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DAM REMOVAL EFFECTS ON FLUVIAL
GEOMORPHOLOGY AND FISH POPULATIONS, AND DIET
OF CATOSTOMIDS IN THE PINE RIVER, MICHIGAN

presented by

BRYAN ALAN BURROUGHS

has been accepted towards fulfillment
of the requirements for the

Master of Science degree in Fisheries and Wildlife

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DAM REMOVAL EFFECTS ON FLUVIAL GEOMORPHOLOGY AND FISH POPULATIONS, AND DIET OF CATOSTOMIDS IN THE PINE RIVER, MICHIGAN

By

Bryan Alan Burroughs

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

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ABSTRACT

DAM REMOVAL EFFECTS ON FLUVIAL GEOMORPHOLOGY AND FISH POPULATIONS, AND DIET OF CATOSTOMIDS IN THE PINE RIVER, MICHIGAN

By

Bryan Alan Burroughs

During the staged removal of Stronach Dam, sediment fill incision occurred throughout the entire former impoundment, and sediment deposition and streambed aggradation occurred downstream of the dam. These processes caused changes in stream width, water depth, gradient, water velocity, and streambed subtrate size. Upstream of the dam, these habitat changes seemed to benefit brown trout (*Salmo trutta*), adversely affect white suckers (*Catostomus commersoni*), and had less influence on other species. Downstream of the dam, the length distributions of brown trout, white suckers, and shorthead redhorse suckers (*Moxostoma macrolepidotum*) shifted to smaller individuals. Fish passage was still restricted during this study, benefits of defragmenting habitat are not yet known.

A diet study of white suckers, shorthead redhorse suckers and silver redhorse suckers (*Moxostoma anisurum*) showed that these species had very similar diets, comprised mainly of immature chironomids. The diets of these catostomids were very different from the diets of brown trout, rainbow trout and brook trout from the Pine River, suggesting competition with trout is unlikely following full dam removal.

Chapter

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Chapter One is dedicated in memory of Sis Schrems, a wonderful lady and devoted conservationist of our coldwater resources.

Chapter Two is dedicated to all the suckers that sacrificed their lives in this study for the greater good of their species.

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I would like to thank my advisor Dan Hayes, for being a great mentor and friend, and for having the foresight to start this study so long ago. My gratitude is extended to my committee members Mike Jones and Rich Merritt for taking time, I know they didn't have, to make sure this thesis was done well. I appreciate Jessica Mistak's help in facilitating the turnover of personnel on this project. My lab mates were always available as sounding boards and sources of advice. I'd like to thank Ed McCoy, Mike Fulk, Matt Klungle, Mark Monroe, Brian Bellgraph, Kevin Mann, Tim Riley, Ryan Mann, Kelly DeGrandchamp, Brent Newell, and Ben Nessia for their hard work in the field and laboratory.

Lastly, I'd like to thank: Ken Sprankle for getting me started in fisheries biology; Randy and Ron Burroughs for their admiration of this profession; my family for their patience and financial support throughout my extended schooling, and Jordan Pusateri for her friendship and numerous draft reviews of this thesis.

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Chapter 1

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INTRODUCTION

Dams provide numerous benefits to society including: recreation, fire and farm ponds, flood control, municipal water supply, irrigation, tailings and waste containment, mechanical and hydroelectric energy generation, navigation, and wildlife management. In North America, the construction of dams began in the 1800's (Petts 1980), and helped to power the Industrial Revolution. Dam building however, reached its peak from 1950 to 1970 (Heinz Center 2002).

There are an estimated 2.5 million dams in the United States (National Resource Council 1992), around 76,000 of which are six feet or greater in height (a criteria for "large" size designation based on dam safety and potential hazard; Federal Emergency Management Agency and U.S. Army Corps of Engineers 1996). This number is equivalent to one dam six feet or greater in height being built each day since the signing of the Declaration of Independence (Babbitt 2001). Dams are ubiquitous in the United States, appearing in nearly every major and minor river system in the lower 48 states (Heinz Center 2002).

The benefits that dams provide to society come at a cost to the environment. Rivers are defined by flowing water. Placing a dam on a river alters the flow of water and fundamentally changes the functioning of a river ecosystem. The effects that dams have on river ecosystems are well documented (e.g. Hammad 1972, Petts 1980, Williams and Wolman 1984, Cushman 1985, Bain et al. 1988, Ward and Stanford 1989, Benke 1990, Ligon et

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al. 1995, Lessard 2000), including interruption to the flow of water, sediment, nutrients, energy and biota.

Dam removal has received increased attention in recent years. Several factors contribute to this. The United States is no longer an industrialized developing country with need for the cheap benefits of dams. Stewardship of natural resources is more prevalent now and the benefits that dams provide must now outweigh the negative ecological impacts they cause in order to justify a dam's continued existence.

Many dams are still viable and provide valuable benefits to society, but there are also many aging dams that no longer fulfill the role they were intended for. The average life expectancy of a dam is approximately 50 years (River Alliance of Wisconsin and Trout Unlimited 2000). Of the dams listed in the United States Army Corps of Engineers (USACE) database, 22,000 (30%) are currently 50 years of age or older. By the year 2020, that number is expected to climb to 60,000 (80%) (Federal Emergency Management Agency and USACE 1996, as cited in Heinz Center 2002). As dams age, they require maintenance and upkeep to maintain their function. These repairs can be costly and uneconomical if the dam no longer serves a purpose. Without repair, dams can become structurally unsafe and pose significant safety hazards. Faced with the often enormous costs of repairing old, unprofitable dams, or mitigating environmental damage they cause, many dam owners are considering dam removal. With this new leverage, natural resource managers are also considering dam removal as a viable option for river ecosystem restoration.

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Few estimates of the number of dam removals that have occurred in the United States to date are available, and it is likely that these underestimate the true number of removals. Despite this, it is safe to say that a minimum of 400 dams have been removed so far (Pohl 2002). Of these, few recorded dam removals occurred before 1970, and the annual removal rate seems to be increasing. Most have been small to medium sized run-of-river structures, removed for safety or environmental reasons (Pohl 2002). It might be expected that states with the highest numbers of dams or the greatest percentage of old dams would have removed the most. However, the majority of dam removals have taken place in states that support removals through funding programs, active leadership and advocacy positions regarding dam removal (Pohl 2002).

Despite the rate of increase in dam removals, the scientific literature on dam removal is sparse. The rate at which new information is being synthesized is encouraging though. Much of the work that has been done, focuses on the technical aspects (River Alliance of Wisconsin and Trout Unlimited 2000, Graber et al. 2001, Bowman 2002), socioeconomic aspects (Born et al. 1998, Trout Unlimited 2001, Johnson and Graber 2002) of executing dam removals and hypothesized effects from proposed dam removals (Shuman 2002, Freeman et al 2002, Heinz Center 2002). Many researchers are also producing insightful work by using dam removal analogies from various disciplines to help predict the response of river ecosystems to dam removal (Pizzuto 2002, Stanley and Doyle 2002, Shafroth et al. 2002, Gregory et al. 2002, Whitelaw and MacMullan 2002). The field of dam removal continues, however, to suffer from a lack of empirical studies.

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studies. Qualitative observations on the effects of dam removal exist for numerous dam removal case studies (American Rivers et al. 1999, Smith et al. 2000), but detailed quantitative observations of the effects of dam removal have been slower coming. A few published studies on the effects of dam removals or failures on fluvial geomorphology (Evans et al. 2000, Wohl and Cenderelli 2000, Stanley et al. 2002), aquatic insects (Stanley et al. 2002) and fish (Hill et al. 1994, Kanehl et al. 1997) exist, but are scarce.

Quantitative empirical documentation of the effects of dam removals needs to be collected over the wide range of dam types, sizes, river characteristics (physical, chemical and biological) and removal strategies (all at once removal and varying staged removals). Information on the effects of dam removals over this spectrum of conditions will allow useful generalizations and models of the effects of dam removals to be made, and will greatly improve the ability of managers to predict the outcomes from, and best strategies for future dam removals.

The goal of this study was to document changes in the fish community and habitat during the staged removal of Stronach Dam. The results from this study should provide insight for aquatic scientists and natural resource managers faced with trying to predict the best strategies for, and outcomes of future dam removals. The major objectives of this study were to: (1) document changes in river channel morphology, gradient, water velocity, and substrate size composition along a 9.7 km (6 mile) stretch of the Pine River; (2) document changes in the abundance of brown trout (*Salmo trutta*), rainbow trout

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(*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), white suckers (*Catostomus commersoni*), and shorthead redhorse suckers (*Moxostoma macrolepidotum*), and monitor the presence of other fish species within the 9.7 km study stretch of the Pine River.

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). Upstream from Stronach Dam, the river drains a 68,635 ha (265 square mile) watershed dominated by sandy glacial outwash plains, recessional moraines, and areas of consolidated clay (Hansen 1971). The Pine River is a 77 km (48 mile) long, riffle-pool stream with an average gradient of 2.8 m/km (15 ft/mi) (Rozich 1998). The section of river impounded by Stronach Dam historically had a gradient of 4.7 m/km (25 ft/mi), and was reported to be the best fish spawning area of the river (Rozich 1998). Mean daily discharge recorded at two U.S. Geological Survey gaging stations on the Pine River (#04125500, 1952-1982, 8 km upstream from Stronach Dam; and #04125460, 1996-present, 13.7 km upstream from Stronach Dam) has averaged 286 cfs during 34 years of record, with a minimum discharge of 161 cfs and a maximum of 2440 cfs. The Pine River is a coldwater stream, dominated by groundwater input. It carries a high bedload of sand due to the local geology and extensive logging operations in the late 1800's, which created unstable banks along the river. Hansen (1971) calculated mean annual sediment

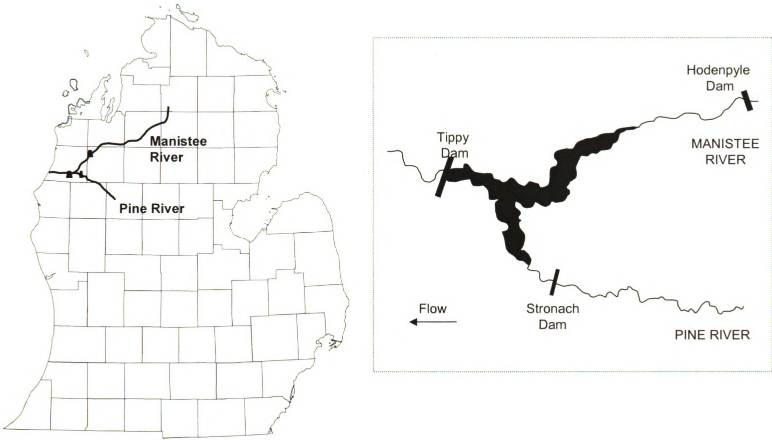

Figure 1. Location of Stronach Dam on the Pine River in relation to the state of Michigan.

discharge at Stronach Dam from 1967 to 1970 to be 50,000 tons, 70 to 75 percent of which was sand.

Stronach Dam was constructed from 1911 to 1912, 5.6 km (3.5 mi) upstream from the confluence of the Pine River and the Manistee River. This was the first hydroelectricity generating plant on the Manistee River system and it supplied power to the cities of Manistee and Cadillac, Michigan (Rozich 1998). The design included an earth embankment dam with a concrete corewall; a 15 foot fixed-concrete spillway section with 3 feet 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) (Figure 2). Stronach Dam, with 18 feet of head height possible, was operated mostly around 17 feet of head. This created a 26.7 ha (66 acre) reservoir with a 640 acre-foot capacity (Hansen 1971, Consumers Power Company 1994). Tippy Dam (56 foot head height) was constructed in 1918 immediately downstream of the confluence of the Pine and Manistee Rivers (Rozich 1998) (Figure 1). This created a 494 ha (39,500 acre-foot) impoundment over the high gradient confluence area of the two rivers, and blocked all upstream fish migration from Lake Michigan.

Due to the Pine River's high sediment load, problems quickly 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

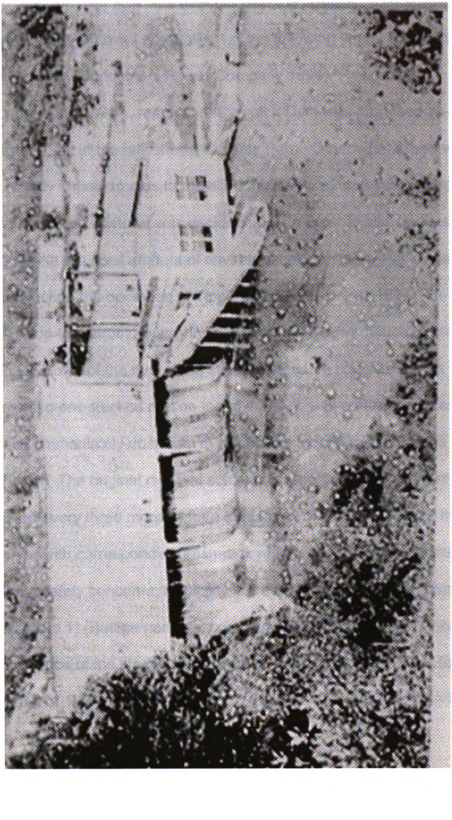

Figure 2. Stronach Dam Circa 1912.

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 proposed as part of a FERC agreement in the relicensing of Tippy Dam. Other alternatives would have involved costly improvements to maintain the safety of the already deteriorating structure. A staged removal was decided upon in order to allow gradual river restoration 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 12 foot high "stop-log" structure was installed in the old powerhouse to allow a gradual drawdown of the river. The stop-log structure consisted of six inch hollow metal pipes 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 six inch stop-log to be removed every three months, for a total of two feet 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 (Table 1) (Battige personal communication 2002). Table 1 shows the actual sequence of the staged dam removal. Removal of Stronach Dam began in the spring of 1997 and is expected to be complete in the fall of 2003.

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Table 1. Schedule of removal events during the staged removal of Stronach Dam on the Pine River, Manistee County, Michigan. Stop-logs are 6-inch diameter hollow metal pipes stacked on top of one another. Trash-rack removal estimates are approximate. Cumulative feet removed are in parentheses. (Dave Battige, Consumers Energy, personal communication 2003).

Date	Number of Stop-logs removed	Feet of Trash-rack removed
March 17, 1997	1 (0.5')	0 (0')
June 5, 1997	1 (1.0')	0 (0')
June 16, 1997	2 (2.0')	0 (0')
June 24, 1997	2 (3.0')	0 (0')
September 15, 1997	1 (3.5')	0 (0')
December 15, 1997	1 (4.0')	0 (0')
March 16, 1998	1 (4.5')	0 (0')
May 7, 1998	0 (4.5')	6 (6')
May 29, 1998	0 (4.5')	1 (7')
June 15, 1998	1 (5.0')	0 (7')
September 8, 1998	1 (5.5')	1 (8')
December 14, 1998	1 (6.0')	1 (9')
March 15, 1999	1 (6.5')	0 (9')
May 11, 1999	1 (7.0')	0 (9')
September 13, 1999	2 (8.0')	0 (9')
September 16, 1999	0 (8.0')	2 (11')
April 17, 2000	2 (9.0')	0 (11')
October 2, 2000	2 (10.0')	0 (11')
October 5, 2000	0 (10.0')	2 (13')
May 8, 2001	2 (11.0')	0 (13')
September 8, 2001	2 (12.0')	0 (13')
November 11, 2002	0 (12.0')	5 (18')

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METHODS

Fluvial Geomorphology

Habitat conditions in the river were documented in 1995, prior to commencement of dam removal activities (Figure 3) (Klomp 1998). At that time, 9.5 km of the Pine River, from a point approximately one km downstream of Stronach Dam to a point approximately 8.5 km upstream from Stronach Dam was surveyed. This assessment involved the mapping and description of physical characteristics, including categorization of the stream into habitat units of runs, riffles, pools, rapids, or complex (a designation where more than one category applied), following the criteria developed by Hicks and Watson (1985). The survey allowed this section of river to be divided into three distinct reaches. The "Impacted zone", extending for 3.88 km upstream from Stronach Dam, was the reach where impoundment had occurred. The Impacted zone of the river was relatively wide, slower-flowing, sand-bottomed, and generally consisted of run habitat. The "Non-Impacted zone", extending for 3.70 km upstream of the Impacted zone, serves as a "control site" or "reference reach" where no impoundment effects from the dam were evident. The river was narrower, faster-flowing, had coarser substrates, and showed high habitat heterogeneity. The third study zone, the "Downstream zone", extends for 0.63 km downstream of the dam. This section of river was wide, slow-flowing, sandy-bottomed, and consisted entirely of run habitat.

Thirty-one permanent cross-sectional transects were established in 1996 to allow for measurement of changes in channel morphology over the course of

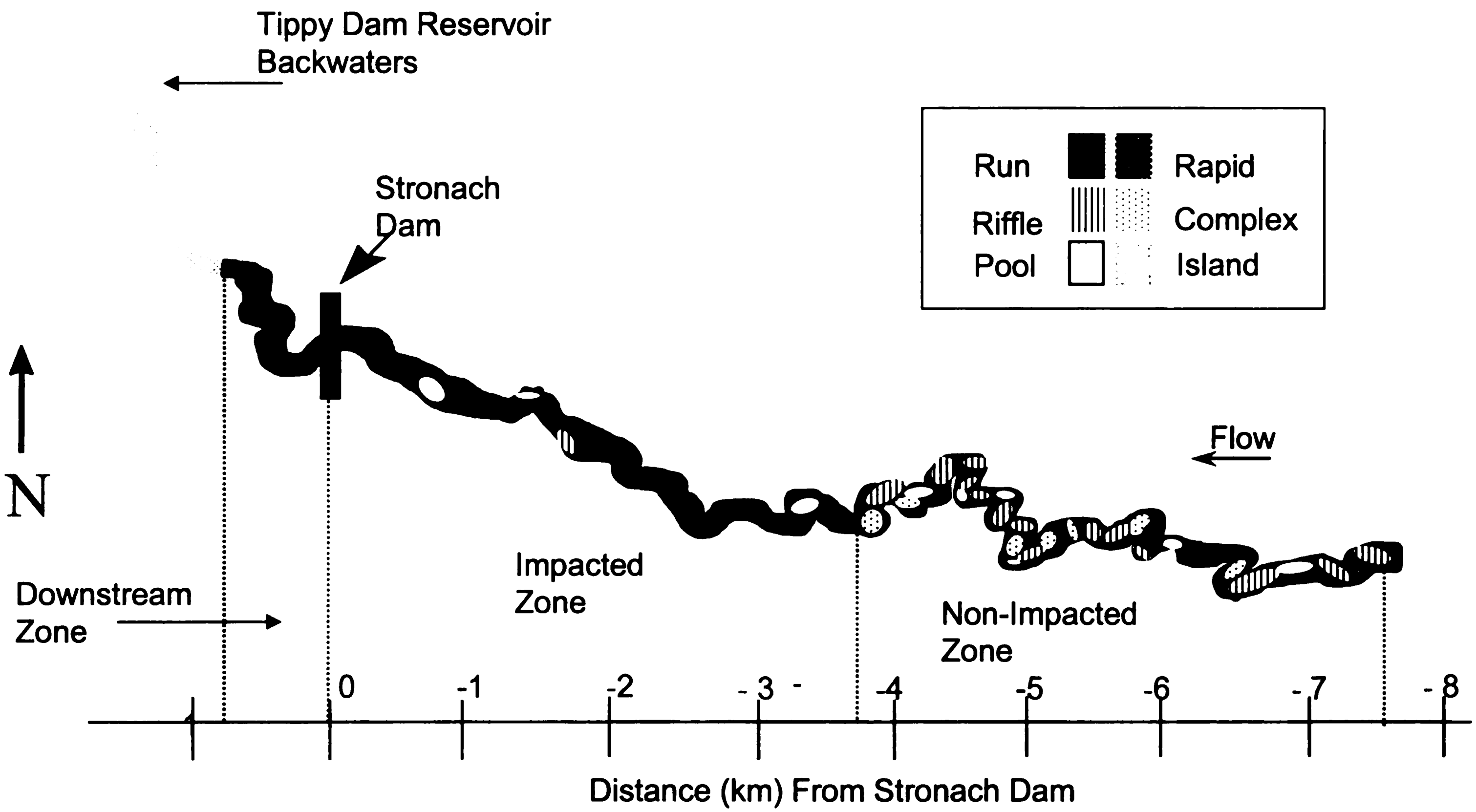

Figure 3. Map of study zone delineations based on habitat types observed in 1995, prior to commencement of dam removal (Klomp 1998). Distances negative in magnitude denote an upstream direction from the dam.

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dam removal. These transects were created with the aid of a Michigan Department of Natural Resources survey crew. Photographs, site descriptions, and latitude-longitude coordinates for each transect are archived at Michigan State University, Department of Fisheries and Wildlife, Fisheries Laboratory. Twenty-nine transects are located upstream of the dam and two are located downstream (Figure 4). Where possible, transects were placed in series, where the elevation of one transect was related to others in the same series. In sites where actual elevation was not known, the highest elevation in a series of transects was arbitrarily set to 100 feet. All transects were measured annually from 1996 to 2002, during June or July of each year. Measurements were taken at varying distance intervals on dry land, and at two foot intervals across the streambed, starting and ending at the water's edge on both stream banks. Elevations, including water surface elevations were measured at each transect to the nearest hundredth of a foot.

Stream width was calculated as the distance from the water's edge on one stream bank to the water's edge on the opposite stream bank, providing a measurement of width that is representative of the habitat available for fish. Gradient was calculated as the difference in water surface elevation from the first transect in a series to the last transect in the same series, over the distance between the two transects.

Water velocity was measured at 10 of the permanent transects (Figure 4) annually from 1996 to 2002. From 1996 to 2000, a Marsh-McBirney Model 201 portable current meter was used. In 2001 and 2002, water velocity

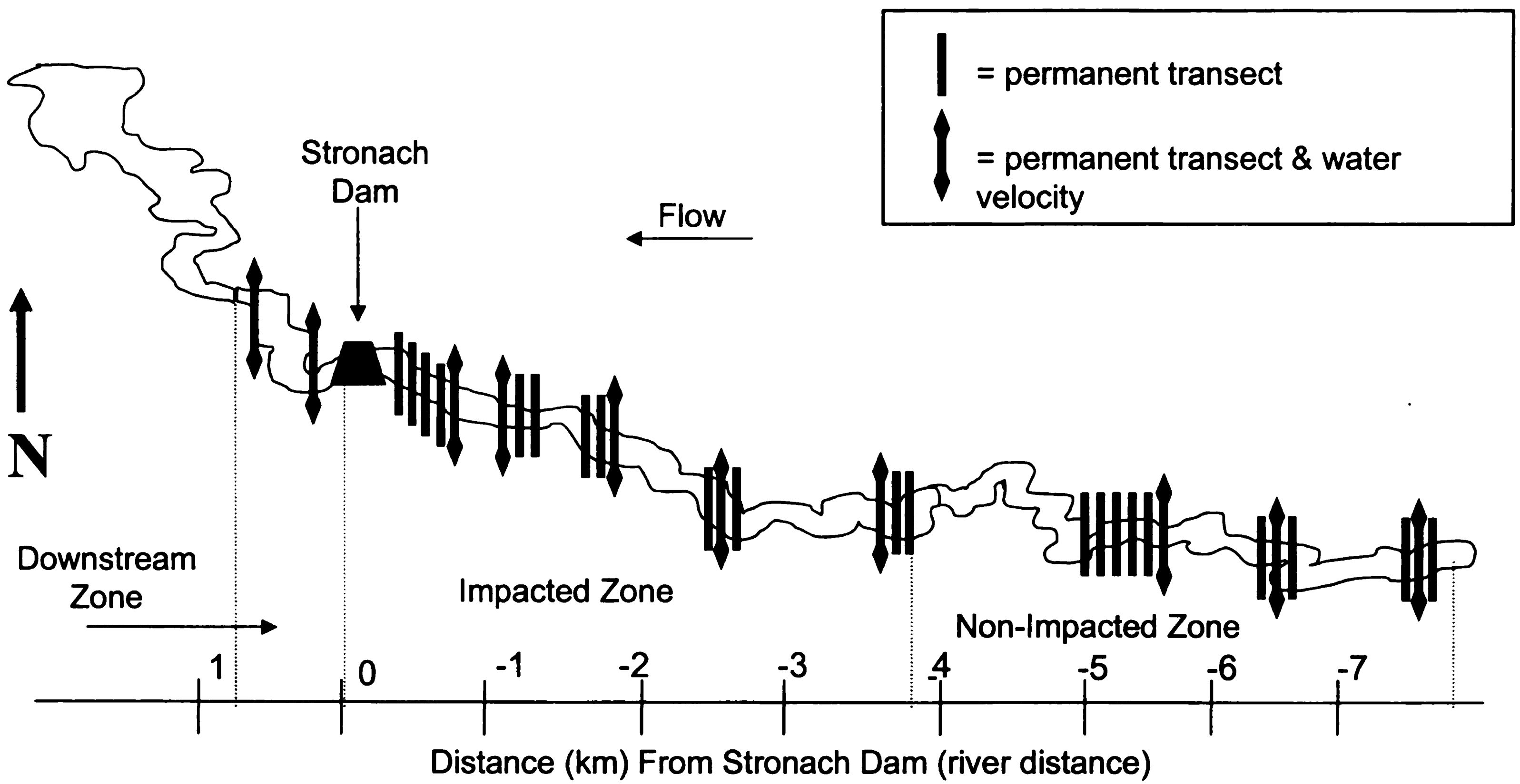

Figure 4. Locations of permanent transect survey sites located on the Pine River. Water velocity was measured at selected sites. Sites upstream from Stronach Dam are denoted by a distance negative in magnitude; sites downstream have distances positive in magnitude.

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was measured using a Global Flow Probe Model FP101, impellor-style flow meter with a 4 cm diameter impellor. Water velocity was measured at two foot intervals, starting at the water's edge on one stream bank and ending at the water's edge on the opposite stream bank. If water depth was less than 75 cm, water velocity was measured at 60% of the water depth from the water surface. If water depth was greater than 75 cm, water velocity was measured at 20% and 80% of the water depth from the water surface, and the two measurements were averaged (Gallagher and Stevenson 1999). The Kolomogorov - Smirnov two sample test (Steel and Torrie 1980) was used to test for differences between water velocity frequency distributions of different years.

