species also make substantial migrations critical to their life histories and survival (Auer 1996, Northcote 1998, Burrell et al. 2000). These movements include downstream drift of juveniles, movements to and from over-wintering habitat, movements to thermal refuges, migrations to preferred spawning habitat, and searching movements crucial for individual fish to locate optimal areas for feeding and holding. While not historically recognized as being as important as migrations of diadromous fishes, these upstream and downstream movements by riverine fishes may also be vital to the sustainability of these fish populations.

For numerous reasons (reviewed by Pohl 2002, Heinz 2002, Stanley and Doyle 2003, and Burroughs 2007) dam removal has recently become a popular stream restoration method for remedying both fish habitat alteration and fragmentation, as well as rehabilitating overall river ecosystem form and function. The popularity of dam removal as a river restoration technique stems almost entirely from the well-documented negative impacts of dams and hypotheses about the reversal of these impacts following dam removal. Empirical information on the effects of dam removal on fish is very limited. Several qualitative observations exist that anadromous fish have been seen to migrate upstream past dam sites following removal (American Rivers 1999, Smith et al. 2000), and one recent study documented and quantified the successful spawning of striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*) and hickory shad (*Alosa mediocris*) upstream of a dam following its removal (Burdick and Hightower 2006). However, despite the more than 400 dams removed in the United States (Pohl 2003), very few published studies exist where the effects of dam removal on fish populations were quantified. Hill et al. (1994) found that following the removal of Chipola Dam in Florida, largemouth bass (*Micropterus salmoides*) recruitment, while becoming highly variable, also increased substantially on average due to restored flow variability. Migratory striped bass were also seen using the river as thermal refuge and the total number of species present in the river upstream of the dam increased from 34 to 61 following dam removal. Kanehl et al. (1997) documented large increases in the recruitment and density of smallmouth bass (*Micropterus dolomieu*) in the Milwaukee River upstream of the Woolen Mills Dam removal site, a decrease in the density of common carp (*Cyprinus carpio*), and an increase in fish community biotic index scores. While these studies provide unique and valuable insight into the effects of dam removal on fish communities, they do not fully represent the range of variability that exists in North American rivers and their fish communities. For example, no published quantitative studies currently exist documenting the effects of dam removals on fish in a coldwater stream. The current state of knowledge regarding the effects of dam removal is limited, providing only a precursory understanding of the outcomes of removing dams on fish. Fishery resources are an important consideration in dam removal decision-making processes. Given the current void in our understanding of this emerging and important topic, additional information on this subject is needed to inform future decision making regarding removing dams.

The “staged” or gradual removal of Stronach Dam, on the Pine River, in Manistee Co. Michigan, created an opportunity to gain insight into both the effects of habitat alteration on a fish community following dam removal and also the effects of restored connectivity and subsequent fish movements and species invasions. The Pine River is a coldwater stream with another moderate –sized reservoir located just downstream from the Stronach Dam removal site and thus has coldwater, coolwater and warmwater fish species utilizing the river, at least seasonally. Self-sustaining populations of resident brown trout (*Salmo trutta*) and rainbow trout (*Onchorynchus mykiss*) provide a valuable sport fishery upstream of the Stronach Dam site, and habitat alteration following the dam removal was anticipated to improve habitat conditions for trout throughout the approximately 4 km long impoundment. Downstream of the dam, a different fish community existed including 18 species of fish not found upstream of the dam. Due to the staged nature of this dam removal, several years of habitat alteration occurred during the early stages of the dam removal before fish passage was possible. This allowed insight into the effects of habitat alteration following dam removal, before connectivity was eventually restored during the final stage of dam removal.

The specific research objectives of this study were to: 1) document the changes in fish habitat that occurred due to dam removal, 2) document changes in the distributions of fish species in the Pine River following the dam removal, 3) document density changes for brown trout, rainbow trout, brook trout (*Salvelinus fontinalis*), white sucker (*Catastomus commersoni*), and shorthead redhorse sucker (*Moxostoma macrolepidotum*) occurring before, during and after the dam removal and 4) document changes in the size structure of those species of fish. Objective 1, the documentation of changes in fish habitat due to the dam removal is covered in detail in Burroughs (2006), and will be summarized here.

Site Description

Stronach Dam is located on the Pine River, a tributary to the Manistee River, in the northwestern Lower Peninsula of Michigan (Figure 1). The Pine River is 77 km long, is a fourth order stream, and drains a 68,635 ha watershed dominated by sandy glacial outwash plains, recessional moraines, and areas of consolidated clay (Hansen 1971, Rozich 1998). It carries a high bedload of sand due to the local geology and extensive logging operations of the late 1800’s, which created unstable banks along the river. The Pine River is a coldwater stream, dominated by groundwater input, and rarely exceeds 21° C. Mean daily discharge recorded at two U.S. Geological Survey gaging stations on the Pine River averaged 8.10 m^3/s during 34 years of record, with an average annual ratio of low to high mean monthly flows of 2.02, indicating “stable to very stable” flows (Rozich 1998). The Pine River is a riffle-pool stream with an average gradient of 2.8 m/km. The section of river impounded by Stronach Dam historically had a gradient of 4.7 m/km, and was reported to be the best fish spawning area of the river (Rozich 1998).

Stronach Dam was constructed from 1911 to 1912, 5.6 km upstream from the confluence of the Pine River and the Manistee River (Figure 1). Stronach Dam was an earth embankment dam with a concrete corewall; a 4.57 m fixed-concrete spillway

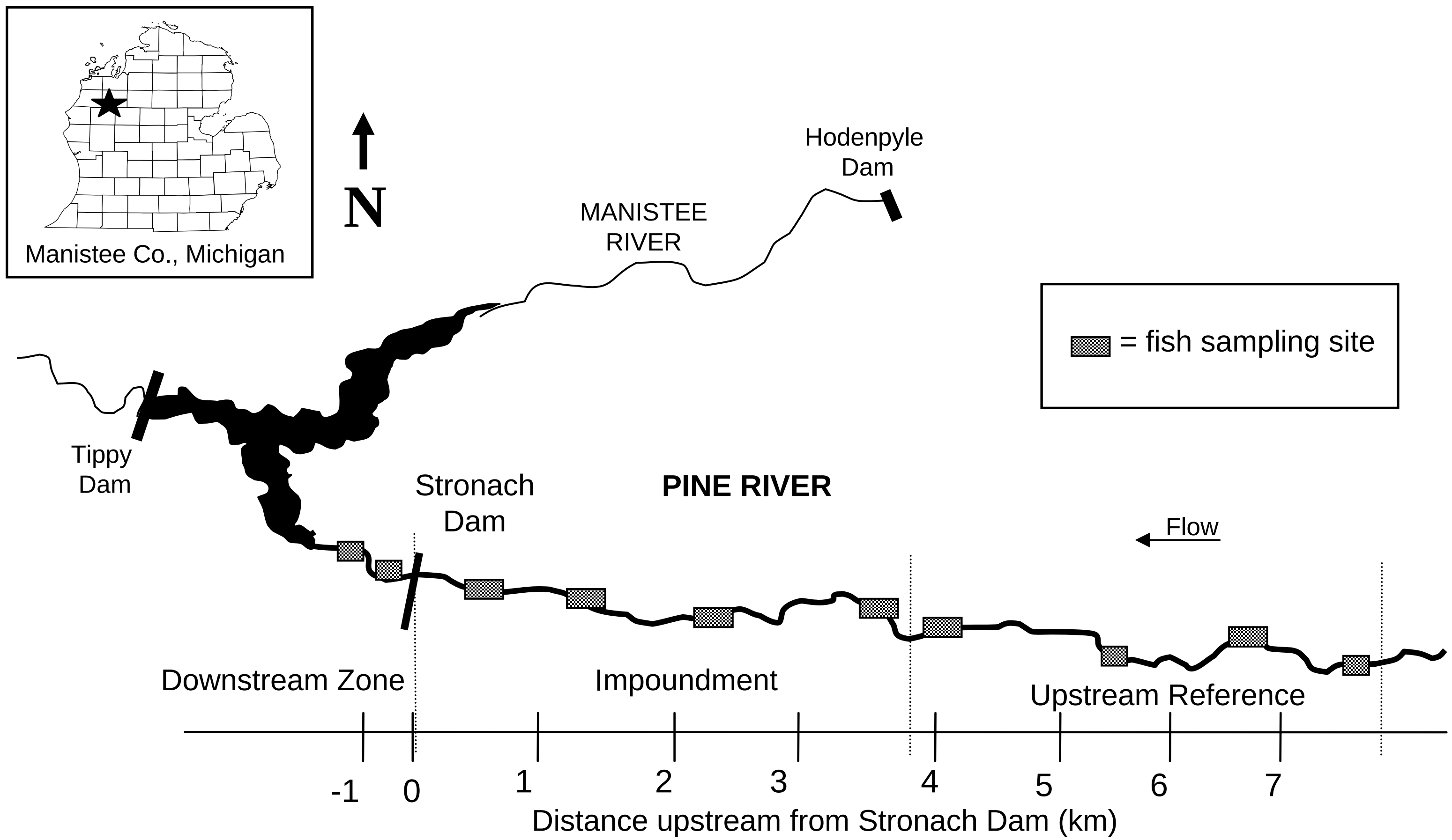


Figure 1. Locations of Stronach Dam and the Pine River in relation to the State of Michigan; and the location of permanent fish sampling sites within the study area of the Pine River.

section with 0.91 m of flashboards on top of the spillway; a concrete and brick powerhouse with two turbine bays; and an upstream fish ladder (Consumers Power Company 1994). Stronach Dam, with 5.49 m of head height possible, was operated mostly around 5.18 m of head. This created a 26.7 ha reservoir with a 789,428 m^3 volume capacity (Consumers Power Company 1994, Hansen 1971). Tippy Dam (17.07 m head height) was constructed in 1918 immediately downstream of the confluence of the Pine and Manistee Rivers (Rozich 1998). It created a 428 ha, 48,722,530 m^3 reservoir which impounded water upstream to Stronach Dam and blocked all upstream fish migration from Lake Michigan (Figure 1).

Due to the Pine River's large sediment load, the reservoir quickly filled with sediment and problems arose with the operation of the dam's turbines. Attempts were made in the 1930's to remove the accumulation of sediment behind the dam. These efforts were only marginally successful and dredging eventually became uneconomical (Consumers Power Company 1994). In 1953, 41 years after the dam's construction, Stronach Dam was decommissioned by the owner, Consumers Power Company. The generator rooms were demolished, the fish ladder was removed, and the river flow was directed over the spillway. The spillway flashboards were removed gradually over the following years; the last was removed in 1983 (Consumers Power Company 1994).

In the early 1990's, removal of Stronach Dam was negotiated as part of a Federal Energy Regulatory Commission (FERC) agreement in the relicensing of Tippy Dam. Removal of Stronach Dam began in the spring of 1997 and was completed in December of 2003. A "staged" or gradual removal was decided upon in order to allow gradual river channel adjustments with the least amount of environmental impact, at the lowest cost, and without impacting the operation of Tippy Dam (Battige et al. 1997). In 1996, a 3.6 m high "stop-log" structure was installed in the old powerhouse to allow a gradual drawdown of the river. The stop-log structure consisted of hollow metal pipes (15 cm diameter) stacked one on top of another, with a metal grate called a "trash-rack" immediately upstream to protect the stop-logs from debris impingement. The original removal schedule called for one stop-log to be removed every three months, for a total of 0.60 m per year, over the course of six years; with corresponding trash-rack removal. This plan was altered due to recreational safety concerns, feasibility issues, and technical difficulties with removal (Battige personal communication). Table 1 shows the actual sequence of the staged dam removal.

METHODS

In 1995, two years prior to the commencement of dam removal activities, the Pine River was assessed to document the spatial extent of impoundment effects due to Stronach Dam. This assessment involved the surveying and description of physical characteristics, including categorization of the stream into bedform units of runs, riffles, pools, or rapids, following the criteria developed by Hicks and Watson (1985). This survey allowed detection of impoundment effects well upstream of the readily noticeable reservoir area. This "impoundment" area of the river extended for 3.89 km upstream of Stronach Dam and was relatively wide, slow-flowing, sand-bottomed, and generally consisted of only run bedform units. An upstream reference reach was chosen, extending for 3.70 km upstream from the upstream boundary of the impoundment. This study zone was chosen as a reference reach because no effects on river morphology

Table 1. Schedule of removal events during the staged removal of Stronach Dam on the Pine River, Manistee County, Michigan. Stop-logs are 15.24 cm diameter hollow metal pipes stacked on top of one another. Trash-rack removal estimates are approximate. Cumulative meters removed are in parentheses. (Dave Battige, Consumers Energy, personal communication 2003).