Discharge was calculated using the cross-section measurement technique described by Gallagher and Stevenson (1999). This technique involves multiplying the depth, width, and mean water velocity of each measurement interval to calculate the volume of water passing through each interval per unit of time (discharge). Total stream discharge for a transect is the total of all individual interval discharges.

Streambed substrate size composition was measured at each of the 31 permanent transect sites (Figure 4), annually from 1997 - 2002. In 1996, substrate size composition was measured only at 10 selected sites. The pebble count method was used(Wolman 1954, Kondolf and Li 1992). This method involves randomly selecting 100 streambed particles along a transect, measuring the intermediate axis, and assigning a size class code to each particle (Table 2; from a modified Wentworth scale (Wentworth 1922, Cummins 1962)). Median

Table 2. Size classes and codes used to denote particle composition (Cummins 1962).

Size Code	Size Class (mm)	Particle
0		Trash
1		Organic
2	0.00024 - 0.004	Clay
3	0.04 - 0.062	Silt
4	0.062 - 2	Sand
5	2 - 4	Very Fine Gravel
6	4 - 8	Fine Gravel
7	8 - 16	Medium Gravel
8	16 - 32	Coarse Gravel
9	32 - 64	Very Coarse Gravel
10	64 - 128	Small Cobble
11	128 - 256	Large Cobble
12	256 - 512	Small Boulder
13	>512	Medium Boulder

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substrate size for a transect was calculated after excluding "organic" or "trash" designations which did not have corresponding size classes. The Kolomogorov-Smirnov two sample test (Steel and Torrie 1980) was used to test for differences between substrate size frequency distributions across years.

Fish Populations

In 1996, the efficiencies of numerous fish sampling methods were tested in the Pine River (Klomp 1998). From 1997 to 2002 a 17-foot Smith-Root Cataraft® electrofishing boat was used for all fish sampling efforts. The electrofishing boat was set to deliver pulsed DC (40% cycle duty) on low range (50 – 500) volts at 4 – 6 amps.

Fish abundance was sampled at 10 sites along the river (Figure 5), once per year (mid-July to early August), from 1997 to 2002. Four sites were located in the Non-Impacted zone, four sites in the Impacted zone, and two sites were located in the Downstream zone. The sites ranged in size from 80 to 428 meters in length. Each site was enclosed with block-nets and multiple pass removal sampling was conducted in order to estimate fish population sizes (VanDeventer and Platts 1985). 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. The total length of fish captured was measured to the nearest millimeter. Starting in 2000, fish were also given a site-specific fin clip and tag in order to determine if fish were moving through the remaining dam structure. All

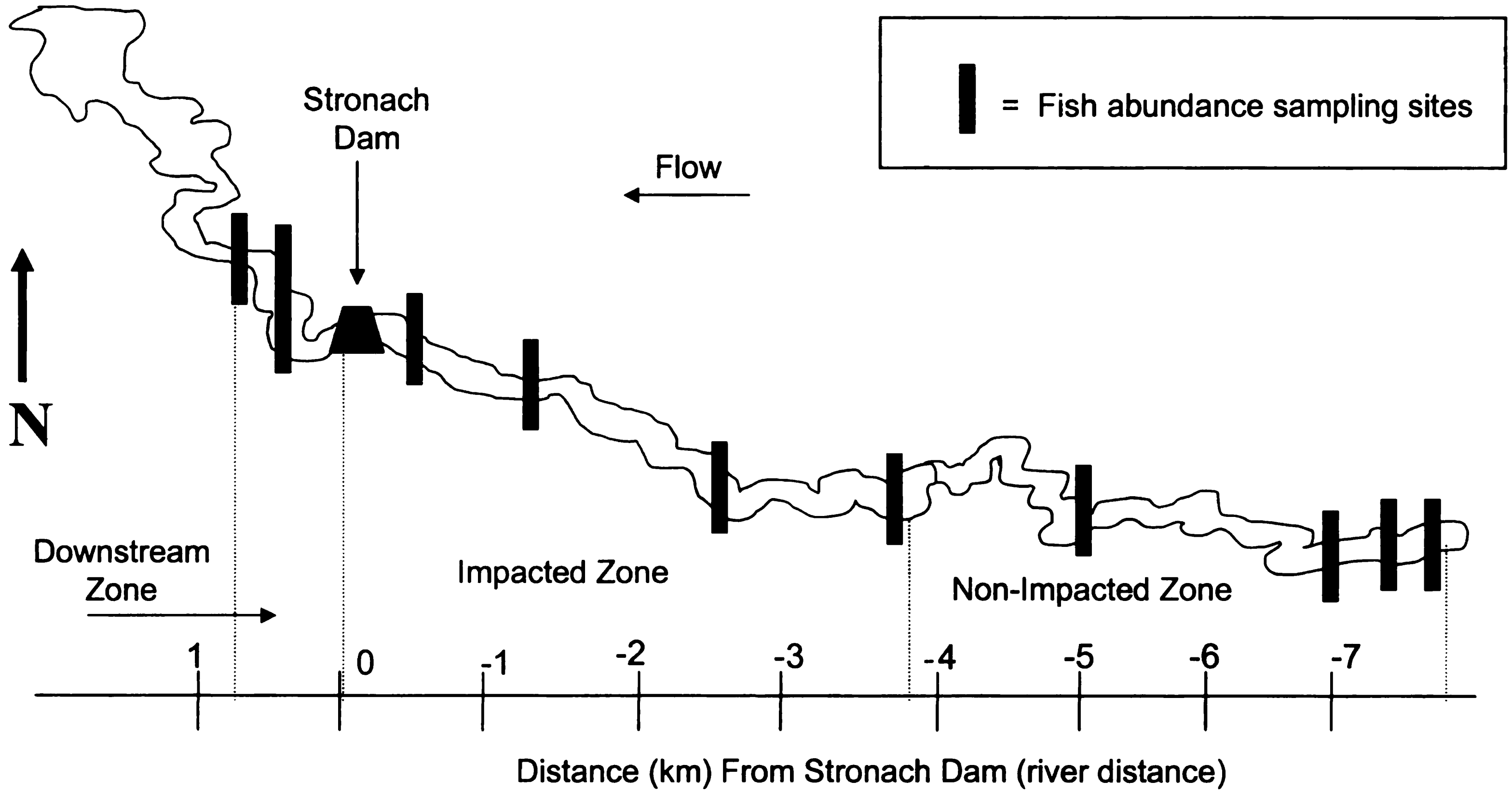

Figure 5. Locations of block netted, multiple-pass removal fish abundance sampling sites located on the Pine River. Sites upstream from Stronach Dam are denoted by a distance negative in magnitude; sites downstream have distances positive in magnitude.

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trout over 200 mm in length were given a Visual Implant alpha-numeric tag, and suckers, pike, and centrachids were given T-bar (Floy) style tags.

Abundance estimates were generated using MicroFish (VanDeventer and Platts 1985), a software program using the Burnham maximum-likelihood estimator (VanDeventer and Platts 1983). Within this software program, the MFISH.EXE statistical package, with its default parameters, was used to generate abundance estimates for selected species, at each site, for each year. The abundance estimates were converted to density estimates (number of fish per hectare or fish/ha) using sampling site width and length information collected in 1997 (Klomp 1998). A general linear model was used to test for differences in the fish densities between years and 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 zones.

RESULTS

Fluvial Geomorphology

During the course of the dam removal, a longitudinal progression of channel adjustment was evident (Figure 6). Using the difference in water surface elevation between years at each transect as an integrated measure of erosion (incision) or deposition (aggradation), substantial change is apparent in the Impacted zone. From 1996 to 2001 the maximum amount of change occurred at the site closest to the dam, with substantial erosion or incision evident. Incision

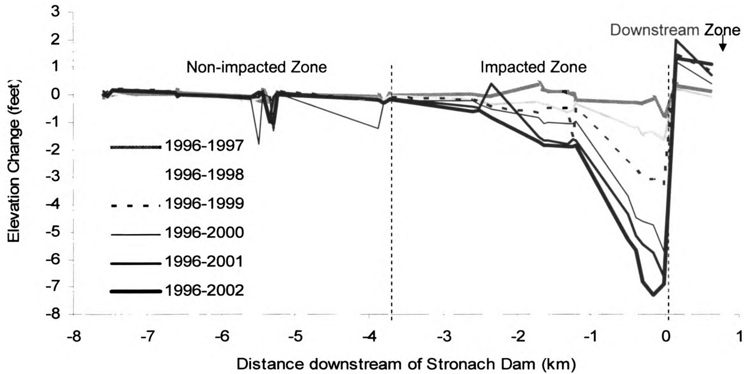

Figure 6. Change in water surface elevations from 1997 - 2002, using 1996 as a baseline. Elevation changes are in feet,with no change from 1996 equal to zero. Distances negative in magnitude denote sites upstream of Stronach Dam.

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was evident nearly 4 km upstream from the dam, but the magnitude progressively decreased upstream through the Impacted zone. In the Downstream zone, deposition of sediment released from the dam removal led to streambed aggradation and increases in water surface elevations. Small transient changes in water surface elevations were observed at some of the transects in the Non-Impacted zone. Between 2001 and 2002 sampling, no additional removal of the dam occurred. During this period, the site with the greatest amount of incision progressed upstream, and the downstream site closest to the dam also experienced some incision.

No consistent pattern of gradient change was observed in the Non-Impacted zone (Figure 7). Gradient has generally increased in the Impacted zone, except for one transect series where a large wood debris dam was formed immediately downstream from the last transect in this series. With this site excluded, gradient in the Impacted zone has increased (Table 3). Gradient in the Impacted zone is still less than in the Non-Impacted zone. Gradient could not be calculated for the Downstream zone since there are only two transects, and relative elevations for each were not coupled. However, differential change in water surface elevations indicate that the gradient has increased in the Downstream zone.

In the Impacted zone, degradation of the streambed has been most evident close to the dam. The streambed in this zone is now approximately seven feet lower in elevation than it was in 1996 (Figure 8). In the Impacted zone, as the river has incised through accumulated sediments, the river channel

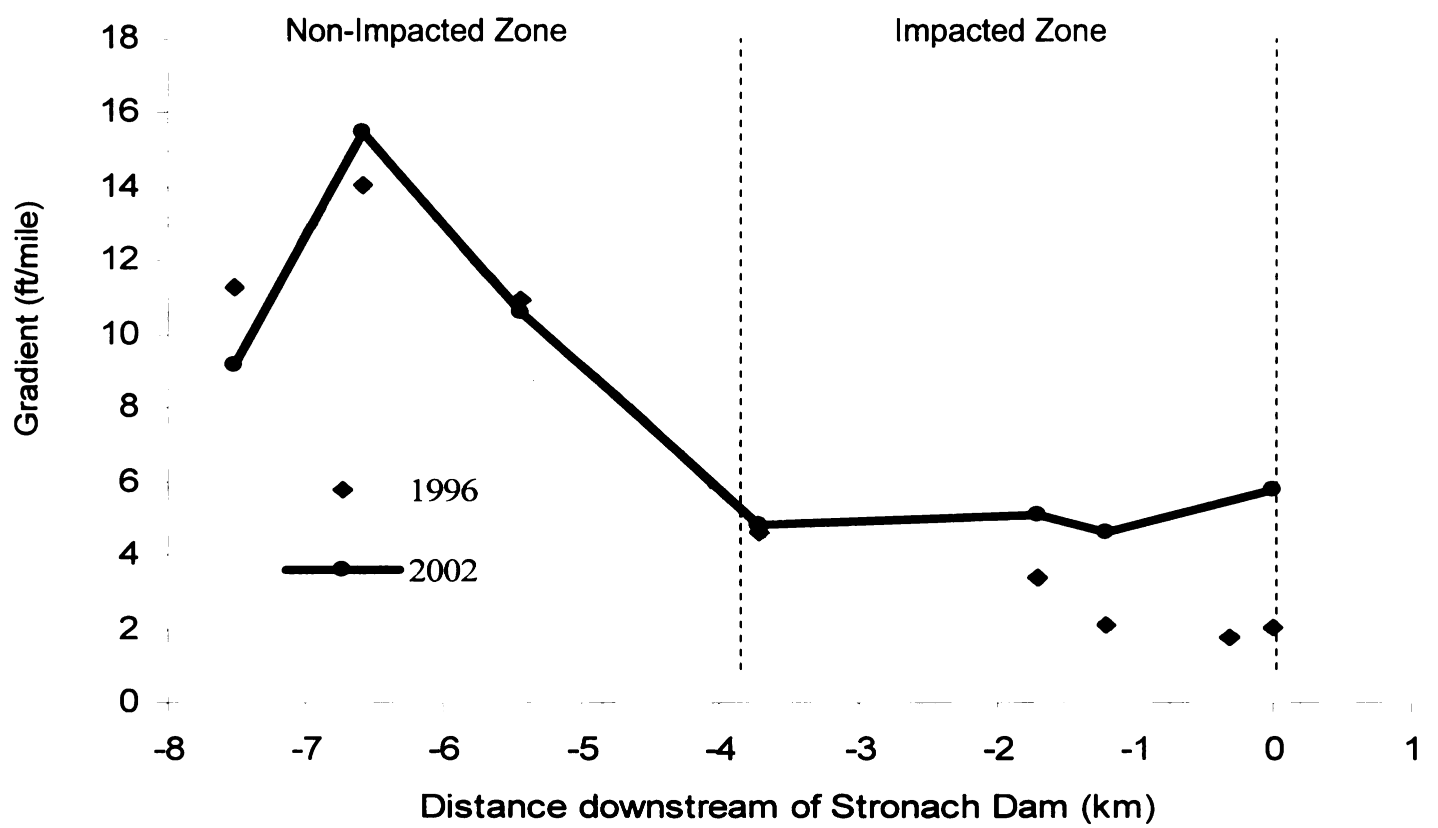
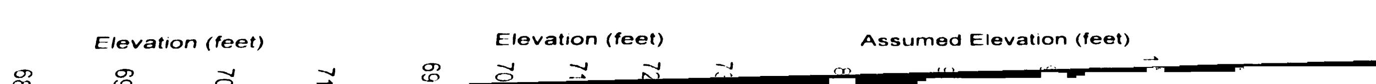


Figure 7. Gradient in 1996 and 2002. Transect series averages used. Distances negative in magnitude denote an upstream direction from Stronach Dam.

Table 3. Selected stream metrics, averaged by study zone, for 1996 and 2002. Impacted zone gradient average excludes one site. Mean 1996 water velocity for the Downstream zone is from 1998, measurements were only taken at one site in 1996 and 1997.

	Mean Stream Width (ft)			Mean Depth (ft)			Maximum Depth (ft)		
Study Zone	**1996**	**2002**	**difference**	**1996**	**2002**	**difference**	**1996**	**2002**	**difference**
Non-Impacted Zone	56.08	56.06	-0.03	1.91	1.97	0.06	2.93	2.99	0.06
Impacted Zone	65.26	57.01	-8.26	2.16	2.14	-0.02	3.40	3.55	0.15
Downstream Zone	107.25	114.60	7.35	1.95	1.54	-0.42	3.35	3.16	-0.19

	Width/Mean Depth Ratio			Gradient (ft/mile)			Mean Water Velocity (ft/sec)		
Study Zone	**1996**	**2002**	**difference**	**1996**	**2002**	**difference**	**1996**	**2002**	**difference**
Non-Impacted Zone	31.27	30.45	-0.82	12.11	11.77	-0.34	2.08	2.45	0.37
Impacted Zone	32.34	30.05	-2.29	3.04	5.07	2.03	1.92	2.20	0.28
Downstream Zone	58.045	76.42	18.38	n.a.	n.a.	n.a.	1.39	2.08	0.69



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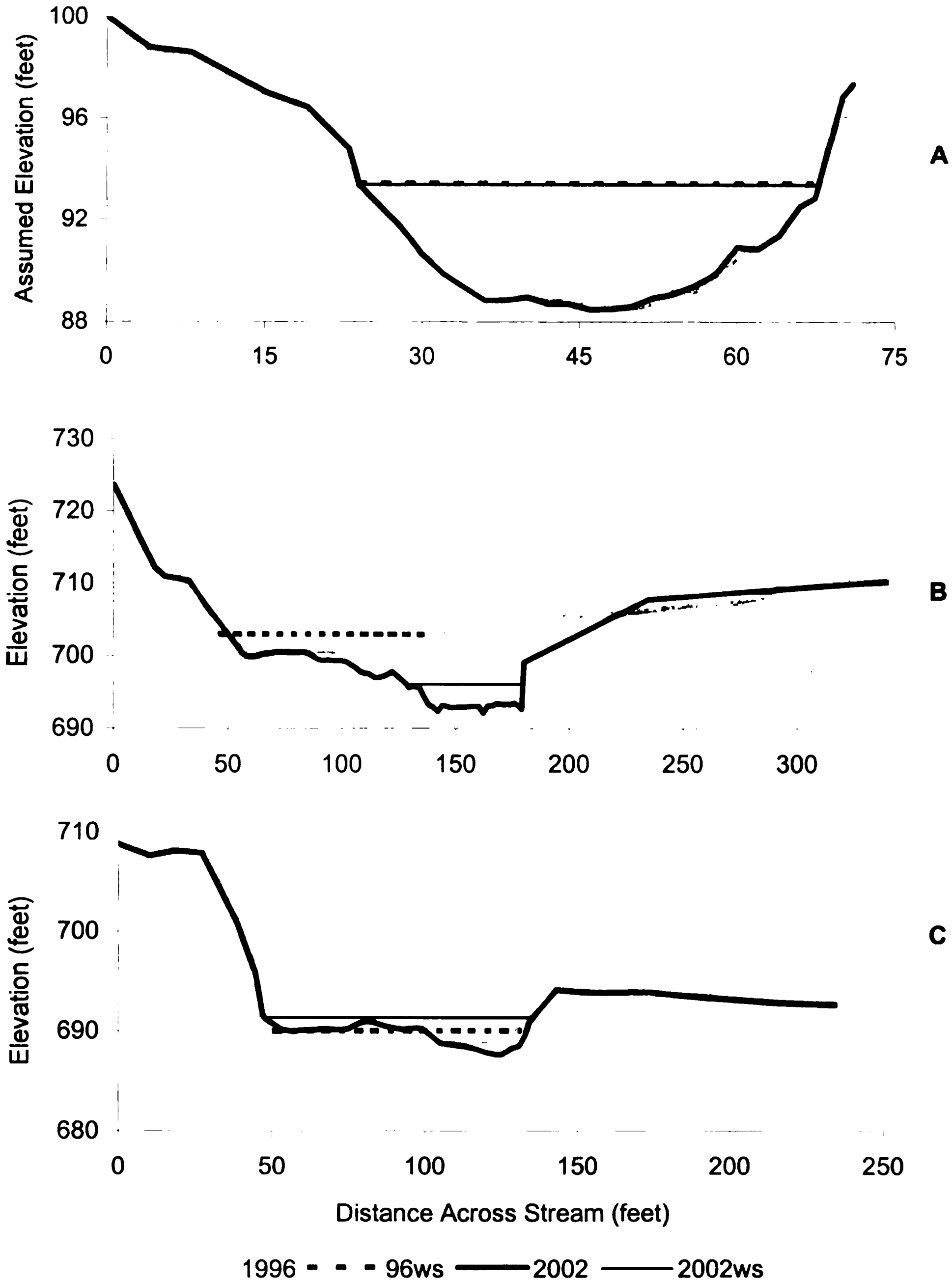

Figure 8. Representative survey transects from each of the three study zones, showing the river channel cross-section and water surface level (ws) for 1996 and 2002. Transect A is located 7.53 km upstream of Stronach Dam, in the Non-Impacted zone. Transect B is located 0.01 km upstream of the dam in the Impacted zone. Transect C is located 0.15 km downstream of the dam, in the Downstream zone.

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has decreased in width and is now similar in width to the Non-Impacted zone (Figure 9; Table 3). Change in mean and maximum depth of sites in the Impacted zone has been variable, with some sites increasing in depth and other sites decreasing in depth (Figure 10). Mean depth and maximum depth (Figure 10) of transects in the Impacted zone are similar to that seen in the Non-Impacted zone (Table 3). Decreases in the width/depth ratio were observed in the Impacted zone (Figure 11), but were primarily driven by decreases in width.

As sediment was eroded from the Impacted zone during the removal process, this sediment was deposited in the Downstream zone. Sediment deposition has raised the streambed in the Downstream zone, by as much as five feet, since 1996 (Figure 8). This streambed aggradation has led to an increase in stream width (Figure 9). In 2002, the Downstream zone was approximately twice as wide as the Non-Impacted zone (Figure 9; Table 3). Mean depth has decreased and this zone is now shallower on average than the Non-Impacted zone (Figure 10; Table 3). Maximum depth and changes in maximum depth differ between the two Downstream zone transects (Figure 10). The site immediately downstream of the dam had a greater maximum depth than the site further downstream, and maximum depth has decreased at this site while increasing slightly at the site further downstream. The width/depth ratio has increased greatly (Figure 11), because the river channel both widened and became shallower since 1996. The width/depth ratio of the Downstream zone is more than twice that of the Non-Impacted zone (Figure 11; Table 3).

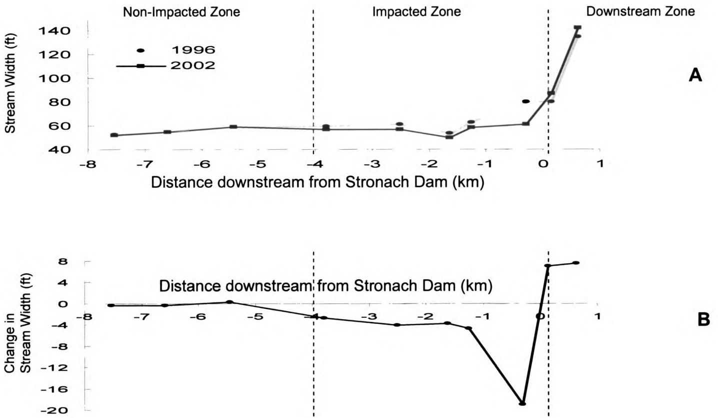

Figure 9. Stream width (A) and change in stream width (B) from 1996 to 2002. Transect series averages used. Distances negative in magnitude are upstream from Stronach Dam.


Non-Impacted Zone
Impacted Zone
Downstream Zone

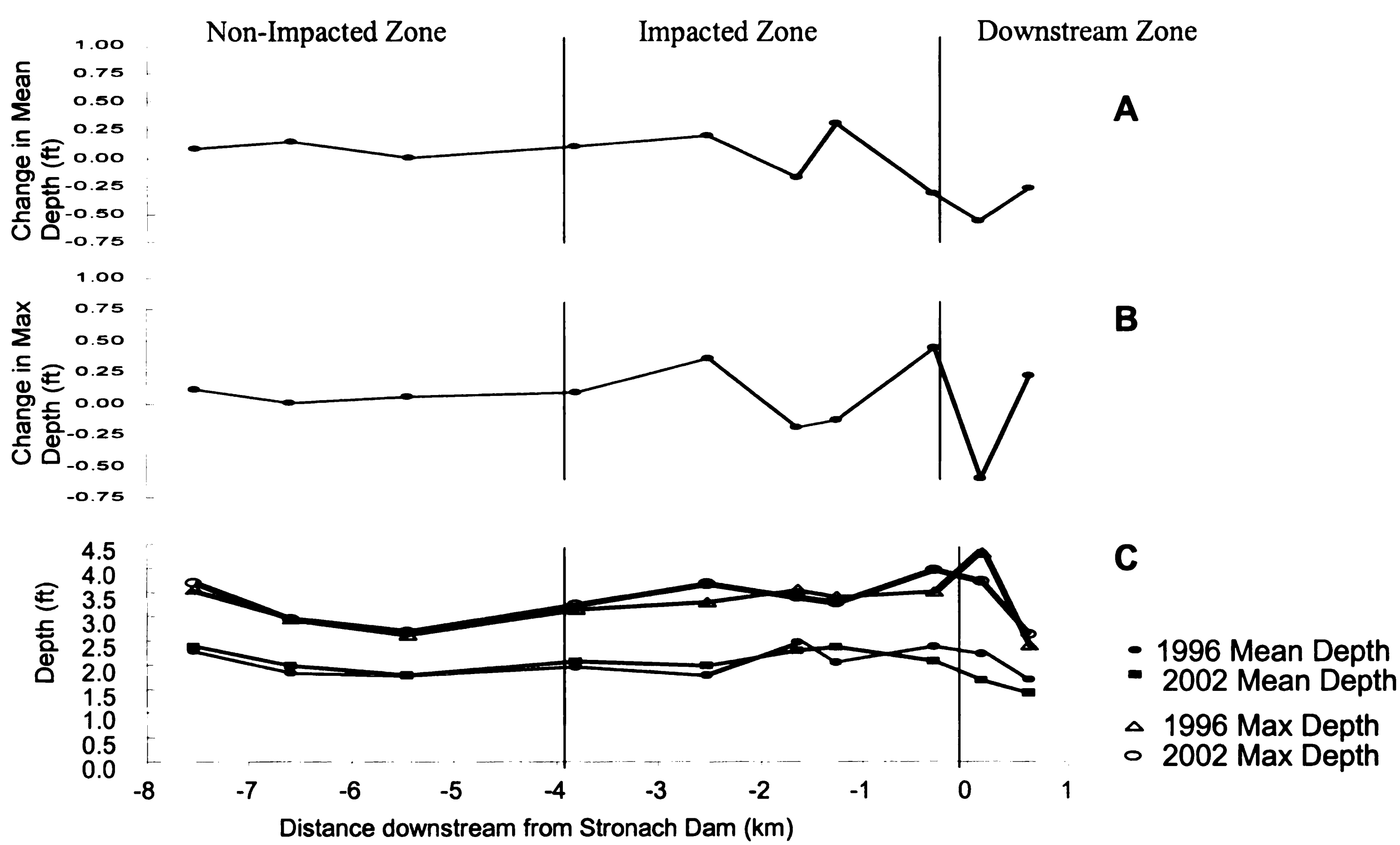

Figure 10. Change in mean depth (A), maximum depth (B) from 1996 to 2002. Mean depth and maximum depth for 1996 and 2002 (C). Transect series averages used. Negative distances are upstream from the dam.