Date	**Number of Stop-logs removed**	**Meters of Trash-rack removed**
March 17, 1997	1 (0.15)	0 (0)
June 5, 1997	1 (0.30)	0 (0)
June 16, 1997	2 (0.61)	0 (0)
June 24, 1997	2 (0.91)	0 (0)
September 15, 1997	1 (1.07)	0 (0)
December 15, 1997	1 (1.22)	0 (0)
March 16, 1998	1 (1.37)	0 (0)
May 7, 1998	0 (1.37)	1.83 (1.83)
May 29, 1998	0 (1.37)	0.30 (2.13)
June 15, 1998	1 (1.52)	0 (2.13)
September 8, 1998	1 (1.68)	0.30 (2.44)
December 14, 1998	1 (1.83)	0.30 (2.74)
March 15, 1999	1 (1.98)	0 (2.74)
May 11, 1999	1 (2.13)	0 (2.74)
September 13, 1999	2 (2.44)	0 (2.74)
September 16, 1999	0 (2.44)	0.61 (3.35)
April 17, 2000	2 (2.74)	0 (3.35)
October 2, 2000	2 (3.05)	0 (3.35)
October 5, 2000	0 (3.05)	0.61 (3.96)
May 8, 2001	2 (3.35)	0 (3.96)
September 8, 2001	2 (3.66)	0 (3.96)
November 11, 2002	0 (3.66)	1.52 (5.49)
December 2003	Remaining spillway and dam superstructure removed	

were evident. The river was narrower, faster-flowing, had coarser substrates, and showed high bedform heterogeneity. A third study zone was chosen downstream of Stronach Dam, where the river was wide, very slow-flowing, sand-bottomed, and consisted entirely of run bedforms. Prior to the removal of Stronach Dam, water was impounded in this study zone from Tippy Dam Reservoir, and the zone extended for only 0.63 km downstream of Stronach Dam.

Bedform frequency (also referred to as meso-habitat), latitudinal and longitudinal channel morphology, water velocity, and substrate size composition were documented in the three study zones, annually from 1996 through 2006 (see Burroughs 2007 for full review of the methodology used).

Fish were sampled in the Pine River from 1997 through 2006 with a 17-foot Smith-Root Cataraft® electrofishing boat. The electrofishing boat was set to deliver pulsed DC (40% cycle duty) on low range (50 – 500) volts at 4 – 6 amps. Fish community composition and species abundances were sampled at 10 sites along the river (Figure 1), once per year (mid-July to early August), from 1997 through 2006. Four sites were located in the upstream reference reach, four sites were located in the impoundment, and two sites were located in the downstream reach. Each site was enclosed with block-nets and multiple pass removal sampling was conducted in order to estimate fish population sizes (VanDeventer and Platts 1983). A minimum of three passes were made at each site; occasionally, additional passes were made in order to achieve a clear depletion pattern in catch. Fish captured were identified and total length was measured to the nearest millimeter.

Abundance was estimated for brown trout, rainbow trout, brook trout, white suckers, and shorthead redhorse suckers. Preliminary analyses suggested lower gear selectivities for smaller fish. As such, abundance estimates were conducted by size class. For brown trout the two size classes were <130 mm and ≥130 mm total length. For rainbow trout the two classes were ≤100 mm and >100 mm, for brook trout the classes were ≤110 mm and >110 mm, and for white suckers the classes were ≤100 mm and >100 mm. One size class was adequate for shorthead redhorse suckers since few fish less than 300 mm were captured. Catch patterns were tabulated for each size class for each species, and abundance estimates were calculated using the equations of Seber (1982) for triple removal pass population estimates (Junge and Libosvarsky 1965, Seber 1982). For sites and species size classes in which catch patterns produced unreliable abundance estimates (due to low catches or irregular depletion patterns) the average gear selectivity, or catchability, for that species size class, for all sites in all years, in all passes, was used to estimate the abundance, using the following formula: $[Y(1+(1-q)^3]$, where Y= the total catch over three passes and q= the average catchability or probability of an individual being captured during a sampling pass (Seber 1982). Abundance estimates for each length group for each species were then combined to produce an overall abundance estimate for that species, for each site in a given year. The abundance estimates were then converted to density estimates using sample site average width and length information. A one-way analysis of variance was used to test for significant year effects in fish densities, for each species in each of the three study zones. The Kolmogorov-Smirnov two sample test (Steel and Torrie 1980) was used to test for differences between fish length-frequency distributions between years and study zones, for each species.

Brown trout density estimates for several other Michigan trout streams, during the study period from 1997 – 2006, were estimated as part of ongoing monitoring by the Michigan Department of Natural Resources. These estimates were calculated using the Petersen mark-recapture estimation method (Seber 1982), utilizing electrofishing equipment. These data were analyzed and presented in this study as a secondary form of reference for changes in trout densities during the study period.

Morista's similarity index was used to compare the proportional numeric composition of the fish community between study zones (Morista 1959, Krebs 1989). An index value of 0.00 indicates complete dissimilarity, a value of 1.00 indicates complete similarity, and values greater than 0.60 are generally interpreted as "similar" (Angradi and Griffith 1990). The Shannon-Weaver diversity index (H')(Shannon and Weaver 1949, Ricklefs 1990) was used to estimate the fish species diversity in each study zone. This index considers both the number of species present and evenness of numerical proportions of each species, rewarding higher diversity values to species compositions not numerically dominated by a just a few of the species present.

RESULTS

Fish Habitat

From 1997 through 2005, substantial changes occurred to the fluvial geomorphology of the Pine River, due to the removal of Stronach Dam. Those changes are described in detail by Burroughs (2006), and are reviewed here briefly to provide context for understanding changes to the fish community mediated by habitat alteration following dam removal. In the reach immediately upstream of Stronach Dam, progressive erosion of the accumulated reservoir sediment fill occurred with each subsequent stage of dam removal. This erosion increased gradient throughout the entire former impoundment (~4 km), increased water velocities, and eroded large volumes of sediment as a new channel was carved downward through the reservoir sediment fill. This resulted in a narrower river channel, with steepening banks, increasing frequency of riffle and pool bedforms, and slightly increased median substrate size composition (Table 2). Large amounts of the reservoir sediment fill were transported downstream of the dam, eventually being deposited at the next impoundment downstream. Significant amounts of this sediment were also deposited in the river channel along the way and a smaller portion was deposited onto floodplains during high flow events. Sediment deposition downstream of the dam resulted in streambed aggradation and increases in stream width and decreased water depth. Gradient was increased downstream of the dam removal through sediment deposition, water velocities increased slightly and substrate size remained small (sand dominated). Bedform diversity did not increase in this reach during the study period, and remains almost entirely run bedforms (Table 2).

Fish Community

A total of 35 fish species were identified during sampling in the Pine River. Prior to dam removal, a coldwater fish community existed upstream of Stronach Dam, numerically dominated by slimy sculpin (*Cottus cognatus*), brown trout, rainbow trout, and white suckers (Appendix A). Downstream of Stronach Dam, a coolwater fish community existed, numerically dominated by white sucker and shorthead redhorse

Table 2. A summary of key fish habitat changes that occurred during the Stronach Dam removal (1997 -2003). Fish passage past the dam site was not possible until 2003. Bedform frequencies were surveyed in 1995 and 2004.

Habitat Characteristic	**1996**	**2002**	**2006**
Wetted Stream Width (mean, m)			
Reference	17.0	17.0	16.9
Impoundment	19.9	17.4	17.6
Downstream	32.7	34.9	34.8
Gradient (% slope)			
Reference	0.159	0.157	0.155
Impoundment	0.128	0.181	0.206
Downstream	0.061	0.074	0.104
Water Velocity (mean, m/s)			
Reference	0.66	0.68	0.69
Impoundment	0.54	0.71	0.86
Downstream	0.15	0.63	0.57
Substrate Size (median, mm)			
Reference	35.6	39.0	25.2
Impoundment	6.4	8.5	6.4
Downstream	1.0	2.0	1.0
Bedform Frequency			
Reference	High diversity		no change
Impoundment	Run bedforms		more pools and riffles
Downstream	Run bedforms		no change

sucker, but also with frequent smallmouth bass, northern pike (*Esox lucius*) and brown trout. Most of these fish utilized the reservoir ~2 km downstream of Stronach Dam, and were found in the downstream reach of the Pine River seasonally. Prior to the removal of Stronach Dam, 18 fish species were found only downstream of the dam, 14 species were found both upstream and downstream of the dam, and three species were found only upstream of the dam (Table 3).

Within three years after the dam removal (2006), 17 of the 18 species previously found only downstream of the dam had been found upstream of the dam site. Only one of the three species previously only found upstream of the dam, had been discovered downstream of the dam site. Prior to the removal of Stronach Dam, the fish community in the impoundment was intermediate in similarity between the reference and the downstream reaches while the reference and downstream reaches were highly dissimilar (Table 4). By 2006 all three zones became highly similar. This increase in fish community similarity was manifested through changes in the species compositions of all three study zones, resulting in a homogenization of species compositions among zones of the river (Table 4). However, species diversity also increased in all three zones following the dam removal, with all three study zones having higher species diversity than observed in any zone prior to the dam removal (Reference H’ 1997 = 1.31, 2006 = 1.81; Impoundment H’ 1997 = 1.55, 2006 = 1.99; Downstream H’ 1997 = 1.63, 2006 = 2.25).

Fish Populations

At the beginning of the staged dam removal, brown trout density was low throughout all three study zones of the Pine River, and remained low for the first several years of the dam removal (1997 -1999: Reference mean = 46 fish/ha., st.dev. = 19; Impoundment mean = 33 fish/ha., st.dev. = 9; and Downstream mean = 14 fish/ha., st.dev. = 13). After the initial three years, brown trout density began to increase in both the reference and impoundment zones, with large differences in the magnitude of response among sites within zones (Figure 2). This increasing trend continued through the end of the study in 2006 (2004 -2006: Reference mean = 129 fish/ha., st.dev. = 26; Impoundment mean = 157 fish/ha., st.dev. = 40; and Downstream mean = 48 fish/ha., st.dev. = 34). Brown trout density in the downstream zone remained relatively low throughout most of the study period, increasing only in the last several years of the study (Figure 2). While brown trout density increased in all three zones from the beginning of the dam removal to the end of the study period, one-way analysis of variance revealed a statistically significant Year effect for the Impoundment (F = 4.00, p = 0.002, df = 39) and the Downstream zones (F = 3.70, p = 0.027, df = 19), but not the Reference zone (F = 1.82, p = 0.105, df = 39).

Rainbow trout density was also low throughout all three study zones during the first several years of the dam removal (1997 – 1999: Reference mean = 49 fish/ha., st.dev. = 9; Impoundment mean = 24 fish/ha., st.dev. = 6; and Downstream mean = 1 fish/ha; st.dev. = 1). After the initial three years of the dam removal, rainbow trout densities increased in both the reference and impoundment zones, and continued to increase through the end of the study period (Figure 3). This increasing trend, while somewhat slower than for brown trout, also showed similar spatial variability between sites in the magnitude of density increases. In particular, two sites within the former impoundment, and within the reference increased greatly while other sites increased only slightly, or not at all (Figures 2 and 3). Rainbow trout density downstream of the dam removal, while increasing slightly, has remained relatively low throughout the entire study period. By the end of the study, average rainbow trout density in each of the zones was higher than at the beginning of the study (2004 - 2006: Reference mean = 128 fish/ha., st.dev. = 37; Impoundment mean = 107 fish/ha., st.dev. = 35; and Downstream mean = 8 fish/ha., st.dev. = 6), but a significant Year effect was found only for the impoundment zone (F = 5.32, p = 0.0002, df = 39) (Reference: F = 1.67, p = 0.14, df = 39; Downstream: F = 2.90, p = 0.056, df = 19).

Because brown trout and rainbow trout densities increased in both the impoundment and reference study zones during and following the Stronach Dam removal, data on the brown trout density trends in other similar Michigan trout streams were acquired from the Michigan Department of Natural Resources. Rainbow trout density trends were not available for other Michigan trout streams, because the Pine River’s rainbow trout population is uniquely non-migratory, whereas most other populations of rainbow trout in Michigan streams are migratory (i.e., “steelhead”). Brown trout density data for the other Michigan streams were derived from estimates at

Table 3. Fish species occurrences in the Pine River, before and after the removal of Stronach Dam. Arrows and italics represent fish species that were not found both upstream and downstream of the dam prior to removal, but were found both upstream and downstream following the dam removal.