Non-Impacted zone | *Impacted zone*

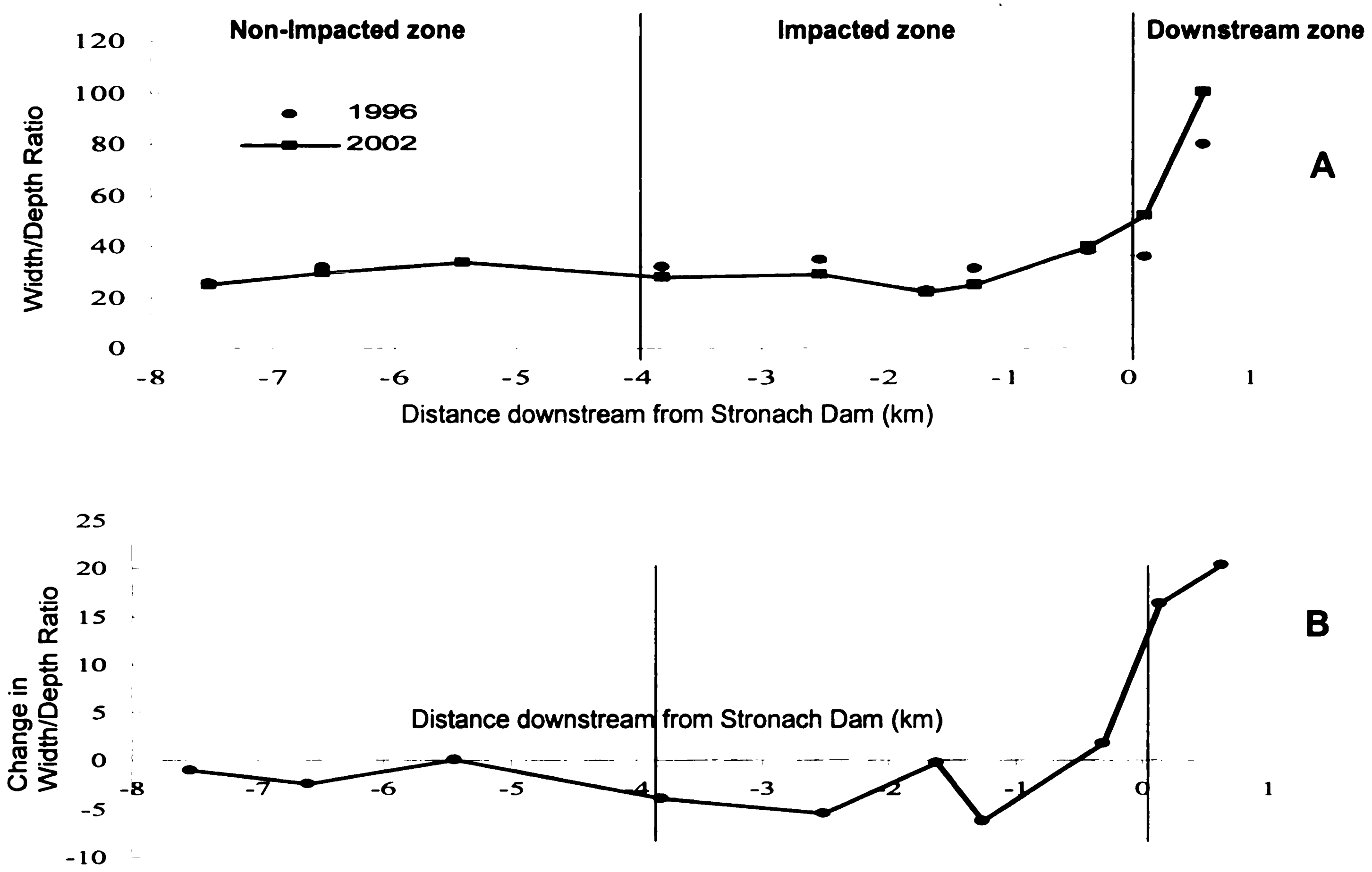

Figure 11. Width to Depth ratio (A) and change in width to depth ratio (B) from 1996 to 2002. Transect series averages used. Distances negative in magnitude are upstream from the dam.

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Total stream discharge for the years 1996 to 2002 (Appendix A) shows no consistent trends over time and increases only slightly in a downstream direction. Variability from year to year may be attributed to seasonal or daily fluctuations in water level. For each year of survey, the discharge has ranged between 247 – 353 cfs.

There is considerable within zone variation in mean water velocity, and no significant changes in mean water velocity were detected for any of the zones (Paired T-test using site means within a zone: Non-Impacted zone 1996 vs. 2002, n=3, t=2.05, p=0.18; Impacted zone 1996 vs. 2002, n=5, t=0.89, p=0.42; Downstream zone 1998 vs. 2002, n=2, t=1.68, p=0.34); (Figure 12; Table 3). Water velocity frequency distributions for 1996 and 2002 for each study zone were analyzed (Figure 13). All zones had significantly different distributions in 2002 than in 1996 (Non-Impacted zone: D = 0.306, n_1 = 77, n_2 = 95, p<0.01; Impacted zone: D = 0.247, n_1 = 138, n_2 = 192, p<0.01; Downstream zone: D = 0.405, n_1 = 107, n_2 = 128, p<0.01). All zones had more uniformly-spread distributions with increased frequencies of higher water velocities in 2002.

Median substrate size decreases in a downstream direction, with no consistent trend through time (Figure 14). Substrate size frequency distributions for 1997 and 2002 for each study zone were analyzed (Figure 15). The substrate size distributions of the Impacted and Downstream zones, for 1997 and 2002 were significantly different (Impacted zone: D = 0.155, $n_{1,2}$ = 1700, p<0.01)(Downstream zone: D = 0.170, $n_{1,2}$ = 200, p<0.01), and the Non-Impacted zone was not significantly different (Non-Impacted zone: D = 0.047, $n_{1,2}$

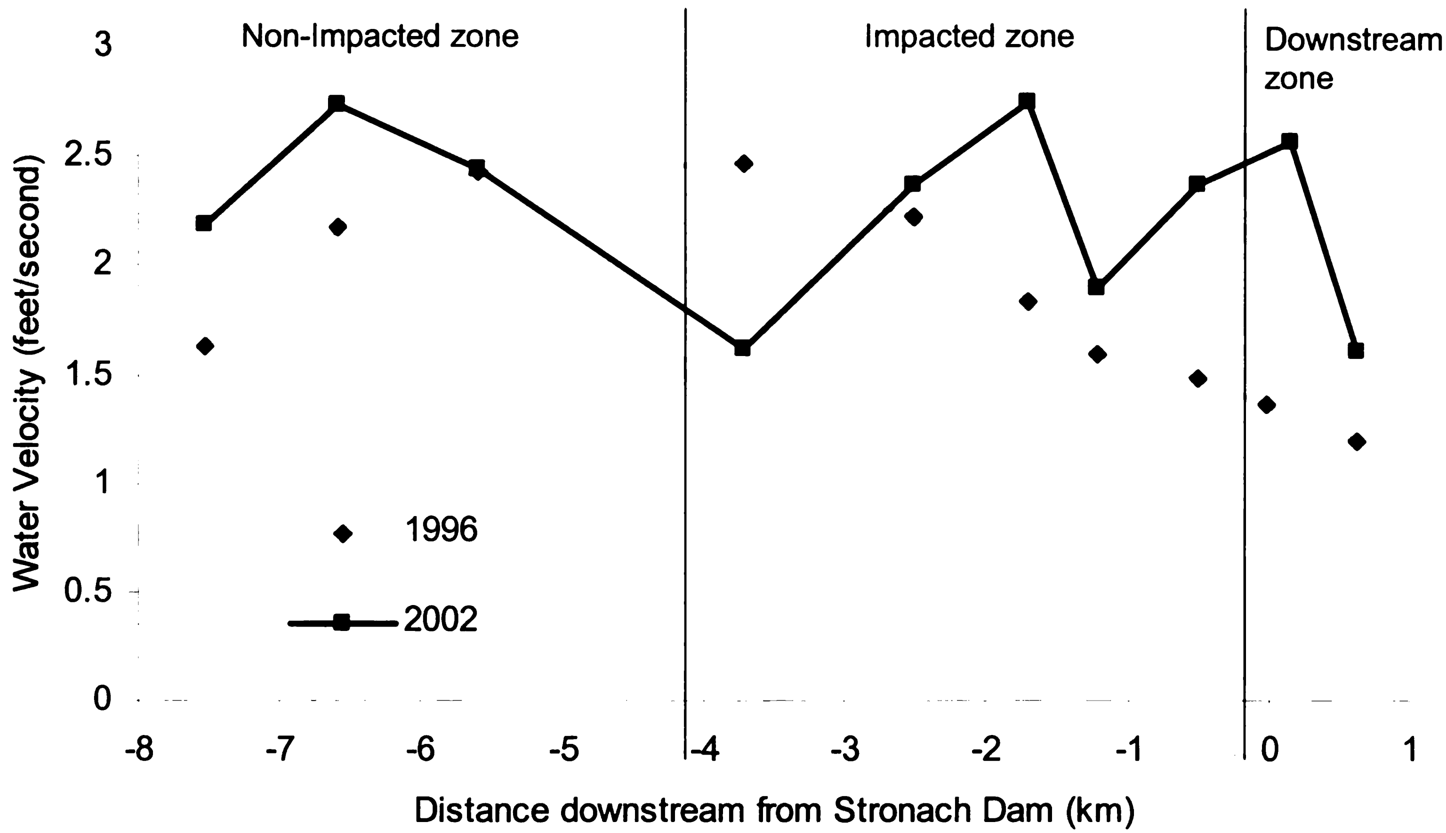

Figure 12. Mean water velocities in the Pine River, in 1996 and 2002. Distances negative in magnitude are upstream from the dam.

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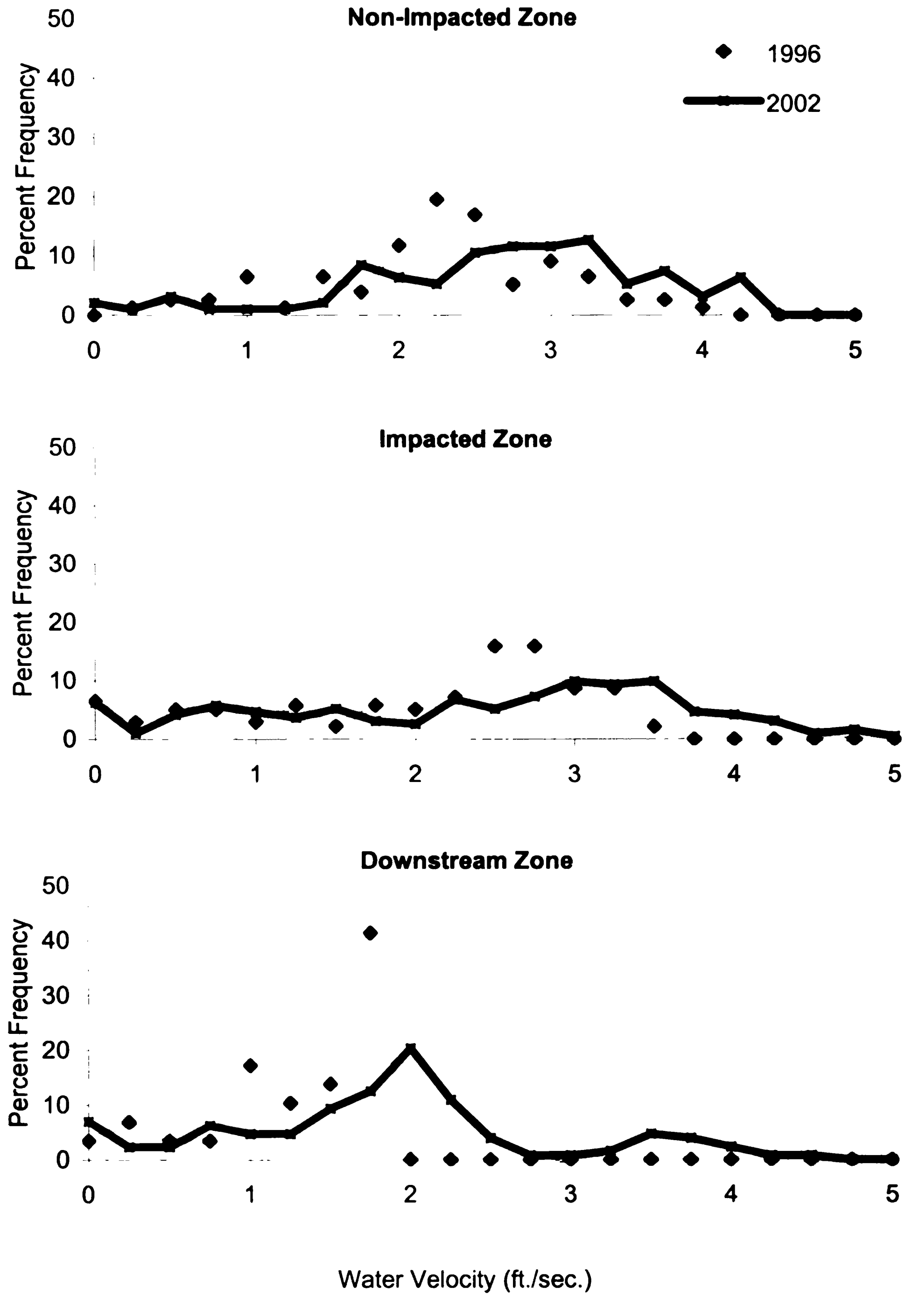


Figure 13. Water velocity percent frequency distribution charts for each of the study zones, 1996 and 2002.

Non-Impacted zone | Impacted zone | Downstream

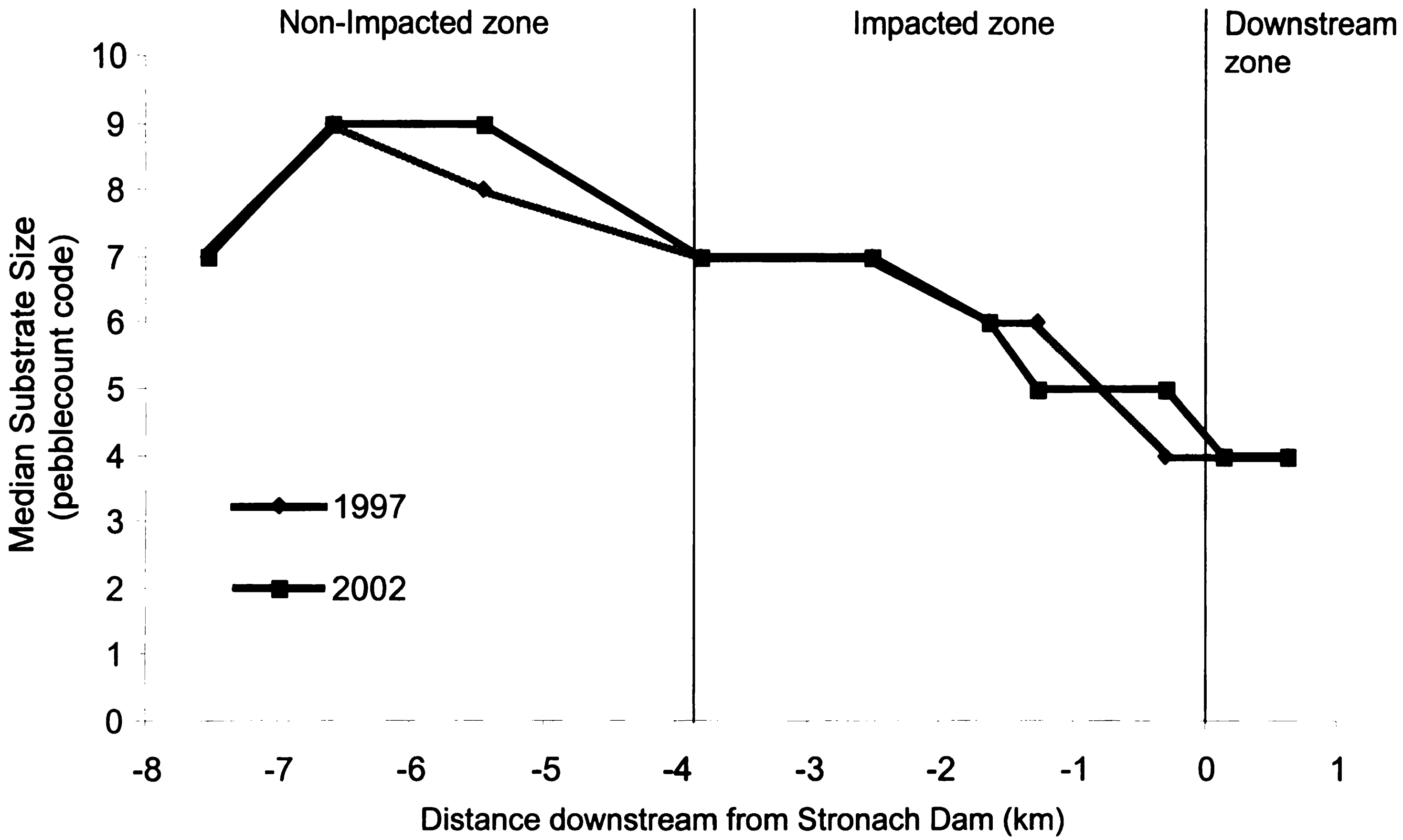


Figure 14. Median substrate size longitudinally in the Pine River. Pebblecount codes correspond to size classes (Table 2).Sites with river distances negative in magnitude denote upstream from Stronach Dam, sites with positive river distance are downstream from dam.

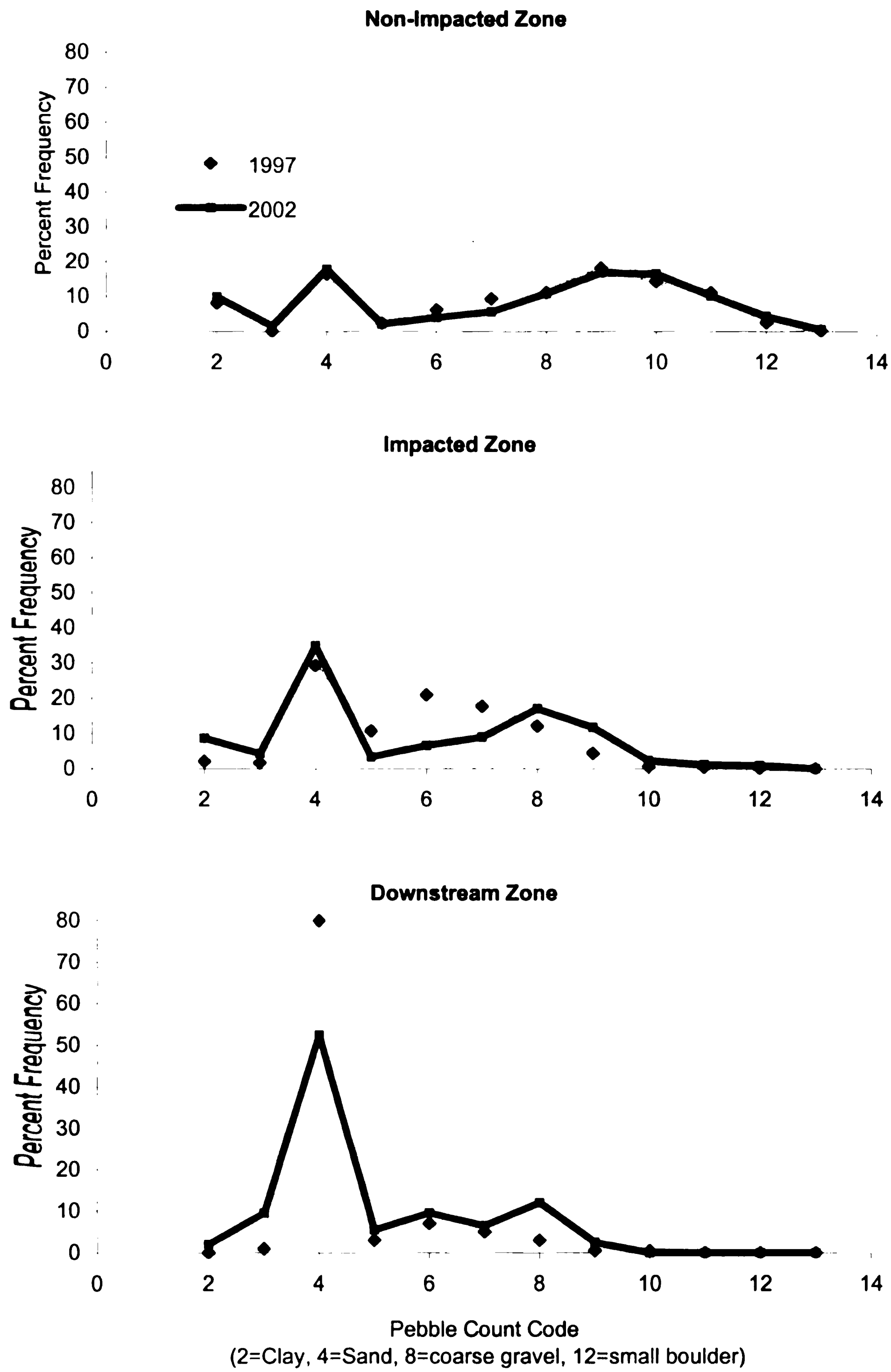


Figure 15: Substrate size percent frequency distribution, for each zone, 1997 and 2002.

=1200, p>0.05). The Impacted zone has a lower frequency of fine gravel and a higher frequency of coarse gravel. The Downstream zone had a lower frequency of sand in 2002, and higher frequencies of silt and coarse gravel. The Non-Impacted zone had the widest range of substrate sizes, the most evenly-spread distribution, and the highest frequency of small boulders and cobble.

Fish Populations

Since 1996, a total of 35 fish species have been encountered in the Pine River (Table 4). Sixteen species were found only downstream of Stronach Dam, three species were found only upstream of the dam, and 16 species were found both upstream and downstream of the dam. Upstream of the dam, a coldwater fish community dominates, with brown trout, rainbow trout, slimy sculpin (*Cottus cognatus*), mottled sculpin (*Cottus bairdi*), American brook lamprey (*Lampetra appendix*) and white suckers being the most abundant species. Downstream of Stronach Dam, a coolwater fish community is dominant, with various sucker, minnow, and darter species, northern pike (*Esox lucius*), and smallmouth bass (*Micropterus dolomieu*) being the most abundant species. The fish community in this zone is heavily influenced by migrations to and from Tippy Dam Reservoir, which begins approximately 2 km downstream.

Annual density estimates of brown trout, rainbow trout, brook trout, white suckers, and shorthead redhorse suckers were calculated for each sampling site (Appendix B) and averaged for each study zone (Appendix C). Brown trout were the most abundant coldwater game fish in all three study zones, averaging 72/ha

Table 4. Pine River fish species occurrence from 1996 -2002.
(* indicates Non-Indigenous species)

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

in the Non-Impacted zone, 64/ha in the Impacted zone, and 12/ha in the Downstream zone. Brown trout densities in the Non-Impacted and Impacted zones have displayed a similar trend (General linear model: Year, Zone, Year*Zone R^2=0.661, Year*Zone p=0.1094). Brown trout density in these zones were between 30 – 50/ha from 1997 to 1999, and increased substantially between 1999 and 2000, remaining between 90 – 130/ha through 2002 (Figure 16). Brown trout density in the Downstream zone has been consistently low (5 – 20/ha) throughout the entire study.

Brown trout length compositions in the Non-Impacted and Impacted zones in 1997 were similar (K-S Test: D = 0.201, n_1 = 48, n_2 = 54, p>0.05). Both of these zones also showed similar patterns of length composition change. No change in length compositions occurred from 1997 to 1999, and from 2000 to 2002 the abundance of all length classes increased (Figure 17), but the distribution of lengths did not (K-S Test: Non-Impacted zone 1997 vs. 2002, D = 0.163, n_1 = 48, n_2 = 124, p>0.05; Impacted zone 1997 vs. 2002, D = 0.196, n_1 = 54, n_2 = 191, p>0.05). In the Downstream zone, relatively few brown trout were sampled each year. However, length composition in this zone from 1997 to 2002 has changed from mostly larger fish to mostly smaller fish (K-S Test: D = 0.875, n_1 = 8, n_2 = 5, p<0.05). All brown trout sampled in 1997 were greater than 225 mm in length, and in 2002 all brown trout sampled were less than 250 mm.

Rainbow trout were the second most abundant coldwater gamefish, averaging 42/ha in the Non-Impacted zone, 27/ha in the Impacted zone, and 3/ha in the Downstream zone. Rainbow trout density in the Non-Impacted and

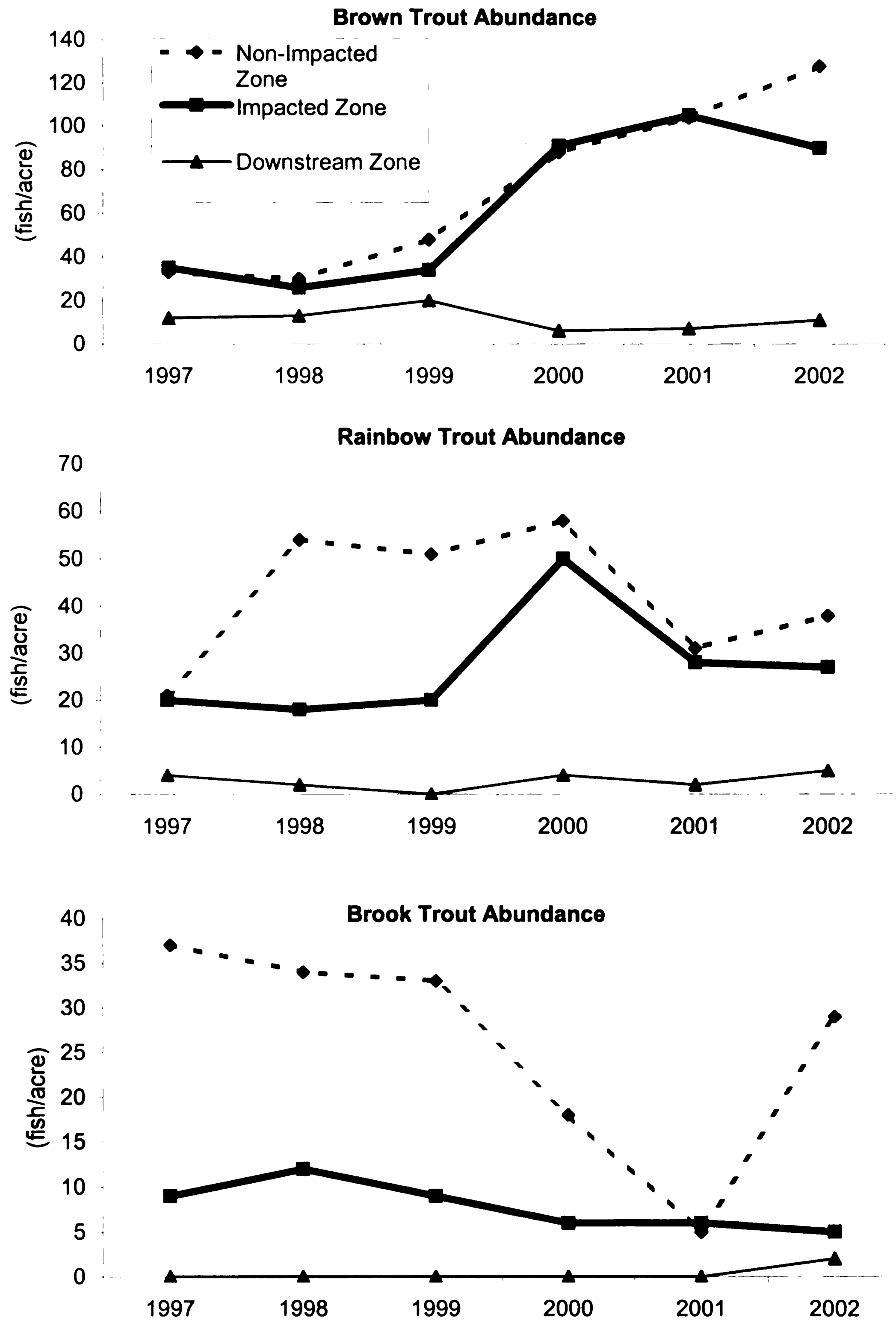


Figure 16: Annual density estimates for brown trout, rainbow trout and brook trout, in each study zone, for years 1997 - 2002.

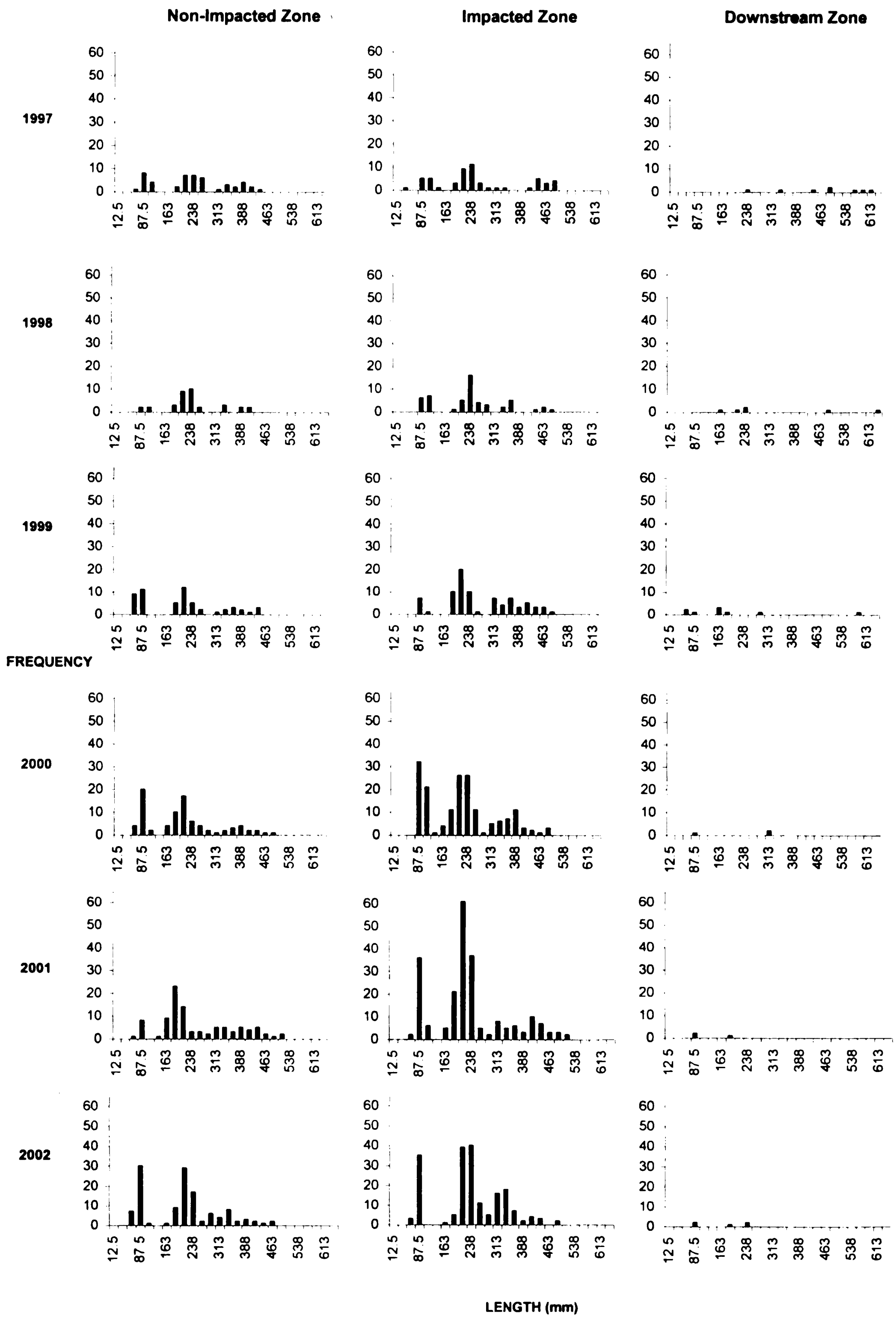


Figure 17. Length frequency distributions for brown trout in the Pine River, for each study zone (columns) and for each year (rows) from 1997 - 2002.

Impacted zones was nearly identical in 1997, averaging 21 and 20/ha respectively. In 1998, rainbow trout density in the Non-Impacted zone increased and stayed between 50 – 60/ha through 2000. Rainbow trout density in the Impacted zone stayed around 20/ha until it peaked at 50/ha in 2000. Density declined in both zones in 2001, and stayed between 30 – 40/ha through 2002 (Figure 16). Rainbow trout density in the Downstream zone was low (0 – 5/ha) throughout the entire study period.

Few rainbow trout less than 125 mm and greater than 350 mm where captured in any of the zones from 1997 to 2002. Rainbow trout spawn in the spring, and during our summer sampling the young of the year fish have a low susceptibility to boat electrofishing due to their small size. In 1997, length composition of rainbow trout in the Non-Impacted and Impacted zones was similar (K-S Test: $D = 0.312$, $n_1 = 25$, $n_2 = 43$, $p>0.05$). In the Non-Impacted zone, numbers of fish in the 150 – 250 mm length class increased from 1998 to 2000 (Figure 18). In the Impacted zone, length composition was similar from 1997 to 1999, with an increase in the numbers of rainbow trout in the 150 – 275mm size range in 2000. Despite these changes, the distribution of length classes did not change significantly from 1997 to 2002 (K-S Test: Non-Impacted zone 1997 vs. 2002, $D = 0.190$, $n_1 = 25$, $n_2 = 36$, $p>0.05$; Impacted zone 1997 vs. 2002, $D = 0.271$, $n_1 = 43$, $n_2 = 56$, $p>0.05$). Too few rainbow trout were sampled in the Downstream zone in any one year to draw conclusions about their length composition.

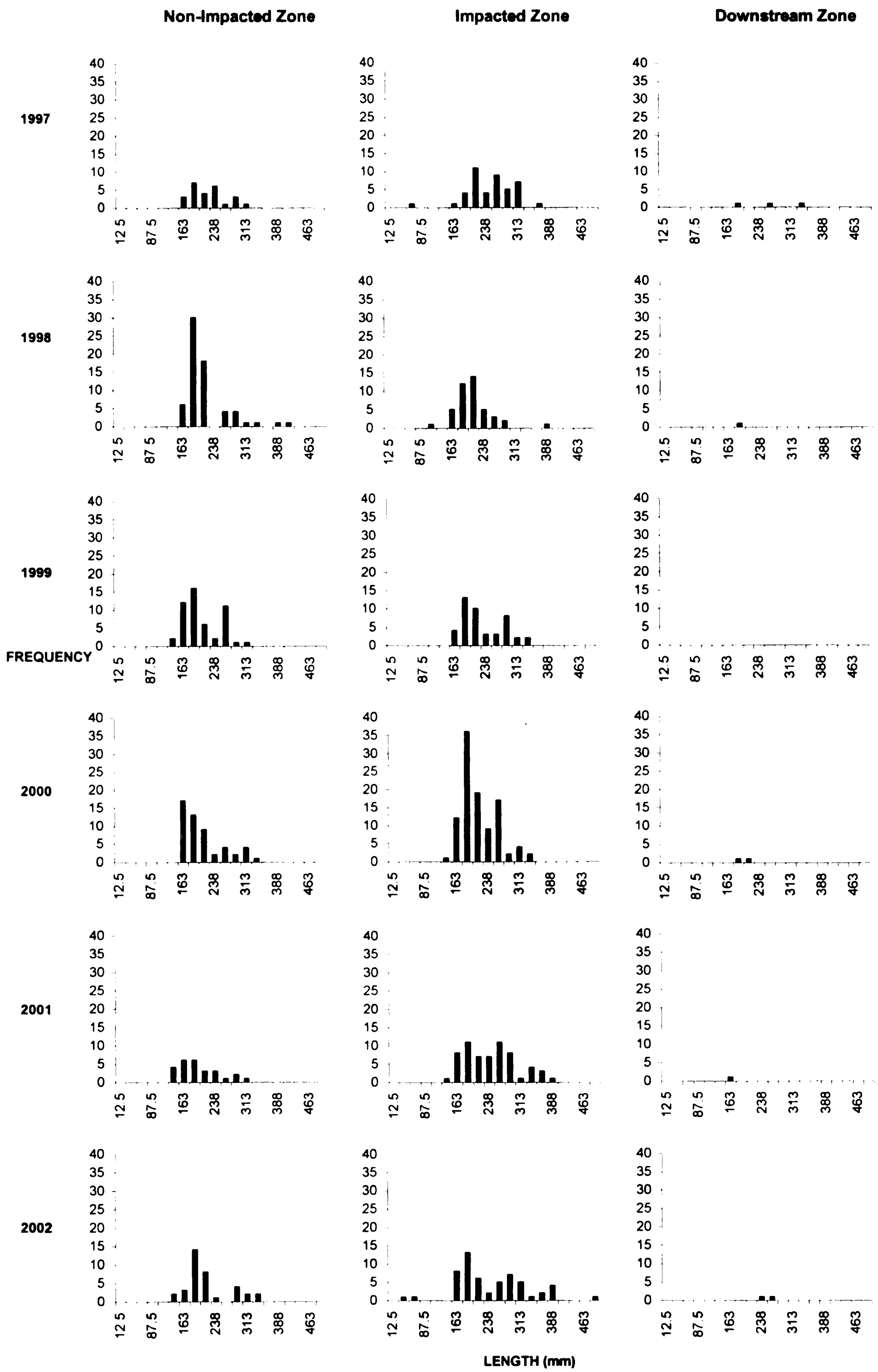


Figure 18: Length frequency distributions for rainbow trout in each study zone (columns) of the Pine River, for each year (rows) from 1997 - 2002.

Density of brook trout in the Non-Impacted zone generally stayed between 30 – 40/ha throughout the study, with the exception of a sharp decline down to 5/ha between 2000 and 2001 (Figure 16). Brook trout densities in the Impacted zone have stayed consistently low, (5 – 12/ha) during the entire study. Brook trout were rarely caught in the Downstream zone. Brook trout density generally declined in a downstream direction within the study area.

Brook trout length composition in the Non-Impacted and Impacted zones was similar in 1997 (K-S Test: $D = 0.259$, $n_1 = 46$, $n_2 = 29$, $p>0.05$), with most of the fish generally being between 150 – 225 mm in length (Figure 19). Brook trout length composition in the Non-Impacted and Impacted zones appears variable due to the relatively low number of them captured in the Pine River. Statistically significant differences in the length composition of brook trout were not detected between 1997 and 2002 (K-S Test: Non-Impacted zone 1997 vs. 2002, $D = 0.241$, $n_1 = 46$, $n_2 = 20$, $p>0.05$; Impacted zone 1997 vs. 2002, $D = 0.127$, $n_1 = 21$, $n_2 = 9$, $p>0.05$). In the Downstream zone, only one brook trout has been captured from 1997 to 2002.

In the Non-Impacted zone, white sucker density steadily increased from 11/ha in 1997 to 68/ha in 2000, and then decreased in 2001, remaining between 13 – 18/ha through 2002 (Figure 20). White sucker density in the Impacted zone steadily declined from 1997(62/ha) to 1999(8/ha) and then increased in 2000, remaining between 20 – 25/ha through 2002. In the Downstream zone, white sucker densities were much higher than in the two upstream zones. In this zone, density increased from 1997(157/ha) to 1999(250/ha); decreased through

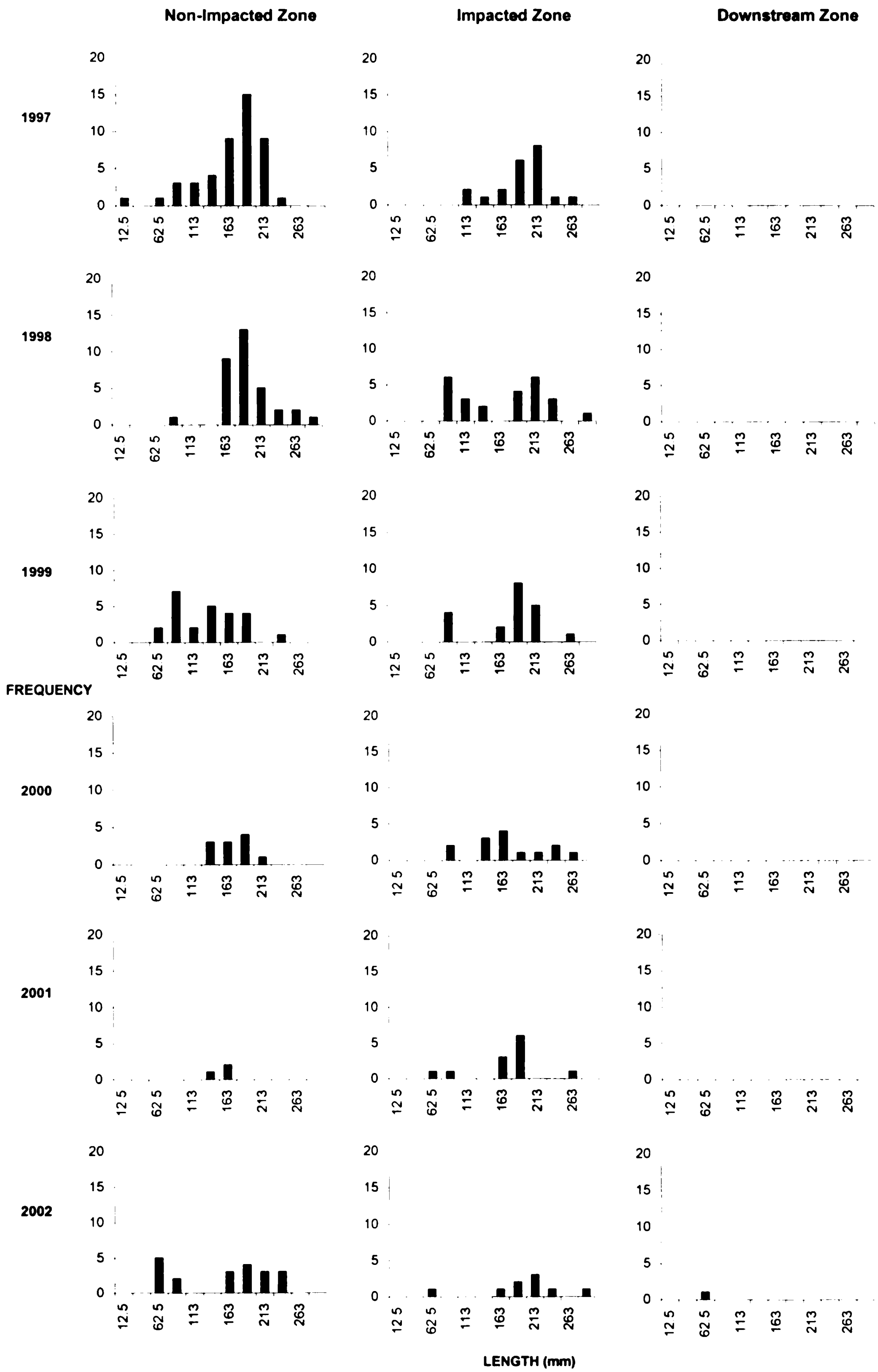
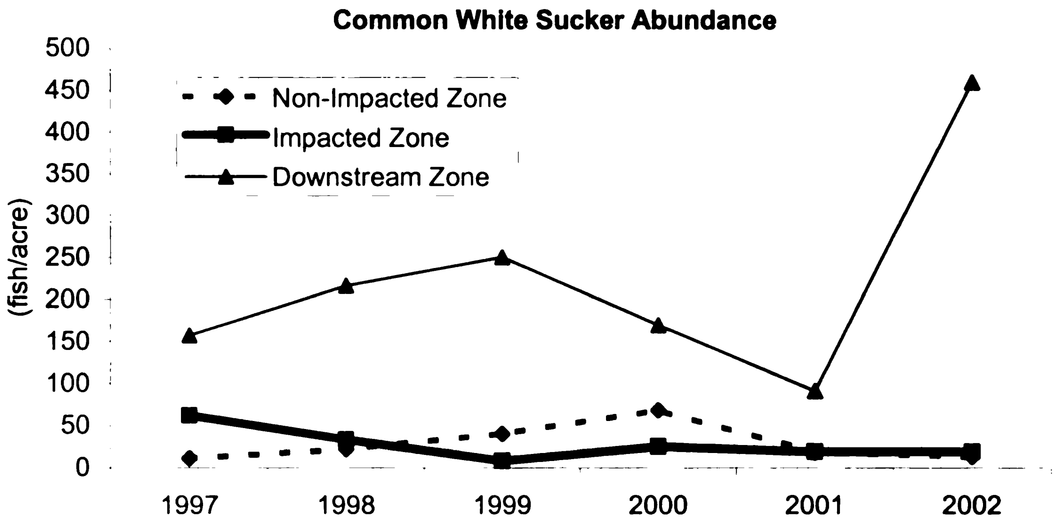


Figure 19. Length frequency distributions for brook trout in each study zone (columns) of the Pine River, for each year (rows) from 1997 - 2002.



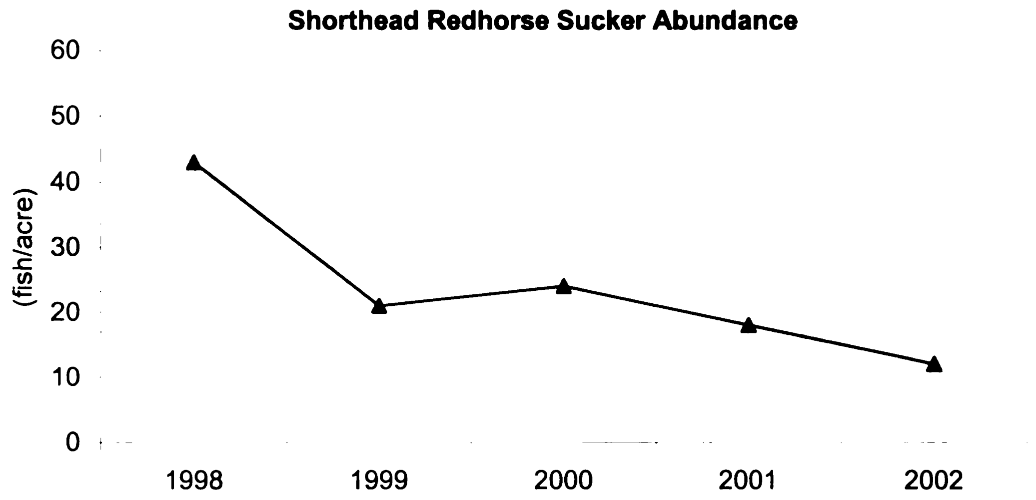


Figure 20. Annual density estimates for white sucker and shorthead redhorse sucker, in each study zone, for years 1997 - 2002.

2001(91/ha); and increased substantially in 2002(460/ha). White sucker abundance increases in a downstream direction with the study area.

Length composition of white suckers in the Non-Impacted zone shifted from a relatively even length distribution in 1997, with fish from 100 – 500 mm, to a skewed distribution in 2000 of fish less than 225 mm in length (Figure 21). In 2002, the length composition of white suckers in the Non-Impacted zone is still relatively skewed to smaller fish, less than 275 mm, and is significantly different from the 1997 length composition (Non-Impacted zone 1997 vs. 2002, $D = 0.488$, $n_1 = 15$, $n_2 = 16$, $p=0.05$). White sucker length composition in the Impacted zone shifted from a large number of fish between 75 – 325 mm and the presence of larger fish between 400 – 525 mm in 1997, to exclusively small fish under 125 mm in length (Impacted zone 1997 vs. 2002, $D = 0.884$, $n_1 = 129$, $n_2 = 21$, $p<0.01$). In the Downstream zone, the length composition is relatively evenly distributed, with fish from 50 – 400 mm sampled each year of the study. The length composition in this zone has not changed much from year to year, even though the abundance has varied considerably. An exception to this occurred in 2002, when a large number of white suckers between 75 – 100 mm were sampled, changing the length composition of fish in this zone significantly (Downstream zone 1997 vs. 2002, $D = 0.378$, $n_1 = 50$, $n_2 = 193$, $p<0.01$).

Shorthead redhorse suckers were found in the Downstream zone only. Density of this species was relatively high in 1997(107/ha) and generally declined through 2002(30/ha) (Figure 20). In 2002, shorthead redhorse suckers were at approximately one third the density they were at in 1997. No shorthead redhorse

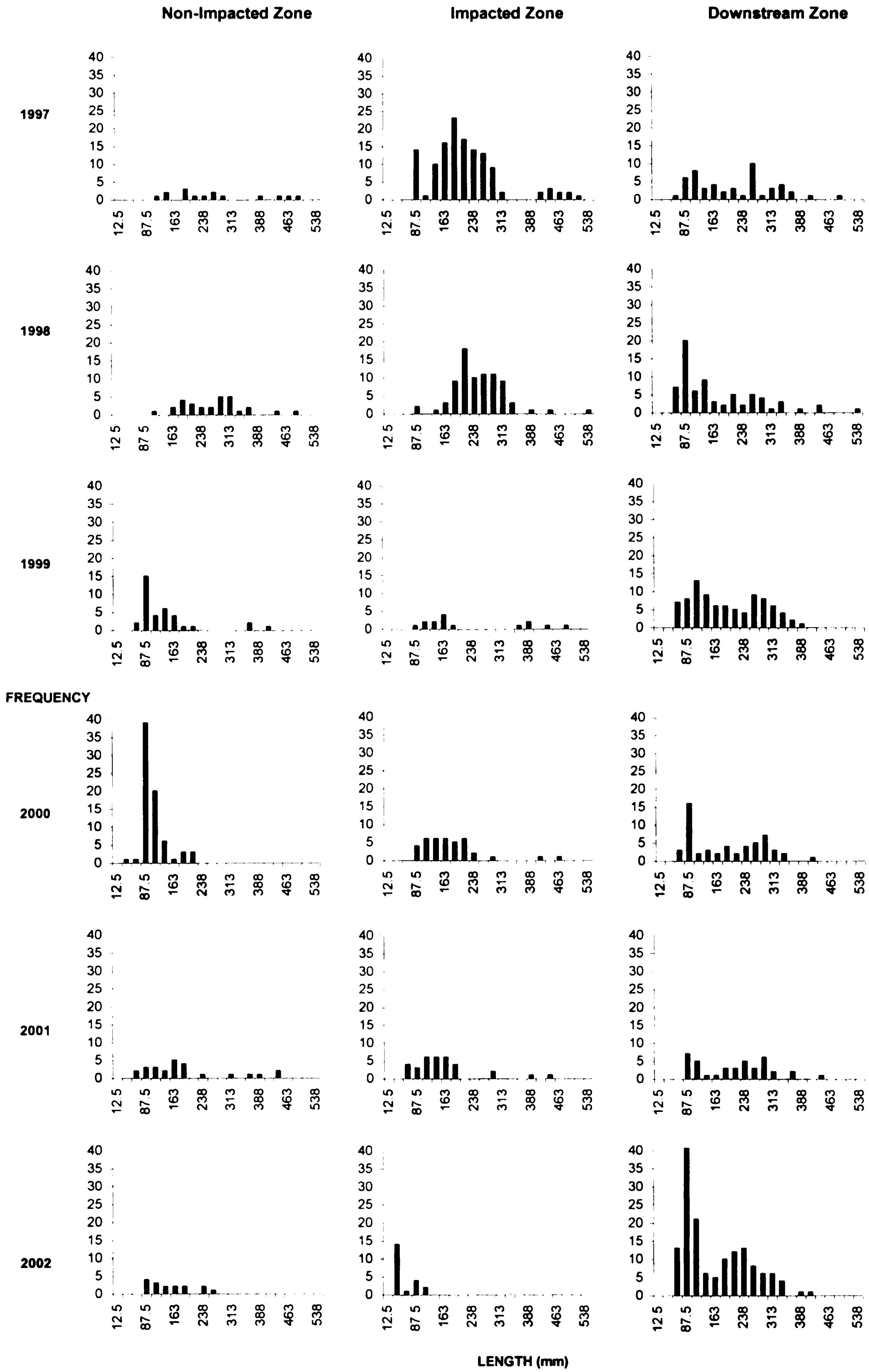


Figure 21. Length frequency distributions for white sucker in each study zone (columns) of the Pine River, for each year (rows) from 1997 - 2002.

suckers less than 125 mm in length have been sampled, and in general most fish sampled are over 300 mm in length (Figure 22). Minimum length of this species sampled in the Pine River has gradually shifted from >175mm in 1997 to >300 mm in 2002. However, no significant differences in length composition between 1997 and 2002 were detected (Downstream zone 1997 vs. 2002, $D = 0.214$, $n_1 = 28$, $n_2 = 13$, $p>0.05$).