Downstream of Dam Only	**Upstream and Downstream of Dam**	**Upstream of Dam Only**
		Brook stickleback
		Banded killifish
	Blacknose dace	◄ Blacknose dace
Common carp		
Largemouth bass ►	*Largemouth bass*	
Trout perch ►	*Trout perch*	
Rock bass ►	*Rock bass*	
Pumpkinseed ►	*Pumpkinseed*	
Emerald shiner ►	*Emerald shiner*	
Blackside darter ►	*Blackside darter*	
Logperch ►	*Logperch*	
Chestnut lamprey ►	*Chestnut lamprey*	
Walleye ►	*Walleye*	
Central mudminnow ►	*Central mudminnow*	
Silver redhorse ►	*Silver redhorse sucker*	
Shorthead redhorse ►	*Shorthead redhorse sucker*	
Golden shiner ►	*Golden shiner*	
Yellow bullhead ►	*Yellow bullhead*	
Johnny darter ►	*Johnny darter*	
Northern pike ►	*Northern pike*	
Yellow perch ►	*Yellow perch*	
	Common shiner	
	American brook lamprey	
	Longnose dace	
	Creek chub	
	Bluegill	
	Mottled sculpin	
	Slimy sculpin	
	White sucker	
	Brown trout	
	Rainbow trout	
	Brook trout	
	Black bullhead	
	Spottail shiner	
	Smallmouth bass	

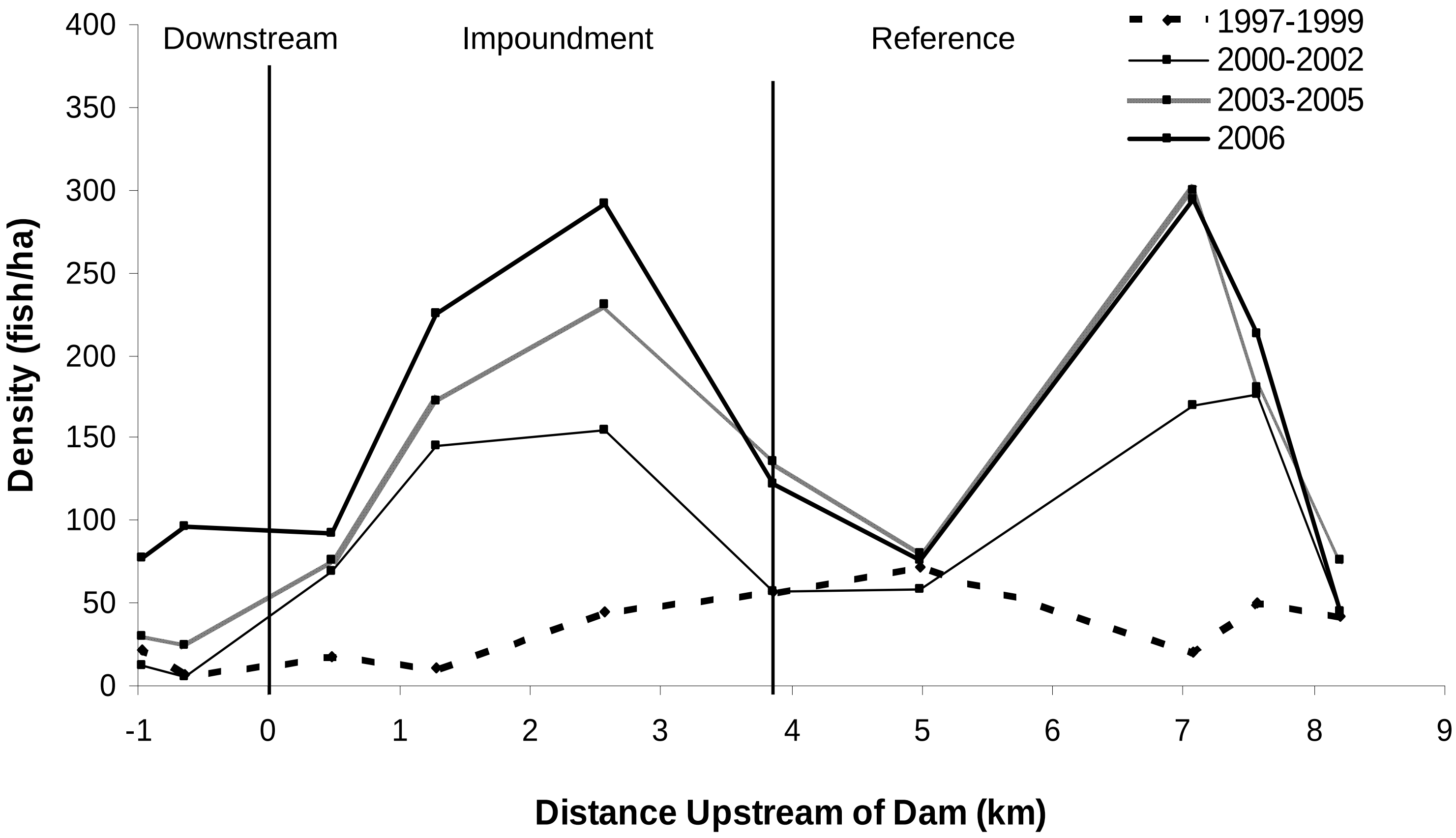


Figure 2. Brown trout density (number of fish per hectare), longitudinally in the Pine River. Densities averaged in three year blocks to minimize year to year variability, and for presentation simplicity.

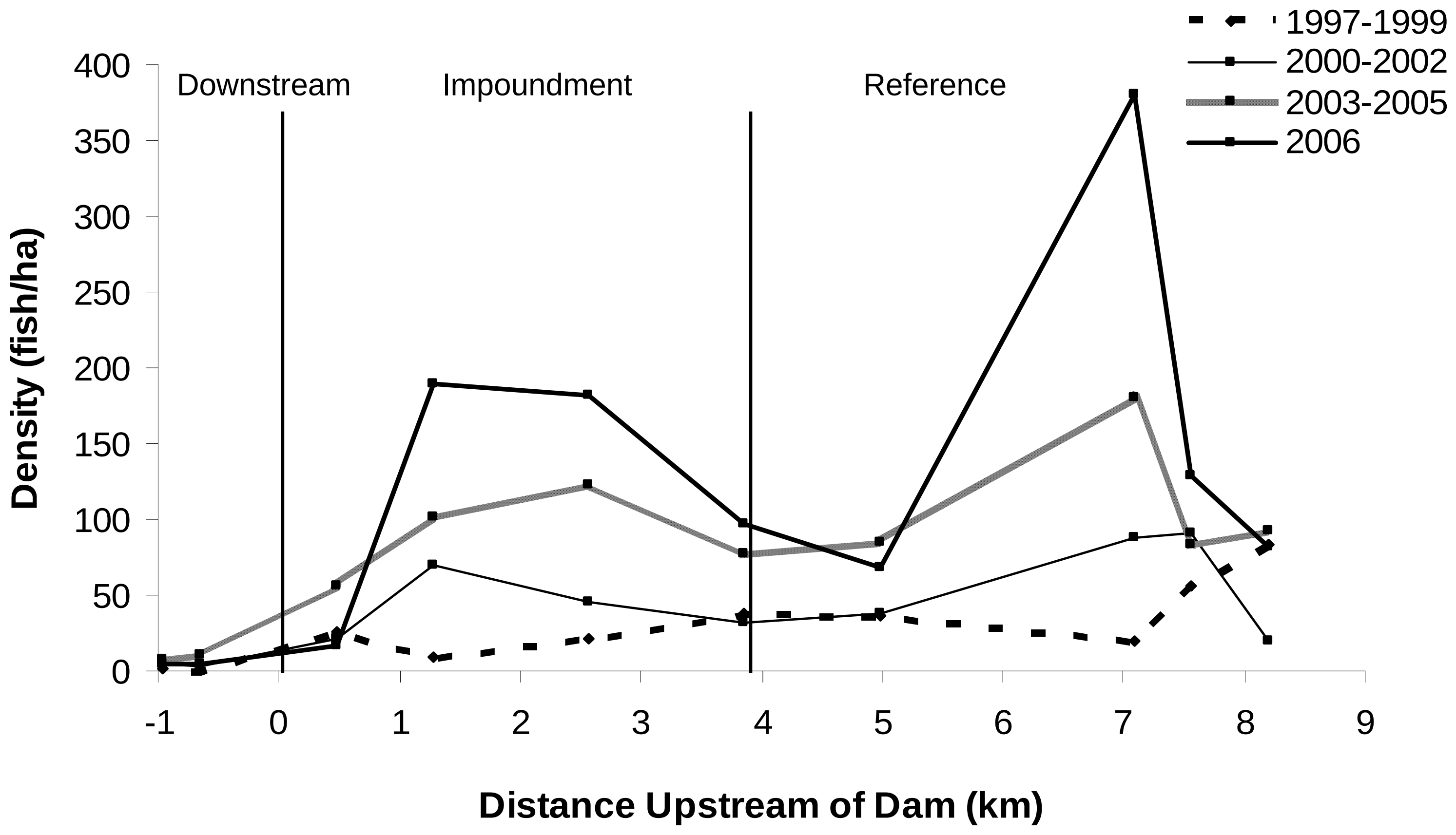


Figure 3. Rainbow trout density (number of fish per hectare), longitudinally in the Pine River. Densities averaged in three year blocks to minimize year to year variability, and for presentation simplicity.

Table 4. Morista similarity index values for each study zone before and after dam removal (1997 and 2006). Morista similarity index compares the proportional numerical species composition; 0.00 indicates complete dissimilarity, 1.00 indicates complete similarity, and values greater than 0.60 generally indicate "similar" fish species compositions.

	Reference 1997	Impoundment 1997	Downstream 1997	Reference 2006	Impoundment 2006
Reference 1997	-	-	-	-	-
Impoundment 1997	0.79	-	-	-	-
Downstream 1997	0.11	0.62	-	-	-
Reference 2006	0.70	0.55	0.64	-	-
Impoundment 2006	0.49	0.65	0.72	0.95	-
Downstream 2006	0.30	0.55	0.73	0.80	0.87

single sites on other streams. Density of brown trout in the Pine River was lower than sites on other streams for which data were available. Many of the other streams also experienced increases in brown trout density during this study period. The increase in density in the Pine River, expressed on an arithmetic scale, was not unique (Figure 4). However, when expressed as a rate of increase, Pine River brown trout density increases were substantially greater than the other trout streams, and this increase was greatest in the Pine River former impoundment reach (Figure 5).

Prior to the dam removal, size structure of brown trout did not differ significantly between the reference and the impoundment (K-S test, $D_{max} = 0.18$, $p > 0.05$, n = 78, 71). The downstream zone contained so few brown trout that annual estimates of the size structure were not reliable. Following dam removal, the abundance of brown trout of nearly all length classes increased in all three study zones (Figure 6). The size structures of brown trout in the reference zone in 1997 and 2006 were not significantly different (K-S test, $D_{max} = 0.18$, $p > 0.05$, n = 78, 143), and neither were the size structures of brown trout in the impoundment zone in 1997 and 2006 (K-S test, $D_{max} = 0.15$, $p > 0.05$, n = 71, 292). Although the size structure of both zones did not change significantly over time, the difference in size structure between the reference and impoundment zones became significant by 2006 (K-S test, $D_{max} = 0.19$, $p < 0.01$, n = 143, 292), indicating a smaller proportion of individuals over 200 mm in length in the reference. Downstream of the dam, more brown trout were seen in 2006 than in 1997, and a significant change in size structure occurred (K-S test, $D_{max} = 0.56$, $p < 0.05$, n = 8, 32). Brown trout in this zone were still relatively low in number compared to the other study zones, but ranged in size from approximately 50 – 550 mm in length.

Rainbow trout in the reference and impoundment zones had significantly different size structures prior to dam removal (K-S test, $D_{max} = 0.49$, $p < 0.01$, n =38, 51), but

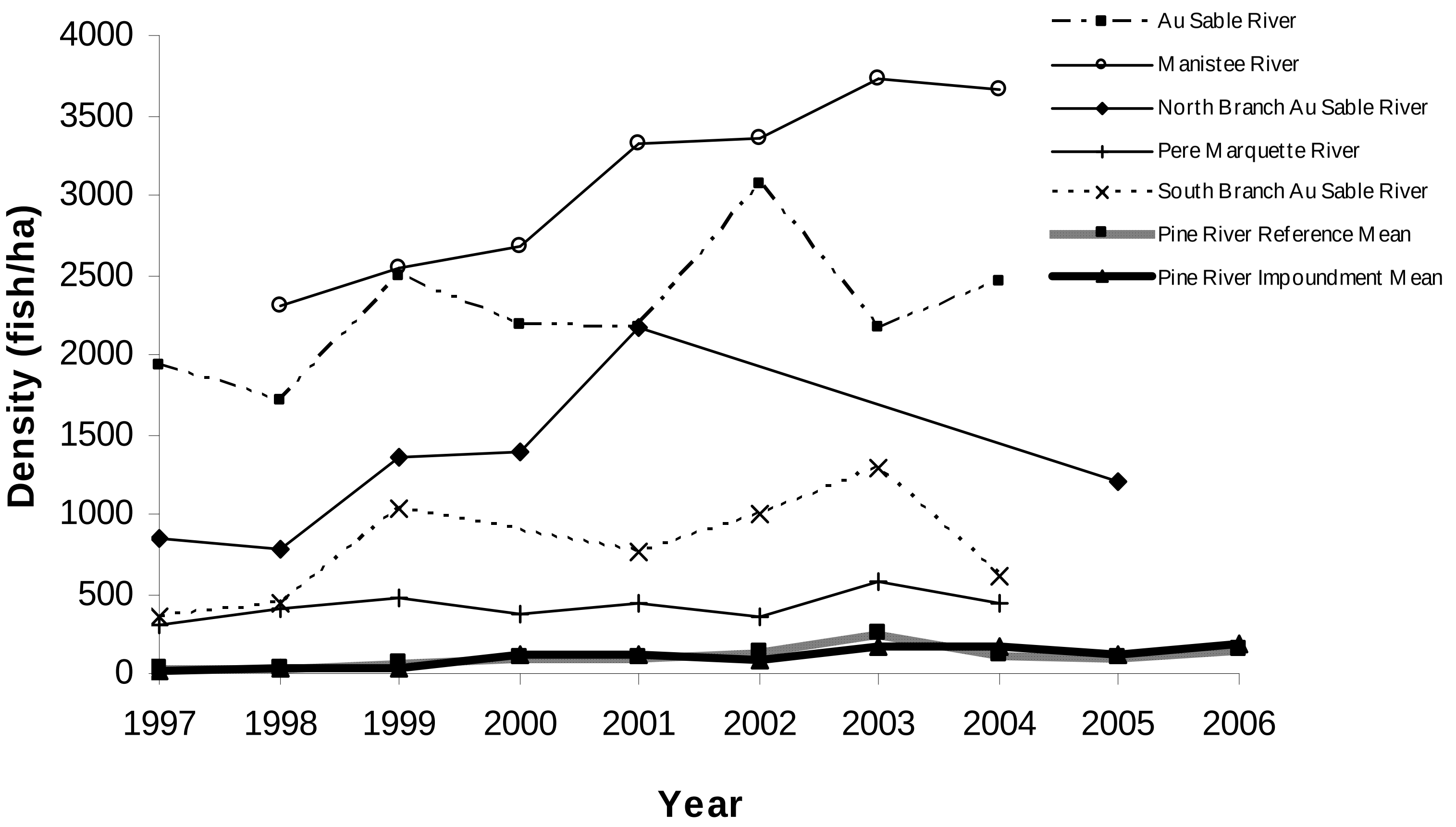


Figure 4. Brown trout densities (number of fish per hectare) in several Michigan trout streams and in the reference and impoundment study zones of the Pine River. Density was estimated for the other MI trout streams using mark-recapture estimation, while the Pine River estimates were derived from depletion sampling.