DISCUSSION

Fluvial Geomorphology

When a dam is erected, it halts the flow of water coming down a river, backing water up, raising the water surface elevation and flooding adjacent riparian lands. This continues until the water surface elevation is equal to the operating height of the dam, and causes water to be impounded upstream to a point where the streambed of the river is higher in elevation than the water surface of the impoundment. Where the river enters the impoundment, a sediment delta forms from the river's sediment load reaching the stiller waters of the impoundment. As sediment continues to be delivered to the impoundment, the sediment delta grows and its leading edge progresses downstream toward the dam. Over time, the sediment delta can reach the dam and continue to accumulate. As this occurs, the difference in streambed elevation between the upstream boundary of the impoundment and the upstream face of the dam diminishes. While this occurs, the river downstream of a dam is usually starved

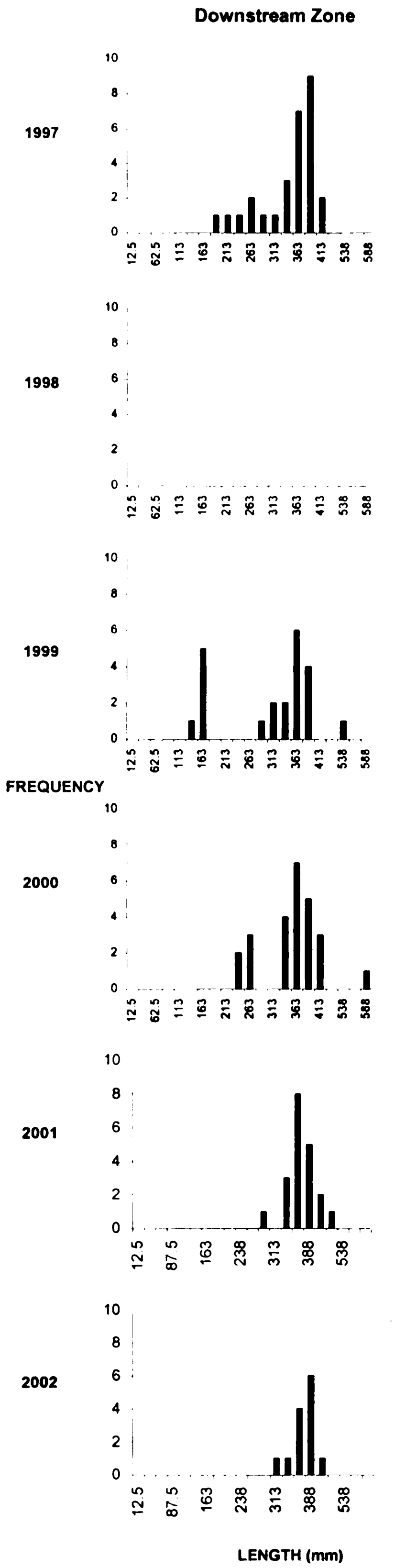


Figure 22. Length frequency distributions for shorthead redhorse sucker in each study zone (columns) of the Pine River, for each year (rows) from 1997 - 2002.

of sediment, and bank erosion, streambed erosion, substrate coarsening and channel adjustments can occur (Rathburn and Wohl 2003; provides a valuable review of the downstream effects of dams). If a reservoir becomes completely filled with sediment, additional sediment load entering the reservoir is translated to the downstream zone, acting to reverse the previously mentioned processes (Randle 2003).

When a dam is removed, the accumulated sediment, no longer held in place by the dam, loosens and is eroded by water force. As this sediment moves downstream, the sediment immediately upstream is now loosened and eroded downstream. This process, called sediment fill incision (also called headcut migration, knickpoint migration, degradation, or downcutting) continues to progress upstream until the boundary between the impounded and unimpounded river is reached (Pizzuto 2002; Doyle et al 2002). As this erosion is occurring above the dam, the river's elevation will lower as it incises through the sediment fill. The impoundment will decrease in width; as gradient is re-established water velocity will increase; and eventually as fine-sediment fill is transported downstream, substrate coarsening is expected. As the incision continues and streambed elevation is lowered, bank steepness will increase to a critical point (depending on soil characteristics), at which point bank slumping will occur, allowing the formation of floodplains and an equilibrium channel (Doyle et al 2002 provide a useful review of channel incision processes and channel evolution models in the context of dam removal).

At the same time, the downstream zone will receive inputs of sediment from the upstream reaches unless active measures are taken to remove sediment deposits in the impoundment. Sediment being deposited in the downstream zone can fill in deep areas like pools where water velocity is slower (selective sediment accumulation), and/or be deposited throughout a channel (generalized sediment accumulation) causing decreases in depth, increases in width, decreases in substrate size, and channel morphology changes such as the initiation of braiding and floodplain aggradation (Rathburn and Wohl 2003). The changes in the downstream zone should be transient as normal sediment loads and sediment transport dynamics are re-established.

The removal of Stronach Dam was done in stages in order to minimize the amount of exposed sediment fill vulnerable to flooding and allow for gradual revegetation, hopefully minimizing excess sedimentation downstream of the dam. This case study provides a clear, well-documented example of sediment fill incision and subsequent downstream sediment deposition following a dam removal in which sediment management was accomplished through river erosion.

As the staged removal of Stronach Dam progressed, corresponding amounts of sediment fill incision where documented upstream of the dam. The amount of incision, measured here as decreases in water surface elevation, was greatest closest to the dam and attenuated in an upstream direction. This incision process progressed upstream over 1 km during the first 3 months after the initial stage of the removal, and by the fourth year of annual surveying, had progressed through the entire 4 km formerly impounded area. During the subsequent stages of removal, the total amount of incision increased. In 2002, the water surface elevation immediately upstream of the dam was approximately 7 feet lower than in 1996, before the dam removal began. This can also been seen in the amount of gradient increase being greatest closest to the dam and progressively decreasing in an upstream direction. During this period, lateral adjustments in channel position, decreased channel width, decreased water depth, increased water velocity, and increased frequency of coarse substrates were observed in the former impoundment.

Between annual surveying in 2001 and 2002, no removal activities occurred, providing insight into future river channel adjustments following completion of the staged removal. Each year of removal from 1997 to 2001, the maximum amount of sediment fill incision, as shown by a decrease in water surface elevation, occurred at the upstream site closest to the dam, and attenuated in an upstream direction for approximately 4 km through the former impoundment. However, between 2001 and 2002 the maximum amount of incision progressed upstream approximately 100 meters. This indicates that the stream channel in the former impoundment will likely continue to incise and evolve long after dam removal is complete. Monitoring studies of incised channels suggest that this continued channel evolution could take decades before an equilibrium is reached (Pizzuto 2002).

Sediment eroded from the former impoundment was deposited downstream from Stronach Dam. This downstream zone is different from many sections of rivers downstream from dams in that the reservoir had completely filled with sediment by 1940, a short 30 years or so after it was built. At this time, additional sediment load was transported through the reservoir and delivered to the Downstream zone. Also, during the subsequent decommissioning and partial dismantling of the dam, additional sediment fill from the reservoir was delivered to the Downstream zone. At the initiation of this study, the Downstream zone was characterized as homogenous "run" habitat dominated by sand substrate, indicating streambed aggradation had occurred to some extent.

During the staged removal, more sediment was deposited in this zone, further aggrading the streambed, raising the water surface elevation, increasing the stream width and decreasing the water depth. This section of river could now be described as relatively wide, shallow, and dominated by loose sand substrate. Based on observations from different sections of the Downstream zone, both processes of selective and general sediment aggradation likely occurred.

Between 2001 and 2002, when no removal activities occurred, streambed degradation and coarsening of the substrate were documented at the closest site downstream of the dam. This could indicate that the magnitude of sediment load resulting from continued sediment fill incision following complete dam removal is within the normal transport capabilities of the Downstream zone. If this is the case, habitat recovery in the Downstream zone could proceed relatively quickly.

These processes of sediment fill incision upstream of the dam, subsequent streambed aggradation in the Downstream zone, and eventual transport of sediment through the Downstream zone are expected to continue until an equilibrium channel is formed. For some dam removal situations, this process could continue until a longitudinal elevation (gradient) profile similar to pre-dam conditions is reached. In the case of Stronach Dam and the lower Pine River, this is unlikely because the river downstream of the dam becomes impounded by Tippy Dam Reservoir only 2-3 km downstream from Stronach Dam. This impoundment is believed to limit the rate of sediment transport through the Downstream zone and is likely to limit the equilibrium gradient potential of the river following dam removal.

The Non-Impacted zone showed only small transient changes in channel morphology and water surface elevation change. This seems to indicate that the initial study zone delineation, based on habitat conditions prior to dam removal, was an effective method for predicting the spatial scope of habitat change due to dam removal.

Water velocity increased in all three zones from 1996 to 2002. An increase in water velocity was hypothesized for the Impacted zone, as sediment fill incision increased gradient in this zone. Water velocity has increased in the Downstream and Non-impacted zones as well. In the Downstream zone streambed aggradation has been greatest closest to the dam and has led to an increased gradient in this zone, which in turn has increased the water velocities. Increased water velocity in the Non-Impacted zone was an unexpected result not easily explained. Measurements of water velocity can include considerable variability due to seasonal or daily fluctuations in water levels, meso or micro scale changes in instream habitat such as aquatic vegetation growth, wood material recruitment and logjam formation, and measurement variability due to equipment. Any of these sources of variability could be responsible.

The frequency distribution of water velocities within each zone has the utility of showing the range of available habitat for various fish species. The Non-Impacted zone has generally had the greatest frequencies of high water velocities - suitable for trout, and also the highest densities of all three species of trout. Prior to the dam removal, the Impacted zone lacked high water velocities. However, this zone now has the greatest frequencies of high water velocities, the widest range of water velocities and the most even distribution of water velocities of any of the study zones. The increase in high water velocities should benefit the trout populations by providing more suitable habitat. A study by Ford (1984) found a simultaneous increase in brown trout abundance and decrease in white sucker abundance as water velocity increased in response to habitat restoration (Mistak 2000). White suckers prefer to inhabit areas of water velocity less than 1.30 ft/sec (Twomey et al. 1984). Habitat with these water velocities is most abundant at Tippy Dam Reservoir and decreases in an upstream direction to the Non-Impacted zone. As gradient and water velocities increase upstream of the dam, this habitat will likely become increasingly unsuitable to white suckers and many of the cool-water fish species found downstream of the dam.

Median substrate size showed clear longitudinal trends within the river, but no consistent temporal trends. Median substrate size decreases in a downstream direction corresponding to gradient and water velocity measurements. The frequency of substrate sizes provides clearer insight into substrate response to dam removal. Substrate sizes in the Non-Impacted zone did not change. This zone has the widest range of substrate sizes and the highest frequencies of cobble and small boulders. Substrate coarsened in both the Impacted and Downstream zone. In the Impacted zone, a higher percent of coarse gravel was observed, but the percent of sand did not decrease. This is an expected result because, as sediment fill incision occurs at sites close to the dam, coarse substrate not easily transported would be expected to remain. However, sediment fill incision would progress upstream and still lead to the transport of fine sediments through the sites closer to the dam. Therefore, even though substrate has shown some significant coarsening already, the full extent of this coarsening will likely not be realized until sediment fill incision is complete.

In the Downstream zone, frequencies of silt and small gravel increased during the 2001 -2002 period of no removal activity. Sand is by far still the dominant substrate type in this zone though. Increased frequency of small gravel was recorded at the site closest to the dam, and is associated with the process of stream degradation that occurred only at this site in the downstream zone during the study year of no additional dam removal. This local change is likely temporary; as the remaining dam structure is removed in the Fall of 2003, fine sediment will be released and will likely cover up existing gravel. As mentioned earlier though, this change does give an indication of the temporal scale in which habitat restoration could proceed.

Sand is generally considered a poor substrate for aquatic insect production, due to its instability and tight packing which can limit detritus trapping and oxygen availability (Hynes 1970, Allan 1995). Removal of these fine sediments is predicted to increase the density of aquatic insects which in turn is expected to benefit insectivorous fish species including salmonids. Substrate coarsening is also expected to benefit fish populations by increasing the amount of suitable substrate for lithophilic spawners; and by providing more diverse hydraulic conditions beneficial for resting and feeding behavior (Heggenes 1988).

Fish Populations

Upstream from Stronach Dam, a coldwater fish community dominates with self-sustaining populations of brown, rainbow and brook trout. The Pine River is unique in Michigan because it contains one of the few populations of non-migratory rainbow trout found within the state. These rainbows appear to be the descendants of steelhead from past stockings in the river system, based on genetic analysis (Scribner and Warrillow 2001). Downstream from Stronach Dam, numerous species use the lower section of this river. They migrate out of Tippy Dam Reservoir, using the Pine River seasonally. As an example, brown trout abundance was consistently low during sampling in July, but samples during May indicate the Downstream zone has a high density of large brown trout during the spring. It is possible that these fish use Tippy Reservoir as a refuge in winter, and ascend the river during the high flows of spring to pursue spawning baitfish such as trout-perch (*Percopsis omiscomaycus*). Spawning white suckers and redhorse suckers can also be found in high numbers in this section during May and early June, but most of the fish return to Tippy Reservoir after spawning. During the summer, many coolwater species like smallmouth bass, northern pike, walleye, and rock bass utilize this section of river.

During the staged removal process, there was only one period in the removal where fish passage was confirmed. During the 2000 season, there were two "drops" in elevation associated with the dam. Swimming in an upstream direction from downstream of the dam, a fish would encounter a drop which was the remaining 3 feet of stop-logs, upstream from there a short distance was another drop which was 3 to 4 feet of trash rack. During 2000, one rainbow trout and one brown trout, with site-specific fin clips from the Downstream zone, were captured upstream of the dam, in the first and second sites above the dam respectively. One northern pike was also captured upstream of Stronach Dam during 2000. This species had not previously been found above the dam. However, the fish had not been tagged or fin clipped, so an absolute determination of its origin, or its passage of the partially removed dam was not possible. The following year, the rest of the stop-logs were removed, and one drop of 5 feet (trash rack) remained. No fish were detected to have passed the dam in either 2001 or 2002.

In November 2002, the remaining stop-logs and trash racks were removed, and fish passage was possible for the first time since the fish ladder on Stronach Dam was removed in 1953. This provides the fish downstream of the dam an opportunity to access habitat upstream, and fish upstream to access habitat downstream. This should enable fish to choose habitats most suitable to feeding, spawning and survival and is expected to increase the productivity of the fish community. This could also be seen as undesired however, if the increase in overall fish productivity comes at a cost to the angler-valued self-sustaining trout fishery. Continued monitoring is planned in order to document the effects of this newly opened fish passage.

This dam removal provides valuable information, unique to fisheries and dam removal studies, in several ways. First, the removal of Stronach Dam provides novel information as a case study, due to the presence of both cold-water and cool-water fish communities above and below the dam respectively. Other dam removal case studies have focused on the effects of dam removal on warm-water fish communities (Hill et al. 1994, Kanehl et al. 1997). Secondly, dam removal is most commonly thought to help fisheries in the context of allowing anadromous fish species access to historical spawning grounds. In the future,this study will examine the benefits of dam removal to inland fish species, not anadromous, but still highly mobile (Northcote 1998, Burrell et al. 2000). The need for "resident" fish species to migrate between habitats suitable for different life history requirements is not well documented, but is thought to be important (Northcote 1998). The benefits of allowing fish passage should include increased productivity and diversity of fish species. The removal of Woolen Mills Dam, on the Milwaukee River in Wisconsin, lead to increased numbers of smallmouth bass in the formerly impounded area, by allowing smallmouth bass migration into the zone from downstream, for spawning habitat utilization (Kanehl et al. 1997). Following the removal of Dead Lake Dam on the Chipola River, Florida, the total number of fish species present upstream of the dam increased from 34 to 61, and largemouth bass (*Micropterus salmoides*) recruitment was improved (Hill et al. 1994). Another way that this project is unique is that it provides insight into the effects of dam removal on fish populations, due only to habitat changes associated with dam removal; and not confounded with the effects of fish passage. The monitoring of fish populations in this study, conducted from 1996 through 2002, documented changes resulting from habitat alterations, and normal environmental fluctuations, and excluded effects from fish passage. Future monitoring will be aimed at documenting changes in these fish populations due to continued habitat changes and fish passage.

During the entire study period, 1997 – 2002, brown trout in the two zones upstream of Stronach Dam exhibited remarkably similar dynamics of both abundance and length composition. At the beginning of the staged dam removal, 1997, the length composition of brown trout in the two upstream zones was nearly identical, as was the abundance, and age distribution (Mistak 2000) in each of these zones. Abundance of brown trout began to increase slightly during the third year of the removal, increased substantially during the fourth year, and by the fifth year of the staged removal, the abundance of this species had tripled in both upstream zones. Abundance of brown trout in both upstream zones remained high through 2002. Analysis of length composition data shows that these increases in abundance have occurred equally for all lengths of brown trout, and length compositions are not statistically different in 2002 than they were in 1997 for either of the two upstream zones. These results indicate that brown trout from both the Impacted and Non-Impacted zones have been acting in unison, governed by the same set of controlling variables, and are one population.

Starting in the spring of 2000, trout harvest regulations on the portion of the Pine River encompassing the study area were altered. 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. Then in 2001, the regulations were again changed. In 2001 and 2002, the regulations for trout harvest were; 254 mm (10") minimum length of brook trout, 305 mm (12") minimum length on brown trout and rainbow trout, and 5 fish per day creel limit with no more than 3 fish over 381 mm in length. Increases in the abundance of brown trout of the sizes that would have benefited from these increasingly protective regulations were observed. However, as mentioned, increases in the abundances of all lengths of brown trout were observed during that time, and length compositions were not significantly different in 2002 than in 1997. Rainbow trout and brook trout did not show changes consistent with the regulation changes either. Trout harvest in the stretch of the Pine River encompassing the study area is thought to be low compared to other local rivers and other sections of the Pine River.

Several conclusions can be drawn from these results. First, it is possible that the documented effects of this staged dam removal on habitat conditions in the Impacted zone have had no effect on the brown trout in this zone, and all changes that have been documented are due to natural variability in the population of brown trout upstream of the dam. Alternatively, it is also possible that as the habitat conditions in the Impacted zone have changed during the staged dam removal, they have brought about the increases in brown trout numbers that have been observed in both upstream zones. The study zones were delineated based on impacts of the dam on habitat conditions in the river. This delineation method proved quite accurate for predicting the observed spatial scope of habitat change during the removal of Stronach Dam. However, it's likely that the spatial scope of fish population response to dam removals would be larger in spatial scale than those observed for habitat. Brown trout in both upstream study zones were acting as one population at the start of the dam removal. Brown trout are a highly mobile species, found to move between these study zones (Burroughs unpublished). Hence, it is conceivable that the habitat changes in the Impacted zone, due to dam removal, have acted to increase brown trout numbers not only in the area of restored habitat, but also further upstream. Following the removal of Woolen Mills Dam on the Milwaukee River, Wisconsin, smallmouth bass abundance increased at all sites upstream of the dam, but the increase was greatest at the site located above the former impoundment (Kanehl et al. 1997). Future dam removal studies should incorporate larger spatial scales for fish response than habitat response in experimental design and site selection.

Brown trout downstream from Stronach Dam have been disconnected from the upstream population, and not surprisingly, show different patterns of abundance and length composition. Fish in this section of the river can move freely between the Pine River, Tippy Dam Reservoir, and approximately 19 km (12 mi) of the Manistee River upstream to Hodenpyle Reservoir (Figure 1). Through all years of the study, brown trout have been in relatively low abundance in this zone during annual abundance estimation sampling, conducted during the summer. As mentioned earlier, abundance of brown trout in the Downstream zone can be quite high during early spring sampling. The length composition of brown trout remaining in the river during the summer has shifted from individuals between 225 – 625 mm in 1997, to only fish less than 250 mm in 2002. Through the course of the dam removal, this short section of river has increased in width and decreased in depth, and likely its ability to provide adequate cover for larger sized brown trout during the summer has diminished.

Rainbow trout had similar length compositions in the two upstream zones, and this species' abundance in the Impacted zone was characterized by delayed increases and similar decreases compared to the Non-Impacted zone. This might suggest possible source-sink population dynamics. In this case, the Non-Impacted zone may serve as the source and the Impacted zone may be a "pseudo-sink", where the habitat can only sustain a lower number of individuals than the source (Boughton 1999). Reproduction is lower in the pseudo-sink than in the source, and in years when excess reproduction occurs in the source, net migration into the pseudo-sink will occur. Rainbow trout prefer spawning substrate between 15 – 60 mm (Raleigh and Hickman 1984), which occurs most frequently in the Non-Impacted zone. Additionally, coarse substrate, most abundant in the Non-Impacted zone, provides cover for trout fry by offering shelter from high water velocities (Heggenes 1988). Higher recruitment rates in the Non-Impacted zone could lead to the observed population dynamics. Regardless of the explanation, rainbow trout population dynamics in the upstream zones seem to be linked, and more influenced by factors other than habitat change in the Impacted zone.

Brook trout abundance declines in a downstream direction through the study zones. Brook trout were found in substantial numbers only in the Non-Impacted zone. In the Impacted zone the abundance of this species was maintained a very low levels, and brook trout were rarely found in the Downstream zone. Generally, in rivers with coexisting populations of brook trout, brown trout, and rainbow trout, upstream areas were typically characterized by brook trout, while brown and rainbow trout were found more often downstream (Vincent and Miller 1969, Gard and Seegrist 1972, Magoulick and Wilzbach 1997). Most of the reasons for this pattern were 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 optimal habitat has been reduced, such as in the Impacted and Downstream zones, 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). The observed dynamics of this species in the upstream zones is likely not directly related to the dam removal.

White sucker density increases in a downstream direction in the Pine River. At the beginning of the dam removal, white sucker abundance was higher in the Impacted zone than in the Non-Impacted zone. During the course of the dam removal, the abundances seem to have alternated, with decreases in the Impacted zone and corresponding increases in the Non-Impacted zone, through 2001. Because white suckers are characterized as benthic feeders (Magnan 1988), the instability of substrate in the Impacted zone during the sediment fill incision process could have caused them to seek more stable substrates in the Non-Impacted zone. In 2002, the year of no removal activity, the abundance of white suckers in each of these zones became similar. The shift of length compositions from relatively evenly spread distributions, to distributions with only small individuals present, in both upstream zones was unexpected. One possible explanation is that the amount of deeper water with slower water velocity (suitable for the adult fish) has decreased, but the amount of shallower water with slower velocity (suitable for juvenile fish) has not decreased.

In the Downstream zone, white suckers have access to Tippy Dam Reservoir, which could provide more suitable habitat and explain the greater abundance of this species in this zone. The length composition of fish in this zone is evenly distributed, and in general has remained similar despite large fluctuations in population abundance. During the process of dam removal, and subsequent streambed aggradation, and fine sediment domination in this zone, white sucker abundance appeared to be decreasing. However, during 2002, the density of white suckers in this zone dramatically increased, primarily through the presence of large numbers of small white suckers (75-100 mm).

Shorthead redhorse suckers were found only downstream of Stronach Dam. 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 are rarely sampled. Therefore it is likely that shorthead redhorse suckers migrate up from Tippy Dam Reservoir utilizing the Pine River primarily for spawning. The abundance of this species has decreased throughout the dam removal. However, shorthead redhorse suckers prefer gravel substrates with water velocities between 2 -3 ft/sec for spawning (Curry and Spacie 1984). In the Downstream zone, frequency of water velocities within this range were rare prior to dam removal, and have increased significantly during the dam removal, as has the relative frequency of gravel. Therefore, it is possible that these decreases in abundance could be the result from either; population fluctuations controlled by factors affecting the fish while resident in Tippy Dam Reservoir, or a decrease in the suitability of post-spawning adult habitat in the river.

SUMMARY

The direct effects of Stronach Dam removal on habitat conditions in the Pine River were documented. During the staged removal of the dam, the Pine River in the area of the former impoundment experienced incision through the reservoir sediment fill. This incision has lead to decreases in stream width, and increases in gradient, water velocity, and frequency of coarse substrate. As of 2002, the river in the former impoundment was similar in width, depth and water velocity to the upstream control site. Gradient and substrate size is still less than the upstream control site, and is expected to be so until more sediment fill incision occurs and an equilibrium channel is established. The streambed downstream from the dam has aggraded due to large amounts of sediment being deposited here from the incision process occurring upstream of the dam. This deposition of sediment has led to, most notably, increases in width, decreases in depth, increases in gradient and water velocity, and a predominance of loose sand substrate. As of 2002, the section of river downstream of the dam is wider, shallower, slower-flowing, and sandier than the control site upstream of the dam.