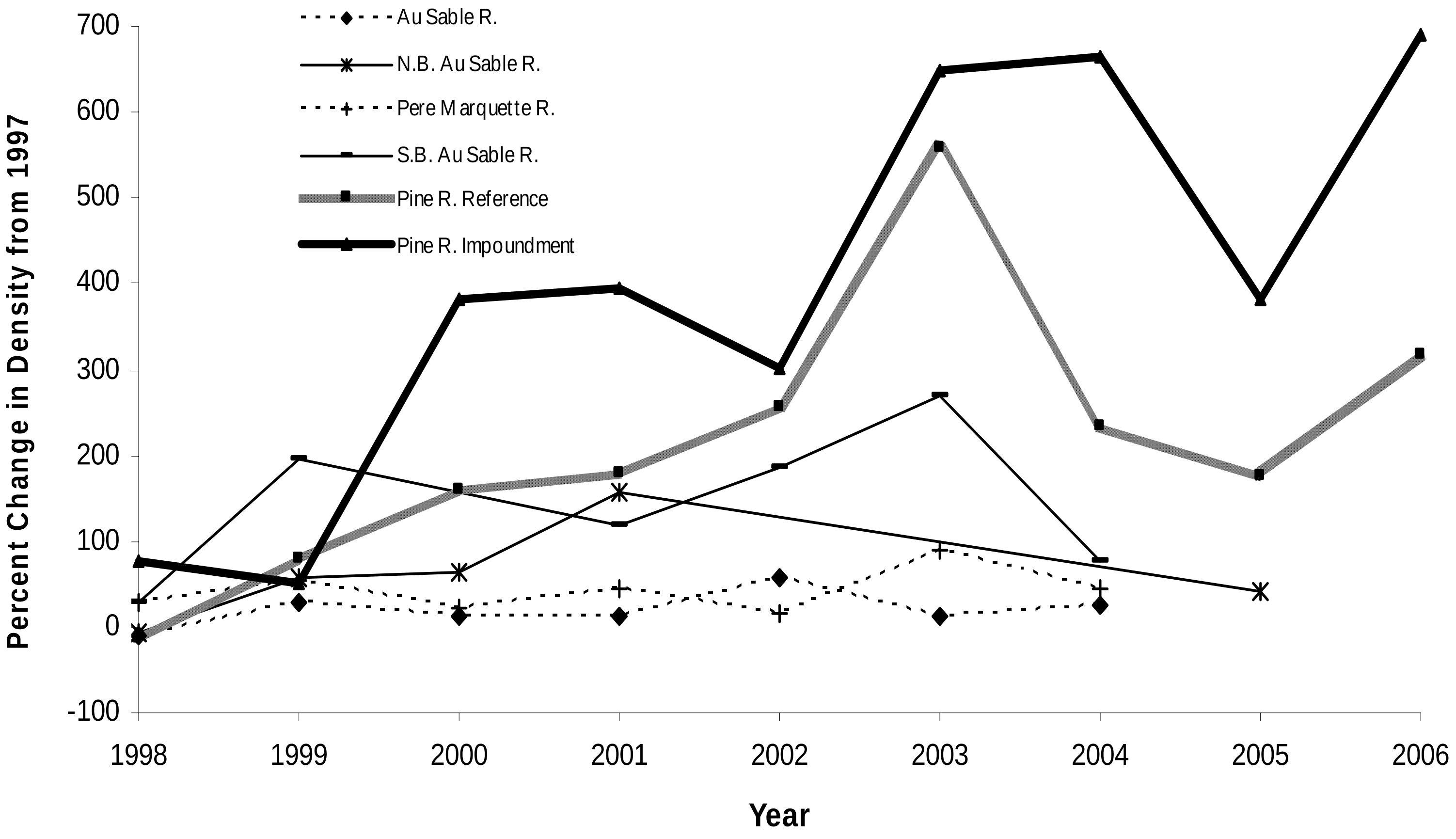
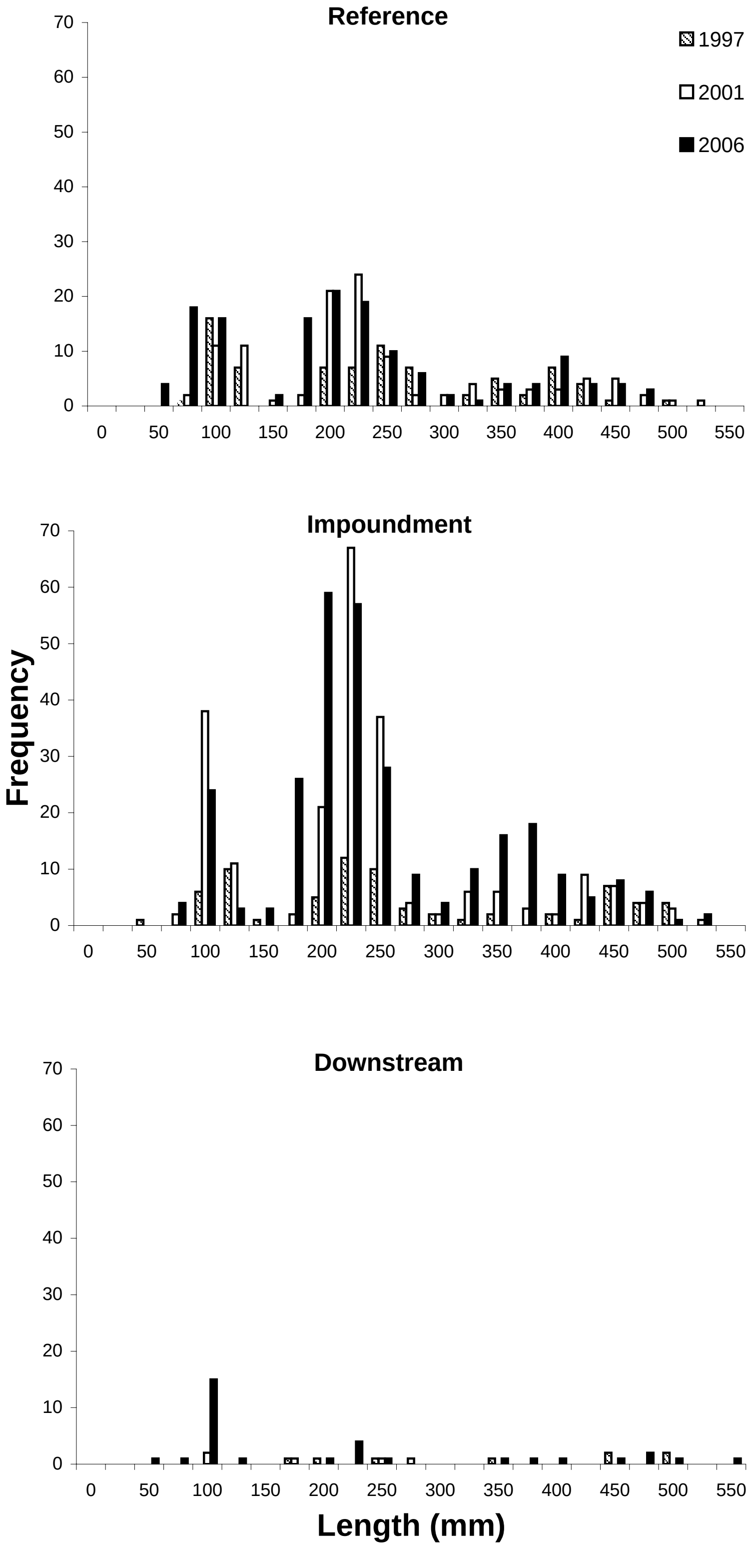


Figure 5. Population growth rate, or percent change in the density (number of fish per hectare) of Pine River brown trout, from 1997, compared to the percent changes in brown trout density of several other Michigan trout streams of comparable size.

Figure 6. Brown trout length frequency distributions, for each study zone of the Pine River, before (1997), during (2001), and after (2006) the removal of Stronach Dam.



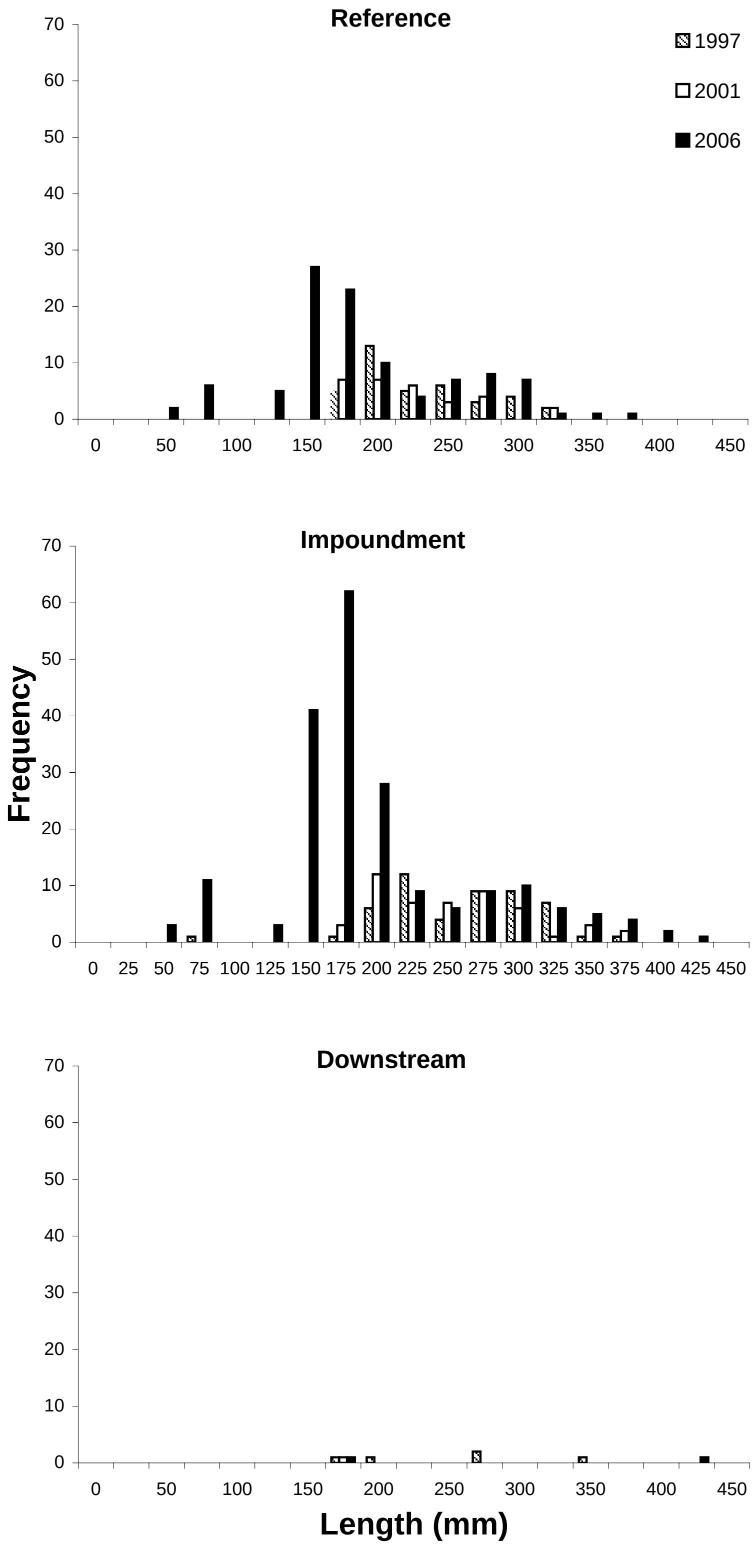
both zones were characterized by having relatively few rainbow trout, and those present were mostly from 200 – 400 mm in length (Figure 7). The size structures of these zones were significantly different between 1997 and 2006, mainly due to much higher frequencies of rainbow trout <200 mm length (Reference: K-S test, $D_{max} = 0.49$, $p < 0.01$, n = 38, 102) (Impoundment: K-S test, $D_{max} = 0.58$, $p < 0.01$, n = 51, 200). Very few rainbow trout were captured in the downstream zone in either 1997 or 2006.

Density of brook trout generally declined in the downstream direction through the study zone of the Pine River, both before and after the dam removal (Figure 8). Similar to the brown trout and rainbow trout, brook trout density was low in all three study zones of the Pine River during the initial stages of the dam removal (1997-1999: Reference mean = 40 fish/ha., st.dev. = 12; Impoundment mean = 11 fish/ha., st.dev.= 1; Downstream mean = 0 fish/ha., st.dev. = 0), but remained low throughout the entire study period (2004 – 2006: Reference mean = 20 fish/ha., st.dev. = 2; Impoundment mean = 7 fish/ha., st.dev. = 1; Downstream mean = 0 fish/ha., st.dev. = 0). While average brook trout density appeared to have decreased slightly within the two upstream zones, densities at individual sites within zones were highly variable and showed no consistent trends among sites within zones (Figure 8). The low density of brook trout restricted comparisons of the size structures of this species in the three study zones before and after dam removal.

Fish passage during the staged drawdown was limited until 2003. Before that time, white sucker density was relatively high downstream of the dam, due to influxes of spawning adults from the reservoir located immediately downstream. Densities were consistently much lower in both the impoundment and reference zones upstream of the dam (Figure 9) (1997-1999: Reference mean = 19 fish/ha., st.dev. = 12; Impoundment mean = 41 fish/ha., st.dev. = 36; Downstream mean = 134 fish/ha., st.dev. = 155). After 2003, spawning white suckers from the downstream reservoir, previously prevented from accessing potential spawning habitats upstream of Stronach Dam, were allowed access due to the dam removal. Consequently, density of white suckers increased substantially in both the impoundment and reference zones, while remaining relatively high in the downstream zone (Figure 9) (2004 - 2006: Reference mean = 240 fish/ha., st.dev. = 52; Impoundment mean = 174 fish/ha., st.dev. = 65; Downstream mean = 161 fish/ha., st.dev. = 53). Large changes in the size structure of white sucker in the Pine River were also observed. Prior to the dam removal, the downstream zone had a relatively uniform size distribution from ~100 – 500 mm, the impoundment had relatively low frequencies of white suckers of intermediate lengths (~100 – 350 mm), and the reference had few white suckers of any length (Figure 10). Following dam removal, the size structure downstream of the dam changed significantly (1997 vs 2006) (K-S test, $D_{max} = 0.50$, $p < 0.01$, n = 128, 56) and only contained individuals from ~100 – 200 mm length. Upstream of the dam removal, size structures also changed significantly, through the addition of large frequencies of juvenile white suckers (~75 – 200 mm) (Reference: K-S test, $D_{max} = 0.58$, $p < 0.01$, n = 33, 266) (Impoundment: K-S test, $D_{max} = 0.55$, $p < 0.01$, n = 140, 452).

Prior to 2003 shorthead redhorse suckers were found only downstream of the dam. The density of this species downstream from the dam was variable during the study period (Figure 11). From 2003 through the end of the study in 2006, shorthead redhorse suckers were found in relatively low densities throughout both the

Figure 7. Rainbow trout length frequency distributions, for each of the study zones of the Pine River, before (1997), during (2001), and after (2006) the Stronach Dam removal.



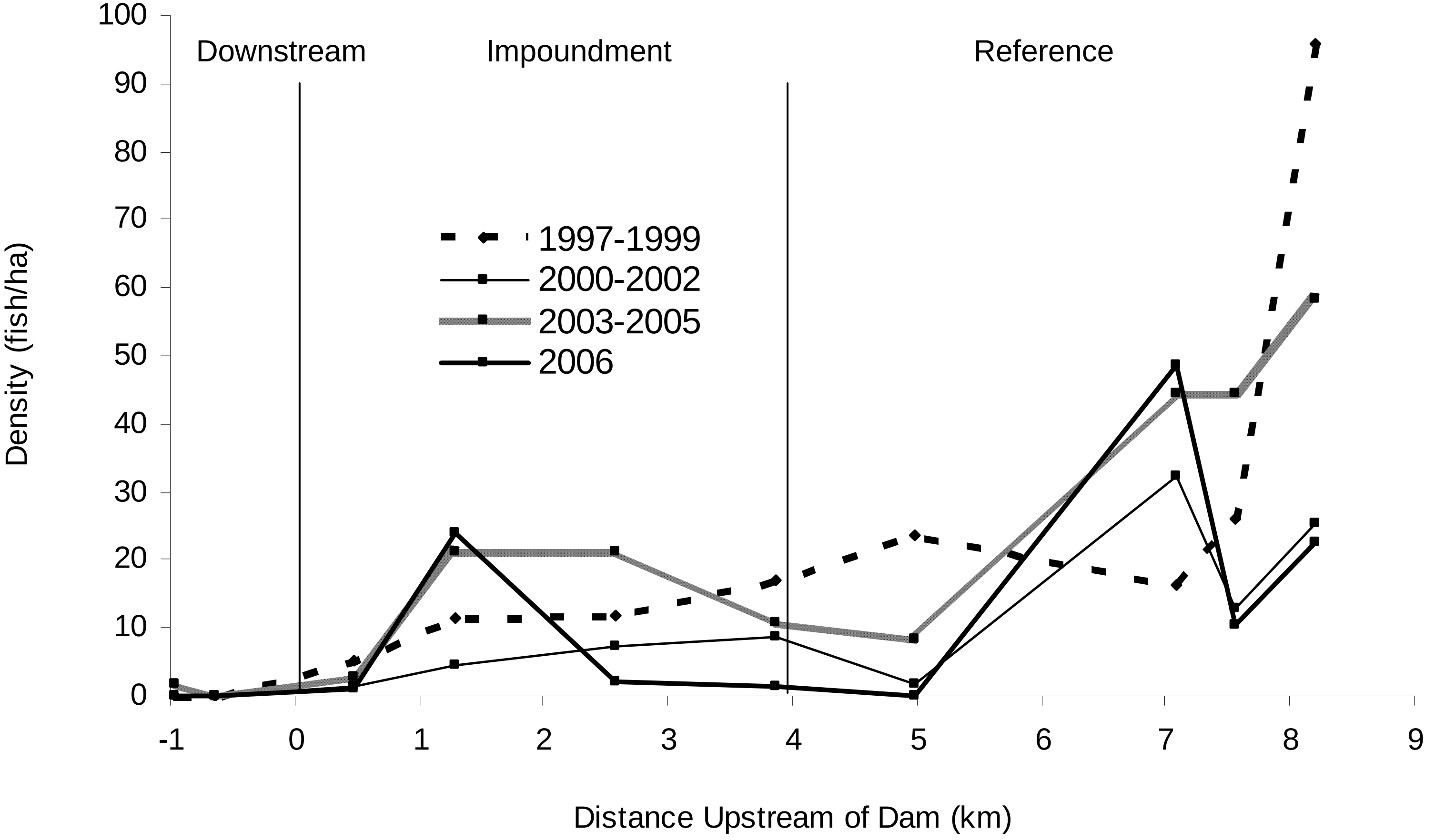


Figure 8. Brook trout density (number of fish per hectare), longitudinally in the Pine River. Densities averaged in three year blocks to minimize year to year variability, and for presentation simplicity.

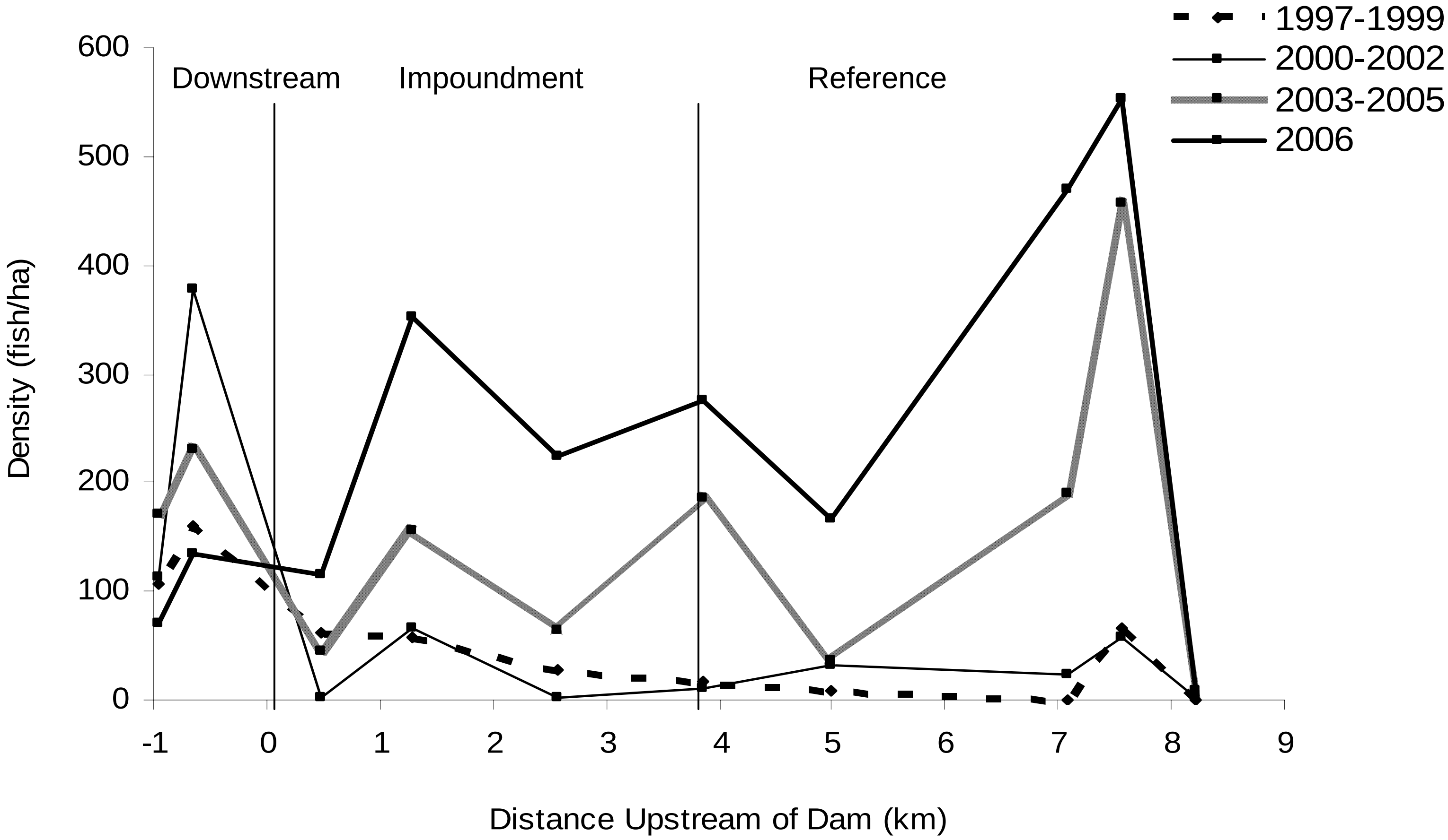
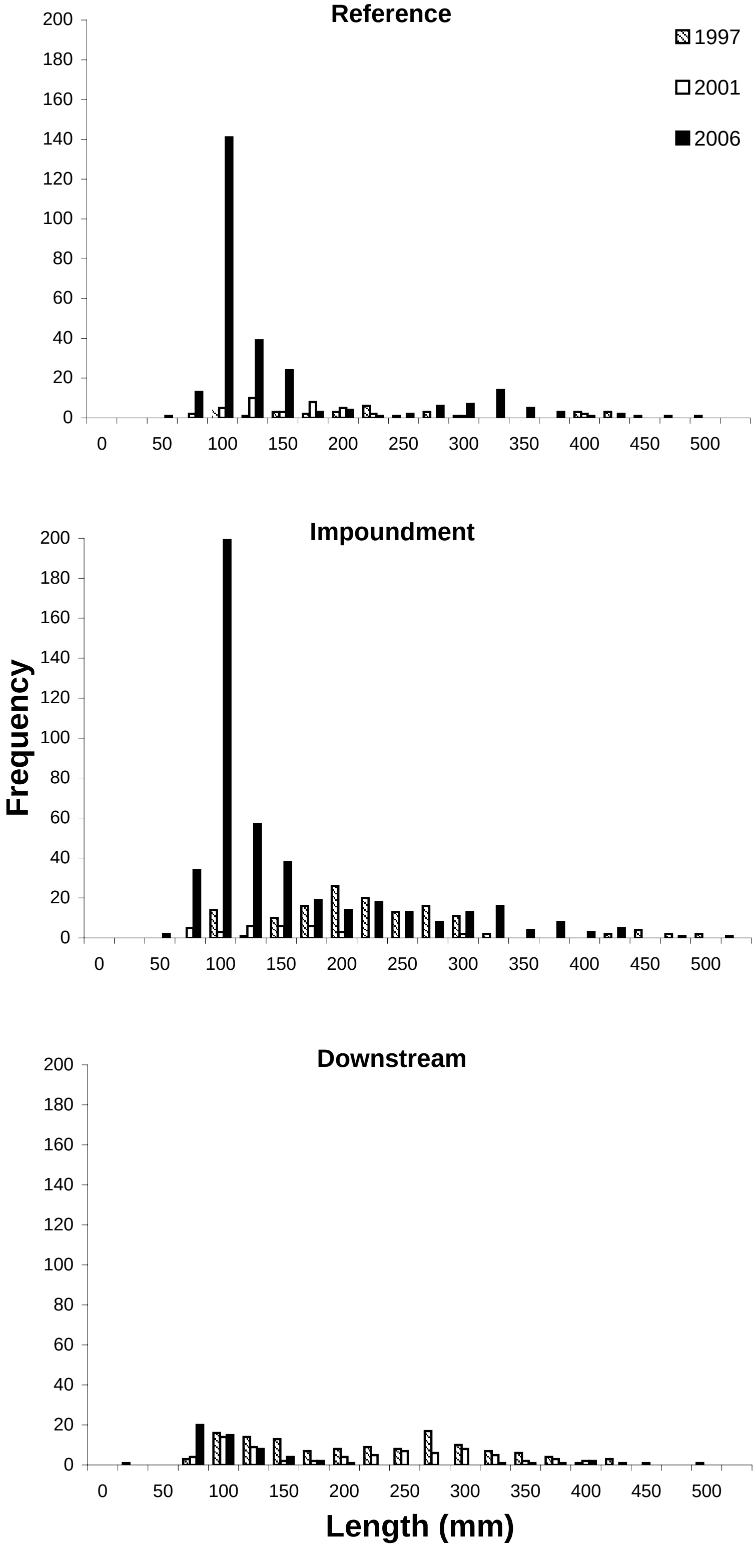


Figure 9. White sucker density (number of fish per hectare), longitudinally in the Pine River. Densities averaged in three year blocks to minimize year to year variability, and for presentation simplicity.