The indirect effects of Stronach Dam removal, as mediated by changes in habitat conditions, on fisheries resources in the Pine River have been more difficult to interpret. Fish populations fluctuate under natural conditions, making it difficult to sort out the effects of human activities, including dam removal. Given this, the fish population fluctuations documented during this dam removal, and any conclusions drawn from them, should be interpreted cautiously. With this

said, it appears that habitat changes have likely lead to decreased density of white suckers in the former impoundment, and increased the density of brown trout both in the former impoundment and the section of river immediately upstream of the former impoundment. Rainbow trout and brook trout, both at lower densities than brown trout, appear less influenced by the dam removal and resulting habitat changes. Downstream from the dam the most apparent effect of dam removal could be the overall decrease in water depth associated with streambed aggradation. This has likely reduced the amount of deeper water used as cover for larger adult fish, and led to the decrease in adult fish and shift of length compositions of brown trout and white suckers to higher frequencies of smaller fish.

Monitoring of habitat and fish response to the removal of Stronach Dam will continue during the last phase of removal, planned for fall 2003, and post-removal. Further sediment fill incision and channel evolution is expected. The fish community of the Pine River is expected to continue being influenced by these habitat alterations, as well as newly restored fish migration potential between upstream and downstream sections the river. Continued monitoring of the effects of Stronach Dam on habitat and fish in the Pine River will provide information valuable to people considering dam removal in the future. As a case study, some results from this study will not be broadly applicable. However, many of the results will be applicable on a local or regional basis, and other conclusions from this study will be fundamental to all rivers and provide information useful and needed by people considering dam removal everywhere.

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APPENDICES

Appendix A. Discharge calculated at selected sites from 1996 - 2002.

Site Name	Distance Downstream of Stronch Dam (km)	Cubic Feet Per Second (CFS) 1996	1997	1998	1999	2001	2002	Mean
Loggers Camp 2	-7.53	261	244	211	301	264	352	272
Tip of the Tit 2	-6.59	251	259	246	274	312	291	272
Harley Hill 9-10	-5.59	285	270	213	281	283	280	269
Boundary Waters 5-6	-3.72	268	263	259	241	306	269	268
Schofield 3-4	-2.51	264	263	260	258	268	307	270
Downstream Schofields 1-2	-1.70	281	298	237	246	311	309	280
Roys Run 5-6	-1.21	261	277	249	266	291	302	274
Stronach Pond 1-2	-0.50	277	280	259	288	321	324	291
Stronach Pond 9-10	-0.01	259	275					267
Below Dam 1-2	0.15			254	276	350	418	324
Low Bridge 1-2	0.63	309	253	266	269	313	318	288

Appendix B. Fish population density estimates from 1997 - 2002.

Site	Distance from Dam (km)	Area (Hectare)	Brown Trout (fish/hectare)						Rainbow Trout (fish/hectare)					
	(negative is upstream)	1996	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
Sandy B.'s	-8.2	0.13	39	30	15	22	67	37	62	67	60	7	15	30
Logger's Camp Up	-7.6	0.32	20	44	88	196	92	199	7	85	66	82	25	16
Logger's Camp Down	-7.1	0.12	18	24	32	73	203	211	0	16	41	89	73	81
Boundary Water Up	-5.0	0.64	54	22	55	63	53	64	15	49	38	53	11	27
Boundary Water Down	-3.9	0.70	22	43	48	53	54	63	20	41	44	51	16	21
Schofield Up	-2.6	0.47	37	38	63	164	162	86	27	11	21	61	42	29
Roy's Run	-1.3	0.37	62	8	3	91	134	136	7	13	5	67	27	48
Stronach Pond	-0.5	0.84	20	17	21	55	72	76	25	8	10	23	26	11
Low Bridge Up	0.6	0.21	20	5	14	0	5	10	0	0	0	0	5	5
Low Bridge Down	1.0	0.23	5	22	26	13	9	13	7	4	0	9	0	4

Site	Distance from Dam (km)	Area (Hectare)	Brook Trout (fish/hectare)						White Sucker (fish/hectare)					
	(negative is upstream)	1996	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
Sandy B.'s	-8.2	0.13	89	75	30	15	7	52	0	0	0	0	0	7
Logger's Camp Up	-7.6	0.32	25	28	50	6	3	19	22	79	148	95	63	38
Logger's Camp Down	-7.1	0.12	7	0	41	49	8	41	17	0	0	65	8	0
Boundary Water Up	-5.0	0.64	27	33	13	2	0	3	2	11	13	113	0	5
Boundary Water Down	-3.9	0.70	12	18	6	7	7	16	44	11	4	13	7	6
Schofield Up	-2.6	0.47	12	13	13	8	11	2	49	36	6	2	2	0
Roy's Run	-1.3	0.37	2	19	13	8	5	0	37	27	21	75	64	69
Stronach Pond	-0.5	0.84	7	0	6	2	0	1	119	60	1	10	1	0
Low Bridge Up	0.6	0.21	0	0	0	0	0	0	153	82	375	259	134	687
Low Bridge Down	1.0	0.23	0	0	0	0	0	4	161	350	125	78	47	233

Appendix B. (continued)

Site	Distance from Dam (km) (negative is upstream)	Area (Hectare) 1996	Shorthead Redhorse Sucker (fish/hectare) 1997	1998	1999	2000	2001	2002
Sandy B.'s	-8.2	0.13	0	0	0	0	0	0
Logger's Camp Up	-7.6	0.32	0	0	0	0	0	0
Logger's Camp Down	-7.1	0.12	0	0	0	0	0	0
Boundary Water Up	-5.0	0.64	0	0	0	0	0	0
Boundary Water Down	-3.9	0.70	0	0	0	0	0	0
Schofield Up	-2.6	0.47	0	0	0	0	0	0
Roy's Run	-1.3	0.37	0	0	0	0	0	0
Stronach Pond	-0.5	0.84	0	0	0	0	0	0
Low Bridge Up	0.6	0.21	-	106	67	91	43	38
Low Bridge Down	1.0	0.23	-	108	35	26	47	22

Appendix C. Fish population density estimates (#/ha), from each site, averaged for each zone.

Species	Year	Zone		
		Non-Impacted	Impacted	Downstream
Brown Trout	1997	33	35	12
	1998	30	26	13
	1999	48	34	20
	2000	88	91	6
	2001	104	105	7
	2002	128	90	11
	Average	72	64	12
Rainbow Trout	1997	21	20	4
	1998	54	18	2
	1999	51	20	0
	2000	58	50	4
	2001	31	28	2
	2002	38	27	5
	Average	42	27	3
Brook Trout	1997	37	9	0
	1998	34	12	0
	1999	33	9	0
	2000	18	6	0
	2001	5	6	0
	2002	29	5	2
	Average	26	8	0
Common White Sucker	1997	11	62	157
	1998	22	33	216
	1999	40	8	250
	2000	68	25	169
	2001	18	19	91
	2002	13	19	460
	Average	29	28	224
Shorthead Redhorse Sucker	1998	0	0	107
	1999	0	0	51
	2000	0	0	59
	2001	0	0	45
	2002	0	0	30
	Average	5	5	86

Chapter 2

Diet of Catostomids in the Pine River, Michigan

INTRODUCTION

Members of the family Catostomidae, also known as suckers, are a unique group of fish, adapted largely for the vacuum ingestion of food items. Sixty-three catostomids are found in North America, north of Mexico (Page and Burr 1991). As a group, suckers have been relatively underutilized as recreational and commercial fishery resources, and consequently have received less management and research attention. Many species of suckers are threatened or endangered (e.g., Lost River sucker (*Deltistes luxatus*), shortnose sucker (*Chasmistes brevirostris*), blue sucker (*Cycleptus elongates*), June sucker (*Chasmistes liorus*), razorback sucker (*Xyrauchen texanus*), river redhorse (*Moxostoma carinatum*), robust redhorse (*Moxostoma robustum*), Santa Ana sucker (*Catostomus santaanae*), warner sucker (*Catostomus warnererensis*)). Others species, like the white sucker (*Catostomus commersoni*) are widespread and abundant in many waters (Scott and Crossman 1973).

Redhorse suckers, Genus Moxostoma, have been reported to be one of the most perplexing groups of fishes for American ichthyologists (Robins and Raney 1956, Scott and Crossman 1973). Difficulties with sampling, few interspecific meristic differences, misidentification at the species level, uncertain taxonomic positioning, and differences in nomenclature have all been suggested as possible impediments limiting the amount of basic biological and ecological information available for these species (Robins and Raney 1956, Scott and Crossman 1973). Consequently, little is known about the redhorse suckers

(Meyer 1962, Scott and Crossman 1973). Despite their wide distribution in North America (Scott and Crossman 1973, Page and Burr 1991), the relatively large numbers of some species and threatened and endangered status of other species, this group of suckers has remained relatively unstudied.

The shorthead redhorse (*Moxostoma macrolepidotum*) has also been referred to as the northern redhorse (Cross 1967), and the northern shorthead redhorse and also labeled as *Moxostoma aureolum aureolum* (Trautman 1957). Both the shorthead and the silver redhorse (*Moxostoma anisurum*) occur throughout much of the upper mid-west United States including the Great Lakes region. Information pertaining to the basic biology and ecology of shorthead and silver redhorse suckers is limited (Meyer 1962, Scott and Crossman 1973). Adult shorthead redhorse have been reported to prefer fast moving water over rocky streambeds, but occasionally are found over thick layers of silt behind eroded bank vegetation (Meyer 1962). Scott and Crossman (1973) noted the use of lake habitat by shorthead redhorse suckers. Galloway (1976) stated that "the species must now be said to inhabit the shallow clear waters of lakes or rivers". Silver redhorse were found to prefer slow moving lotic habitat, with adults showing little preference for substrate type (Gerking 1945, McReynolds 1960, Meyer 1962). Scott and Crossman (1973) accepted this description of silver redhorse habitat and added the species was more common in streams than lakes. However, Hackney et al. (1970) found that in the population they studied, the silver redhorse remained in a reservoir except to spawn, suggesting that this species preferred lentic habitat (Galloway 1976).

A fish's diet is among the most basic biological and ecological information for a species. The productivity of a population is influenced by the quantity and quality of food they are able to attain (Ney 1990, Bowen et al. 1995, from Bowen 1996). Therefore, understanding the diet of a species of fish is important for understanding its ecological role, growth, and productive capacity (Bowen 1996). Understanding the productive capacity of a population is key to interpreting changes in the abundance of a population, for management with either utilization or conservation in mind. Little information is available on the diets of shorthead and silver redhorse but it is needed for future management of these species.

Shorthead and silver redhorse have both been reported to feed by sucking up bottom material and straining from it a variety of invertebrates (Scott and Crossman 1973). Galloway (1976) suggested that due to this mode of feeding, the diets of redhorse suckers probably vary greatly with the habitats used. In a study of the life history of the shorthead, silver and golden redhorse sucker (*Moxostoma erythrurum*), in the Des Moines River, Iowa, Meyer (1962) reported that all three species contained the same food items throughout the spring, summer and fall. Subsequently he grouped the samples of 28 shortheads, 42 silvers and 49 goldens and reported only the three taxa of highest frequency of occurrence; immature chironomids (91%), immature Ephemeroptera (62%) and immature trichoptera (18%). The only other other diet data for shorthead redhorse specimens was obtained from Lake Nipigon (Clemens et al. 1924). They reported that the diet contained immature forms of Ephemeroptera, Trichoptera, Chironomidae, Tipulidae, Stratiomyidae, Ostracoda, mollusks,

Oligochaeta, various crustaceans, Hydracarina and diatoms (Scott and Crossman 1973).

White suckers are among the most widely distributed and abundant sucker species (Scott and Crossman 1973, Page and Burr 1991). They are found in a wide array of habitats from cool, high gradient headwater streams to large warmwater lakes (Page and Burr 1991). The native distribution of white suckers encompasses much of North America, and they have been introduced widely outside of this range (Page and Burr 1991). Due probably to the ubiquitous and abundant nature of the white sucker, more detailed studies of the biology and ecology of this species have been conducted than for redhorse suckers.

There are many reports of the diets of white suckers in various habitat (e.g., Stewart 1926, Campbell 1935, Eder and Carlson 1977, Lalancette 1977, Koehler 1978, Borgmann and Ralph 1985, Trippel and Harvey 1987, Hayes 1990, Logan et al. 1991, Ahlgren 1996), but few have analyzed how the diet of white suckers differs from similar species occupying the same habitat. White suckers, shorthead redhorse suckers, and silver redhorse suckers coexist throughout the distribution of shortheads and silvers. Information on the diet of these three species could provide valuable insight into the partitioning of resources among similar species that share the same habitat. Thus, one of the major goals of this study was to document the summer diets of three coexisting species of suckers, the shorthead redhorse sucker, silver redhorse sucker, and the white sucker. Another goal of this research was to gain insight into the food resource partitioning of three suckers which coexist and have coevolved within the same native range.

A diet study of wild brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*) was conducted May through August one year previous to the start of this study, in the same habitat (Mistak et al. 2003). This provides a unique opportunity to examine the diet similarity between three species of suckers and three species of trout coexisting in the Pine River. Despite the large overlap in distributions, the prevalence of waters where salmonids and suckers species coexist, and the commonly stated management concern of suckers competing with trout among other gamefish, few studies have examined their dietary overlap. Further, most of the studies of sucker and salmonid diet overlap have focused on white sucker and salmonids in lentic environments (Holey et al. 1979; Lachance and Magnan 1990; Schneidervin and Hubert 1987; Barton and Bidgood 1980; Martin and Erman 1982). No studies were found that examined dietary overlap between suckers and salmonids in lotic environments. The insight gained from this comparison will allow an assessment of the diet overlap between suckers and trout, and have implications for understanding how these two groups of fish partition food resources in the same habitat. In the context of the Pine River, Michigan, this information will also provide valuable insight into the probable effects of changes in fish distributions following the removal of Stronach Dam on the Pine River. With the removal of the dam, suckers, which are abundant downstream of the dam, will have access to the upstream reaches of the Pine

River which support a highly valued self-sustaining trout fishery. The potential for suckers to compete with trout for food resources and feed on trout eggs is uncertain, and has led to concern for the future of the trout fishery. Thus, the third main goal of this research was to assess the dietary overlap of suckers and trout, and examine the extent of fish egg predation by suckers.

METHODS

Site Description

The Pine River, a tributary to the Manistee River, is located in the northwestern Lower Peninsula of Michigan (Figure 1). The Pine River is a 77 km long, riffle-pool stream with an average gradient of 2.8 m/km (Rozich 1998). It drains a 68,635 ha watershed dominated by sandy glacial outwash plains, recessional moraines, and areas of consolidated clay (Hansen 1971). Mean daily discharge recorded at two U.S. Geological Survey gaging stations on the Pine River has averaged 8.1 m^3/sec during 34 years of record. The Pine River is a coldwater stream, dominated by groundwater input. It carries a high bedload of sand due to the local geology and extensive logging operations in the late 1800's, which created unstable banks along the river. Tippy Dam is located at the confluence of the Pine and Manistee Rivers and forms a 494 ha reservoir (Tonello personal communication). Stronach Dam is located on the lower Pine River, approximately 2.5 km upstream from the Tippy Dam Reservoir. At the

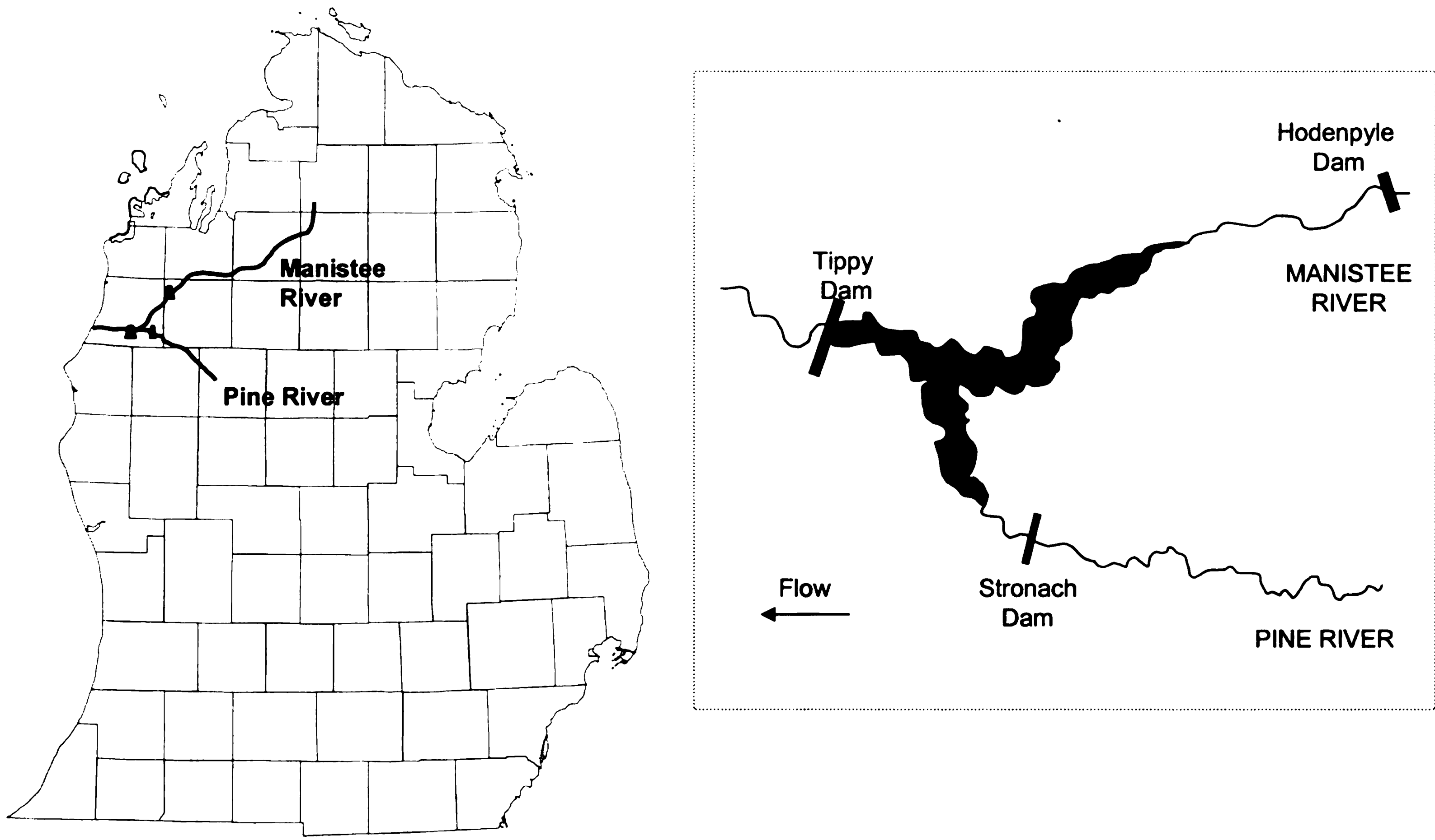

Figure 1. Location of Stronach Dam on the Pine River in relation to the state of Michigan.

time this study was conducted, Stronach Dam was in the process of being removed in a staged fashion, but still prevented upstream fish passage.

Collection of fish for diet anaylsis in this study occurred from the confluence of the Pine River with Tippy Dam Reservoir to a point upstream on the Pine River approximately 9 km. The Pine River, downstream of Stronach Dam was largely run type habitat, averaged 37.5 m in width, 0.52 m in water depth, and 0.55 m/sec in water velocity. The streambed in this downstream area was dominated by sand. Shorthead redhorse and silver redhorse suckers occurred only downstream of Stronach Dam. White suckers occurred both upstream and downstream of the dam, but were in much higher abundance downstream of the dam. Upstream of the dam, the Pine River had more diverse habitat including runs, riffles and pools, averaged 17 m in width, 0.64 m in depth, 0.64 m/sec in water velocity, and had more diverse streambed substrate.

Field Collection

All fish were sampled during the summer (May through August) in 2000 and 2001, using 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. For logistic and safety reasons, all sampling was conducted during daylight hours, normally from 0800 – 1800 hours. Efforts were made to randomly sample approximately 30 individuals of each sucker species per month, distributed as evenly as possible over the length range. Trout were sampled upstream and downstream of the dam, using the same electrofishing boat, and diets were collected using gastric lavage. For complete methodology in the collection of trout diet information refer to Mistak et al. (2003).

Once fish were captured, total length of the fish to the nearest millimeter was recorded and the fish was euthanized. The subterminal mouths and stomachless alimentary canals (referred to as the "gut") of these species necessitated the dissection and removal of the gut for diet analysis. The gut was severed as far anterior on the esophagus and posterior by the anus as possible. The gut was removed and immediately placed in separate labeled containers with 10% formalin solution, and stored at room temperature, away from sunlight.

Laboratory Processing

To avoid potential problems with differential rates of digestion of food, only food items from the foregut (esophagus to the first intestinal coil) were used. All foregut contents were removed and preserved in alcohol, and are archived at Michigan State University Fisheries Laboratory. Due to the large number of food items often found, a subsample of 0.5 grams of gut contents was taken for further analysis. This quantity was chosen to yield around 100 food items, a number found to reduce subsampling error (Allanson and Kerrich 1961). These contents were examined and all food items were identified to the taxonomic level of family whenever possible, using Pennak (1989) and Merritt and Cummins (1996). Eggs found in the diet were placed in one of two groups, large-sized (>1 mm in diameter), and small-sized (<1 mm in length). The majority of small-sized eggs were non-spherical in shape. Only characteristic body parts, found once per food item were counted (i.e. 2 legs from the same type of taxa did not count as two food items eaten). Total counts of each taxonomic group in the diets were made. Observations on the presence or absence and qualitative abundance of sediment, detritus, and plant material were made.

Analysis

Two quantitative descriptions of diet were used, frequency of occurrence and percent composition by number. Frequency of occurrence is the proportion of fish that had foregut contents (referred to as "feeding fish"), from a given sample, that contained one or more of a particular diet item. Frequency of occurrence describes the uniformity with which a species, in a given time period, select their diet, but does not indicate the importance of the various types of food (Bowen 1996). Percent composition by number is the number of items of a given food type, expressed as a percentage of the total number of all food items summed across all fish in the sample. Percent composition by number indicates the relative numeric importance of different food types.

Diet similarity was examined using Morista's index (Morista 1959) to compare the relative abundance of items in the diet by months, sampling zones in relation to the dam, sucker species, and to compare the diets of the three species of sucker with three species of trout.

Morista's index (C_λ) is calculated as:

$$C_\lambda = \frac{2 \Sigma n_{i1} n_{i2}}{(\lambda_1 + \lambda_2) N_1 N_2} \quad \text{where} \quad \frac{\lambda_j = \Sigma n_{ji} (n_{ji} - 1)}{N_j (N_j - 1)}$$

and where n_{i1} and n_{i2} equal the number of individuals of species i in samples 1 and 2 respectively and N_j represents the total number of individuals in sample j.

The index values range from 0 (no overlap) to 1 (complete overlap). The index gives a ratio of the probability that an individual selected from sample 1 and one from sample 2 will belong to the same species versus the probability that two individuals drawn from either sample 1 or 2 will belong to the same species (Krebs 1989). Angradi and Griffith (1990) suggested that a Morista similarity index value of greater than 0.60 should be considered as significant diet overlap. This guideline was used in this study.

RESULTS

Diet Composition

In 2000 and 2001, 130 shorthead redhorse suckers, ranging in length from 193 to 443 mm, were sampled from May through August (Table 1). The average proportion of feeding fish (containing foregut contents) out of the total number of fish sampled was 46% (range: 33 – 65%). For all samples combined, eight orders of aquatic Insecta, Oligochaeta, Crustacea, Arachnoidea, Gastropoda, Pelecypoda, insect and fish eggs, plant material, Acanthocephalic parasites, and sediment were observed in the shorthead redhorse sucker gut contents (Appendices A – D). For the entire period from May through August, immature chironomids were the most prevalent food item type in the diet of shorthead redhorse suckers, comprising on average 66% of the diet numerically and

Table 1 . Percent composition by number and frequency of occurrence (in parantheses) for diet items of shorthead redhorse suckers collected in the Pine River, Manistee County, Michigan; during 2000 and 2001. Only diet items comprising at least 5% of the diet by number, for at least one month, for either shorthead redhorse suckers, silver redhorse suckers, or white suckers, in the Pine River, are shown. Frequency of occurrence is calculated using the number of specimens sampled in a given month that contained foregut contents. Total sample size and the number of specimens in a month containing foregut contents (in parantheses) are given. Order-level summaries include lower taxa plus food items that could not be assigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Class	Order	Family (or Lowest Taxon)	May	June	July	August	Average
Arachnoidea	**Trombidiformes**	**Hydracarina**	**0 (0)**	**1 (33)**	**1 (45)**	**1 (50)**	**1 (32)**
Insecta			**100 (100)**	**99 (89)**	**98 (85)**	**99 (100)**	**99 (93)**
	Diptera		19 (63)	95 (78)	95 (83)	93 (100)	75 (81)
		Athericidae	0 (13)	0 (11)	0 (8)	0 (70)	0 (25)
		Ceratopoginidae	0 (0)	0 (11)	0 (28)	0 (0)	0 (10)
		Chironomidae	17 (63)	92 (78)	88 (80)	68 (100)	66 (80)
		Simuliidae	0 (0)	1 (33)	3 (28)	24 (90)	7 (38)
		Pupal Diptera	1(25)	2 (44)	3 (60)	1 (90)	2 (55)
	Ephemeroptera		11 (63)	1 (67)	1 (38)	4 (90)	4 (64)
	Trichoptera		66 (88)	3 (89)	1 (38)	2 (90)	18 (76)
		Brachycentridae	15 (50)	1 (67)	0 (10)	0 (50)	4 (44)
		Lepidostomatidae	9 (50)	0 (11)	0 (5)	0 (10)	2 (19)
Pelecypoda			**0 (0)**	**0 (0)**	**0 (3)**	**0 (0)**	**0 (1)**
Eggs			**0 (0)**	**0 (0)**	**1 (13)**	**0 (0)**	**0 (3)**
		Small (insect sized) eggs	0 (0)	0 (0)	1 (13)	0 (0)	0 (3)
Other			**0**	**0**	**0**	**0**	
		Sample Size	17 (8)	27 (9)	62 (40)	24 (10)	
		Length Range (mm)	242-443	279-440	193-429	323-418	

consumed by 80% of the feeding fish. Similarity of shorthead redhorse sucker diets among months was high, with the exception of May, which had little overlap with June, July or August (Table 2).