Figure 10. White sucker length frequency distributions for each study zone of the Pine River, before (1997), during (2001), and after (2006) the Stronach Dam Removal.



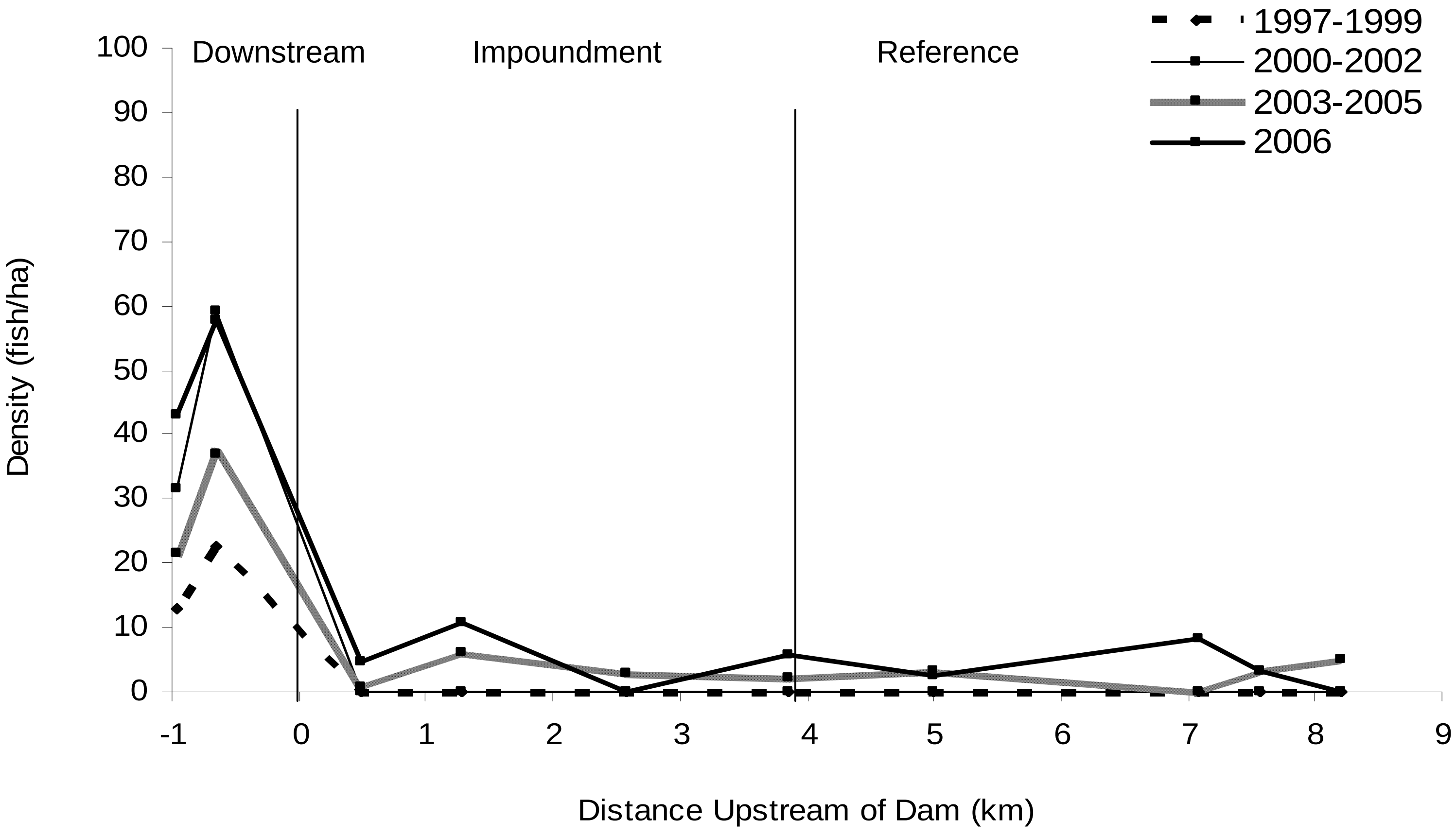


Figure 11. Shorthead redhorse sucker density (number of fish per hectare), longitudinally in the Pine River. Densities averaged in three year blocks to minimize year to year variability, and for presentation simplicity.

impoundment and reference zones (Figure 11). The few individuals that have been sampled upstream of the dam were greater than 200 mm in length. Downstream of the dam, this species is more abundant than upstream, but still relatively low in abundance. Here, the size structure changed significantly (K-S test, $D_{max} = 0.63$, $p < 0.01$, $n = 28, 21$), with higher frequencies of larger fish than were present before the dam removal (Figure 12).

DISCUSSION

Fish Habitat

Fish habitat was altered greatly due to the dam removal. In the former impoundment, habitat quality generally improved for lotic fish species. Prior to the dam removal, this section of river was characterized by low gradient and wide, sand-dominated run bedforms. During the removal process substantial amounts of sediment erosion occurred leading to drastic changes in the habitat characteristics of this section of river. Gradient increased substantially, leading to faster and more diverse water velocities, narrower stream width, substrate coarsening, and a higher diversity of bedforms (i.e., more riffles and pools). While these changes represent significant improvements in the heterogeneity and quality of lotic habitat, this section of stream was not restored to habitat condition levels seen in the reference reach of the Pine River.

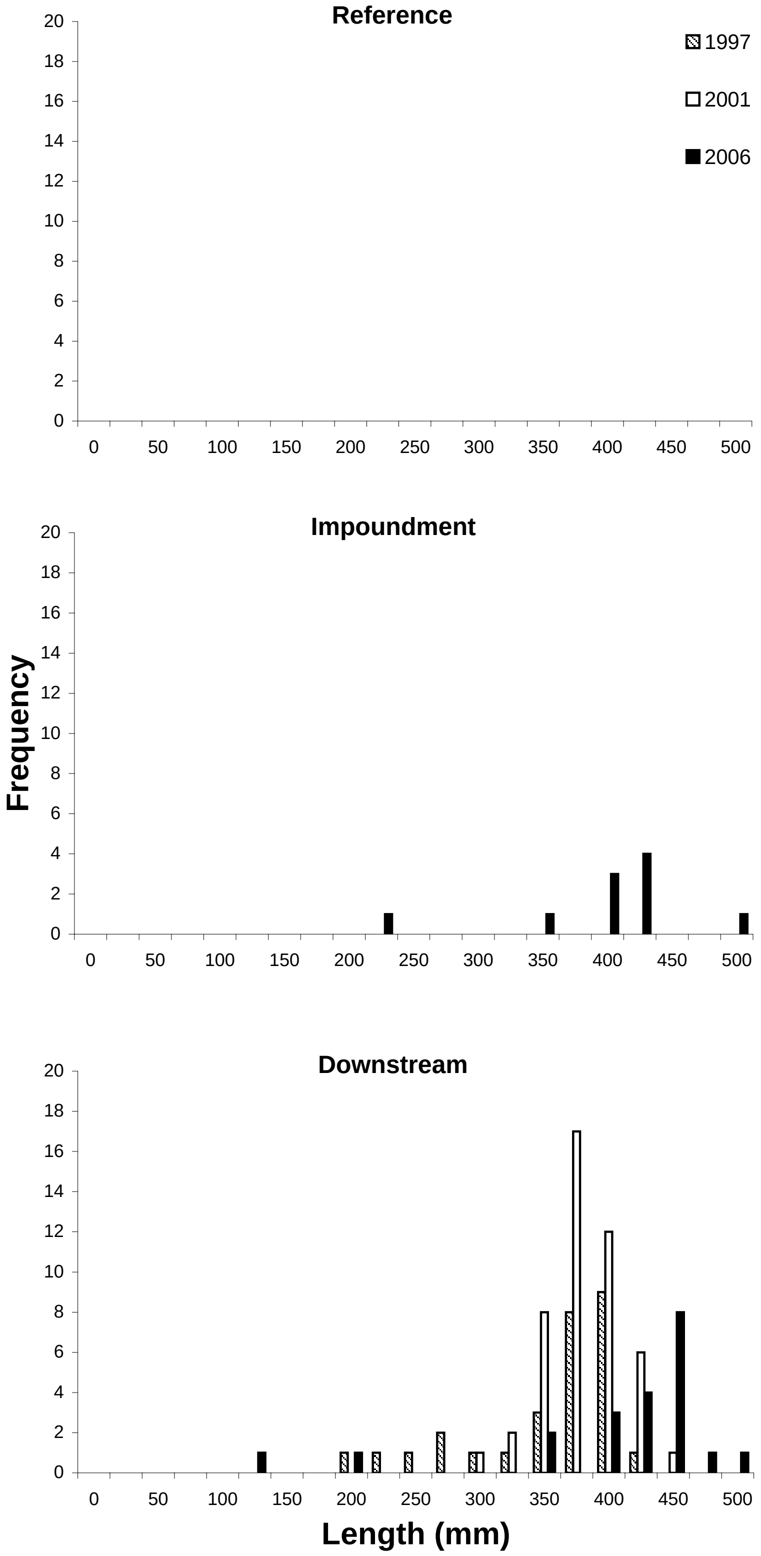
Downstream of the dam removal, habitat quality for most lotic species was generally degraded during the dam removal. This section of river received large amounts of sediment deposition and transport due to the dam removal. This created unstable and shifting fine substrates and eliminated deeper water habitats. This section of river was characterized as overly wide and shallow, sand-dominated, run bedform habitat throughout the duration of this study. While some of these impacts to the downstream section of river may be transient and reversed after sediment erosion in the former impoundment ceases, those changes were not observed during this study. One incidental benefit to the fish community downstream of the dam removal, may occur due to the streambed aggradation that occurred. With a streambed higher in elevation, overbank flooding requires less discharge to occur and happens more frequently, recharging adjacent floodplain wetlands and ponds. Fish species utilizing these habitats may benefit from this, but those habitats were not directly sampled in this study.

Fish Community

Prior to the removal of Stronach Dam, the three study zones had distinctive fish communities. The species composition of the impoundment was intermediate to both the reference and the downstream, but the reference and downstream zones were highly dissimilar. These differences were the result of both habitat differences between the zones, and the effects of the dam on connectivity between the zones. The reference and impoundment differed in habitat conditions, but possessed connectivity that allowed fish to move freely between the two zones. The impoundment and downstream zones had similar habitat conditions, but only possessed limited connectivity in the downstream direction. The reference and downstream zones possessed neither habitat similarities nor significant connectivity (Figure 13).

The dam removal resulted in habitat changes to the impoundment and downstream zones, and restored connectivity between all three zones. This led to

Figure 12. Shorthead redhorse sucker length frequency distributions for each study zone of the Pine River, before (1997), during (2001), and after (2006) the Stronach Dam removal.



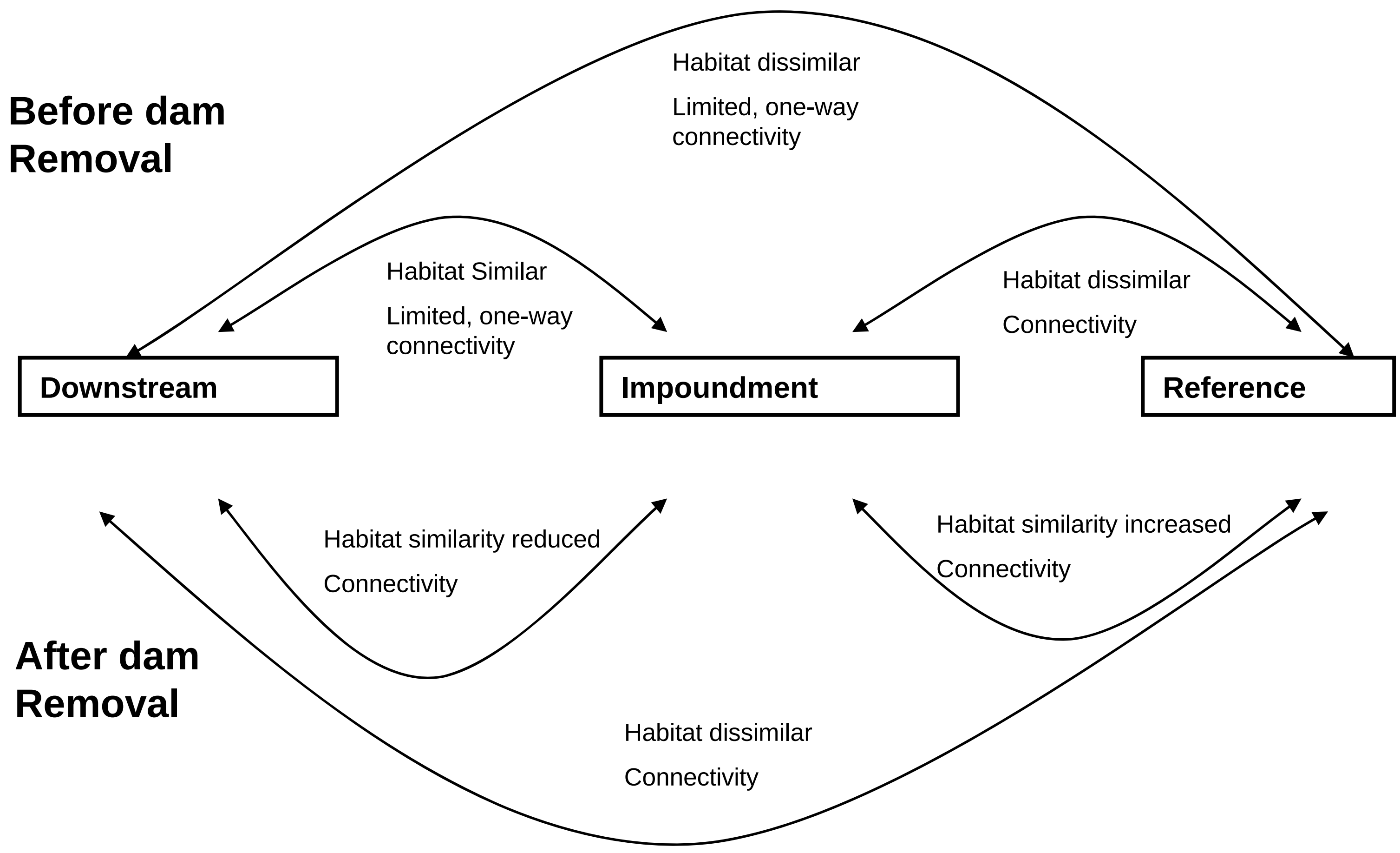


Figure 13. Conceptual diagram depicting the influences on fish species composition similarity between zones, before and after dam removal.

changes in the fish species compositions of all three study zones. Nearly all of the fish species (17 of 18) found only downstream of the dam prior to removal were found upstream of the dam following its removal. However, many of these species remained in low abundance upstream of the dam due to differences in their habitat preferences and the habitat characteristics of the upstream zones. Only one of three species of fish found only upstream of the dam prior to its removal was found downstream of the dam following its removal. These species were likely to have been found only upstream of the dam due to habitat differences upstream and downstream of the dam and not due to lack of connectivity. Following dam removal, the fish communities found within each of the three zones became similar, and the diversity of fish species within in each zone increased. In light of this, it is important to recognize that dam removal did not necessarily result in "restoration" of the fish community, but did increase fish diversity in each zone, while increasing homogenization of the fish community throughout the river.

Fish Populations

For the first three years of the study, brown trout densities in all three study zones of the Pine River remained relatively low and stable. Between 1999 and 2000, substantial erosion and habitat changes were observed in the former impoundment and brown trout density began to increase. Brown trout density continued to increase, with variability, through 2006, when density was 450% higher than it was at the beginning of the dam removal. Examination of length-frequency distributions showed that recruitment increased significantly. As recruitment increased, the abundance of each size class increased, and by the end of the study all size classes were more abundant, but the shape of the length-frequency distribution was the same as before the dam removal.

Given that changes were also observed in the reference zone, it is possible that other factors also contributed to the observed increases. Three plausible hypotheses for the substantial increase in brown trout recruitment and density are: 1) favorable environmental influences during the study period, 2) potential changes in trout harvest during the study period and, 3) the dam removal improved and increased spawning habitat for brown trout in the river. The first hypothesis is partially supported by the observation that brown trout density increased in both the impoundment and the reference reach, suggesting system-wide changes unrelated to the dam removal. Several pieces of evidence suggest this is not entirely responsible for the trout density increases. First, the reference reach was chosen to be immediately adjacent to the impoundment, because no effects of the dam on habitat conditions were seen in the reference reach. This proved to be a very effective reference reach for habitat conditions, as no changes in habitat conditions associated with the dam removal were seen in this zone. However, tagged and marked trout were seen to frequently move between the sites (Burroughs unpublished data). Also, at the beginning of the dam removal, trout density and size structure of each zone were similar. Together, this suggests that the trout in each of the two zones were acting as one population due to their close proximity and connectivity, and as such, changes affecting trout in one of these study zones should also impact the trout in the other zone. Therefore, the large increases in recruitment and density of trout in the former impoundment could also be expected have contributed to increased density of trout in the reference zone. In future studies on the effects of dam removals, we therefore suggest that additional fish reference areas be located further from the influence of the dam removal, possibly including other independent reference streams.

Following the removal of the Woolen Mills Dam in Wisconsin, Kanehl et al. (1997) also observed significant increases in smallmouth bass density in both the former impoundment and the adjacent reference reach, but not in another nearby reference stream. We examined the trout dynamics in other similar Michigan trout streams, where data were available as part of ongoing population monitoring by the Michigan Department of Natural Resources. These data suggested that abundance of brown trout generally increased during much of the study period in many other Michigan streams. However, the population growth rate observed rate in the Pine River was substantially greater than all other populations. Therefore, environmental factors may have contributed to the observed response, but the increases are likely to be at least partially due to the dam removal.

Starting in the spring of 2000, trout harvest regulations were altered on many Michigan trout streams, including the portion of the Pine River encompassing the study area. From the beginning of the study through 1999, there was a 203 mm (8”) minimum length and 10 fish per day creel limit on all three species of trout. In the spring of 2000, the regulations were changed to 5 fish per day, 203 mm minimum length, with no more than three over 381 mm (15”) in length. In 2001, the regulations for trout harvest were changed to 254 mm (10”) minimum length for brook trout, 305 mm (12”) minimum length for brown trout and rainbow trout, and 5 fish per day creel limit with no more than 3 fish over 381 mm in length. These regulation changes may have increased the survival, and subsequently the abundance, of larger sized brown trout in the study zones of the Pine River. However, if this had occurred, a significant shift in the proportion of fish over the regulatory minimum lengths would have been expected in the length frequency distributions. This was not observed, however trout harvest in the Pine River is thought to be low compared to other local rivers (M. Tonello, Michigan Department of Natural Resources, personal communications), thus the influence of harvest in explaining the trout density increases in the Pine River is doubtful.

Habitat conditions in the former impoundment changed significantly during the dam removal, and those changes were generally favorable to the spawning requirements of stream trout. Perhaps most influential were the observed increases in water velocity, substrate size, and the frequency of riffle bedforms. Average water velocity, the diversity of water velocities, and the occurrence of faster water velocities all increased. Additionally, median substrate size increased from “small gravel” to “medium gravel”, and the diversity of substrate sizes increased due to increased proportions of large substrates, and less sand. As an example, most brown trout redds contain substrate between 18 – 30 mm, and larger substrate (>50 mm) is commonly selected for (Grost et al 1991), which was rare in the impoundment zone prior to dam removal, but significantly increased in abundance following the removal (Burroughs 2007). Additionally, this coarse substrate also provides cover for trout fry by offering shelter from high water velocities (Heggenes 1988). Moreover, Zimmer and Power (2006) found that brown trout favored riffles over pools, over runs for redd construction; and the frequencies of riffles and pools increased in the former impoundment section. These changes in water velocity, substrate coarseness, and bedform frequencies likely improved spawning conditions for trout in the impoundment zone, and provide evidence for explaining the increased recruitment of brown trout in the Pine River.

Rainbow trout density showed a remarkably similar pattern to that of brown trout. However, the steady increase in density of rainbow trout did not begin until almost 2003. At the end of the study in 2006, rainbow trout density had increased to 300% of the density observed at the beginning of the dam removal. Analysis of the size structure of the rainbow trout in both the impoundment and reference zones indicated that recruitment and the proportion of juvenile rainbow trout increased substantially, with the frequency of larger rainbow trout increasing only slightly. Rainbow trout prefer spawning substrate between 15 – 60 mm (Raleigh and Hickman 1984), which was rare in the impoundment zone prior to dam removal, but significantly increased following the removal. This is likely to have improved spawning conditions for rainbow trout and contributed to improved recruitment. The lack of proportional increases in the abundance of larger adult rainbow trout could result from the relatively recent increases in rainbow trout density and recruitment, with those effects not carrying through to the older age groups yet.

While average brook trout densities for both the reference and impoundment zones seemed to decline from the beginning to the end of the study, this could be attributed to factors other than the dam removal. Generally, in rivers with coexisting populations of brook trout, brown trout, and rainbow trout, upstream areas are typically characterized by brook trout, while brown and rainbow trout are found more often downstream (Vincent and Miller 1969, Gard and Seegrist 1972, Magoulick and Wilzbach 1997). This pattern is thought to stem from differences in competitive abilities (Rose 1986, Lohr and West 1992), or the adaptation to and selection of different environmental conditions (Cunjak and Green 1983). For example, where habitat is sub-optimal for brook trout, brown trout have been shown to exclude brook trout from preferred resting positions (Fausch and White 1981). Also, there is evidence that rainbow trout dominance over brook trout can result from reduced brook trout fecundity or year class failures giving rainbow trout a competitive advantage (Clark and Rose 1997). It is possible that this section of the Pine River was suboptimal habitat for brook trout, and the increased brown trout and rainbow trout densities eventually lead to the overall decreased density of brook trout.

White suckers were found upstream and downstream of the dam throughout the study period. However, the density of this species was relatively low and stable in both the reference and impoundment zones from 1997 – 2002, the period in which fish passage upstream past the dam was restricted. Downstream of the dam, white sucker density was variable, but consistently higher than seen upstream of the dam, due to the influx of spawning adults from the reservoir located immediately downstream. These spawning adults were prevented from accessing upstream habitats that might have been used for spawning. In 2003, the last phase of the dam removal was completed, and fish passage past the dam site was possible. Spawning adult white suckers then moved upstream in the Pine River, and length composition of white suckers downstream of the dam was limited to small individuals. Those adult spawning fish utilized both the reference and the impoundment for spawning, and the overall density of this species upstream of the dam site increased approximately 550% from 1997 levels. While the abundance of juvenile fish increased tremendously, similarly low frequencies of adult fish were seen in both of these upstream zones in 1997 and 2006. This suggests that white suckers in the reference and impoundment zones may be limited by adult habitat availability. The dam removal allowed this species to access habitats available in the river system that are beneficial to different life stages and resulted in higher productivity and abundance of this species, through the use of available spawning habitat. A similar type of response may also be expected from many other fish species that make spawning migrations in streams, but have been prevented from accessing suitable spawning habitat.

Prior to dam removal, shorthead redhorse suckers were found only downstream of Stronach Dam. Density levels of this species downstream of the dam were also influenced by the influxes of spawning adults from the downstream reservoir. In the spring, this species migrates out of large bodies of water into smaller rivers or streams to spawn (Scott and Crossman 1973). Meyer (1962) found that in Iowa, shorthead redhorse suckers became sexually mature at age 3, corresponding to approximately 300 mm in length. In the Downstream zone of the Pine River, shorthead redhorse suckers less than 300 mm in length were rarely sampled. After 2003, this species was found widely distributed throughout both the reference and impoundment zones, but in very low densities. Juveniles of this species were not sampled in the Pine River, as with the case of white suckers, suggesting that the lotic habitat of the Pine River is not the preferred habitat of juvenile shorthead redhorse suckers. This species is likely not unique in that dam removal allowed them to access habitats that may benefit certain life history stages, but the lotic habitat of the Pine River is not likely preferred for a majority of the life history, and thus this species was not found to substantially increase in density in the lotic habitat, following dam removal. Many of the other 17 species of fish found only downstream of the dam prior to removal, may benefit from the dam removal in a similar way (e.g., northern pike, trout perch (*Percopsis omiscomaycus*), walleye (*Stizostedion vitreum*)).

Synthesis

Removal of the barrier to fish migration alleviated many of the impacts of habitat fragmentation. As fish in the Pine River were allowed to freely move between areas of the river, species diversity both upstream and downstream of the dam increased. Productivity of the fish community also increased as fish were able to choose and access those habitats that best fulfill their life history requirements.

Dams alter the habitat for lotic fish in streams. In the former impoundment zone of the Pine River we observed habitat conditions improve for brown and rainbow trout and documented improved reproductive success and significant increases in the density of these important sport fishes. With the dam removal, habitat conditions in the downstream zone worsened through the deposition and transport of large quantities of fine sediment. Fish populations in this zone did not benefit as observed upstream of the dam removal. However, three years after the dam removal was completely finished, habitat conditions were still changing. While conditions improved significantly in the former impoundment, they were not restored to reference levels. The last year of this study, 2006, was the first year in which no new net erosion occurred in the former impoundment (Burroughs 2007). In the future, without this influx of sediment, habitat conditions in the downstream zone may also begin to improve. The extent to which these habitat characteristics will be restored to reference levels, and the timeframes needed to realize these benefits of dam removal are still uncertain, but the potential for dam removal to be a useful tool for improving riverine fish communities appears strong.

LITERATURE CITED

American Rivers, Friends of the Earth, and Trout Unlimited. 1999. Dam removal success stories: restoring rivers through selective removal of dams that don't make sense.

Angradi, T. R., and J. S. Griffith. 1990. Diel feeding chronology and diet selection of rainbow trout (*Onchorynchus mykiss*) in the Henry's Fork of the Snake River, Idaho. Canadian Journal of Fisheries and Aquatic Sciences, 47:199-209.