Immature Trichoptera were the most numerically abundant and widely consumed food item in the diet during May, comprising 66% of the diet and consumed by 88% of the shorthead redhorse suckers that contained anterior gut contents (Table 1). During June and July, Diptera, primarily immature chironomids, made up the majority of the diet. During these two months, chironomids numerically accounted for approximately 90% of the food items and were consumed by approximately 80% of the fish. During August, Diptera, primarily immature chironomids, still comprised the majority of the diet but simuliids became more prevalent. Chironomids numerically comprised 68% of the diet and were consumed by 100% of the feeding fish, while simuliids comprised 24% of the diet and were consumed by 90% of the fish.

Other taxa were commonly ingested but did not comprise a substantial proportion of the shorthead redhorse diet numerically (Appendices A - D). In any given month Coleoptera were consumed by 39% of the feeding fish on average; immature Ephemeroptera 64%, immature Plecoptera 40%, Diptera pupae 55%, and Arachnoidea Hydracarina (water mites) 32%. Immature Trichoptera, while only consumed in numerically high percentages in May, where also commonly consumed by shorthead redhorse suckers in all months (average frequency of occurrence = 76%) (Table 1). Out of all of the shorthead redhorse sampled in

Table 2. Morista similarity index values for month to month comparisons of sucker diets sampled on the Pine River in 2000 and 2001.

Species	May-June	May-July	May-August	June-July	June-August	July-August
shorthead redhorse sucker	0.30	0.31	0.33	1.00	0.92	0.93
silver redhorse sucker	0.61	0.46	1.00	0.92	0.58	0.44
white sucker downstream	0.78	0.43	0.54	0.80	0.77	0.69
white sucker upstream	-	-	-	0.80	0.83	0.73

this study, few fish consumed large-sized eggs (0.77%) or small-sized eggs (3.8%).

Non-countable items, such as plant material (43%), sediment (55%), and detritus (75%) also frequently occurred in the gut contents of shorthead redhorse suckers. While these items were ingested by many of the shorthead redhorse suckers, these items were generally seen in relatively small quantities within an individual fish.

In 2000 and 2001, 41 silver redhorse suckers, ranging in length from 245 to 623 mm, were sampled from May through August (Table 3). The average proportion of feeding fish out of the total number of fish sampled was 91% (range: 86 – 100%). For all samples combined, five orders of aquatic Insecta, Arachnoidea, insect and fish eggs, plant material, Acanthocephalic parasites, and sediment were observed in the silver redhorse sucker gut contents (Appendices E – H). For the entire period from May through August, immature chironomid were by far the most prevalent food item in the diet of silver redhorse suckers, comprising on average 62% of the diet numerically and consumed by 92% of the feeding fish. Immature chironomids were the most numerically abundant food item in the diet during May, comprising 90% of the diet and consumed by 100% of the silver redhorse suckers that were feeding (Table 3). In June, chironomids were still the most numerically abundant and frequently occurring food item in the diet, but the prey items became more diverse. A small percentage of the feeding fish (10%) also consumed a large number of small-sized eggs (27% of the diet numerically), and immature ceratopogonids made up

Table 3. Percent composition by number and frequency of occurrence (in parantheses) for diet items of silver redhorse suckers collected in the Pine River, Manistee County, Michigan; during 2000 and 2001. Only diet items comprising at least 5% of the diet by number, for at least one month, for either shorthead redhorse suckers, silver redhorse suckers, or white suckers, in the Pine River, are shown. Frequency of occurrence is calculated using the number of specimens sampled in a given month that contained foregut contents. Total sample size and the number of specimens in a month containing foregut contents (in parantheses) are given. Order-level summaries include lower taxa plus food items that could not be assigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Class	Order	Family (or Lowest Taxon)	May	June	July	August	Average
Arachnoidea	**Trombidiformes**	**Hydracarina**	**0 (0)**	**0 (20)**	**0 (0)**	**0 (0)**	**0 (5)**
Insecta			**100 (100)**	**71 (100)**	**54 (85)**	**100 (100)**	**81 (96)**
	Diptera		97 (100)	64 (100)	49 (85)	100 (100)	78 (96)
		Athericidae	0 (0)	1 (30)	1 (15)	0 (0)	0 (11)
		Ceratopoginidae	2 (50)	22 (60)	14 (38)	0 (0)	10 (37)
		Chironomidae	90 (100)	35 (90)	28 (77)	96 (100)	62 (92)
		Simuliidae	0 (0)	0 (20)	1 (15)	0 (0)	0 (9)
		Pupal Diptera	5 (42)	6 (50)	4 (54)	4 (100)	5 (61)
	Ephemeroptera		0 (0)	5 (30)	3 (38)	0 (0)	2 (17)
	Trichoptera		3 (50)	0 (10)	0 (0)	0 (0)	1 (15)
		Brachycentridae	1 (8)	0 (0)	0 (0)	0 (0)	0 (2)
		Lepidostomatidae	1 (33)	0 (0)	0 (0)	0 (0)	0 (8)
Pelecypoda			**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**
Eggs			**0 (8)**	**27 (10)**	**46 (15)**	**0 (0)**	**18 (8)**
		Small (insect sized) eggs	0 (0)	27 (10)	46 (15)	0 (0)	18 (6)
Other			**0**	**2**	**0**	**0**	
		Sample Size	14 (12)	11 (10)	15 (13)	1 (1)	
		Length Range (mm)	316-623	245-598	435-601	574	

22% of the diet items and were eaten by 60% of the feeding silver redhorse. This same pattern continued in July, but with small-sized eggs eaten by 15% of the feeding fish and comprising 46% of the diet numerically. In August, the gut contents of the one fish that was sampled contained 96% chironomids and 4% Diptera pupae. Due to the occurrence of small-sized eggs in the diet during June and July, monthly similarity of silver redhorse sucker diets varied (Table 2). May and August were the most similar, having complete overlap (1.00), and June and July were also highly similar (0.92). May and August had lower overlap with June and July.

Diptera pupae were commonly ingested in all months but did not comprise a substantial proportion of the silver redhorse sucker diet numerically (Appendices E – H). Other taxa that frequently occurred in the diet seasonally include: Coleoptera (July 46%), immature Ephemeroptera (June 30%, July 38%), immature Plecoptera (June 30%), and immature Trichoptera (May 50%) (Table 3). Out of all of the silver redhorse sampled in this study, very few of the fish consumed large-sized eggs (2.4%) or small-sized eggs (4.8%).

Non-countable items such as plant material (42%), sediment (53%), and detritus (86%) also frequently occurred in the gut contents of silver redhorse suckers. These proportions are similar to the shorthead redhorse suckers. Also like that species, these items were generally seen in relatively small quantities with an individual silver redhorse sucker.

In 2000 and 2001, 186 white suckers, ranging in length from 52 to 507 mm, were sampled from May through August, downstream of the Stronach Dam site (Table 4). The average proportion of feeding fish out of the total number of fish sampled was 42% (range: 31 – 69%). Five orders of aquatic Insecta, Oligochaeta, Crustacea, Arachnoidea, Gastropoda, Pelecypoda, insect and fish eggs, plant material, Acanthocephalic parasites, and sediment were observed in the white sucker (from downstream of the dam) diets (Appendix I – L). For the entire period from May through August, immature chironomids were the most prevalent food item in the diet of white suckers downstream of the Stronach Dam site, comprising on average 51% of the diet numerically and consumed by 89% of the feeding fish. In May, a small percentage of the feeding fish (8%) consumed a large number of small-sized eggs, which comprised 64% of the food items numerically (Table 4). The second most numerically abundant food item was immature chironomids, which were consumed by 92% of the feeding fish and comprised 31% of the diet numerically. In June, chironomids were the most numerically abundant food item. Small-sized eggs were again numerous but only eaten by a small percentage of the white suckers and Hydracarina (Class Arachnoidea) also comprised 15% of the prey items in June, and were consumed by 73% of the feeding fish. The July diet of white suckers downstream from the Stronach Dam site was largely dominated by chironomids (84%). In August the gut contents were numerically diverse, including chironomids, simuliids, Pelecypoda and small-sized eggs. Chironomids were still the most frequently occurring food item in the diet. Monthly similarity in the diet of white suckers downstream of the dam were generally high between consecutive months, and lower between May-July (0.43) and May-August (0.54) (Table 2).

Table 4. Percent composition by number and frequency of occurrence (in parantheses) for diet items of white suckers collected downstream of the Stronach Dam site in the Pine River, Manistee County, Michigan; during 2000 and 2001. Only diet items comprising at least 5% of the diet by number, for at least one month, for either shorthead redhorse suckers, silver redhorse suckers, or white suckers, in the Pine River, are shown. Frequency of occurrence is calculated using the number of specimens sampled in a given month that contained foregut contents. Total sample size and the number of specimens in a month containing foregut contents (in parantheses) are given. Order-level summaries include lower taxa plus food items that could not be assigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Class	Order	Family (or Lowest Taxon)	May	June	July	August	Average
Arachnoidea	**Trombidiformes**	**Hydracarina**	**0 (8)**	**15 (73)**	**3 (58)**	**0 (0)**	**4 (35)**
Insecta			**36 (100)**	**58 (100)**	**94 (86)**	**69 (90)**	**64 (94)**
	Diptera		33 (100)	54 (91)	91 (86)	63 (90)	60 (92)
		Athericidae	0 (15)	0 (0)	0 (2)	0 (10)	0 (7)
		Ceratopoginidae	1 (31)	3 (27)	1 (11)	0 (0)	1 (17)
		Chironomidae	31 (92)	50 (91)	84 (84)	39 (90)	51 (89)
		Simuliidae	0 (8)	0 (0)	2 (28)	23 (40)	6 (19)
		Pupal Diptera	0 (31)	1 (55)	4 (67)	1 (20)	2 (43)
	Ephemeroptera		0 (8)	2 (45)	1 (37)	6 (60)	2 (37)
	Trichoptera		3 (38)	1 (45)	0 (18)	1 (30)	1 (33)
		Brachycentridae	1 (31)	0 (9)	0 (5)	0 (10)	0 (14)
		Lepidostomatidae	1 (15)	0 (0)	0 (0)	0 (0)	0 (4)
Pelecypoda			**0 (0)**	**0 (0)**	**0 (7)**	**18 (10)**	**4 (4)**
Eggs			**64 (8)**	**27 (9)**	**0 (4)**	**13 (10)**	**26 (8)**
		Small (insect sized) eggs	64 (8)	27 (9)	0 (0)	13 (10)	26 (7)
Other			**0**	**0**	**3**	**0**	
		Sample Size	42 (13)	30 (11)	83 (57)	31 (10)	
		Length Range (mm)	124-494	90-507	84-436	52-352	

Other taxa that frequently occurred in the diet seasonally, but did not comprise a substantial proportion of the diet numerically include: immature Ephemeroptera, immature Trichoptera, Diptera pupae (Table 4), immature Plecoptera, and Coleoptera (Appendices I - L). Out of all of the white suckers sampled in this study from downstream of the dam, very few of the fish consumed large-sized eggs (1.1%) or small-sized eggs (1.6%).

Non-countable items such as plant material (38%), sediment (68%), and detritus (74%) also frequently occurred in the gut contents of white suckers downstream of the dam. While these items were commonly ingested by the white suckers, these items were generally seen in relatively small quantities within an individual fish.

In 2000 and 2001, 81 white suckers, ranging in length from 52 to 507 mm, were sampled from May through August, upstream of the Stronach Dam site (Table 5). The average proportion of feeding fish out of the total number of fish sampled was 69% (range: 55 – 94%). Six orders of aquatic Insecta, Arachnoidea, Pelecypoda, plant material, Acanthocephalic parasites, and sediment were observed in the white sucker gut contents (Appendix M – O). From June through August, immature chironomids were the most prevalent food item in the diet of the white suckers upstream of the dam, comprising on average 57% of the diet numerically and consumed by 91% of the feeding fish. Immature Ephemeroptera were also quite prevalent, comprising on average, 23% of the diet and consumed by 72% of the feeding fish. No samples of white suckers from upstream of the dam were acquired during the month of May. In June, the

Table 5. Percent composition by number and frequency of occurrence (in parantheses) for diet items of white suckers collected upstream of the Stronach Dam site in the Pine River, Manistee County, Michigan; during 2000 and 2001. Only diet items comprising at least 5% of the diet by number, for at least one month, for either shorthead redhorse suckers, silver redhorse suckers, or white suckers, in the Pine River, are shown. Frequency of occurrence is calculated using the number of specimens sampled in a given month that contained foregut contents. Total sample size and the number of specimens in a month containing foregut contents (in parantheses) are given. Order-level summaries include lower taxa plus food items that could not be assigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Class	Order	Family (or Lowest Taxon)	May	June	July	August	Average
Arachnoidea	**Trombidiformes**	**Hydracarina**		**0 (0)**	**1 (27)**	**0 (7)**	**0 (11)**
Insecta				**97 (100)**	**99 (100)**	**99 (100)**	**98 (100)**
	Diptera			70 (100)	93 (100)	52 (100)	72 (100)
		Athericidae		23 (80)	0 (18)	0 (7)	8 (35)
		Ceratopoginidae		2 (40)	1 (29)	1 (21)	1 (30)
		Chironomidae		45 (80)	79 (93)	45 (100)	57 (91)
		Simuliidae		0 (0)	6 (42)	3 (36)	3 (26)
		Pupal Diptera		0 (0)	5 (76)	2 (64)	2 (47)
	Ephemeroptera			18 (80)	5 (51)	45 (86)	23 (72)
	Trichoptera			5 (40)	0 (20)	1 (29)	2 (30)
		Brachycentridae		0 (0)	0 (0)	0 (7)	0 (2)
		Lepidostomatidae		0 (0)	0 (0)	0 (0)	0 (0)
Pelecypoda				**0 (0)**	**0 (0)**	**0 (14)**	**0 (5)**
Eggs				**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**
		Small (insect sized) eggs		0 (0)	0 (0)	0 (0)	0 (0)
Other				**3**	**0**	**1**	
		Sample Size	0 (0)	9 (5)	48 (45)	24 (14)	
		Length Range (mm)	-	113-465	63-284	52-507	

three most numerically abundant food items types were: immature chironomids (45%), immature Athericids (23%), and immature Ephemeroptera (18%), all of which occurred in 80% of the feeding fish (Table 5). Chironomids numerically dominated the diet during July, comprising 79% of the diet and were consumed by 93% of the feeding fish. In August, equal proportions of immature chironomids and immature Ephemeroptera were consumed (45% of the diet numerically for both taxa). Diet overlap between all three months was high (Table 2).

Other taxa that frequently occurred in the diet seasonally, but did not comprise a substantial proportion of the diet numerically include: immature Trichoptera, Diptera pupae (Table 5), and Coleoptera (Appendices M - O). None of the fish consumed large-sized eggs or small-sized eggs. Non-countable items such as plant material (11%), sediment (56%), and detritus (95%) also occurred in the gut contents of white suckers upstream of the dam. While these items were commonly ingested by the white suckers, these items were generally seen in relatively small quantities within an individual fish.

Diet Similarity Among Species

The amount of diet overlap varied substantially between months, but overall was generally high (Table 6). In all months, May through August, the diets of white suckers from downstream and upstream of the dam were significantly similar (0.64 – 0.99). During May, the similarities of the diets of different species was generally low (0.15 – 0.43). In July, the diets of shorthead

Table 6. Morista similarity index values for sucker species and/or sampling location comparisons for sucker diets sampled on the Pine River in 2000 and 2001. Abbreviations are as follows; SHR = shorthead redhorse suckers, SR = silver redhorse suckers, CWS = white suckers, and down = sampled downstream of Stronach Dam site, up = sampled upstream of Stronach Dam site. Average is calculated using the average number of each food type eaten in all months.

Period	SHR-SR	SHR-CWSdown	SHR-CWSup	SR-CWSdown	SR-CWSup	CWSdown-CWSup
May	0.30	0.15	-	0.43	-	-
June	0.60	0.77	0.74	0.86	0.66	0.73
July	0.47	1.00	0.99	0.47	0.48	0.99
August	0.90	0.83	0.71	0.64	0.65	0.64
Average	0.80	0.96	0.98	0.92	0.82	0.96

redhorse suckers and white suckers were highly similar (0.99 – 1.00), but silver redhorse sucker diets showed substantially lower overlap with the other species (0.47 – 0.48). All species showed high diet overlap during June and August (0.60 – 0.90). When diet similarity index values were calculated using the average number of each food type eaten for May through August, the diet similarity between all three species was remarkably high (0.80 – 0.98).

The diets of suckers sampled in 2000 and 2001 were compared with the diets of brown trout, rainbow trout, and brook trout from the Pine River, sampled in 1999 (Table 7, Appendix P) (Mistak 2000). All three species of suckers showed almost no diet overlap with brown trout sampled from either upstream or downstream of Stronach Dam (0.05 – 0.06). All three species of suckers also showed virtually no diet overlap with rainbow trout from either upstream or downstream of the dam (0.00 – 0.01). Brook trout diets from downstream of the dam were similar to the diets of all three suckers species (0.65 – 0.68), but brook trout diets from upstream of the dam were less similar to the three sucker species (0.30 – 0.33).

DISCUSSION

Diet Composition

Shorthead redhorse, silver redhorse and white suckers consumed a wide variety of food items. Immature chironomids, however, were both the most frequently occurring food type and the most abundantly consumed item in the diets of all three species of sucker fishes. Other studies have also found that

Table 7. Morista similarity index values for sucker and trout species diet comparisons. Sucker diets were sampled on the Pine River in 2000 and 2001, and trout diets were sampled on the Pine River in 1999 (Mistak 2000). Abbreviations are as follows; BNT = brown trout, RBT = rainbow trout, EBT = brook trout, and down = sampled downstream of Stronach Dam site, up = sampled upstream of Stronach Dam site.

Species	BNT down	BNT up	RBT down	RBT up	EBT Down	EBT Up
shorthead redhorse sucker	0.05	0.05	0.01	0.01	0.65	0.30
silver redhorse sucker	0.06	0.05	0.01	0.01	0.66	0.32
white sucker downstream	0.06	0.05	0.00	0.00	0.68	0.33
white sucker upstream	0.06	0.05	0.00	0.01	0.68	0.33

immature chironomids were prevalent in the diets of shorthead and silver redhorse suckers (Clemens et al. 1924, Meyer 1962), and white suckers (Stewart 1926, Carlander 1969, Campbell 1935, Koehler 1978, Trippel and Harvey 1986, Hayes 1990, Logan et al. 1991), especially in lotic habitats (Eder and Carlson 1977). While immature chironomids were a large component of the diet of all three suckers species, other taxa frequently occurred, and in some months comprised a substantial proportion of the diets. Immature Trichoptera, immature Ephemeroptera, and immature simuliids were seasonally important to the shorthead redhorse, and immature ceratopogonidae and small-sized eggs were important seasonally to the silver redhorse. White suckers, both downstream and upstream of Stronach Dam, had more diverse diets than the redhorse suckers. Hydracarina (water mites), Pelecypoda, immature simuliids, and small-sized eggs were seasonally important to the white suckers downstream of Stronach Dam, and immature Ephemeroptera and athericids were seasonally important to white suckers upstream of Stronach Dam.

A potential limitation to this study is that a substantial percentage of shorthead redhorse and white suckers sampled were found to have empty foreguts. This may have occurred because our sampling was conducted only during daylight hours, and shorthead redhorse and white suckers may feed more intensely during non-daylight hours. White suckers have been reported to have an aversion to light (Lawler 1969, Galloway 1976), move more actively during darkness (Campbell 1971, Reynolds and Casterlin 1978), and prefer to feed during lowlight periods such as dawn and dusk (Stewart 1926). Hayes (personal communication) studied the food selection of white suckers throughout the diel cycle and found greater feeding activity associated with dark periods, but found no significant differences in diet composition. Thus, I feel that the diet composition found in this study is reflective of the diet over the course of the entire period. Most of the silver redhorse suckers that were sampled contained foregut contents. They were frequently seen in shallow water, away from cover, during daylight hours. This may suggest that silver redhorse actively feed during daylight hours.

Some fisheries biologists have hypothesized that sucker predation on the eggs of important game fish species could be substantial enough to cause significant decreases in gamefish populations. Numerous studies have documented fish egg consumption by suckers (Ellis and Roe 1917, Atkinson 1931, Scott and Crossman 1973, Holey et al. 1979). However, in this study, only one shorthead redhorse, one silver redhorse and two white suckers from downstream of the dam were found to have consumed eggs greater than 1 mm in diameter. Small-sized eggs, less than 1 mm in length were found in high numbers in a small percentage (>5%) of the suckers in this study. These small-sized eggs were usually between 0.30 – 1.00 mm and in most cases were non-spherical. This suggests that they were not fish eggs. Because numerous other fish species were present and gravid during our sampling period, fish eggs were likely to be present and available to the suckers for consumption. The low occurrence of fish eggs in the diets of the suckers in this study is similar to other studies where suckers did not consume fish eggs in the presence of spawning game fish (Stewart 1926, Hubbs 1932, Campbell 1935, Wolfert et al. 1975, Koehler 1978, Holey et al. 1979). Thus, it appears that fish eggs do not routinely occur in the diets of shorthead redhorse, silver redhorse, or white suckers and that reductions in reproductive success of other fish species due to egg predation by these three sucker species is unlikely.

Plant material occurred in the diets of roughly half of the individuals of each species. Detritus was also found in a majority of the feeding fish of each sucker species. While not quantified, these items were observed to comprise a relatively small proportion of the gut contents. No literature accounts of the occurrence of plant material and detritus in the diets of shorthead and silve redhorse were found. White suckers have been reputed to consume plant material, mostly commonly algae, sometimes comprising a significant portion of the diets (Eder and Carlson 1977, Koehler 1978). Detritus, sometimes defined as unidentifiable organic material, and sometimes defined as any diet item not identifiable, including digestive fluids, was reported to frequently occur in most diet studies of white suckers. Although ingested plant material and detritus may provide bioenergetic value and may even be selected for (Ahlgren 1996), its importance in this study appears minimal given the low amount found.

Sediment was found in roughly half of the suckers of each species in this study. Sediment had not been reported as a gut content for shorthead or silver redhorse (Meyer 1962). For white suckers, sediment ingestion has been found to be size and age dependent (Stewart 1926). In a study of white sucker diet composition in two rivers, Eder and Carlson (1977) found sand occurred in the

stomachs of roughly half of the white suckers in each river, but comprised significantly different quantities by volume. The relative lack of uniformity in which each species in this study consumed sediment suggests its ingestion is incidental in the feeding behavior of this group of fishes.

Similarity Among Suckers

The diet of shorthead redhorse was highly similar between all months except May, when immature Trichoptera dominated the diet. The diet of silver redhorse was highly similar between May – August, and June-July. The dissimilarity between May and August and June-July was due to the high number of small-sized eggs in their diet during June – July. Due to the small-size of the eggs (<1 mm), and the small percentage of fish that consumed them, silver redhorse diets are probably best described as dominated by immature chironomids, and in the absence of the small-sized eggs, would be highly similar in all summer months. The diet of white suckers from downstream of Stronach Dam were significantly similar between consecutive months, but less similar among May and non-consecutive months. This dissimilarity was mostly due to a large number of small-sized eggs consumed by a small percentage of the white suckers during May. With the influence of the small-sized eggs removed, the diet across all months would be highly similar. The diets of white suckers from upstream of Stronach Dam were also similar among all months. The high degree of similarity among all summer months, in all three sucker species is difficult to interpret without information on the monthly abundance and composition of food types available in the benthos. The diets of opportunistic generalist feeders, such as stream trout, have been found to be dissimilar between adjacent months, as the prevalence of food types changes throughout the season due to aquatic insect development (Mistak 2000). Alone, the high degree of diet similarity among all months of these three sucker species, can not indicate whether feeding is opportunistic or not. Immature chironomids are abundant throughout the year and present in almost all habitat types (Merritt and Cummings 1996). Without knowing if immature chironomids were the most abundant food type in each month of this study, it is hard to determine with certainty whether these sucker species are selecting for immature chironomids, or just opportunistically feeding on them. Mistak (2000) sampled the taxonomic composition of drifting aquatic invertebrates in the Pine River, and documented that chironomids comprised the largest percentage of the drift in each month. However, Lalancette (1977) demonstrated that white suckers establish preferences among food types and do not simply eat at random whatever they find. Similarly, Saint-Jacques (2000) found that white suckers are selective foragers, not generalists.

For the summer as a whole, the degree of diet similarity among the three sucker species is remarkably high. Upstream and downstream of Stronach Dam, the Pine River differs in the types of habitat present and the amount of those types available. Despite this, white suckers consumed the same food types in nearly identical proportions in each area. The diet of white suckers from upstream of Stronach Dam is also highly similar to the redhorse suckers found only downstream of the dam. Mistak (2000) also found that the growth rates of white suckers upstream and downstream of the dam were similar despite the presence of the shorthead and silver redhorse and higher abundance of white suckers downstream of the dam. This suggests that the food supply in this area of the river is not limiting and no partitioning of the food resources is necessary. Following dam removal, shorthead redhorse, silver redhorse and the abundant white suckers downstream of Stronach Dam will have access to upstream reaches. The results of this study suggest that these suckers will likely continue to feed on chironomids upstream of the dam, but competition for food resources will likely only occur if the abundance of the food types, primarily chironomids, are significantly less abundant upstream compared to downstream.

Similarity Among Suckers and Trout

Salmonids inhabiting streams have been found to feed primarily on drifting food items (e.g. Hunt 1966, Bachman 1984). While suckers are benthic foragers, it is possible that suckers could feed on the same food types as salmonids, thus reducing the quantity of preferred salmonid food types found in the drift. In 1999, Mistak (2000) examined the summer diet of brown trout, rainbow trout, and brook trout in the Pine River, both upstream and downstream of Stronach Dam. This information was compared to the diets of shorthead redhorse, silver redhorse and white suckers collected in this study, at the lowest consistent taxonomic level possible. Brown trout and rainbow trout diets had nearly no overlap with the diets of shorthead redhorse, silver redhorse, or white suckers, either upstream or downstream of the dam. While suckers in the Pine River concentrated mainly on

immature chironomids, brown trout and rainbow trout diets in the Pine river were more diverse and immature chironomids were a minor portion of the diets (Mistak 2000). Brook trout diets from upstream of the dam were not very similar to any of the three sucker species' diets, but the brook trout diets from downstream of the dam were. Brook trout from downstream of the dam were similar to the sucker diets mainly because they fed on a larger number of chironomids, while the diets of brook trout from upstream of the dam were more diverse. The diet composition of brook trout from downstream of the dam was based on a small sample size, however, and the dissimilarity between trout and sucker diets suggests that trout and suckers are not currently using the same food resources to a significant degree.

Mistak (2000) suggested that food was not limiting the growth of the three trout species in the Pine River, and trout growth was actually better in the area downstream of Stronach Dam where abundance of suckers was highest. Based on the results of this study, and from the results of Mistak (2000), the food resources of suckers and salmonids in the Pine River do not seem to be the principal factor limiting their growth and abundance. Furthermore, the low dietary overlap between the suckers and salmonids suggests that competition for food between these fish groups is unlikely.

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LITERATURE CITED

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APPENDICES

Appendix A. Diet description information for 17 shorthead redhorse suckers, collected during May, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Eight of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping: **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**272**	**100**	**100**
Coleoptera		4	1	38
	Dytiscidae	1	0	13
	Elmidae	3	1	25
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		52	19	63
	Athericidae	1	0	13
	Ceratopoginidae	0	0	0
	Chironomidae	47	17	63
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	0	0	0
	Tabanidae	0	0	0

Appendix A. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	0	0	0
	Pupal Diptera	4	1	25
Ephemeroptera		31	11	63
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	0	0	0
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		4	1	38
Trichoptera		181	67	88
	Brachycentridae	40	15	50
	Hydropsychidae	1	0	13
	Hydroptilidae	0	0	0
	Lepidostomatidae	24	9	50
	Limnephilidae	1	0	13
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**0**	**0**	**0**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents		**272**		

Appendix B. Diet description information for 27 shorthead redhorse suckers, collected during June, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Nine of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**9**	**1**	**33**
Insecta		**1443**	**99**	**89**
Coleoptera		5	0	33
	Dytiscidae	0	0	0
	Elmidae	1	0	11
	Gyrinidae	0	0	0
	Haliplidae	2	0	22
	Hydrophilidae	1	0	11
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		1374	95	78
	Athericidae	1	0	11
	Ceratopoginidae	1	0	11
	Chironomidae	1339	92	78
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	9	1	33
	Tabanidae	0	0	0

Appendix B. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	1	0	11
	Pupal Diptera	22	2	44
Ephemeroptera		12	1	67
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	0	0	0
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		3	0	33
Trichoptera		49	3	89
	Brachycentridae	21	1	67
	Hydropsychidae	4	0	22
	Hydroptilidae	8	1	11
	Lepidostomatidae	1	0	11
	Limnephilidae	2	0	22
	Phryganeidae	3	0	11
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**0**	**0**	**0**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents		**1452**		

Appendix C. Diet description information for 62 shorthead redhorse suckers, collected during July, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. 40 of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**3**	**0**	**5**
Crustacea		**3**	**0**	**8**
Amphipoda		1	0	3
Decapoda		2	0	5
Isopoda		0	0	0
Arachnoidea - Hydracarina		**102**	**1**	**45**
Insecta		**8023**	**98**	**85**
Coleoptera		20	0	25
	Dytiscidae	5	0	8
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	2	0	5
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		7766	95	83
	Athericidae	3	0	8
	Ceratopoginidae	40	0	28
	Chironomidae	7243	88	80
	Culicidae	1	0	3
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	260	3	28
	Tabanidae	3	0	8

Appendix C. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	209	3	60
Ephemeroptera	99	1	38
Baetidae	1	0	3
Caenidae	4	0	5
Ephemera	0	0	0
Ephemerellidae	1	0	3
Isonychidae	0	0	0
Hemiptera	1	0	3
Belostomatidae	1	0	3
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	1	0	3
Anisoptera	1	0	3
Zygoptera	0	0	0
Plecoptera	19	0	30
Trichoptera	117	1	38
Brachycentridae	28	0	10
Hydropsychidae	7	0	13
Hydroptilidae	1	0	3
Lepidostomatidae	6	0	5
Limnephilidae	16	0	13
Phryganeidae	0	0	0
Gastropoda	**7**	**0**	**5**
Pelecypoda	**1**	**0**	**3**
Eggs	**49**	**1**	**13**
Large (fish sized) eggs	1	0	3
Small (insect sized) eggs	48	1	13
Total Number of Stomach Contents	**8193**		

Appendix D. Diet description information for 24 shorthead redhorse suckers, collected during August, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. 10 of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping: **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta	**0**	**0**	**0**
Crustacea	**0**	**0**	**0**
Amphipoda	0	0	0
Decapoda	0	0	0
Isopoda	0	0	0
Arachnoidea - Hydracarina	**25**	**1**	**50**
Insecta	**4272**	**99**	**100**
Coleoptera	14	0	60
Dytiscidae	0	0	0
Elmidae	1	0	10
Gyrinidae	0	0	0
Haliplidae	0	0	0
Hydrophilidae	7	0	50
Salpingidae	1	0	10
Adult Coleoptera	0	0	0
Diptera	3999	93	100
Athericidae	17	0	70
Ceratopoginidae	0	0	0
Chironomidae	2913	68	100
Culicidae	0	0	0
Pelecorhynchidae	0	0	0
Psychodidae	0	0	0
Simuliidae	1026	24	90
Tabanidae	0	0	0

Appendix D. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	0	0	0
	Pupal Diptera	43	1	90
Ephemeroptera		161	4	90
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	0	0	0
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		14	0	60
Trichoptera		84	2	90
	Brachycentridae	10	0	50
	Hydropsychidae	19	0	40
	Hydroptilidae	12	0	40
	Lepidostomatidae	1	0	10
	Limnephilidae	2	0	20
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**0**	**0**	**0**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents		**4302**		

Appendix E. Diet description information for 14 silver redhorse suckers, collected during May, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. 12 of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping: **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**617**	**100**	**100**
Coleoptera		0	0	0
	Dytiscidae	0	0	0
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		599	97	100
	Athericidae	0	0	0
	Ceratopoginidae	12	2	50
	Chironomidae	555	90	100
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	0	0	0
	Tabanidae	0	0	0

Appendix E. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	32	5	42
Ephemeroptera	0	0	0
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	0	0	0
Isonychidae	0	0	0
Hemiptera	0	0	0
Belostomatidae	0	0	0
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	0	0	0
Trichoptera	18	3	50
Brachycentridae	7	1	8
Hydropsychidae	0	0	0
Hydroptilidae	0	0	0
Lepidostomatidae	8	1	33
Limnephilidae	0	0	0
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**0**	**0**	**0**
Eggs	**1**	**0**	**8**
Large (fish sized) eggs	1	0	8
Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents	**618**		

Appendix F. Diet description information for 11 silver redhorse suckers, collected during June, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. 10 of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**1**	**0**	**10**
Amphipoda		1	0	10
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**2**	**0**	**20**
Insecta		**530**	**71**	**100**
Coleoptera		1	0	10
	Dytiscidae	1	0	10
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		483	64	100
	Athericidae	4	1	30
	Ceratopoginidae	167	22	60
	Chironomidae	262	35	90
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	2	0	20
	Tabanidae	0	0	0

Appendix F. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	47	6	50
Ephemeroptera	41	5	30
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	0	0	0
Isonychidae	0	0	0
Hemiptera	0	0	0
Belostomatidae	0	0	0
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	3	0	30
Trichoptera	2	0	10
Brachycentridae	0	0	0
Hydropsychidae	2	0	10
Hydroptilidae	0	0	0
Lepidostomatidae	0	0	0
Limnephilidae	0	0	0
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**0**	**0**	**0**
Eggs	**200**	**27**	**10**
Large (fish sized) eggs	0	0	0
Small (insect sized) eggs	200	27	10
Total Number of Stomach Contents	**749**		

Appendix G. Diet description information for 15 silver redhorse suckers, collected during July, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. 13 of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping: **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**537**	**54**	**85**
Coleoptera		24	2	46
	Dytiscidae	4	0	23
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	4	0	8
	Hydrophilidae	11	1	31
	Salpingidae	0	0	0
	Adult Coleoptera	5	1	15
Diptera		481	49	85
	Athericidae	5	1	15
	Ceratopoginidae	143	14	38
	Chironomidae	281	28	77
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	8	1	15
	Tabanidae	0	0	0

Appendix G. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	0	0	0
	Pupal Diptera	44	4	54
Ephemeroptera		31	3	38
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	7	1	0
	Ephemerellidae	0	0	0
	Isonychidae	5	1	8
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		1	0	8
Trichoptera		0	0	0
	Brachycentridae	0	0	0
	Hydropsychidae	0	0	0
	Hydroptilidae	0	0	0
	Lepidostomatidae	0	0	0
	Limnephilidae	0	0	0
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**452**	**46**	**15**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	452	46	15
Total Number of Stomach Contents		**989**		

Appendix H. Diet description information for one silver redhorse sucker, collected during August 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**77**	**100**	**100**
Coleoptera		0	0	0
	Dytiscidae	0	0	0
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		77	100	100
	Athericidae	0	0	0
	Ceratopoginidae	0	0	0
	Chironomidae	74	96	100
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	0	0	0
	Tabanidae	0	0	0

Appendix H. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	3	4	100
Ephemeroptera	0	0	0
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	0	0	0
Isonychidae	0	0	0
Hemiptera	0	0	0
Belostomatidae	0	0	0
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	0	0	0
Trichoptera	0	0	0
Brachycentridae	0	0	0
Hydropsychidae	0	0	0
Hydroptilidae	0	0	0
Lepidostomatidae	0	0	0
Limnephilidae	0	0	0
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**0**	**0**	**0**
Eggs	**0**	**0**	**0**
Large (fish sized) eggs	0	0	0
Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents	**77**		

Appendix I. Diet description information for 42 white suckers, collected during May, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Thirteen of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**2**	**0**	**8**
Amphipoda		2	0	8
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**2**	**0**	**8**
Insecta		**560**	**36**	**100**
Coleoptera		2	0	15
	Dytiscidae	0	0	0
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	1	0	8
Diptera		513	33	100
	Athericidae	2	0	15
	Ceratopoginidae	13	1	31
	Chironomidae	491	31	92
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	1	0	8
	Tabanidae	0	0	0

Appendix I. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	1	0	8
	Pupal Diptera	5	0	31
Ephemeroptera		1	0	8
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	0	0	0
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		0	0	0
Trichoptera		44	3	38
	Brachycentridae	11	1	31
	Hydropsychidae	0	0	0
	Hydroptilidae	1	0	8
	Lepidostomatidae	21	1	15
	Limnephilidae	7	0	15
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**1000**	**64**	**8**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	1000	64	8
Total Number of Stomach Contents		**1568**		

Appendix J. Diet description information for 30 white suckers, collected during June, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Eleven of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**131**	**15**	**73**
Insecta		**520**	**58**	**100**
Coleoptera		7	1	18
	Dytiscidae	6	1	9
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		486	54	91
	Athericidae	0	0	0
	Ceratopoginidae	23	3	27
	Chironomidae	447	50	91
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	0	0	0
	Tabanidae	0	0	0

Appendix J. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	0	0	0
	Pupal Diptera	12	1	55
Ephemeroptera		14	2	45
	Baetidae	1	0	9
	Caenidae	0	0	0
	Ephemera	1	0	0
	Ephemerellidae	3	0	18
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		2	0	9
Trichoptera		11	1	45
	Brachycentridae	4	0	9
	Hydropsychidae	1	0	9
	Hydroptilidae	0	0	0
	Lepidostomatidae	0	0	0
	Limnephilidae	3	0	9
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**0**	**0**	**0**
Eggs		**245**	**27**	**9**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	245	27	9
Total Number of Stomach Contents		**896**		

Appendix K. Diet description information for 83 white suckers, collected during July, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Fiftyseven of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping: **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**1**	**0**	**2**
Crustacea		**14**	**0**	**9**
Amphipoda		0	0	0
Decapoda		1	0	2
Isopoda		13	0	7
Arachnoidea - Hydracarina		**166**	**3**	**58**
Insecta		**4878**	**94**	**86**
Coleoptera		32	1	30
	Dytiscidae	5	0	5
	Elmidae	3	0	5
	Gyrinidae	0	0	0
	Haliplidae	1	0	2
	Hydrophilidae	6	0	9
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		4749	91	86
	Athericidae	2	0	2
	Ceratopoginidae	29	1	11
	Chironomidae	4379	84	84
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	118	2	28
	Tabanidae	0	0	0

Appendix K. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	1	0	2
	Pupal Diptera	212	4	67
Ephemeroptera		57	1	37
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	1	0	2
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		28	1	28
Trichoptera		12	0	18
	Brachycentridae	3	0	5
	Hydropsychidae	4	0	5
	Hydroptilidae	0	0	0
	Lepidostomatidae	0	0	0
	Limnephilidae	4	0	5
	Phryganeidae	0	0	0
Gastropoda		1	0	2
Pelecypoda		4	0	7
Eggs		3	0	4
	Large (fish sized) eggs	3	0	4
	Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents		5211		

Appendix L. Diet description information for 31 white suckers, collected during August, 2000 and 2001; in the Pine River, Manistee County, Michigan; downstream of the Stronach Dam site. Ten of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**1**	**0**	**10**
Amphipoda		1	0	10
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**357**	**69**	**90**
Coleoptera		0	0	0
	Dytiscidae	0	0	0
	Elmidae	0	0	0
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		324	63	90
	Athericidae	1	0	10
	Ceratopoginidae	0	0	0
	Chironomidae	202	39	90
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	117	23	40
	Tabanidae	0	0	0

Appendix L. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	4	1	20
Ephemeroptera	30	6	60
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	0	0	0
Isonychidae	0	0	0
Hemiptera	0	0	0
Belostomatidae	0	0	0
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	0	0	0
Trichoptera	3	1	30
Brachycentridae	1	0	10
Hydropsychidae	0	0	0
Hydroptilidae	0	0	0
Lepidostomatidae	0	0	0
Limnephilidae	0	0	0
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**92**	**18**	**10**
Eggs	**65**	**13**	**10**
Large (fish sized) eggs	0	0	0
Small (insect sized) eggs	65	13	10
Total Number of Stomach Contents	**518**		

Appendix M. Diet description information for 9 white suckers, collected during June, 2000 and 2001; in the Pine River, Manistee County, Michigan; upstream of the Stronach Dam site. Five of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**3**	**3**	**20**
Amphipoda		3	3	20
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**0**	**0**	**0**
Insecta		**85**	**97**	**100**
Coleoptera		2	2	40
	Dytiscidae	1	1	20
	Elmidae	1	1	20
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		62	70	100
	Athericidae	20	23	80
	Ceratopoginidae	2	2	40
	Chironomidae	40	45	80
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	0	0	0
	Tabanidae	0	0	0

Appendix M. (continued)

Identification Grouping **Class**; *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	0	0	0
Ephemeroptera	16	18	80
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	0	0	0
Isonychidae	0	0	0
Hemiptera	0	0	0
Belostomatidae	0	0	0
Corixidae	0	0	0
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	1	1	20
Trichoptera	4	5	40
Brachycentridae	0	0	0
Hydropsychidae	0	0	0
Hydroptilidae	0	0	0
Lepidostomatidae	0	0	0
Limnephilidae	2	2	20
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**0**	**0**	**0**
Eggs	**0**	**0**	**0**
Large (fish sized) eggs	0	0	0
Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents	**88**		

Appendix N. Diet description information for 48 white suckers, collected during July, 2000 and 2001; in the Pine River, Manistee County, Michigan; upstream of the Stronach Dam site. Fortyfive of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**27**	**1**	**27**
Insecta		**3581**	**99**	**100**
Coleoptera		24	1	13
	Dytiscidae	1	0	2
	Elmidae	4	0	4
	Gyrinidae	1	0	2
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	1	0	2
Diptera		3355	93	100
	Athericidae	15	0	18
	Ceratopoginidae	19	1	29
	Chironomidae	2859	79	93
	Culicidae	3	0	2
	Pelecorhynchidae	3	0	4
	Psychodidae	1	0	2
	Simuliidae	217	6	42
	Tabanidae	1	0	2

Appendix N. (continued)

Identification Grouping **Class**, *Order*, or Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Adult Diptera	0	0	0
Pupal Diptera	187	5	76
Ephemeroptera	190	5	51
Baetidae	0	0	0
Caenidae	0	0	0
Ephemera	0	0	0
Ephemerellidae	35	1	11
Isonychidae	0	0	0
Hemiptera	2	0	4
Belostomatidae	0	0	0
Corixidae	2	0	4
Megaloptera	0	0	0
Corydalidae	0	0	0
Odonata	0	0	0
Anisoptera	0	0	0
Zygoptera	0	0	0
Plecoptera	0	0	0
Trichoptera	10	0	20
Brachycentridae	0	0	0
Hydropsychidae	0	0	0
Hydroptilidae	2	0	4
Lepidostomatidae	0	0	0
Limnephilidae	2	0	4
Phryganeidae	0	0	0
Gastropoda	**0**	**0**	**0**
Pelecypoda	**0**	**0**	**0**
Eggs	**0**	**0**	**0**
Large (fish sized) eggs	0	0	0
Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents	**3616**		

Appendix O. Diet description information for 24 white suckers, collected during August, 2000 and 2001; in the Pine River, Manistee County, Michigan; upstream of the Stronach Dam site. Fourteen of the fish had foregut contents and were subsequently analyzed. Frequency of occurrence is calculated using the number of fish that contained foregut contents. Order-level summaries include lower taxa plus food items that could not be asigned to a lower taxa. For all Insecta, larval lifestage is assumed unless otherwise noted.

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
Oligochaeta		**0**	**0**	**0**
Crustacea		**0**	**0**	**0**
Amphipoda		0	0	0
Decapoda		0	0	0
Isopoda		0	0	0
Arachnoidea - Hydracarina		**2**	**0**	**7**
Insecta		**1015**	**99**	**100**
Coleoptera		3	0	14
	Dytiscidae	0	0	0
	Elmidae	3	0	14
	Gyrinidae	0	0	0
	Haliplidae	0	0	0
	Hydrophilidae	0	0	0
	Salpingidae	0	0	0
	Adult Coleoptera	0	0	0
Diptera		534	52	100
	Athericidae	1	0	7
	Ceratopoginidae	15	1	21
	Chironomidae	463	45	100
	Culicidae	0	0	0
	Pelecorhynchidae	0	0	0
	Psychodidae	0	0	0
	Simuliidae	29	3	36
	Tabanidae	0	0	0

Appendix O. (continued)

Identification Grouping **Class**, *Order*, or	Family	Total Count	Percent Composition By Number	Frequency of occurrence (%)
	Adult Diptera	0	0	0
	Pupal Diptera	16	2	64
Ephemeroptera		462	45	86
	Baetidae	0	0	0
	Caenidae	0	0	0
	Ephemera	0	0	0
	Ephemerellidae	0	0	0
	Isonychidae	0	0	0
Hemiptera		0	0	0
	Belostomatidae	0	0	0
	Corixidae	0	0	0
Megaloptera		0	0	0
	Corydalidae	0	0	0
Odonata		0	0	0
	Anisoptera	0	0	0
	Zygoptera	0	0	0
Plecoptera		1	0	7
Trichoptera		15	1	29
	Brachycentridae	1	0	7
	Hydropsychidae	0	0	0
	Hydroptilidae	12	1	21
	Lepidostomatidae	0	0	0
	Limnephilidae	0	0	0
	Phryganeidae	0	0	0
Gastropoda		**0**	**0**	**0**
Pelecypoda		**5**	**0**	**14**
Eggs		**0**	**0**	**0**
	Large (fish sized) eggs	0	0	0
	Small (insect sized) eggs	0	0	0
Total Number of Stomach Contents		**1023**		

Appendix P. Taxonomic grouping and taxa counts that were used in calculating Morista similarity index values for sucker and trout species diet comparisons. All species were collected in the Pine River, Manistee Co., Michigan between 1999 - 2001. Abbreviations are as follows: SHR=shorthead redhorse sucker, SR=silver redhorse sucker, CWS=white sucker, BNT=brown trout, RBT=rainbow trout, EBT=brook trout, down=sampled downstream from the Stronach Dam site, up=sampled upstream of the Stronach Dam site, and AVE=the average number each food type eaten.

Taxa	SHR AVE	SR AVE	CWS down AVE	CWS up AVE	BNT down	BNT up	RBT down	RBT up	EBT down	EBT up
Acarina (Hydracarina)	34	1	75	10	1	2	1	5	3	6
Cicadellidae Adult	0	0	0	0	0	4	1	8	0	1
Acrididae Adult	0	0	0	0	4	5	3	6	2	3
Amphipoda	0	0	1	1	0	1	0	2	1	1
Cottidae	0	0	0	0	7	16	5	16	1	1
Decapoda	1	0	0	0	0	1	0	1	0	0
Diplopoda	0	0	0	0	0	1	2	1	1	3
Fish Egg	0	0	1	0	1	0	1	1	1	1
Formicidae	0	0	0	0	1	5	1	0	5	4
Gastropoda	2	0	0	0	0	113	1	2	0	3
Hirudinea	0	0	0	0	0	2	3	6	0	0
Isopoda	0	0	3	0	1	1	5	1	1	1
Pyralidae Larva	0	0	0	0	0	1	1	1	0	1
Oligochaeta	1	0	0	0	2	1	4	3	2	2
Pelecypoda	0	0	24	2	0	0	0	0	0	0
Percopsidae	0	0	0	0	13	0	0	2	2	0
Petromyzontidae Larva	0	0	0	0	2	0	0	1	0	0
Rodentia	0	0	0	0	0	1	2	11	0	0
Small (insect sized) eggs	12	163	328	0	0	0	0	0	0	0
Unknown Fish	0	0	0	0	1	2	1	1	1	1
Vespidae	0	0	0	0	1	2	0	1	0	1
Hemiptera	0	0	0	1	0	35	3	11	1	24
Plecoptera	10	1	8	1	3	17	5	12	3	1
Lepidoptera Larva	0	0	0	0	3	1	0	2	1	4
Odonata	0	0	0	0	1	1	125	218	0	1

Appendix P. (continued)

Taxa	SHR AVE	SR AVE	CWS down AVE	CWS up AVE	BNT down	BNT up	RBT down	RBT up	EBT down	EBT up
Brachycentridae Larva	25	2	5	0	43	263	146	435	41	49
Hydropsychidae Larva	8	1	1	0	11	42	0	1	24	37
Hydroptilidae Larva	5	0	0	5	0	0	0	0	0	7
Lepidostomatidae	8	2	5	0	0	0	0	0	0	0
Limnephilidae Larva	5	0	4	1	1	0	58	48	0	1
Mollanidae Larva	0	0	0	0	0	2	7	2	0	1
Phryganeidae	1	0	0	0	0	0	0	0	0	0
Trichoptera Adult	0	0	0	0	1	1	1	1	0	0
Trichoptera Larva	56	1	3	3	2	0	8	0	0	1
Trichoptera Pupa	0	0	0	0	1	0	3	1	0	1
Baetidae Adult	0	0	0	0	0	2	0	1	0	24
Baetidae Larva	0	0	0	0	95	139	89	132	74	103
Baetiscidae Larva	0	0	0	0	1	0	0	1	0	0
Caenidae	1	0	0	0	0	0	0	0	0	0
Ephemera	0	2	0	0	0	0	0	0	0	0
Ephemerellidae Larva	0	0	1	12	10	89	0	3	58	137
Ephemeroptera Adult	0	0	0	0	0	26	1	0	0	36
Ephemeroptera Larva	74	15	24	211	0	1	1	9	0	0
Heptageniidae Larva	0	0	0	0	5	14	1	0	2	3
Isonychidae	0	1	0	0	0	0	0	0	0	0
Siphlonouridae Larva	0	0	0	0	0	4	12	4	0	0
Chrysomelidae Adult	0	0	0	0	0	1	232	60	1	3
Coleoptera Adult	0	1	0	0	0	3	0	1	2	2
Curculionidae Adult	0	0	0	0	0	0	0	0	1	1
Dytiscidae	2	1	3	1	0	0	0	0	0	0
Elmidae larvae	1	0	1	3	0	0	0	0	0	0
Elmidae Adult	0	0	0	0	0	3	0	1	0	0
Gyrinidae	0	0	0	0	0	0	0	0	0	0
Haliplidae	1	1	0	0	0	0	0	0	0	0
Hydrophilidae Larva	3	3	2	0	1	1	5	14	0	1

Appendix P. (continued)

Taxa	SHR AVE	SR AVE	CWS down AVE	CWS up AVE	BNT down	BNT up	RBT down	RBT up	EBT down	EBT up
Coleoptera larva	5	0	5	6	0	0	0	0	0	0
Salpingidae	0	0	0	0	0	0	0	0	0	0
Athericidae Larva	6	2	1	12	9	326	26	106	21	59
Ceratopogonidae Larva	10	81	16	12	0	0	0	0	2	1
Chironomidae Larva	2886	293	1380	1121	6	23	1	0	146	105
Diptera Pupae	70	32	58	68	14	19	1	5	15	12
Culicidae	0	0	0	1	0	0	0	0	0	0
Diptera Adult	0	0	1	0	3	13	12	8	2	5
Empididae Larva	0	0	0	0	0	0	0	0	0	2
Other Diptera	2	0	3	20	0	0	0	0	0	0
Pelecorhynchidae	0	0	0	1	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	0	0	0	0	0
Simuliidae Larva	324	3	59	82	1	18	1	0	5	11
Tabanidae Larva	1	0	0	0	2	3	0	1	1	3
Tipulidae Larva	0	0	0	0	1	17	32	48	20	91