Auer, N.A. 1996. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Can.J. Fish. Aquatic Sci. 53 (Supplement 1): 152-160.

Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. Ecology 69(2):382-392.

Battige, D.S., B.L. Fields, and D.L. Sowers. 1997. Removal of Stronach Dam. Proceedings of the International Conference on Hydropower (WaterPower 1997) 2:1341-1350.

Battige, D.S. *personal communication.* Hydro Generation Department, Consumers Energy, Cadillac, Michigan.

Benke, A.C. 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9(1):77-88.

Burdick, S.M. and J.E. Hightower. 2006. Distribution of spawning activity by anadromous fishes in an Atlantic slope drainage after removal of a low-head dam. Transactions of the American Fisheries Society 135: 1290-1300.

Burrell, K.H., J.J. Isely, D.B. Bunnell, D.H. Van Lear, and C.A. Dolloff. 2000. Seasonal movement of brown trout in a southern Appalachian river. Transactions of the American Fisheries Society, 129:1373-1379.

Burroughs, B.A. 2007. The effects of Stronach Dam removal on fluvial geomorphology of the Pine River, Manistee Co., Michigan. Chapter 1 of "The effects of dam removal on fluvial geomorphology and fish; a dissertation of the Department of Fisheries & Wildlife, Michigan State University.

Burroughs, B.A. *unpublished.* Movements of fish in the Pine River, Manistee County, Michigan: results from multiple year mark-recapture tagging efforts.

Clark, M.E. and K.A. Rose. 1997. Factors affecting competitive dominance of rainbow trout over brook trout in southern Appalachian streams: implications of an individual-based model. Transactions of the American Fisheries Society 126(11):1-20.

Collier, M., Webb, R.H., and J.C. Schmidt. 1996. Dams and rivers: primer on the downstream effects of dams. U.S. Geological Survey Circular 1126, Denver, CO 94 p. Consumers Power Company. 1994. Historical perspective: Stronach Dam, Pine River, Michigan. Consumers Power Company, Jackson, Michigan. February 1994.

Cunjak, R.A., and J.M. Green. 1983. Habitat utilization by brook char (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*) in Newfoundland streams. Canadian Journal of Zoology 61:1214-1219.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5:330-339.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38:1220-1227.

Gard, R. and D.W. Seegrist. 1972. Abundance and harvest of trout in Sagehen Creek, California. Transactions of the American Fisheries Society 101:463-477.

Grost, R.T., Hubert, W.A. and T.A. Wesche. 1991. Description of brown trout redds in a mountain stream. Transctions of the American Fisheries Society 120: 582-588.

Hammad, H.Y. 1972. River bed degradation after closure of dams. American Society of Civil Engineers, Journal of the Hydraulics Division 98:591-607.

Hansen, E.A. 1971. Sediment in a Michigan trout stream, its source, movement, and some effects on fish habitat. U.S. Forest Service Research Paper NC-59.

Hayes, D. B., H. R. Dodd, and J. L. Lessard. In press. Conservation considerations for small dams on coldwater streams. Proceedings of the 4th World Fisheries Congress. May 2_6, 2004, Vancouver, BC

Heggenes, J. 1988. Substrate preference of brown trout fry (*Salmo trutta*) in artificial stream channels. Canadian Journal of Fisheries and Aquatic Sciences 45:1801-1806.

Heinz Center, The. 2002. Dam removal: science and decision making. Washington, D.C.: The Heinz Center.

Hicks, B.J., and N.R.N. Watson. 1985. Seasonal changes in abundance of brown Trout (*Salmo trutta*) and rainbow trout (*S. gairdnerii*) assessed by drift diving in the Rangitkei river, New Zealand. New Zealand Journal of Marine and Freshwater Research 19:1-10.

Hill, M.J., E.A. Long, and S. Hardin. 1994. Effects of dam removal on Dead Lake, Chipola River, Florida. Proceedings of the Annual Conference SEAFWA: 512-523.

Junge, C.O. and Libosvarsky, J. 1965. Effects of size selectivity on population estimates based on selective removals with electrofishing gear. Zool. Listy 14, 171-178.

Kanehl, P., D.J. Lyons, and J.E. Nelson. 1997. Changes in the habitat and fish community of the Milwaukee River, Wisconsin, following removal of the Woolen Mills Dam. North American Journal of Fisheries Management 17:387-400.

Krebs, C. R. 1989. Ecological methodology. Harper Collins, New York.

Ligon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream ecological effects of dams. Bioscience 45(3):183-192.

Lohr, S.C. and J.L. West. 1992. Microhabitat selection by brook and rainbow trout in a southern Appalachian stream. Transactions of the American Fisheries Society 121(6)729-736.

Magoulick, D.D., and M.A. Wilzbach. 1997. Microhabitat selection by native brook trout and introduced rainbow trout in a small Pennsylvania stream. Journal of Freshwater Ecology 12(4):607-614.

Martinez, P.J., Chart, T.E., Trammell, M.A., Wullschleger, J.G, and E.P. Bergersen. 1994. Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. Environmental Biology of Fishes 40: 227-239.

Meyer, W.H. 1962. Life history of three species of redhorse (Moxostoma) on the Des Moines River, Iowa. Transactions of the American Fisheries Society, 91(4): 412-419.

Morista, M. 1959. Measuring of interspecific association and similarity between communities. Memoirs of the Faculty Science Kyushu University, Series E Biology 3:65-80.

Northcote, T.G., N.J. 1998. Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. Pages 3-18 in M. Jungwirth, Stefan, S. and Weiss, editors. Fish Migration and Fish Bypasses. Fishing News Books, Oxford, England.

Petts, G.E. 1980. Long-term consequences of upstream impoundment. Environmental Conservation 7(4):325-332.

Pohl, M.P. 2002. Bringing down our dams: trends in American dam removal rationales. Journal of the American Water Resources Association 38(6):1511-1519.

Pohl, M. 2003. American dam removal census: available data and data needs. Chapter 2 *in*; Dam removal research: status and prospects. W.L. Graf *editor*. The H. John Heinz III Center for Science, Economics and the Environment; Washington, D.C.

Pringle, C.M., Freeman, M.C., and B.J. Freeman. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the New World: tropical-temperate comparisons. Bioscience Vol. 50, No. 9: 807-823.

Quinn, J.W. and T.J. Kwak. 2003. Fish assemblage changes in an Ozark river after impoundment: a long-term perspective. Transactions of the American Fisheries Society 132:110-119.

Raleigh, R.F., and T. Hickman. 1984. Habitat suitability information: rainbow trout. U.S. Fish and Wildlife Service FWS/OBS-82/10.60, Washington, D.C.

Ricklefs, R.E. 1990. The economy of nature: a textbook in basic ecology. Fourth edition. W.H. Freeman and Co., New York. Pp. 516-517.

Rose, G.A. 1986. Growth decline in subyearling brook trout (*Salvelinus fontinalis)* after emergence of rainbow trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquatic Sciences 43:187-193.

Rozich, T.J. 1998. Manistee River Assessment. Michigan Department of Natural Resources Fisheries Division Special Report Number 21, Lansing, Michigan.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fish Research Board of Canada, Ottawa; 563-583.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Second Edition. E. Arnold publishing, London.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. Urbana, IL., Univ. of Ill. Press.

Smith, L.W., E. Dittmer, M. Prevost, and D.R. Burt. 2000. Breaching of a small irrigation dam in Oregon: a case history. North American Journal of Fisheries Management 20:205-219.

Stanley, E.H. and M.W. Doyle. 2003. Trading off: the ecological effects of dam removal. Front. Ecol. Environ. 1(1): 15-22.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. Second Edition. Pages 540, 622-623. McGraw-Hill Book Company.

Tonello, M. *Personal communications*. Regional fisheries biologist for the area including the Pine River, Michigan Department of Natural Resources.

Van Deventer, J.S., and W.S. Platts. 1983. Sampling and estimating fish populations from streams. Transactions of the North American Wildlife and Natural Resources Conference 48:349-354.

Vincent, R.E., and W.H. Miller. 1969. Altitudinal distribution of brown trout and other fishes in a headwater tributary of the South Platte River, Colorado. Ecology 50:464-466.

Ward, J.V., and J.A. Stanford. 1989. Riverine ecosystems: the influence of man on catchment dynamics and fish ecology. Pages 56-64 in D.P. Dodge editor. Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Williams, G.P., and M.G. Wolman. 1984. Downstream effects of dams on alluvial rivers. Professional paper 1286. Washington, D.C.: U.S. Geological Survey.

Zimmer, M.P. and M. Power. 2006. Brown trout habitat selection preferences and redd characteristics in the Credit River, Ontario. Journal of Fish Biology 68: 1333-1346.

Appendix A. Number of fish caught and their numeric proportions, for each study zone in the Pine River, before and after the Stronach Dam removal.

			Reference Zone				Impoundment Zone				Downstream Zone			
			1997		2006		1997		2006		1997		2006	
Fish Species Common Name	**Genus**	**species**	**catch**	**%**	**catch**	**%**	**catch**	**%**	**catch**	**%**	**catch**	**%**	**catch**	**%**
White Sucker	*Catostomus*	*commersoni*	33	5.39	266	28.85	140	30.50	452	30.54	128	58.18	56	28.14
Slimy Sculpin	*Cottus*	*cognatus*	368	60.13	258	27.98	157	34.20	217	14.66	0	0.00	15	7.54
Brown Trout	*Salmo*	*trutta*	78	12.75	143	15.51	71	15.47	292	19.73	13	5.91	33	16.58
Rainbow Trout	*Oncorhynchus*	*mykiss*	38	6.21	102	11.06	51	11.11	200	13.51	5	2.27	2	1.01
Logperch Darter	*Percina*	*caprodes*	0	0.00	85	9.22	0	0.00	126	8.51	4	1.82	38	19.10
Brook Trout	*Salvelinus*	*fontinalis*	68	11.11	10	1.08	31	6.75	12	0.81	0	0.00	0	0.00
Longnose Dace	*Rhinichthys*	*cataractae*	23	3.76	17	1.84	3	0.65	57	3.85	1	0.45	1	0.50
Shorthead Redhorse	*Moxostoma*	*macrolepidotum*	0	0.00	3	0.33	0	0.00	10	0.68	28	12.73	21	10.55
Pumpkinseed	*Lepomis*	*gibbosus*	0	0.00	3	0.33	0	0.00	46	3.11	0	0.00	3	1.51
Troutperch	*Percopsis*	*omiscomaycus*	0	0.00	0	0.00	0	0.00	31	2.09	8	3.64	6	3.02
American Brook Lamprey	*Lampetra*	*appendix*	2	0.33	10	1.08	3	0.65	8	0.54	0	0.00	2	1.01
Bluegill	*Lepomis*	*macrochirus*	0	0.00	15	1.63	0	0.00	2	0.14	0	0.00	0	0.00
Northern Pike	*Esox*	*lucius*	0	0.00	0	0.00	0	0.00	4	0.27	6	2.73	7	3.52
Yellow Perch	*Perca*	*flavescens*	0	0.00	5	0.54	0	0.00	6	0.41	0	0.00	2	1.01
Silver Redhorse	*Moxostoma*	*anisurum*	0	0.00	0	0.00	0	0.00	0	0.00	8	3.64	1	0.50
Smallmouth Bass	*Micropterus*	*dolomieu*	0	0.00	0	0.00	0	0.00	0	0.00	7	3.18	2	1.01
Largemouth Bass	*Micropterus*	*salmoides*	0	0.00	0	0.00	0	0.00	5	0.34	0	0.00	2	1.01
Blackside Darter	*Percina*	*maculata*	0	0.00	2	0.22	0	0.00	1	0.07	1	0.45	1	0.50
Rock Bass	*Ambloplites*	*rupestris*	0	0.00	0	0.00	0	0.00	2	0.14	1	0.45	2	1.01
Black Bullhead	*Ameiurus*	*melas*	1	0.16	0	0.00	2	0.44	0	0.00	0	0.00	1	0.50
Chestnut Lamprey	*Ichthyomyzon*	*castaneus*	0	0.00	0	0.00	0	0.00	2	0.14	2	0.91	0	0.00
Common Shiner	*Luxilus*	*cornutus*	0	0.00	0	0.00	0	0.00	1	0.07	2	0.91	1	0.50
Spottail Shiner	*Notropis*	*hudsonius*	0	0.00	0	0.00	0	0.00	0	0.00	4	1.82	0	0.00
Creek Chub	*Semotilus*	*atromaculatus*	1	0.16	0	0.00	1	0.22	0	0.00	0	0.00	1	0.50
Emerald Shiner	*Notropis*	*atherinoides*	0	0.00	1	0.11	0	0.00	2	0.14	0	0.00	0	0.00
Walleye	*Stizostedion*	*vitreum*	0	0.00	0	0.00	0	0.00	1	0.07	2	0.91	0	0.00
Central Mudminnow	*Umbra*	*limi*	0	0.00	1	0.11	0	0.00	1	0.07	0	0.00	0	0.00
Johnny Darter	*Etheostoma*	*nigrum*	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	1.01
Blacknosed Dace	*Rhinichthys*	*atratulus*	0	0.00	0	0.00	0	0.00	2	0.14	0	0.00	0	0.00
Golden Shiner	*Notemigonis*	*crysoleucas*	0	0.00	1	0.11	0	0.00	0	0.00	0	0.00	0	0.00
Sum			**612**		**922**		**459**		**1480**		**220**		**199**	