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FISH AND INVERTEBRATE COMMUNITY COMPOSITION: A COMPARISON OF HEADWATER AND ADVENTITIOUS STREAMS

By

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ABSTRACT

FISH AND INVERTEBRATE COMMUNITY COMPOSITION: A COMPARISON OF HEADWATER AND ADVENTITIOUS STREAMS

By

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The River Continuum Concept (RCC) is an overarching paradigm in stream ecology that makes predictions regarding the trophic status, fish community, and invertebrate community of rivers based on stream order. The RCC, however, ignores the role of adventitious streams, which are low-ordered tributaries to larger rivers. I examined the fish and invertebrate community and habitat of the fifth-order mainstem, two second-order adventitious tributaries to the mainstem, and three second-order headwater streams of the Pine River (Alcona County, Michigan) from May through August 2000. Fish species richness generally increased with increasing stream order and was higher in the adventitious streams than in the headwater streams. The fish species composition of adventitious streams was more similar to the mainstem than to the headwater streams, but showed greater month-to-month variability than either the mainstem or headwater streams. Adventitious streams had a preponderance of tolerant fish and had lower scores for invertebrate Indices of Biotic Integrity, suggesting that water quality was impaired in these streams. Habitat conditions in headwater and adventitious streams were similar except adventitious streams were generally warmer. These results suggest that factors in addition to stream order, such as stream connectivity and temperature, are important determinants of stream fish assemblage.

For my parents, who always encouraged me to learn.

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Introduction

Stream order designation (Horton 1945) has been used extensively by ecologists in recent decades to make predictions concerning a watershed's physical, biotic, and metabolic status. Gradations in many physical features can be attributed to increasing stream order. Naiman (1983) found traits such as watershed area, channel dimensions, and discharge to be directly proportional to stream order. His study also demonstrated that stream width could be predicted for a given stream order. A negative correlation exists between slope gradient and stream order (Platts 1979). Numerous studies have found significant increases in fish species richness related to increasing stream order (Sheldon 1968; Platts 1979; Schlosser 1982a; Naiman et al. 1987; Paller 1994; Fairchild et al. 1998), but Platts (1979) and Fairchild et al. (1998) found that fish species richness is typically maximized in fourth or fifth order streams with a subsequent decline in stream orders of six or more.

The River Continuum Concept (RCC) (Cummins 1977; Minshall 1978; Vannote et al. 1980) hypothesizes that a watershed's trophic structure follows a predictable gradient from low-order headwater streams to high-order large rivers, and that downstream processes are directly influenced by upstream processes. Some of the expected shifts in various trophic, physical, and biotic components along this continuum are summarized in Table 1. Briefly, stream orders 1 through 3 are typically heterotrophic in nature, the primary carbon source being coarse particulate organic matter (CPOM) received from the riparian surroundings (Vannote et al. 1980). Instream photosynthesis is minimized due to

Table 1. Expected shifts in trophic, physical, and biotic components by stream order according to the River Continuum Concept (summarized from Cummins 1977; Vannote et al. 1980).

	Stream Orders	Trophic Status	Slope Gradient	Hydrologic Variability	Temperature Stability	Fish Community	Invertebrate Community
Headwaters	1-3	Heterotrophic	High	High	High	Coldwater Species	Collectors (45%) Shredders (35%) Predators (15%) Scrapers (5%)
Midreaches	4-6	Autotrophic	Moderate	Moderate	Low	Warmwater Species	Collectors (50%) Scrapers (35%) Predators (10%) Shredders (5%)
Large Rivers	7-12	Heterotrophic	Low	Low	Moderate	Bottom Feeders	Collectors (90%) Predators (10%)

vegetative shading of these small streams. The CPOM is reduced to fine particulate organic matter (FPOM) by invertebrate shredders, the second most abundant functional feeding group after collectors (Vannote et al. 1980), as it moves downstream. Stream orders 4 through 6 shift to an autotrophic state due to an increased amount of sunlight reaching the stream, resulting in increased primary production. This increase in periphyton is coupled to an increase in invertebrate grazers. FPOM derived from upstream processes becomes the primary food source of invertebrate collectors, which are the most abundant functional feeding group in mid-order reaches. Stream orders 7 through 12 return to a heterotrophic state due to increased turbidity resulting from the large volume of FPOM and detritus from upstream sources. The macroinvertebrate functional feeding groups consist primarily of collectors in these large rivers. The ratio of annual instream photosynthesis to respiration (P:R) is largely dependent on the amount of sunlight reaching the stream bed, a function of vegetative cover/canopy, water depth, and turbidity.

The RCC, however, is based on an underlying assumption that convergent streams differ by no more than one order of magnitude. One of the disadvantages of this concept is that it ignores lower ordered streams emptying into a higher ordered stream (Allan 1995). Gorman (1986) offered the term adventitious to describe tributaries that flow into streams differing by 3 or more magnitudes of order (e.g., a 2nd order flowing into a 5th order). In an amendment to the RCC, Minshall et al. (1985) realized this and suggested that adventitious tributaries may represent a deviation from the original notion. Losses of streamside vegetation due to varying land uses in a lower gradient region of the watershed could alter the amount of CPOM input and sunlight exposure, creating an autotrophic situation. Therefore, an adventitious stream's trophic structure would more closely resemble its proximal midreach stream than headwaters sharing the same order designation. Grazers and collectors would be expected to comprise the largest proportion of invertebrate functional feeding groups in this situation. The lower gradient associated with the proximity of the midreach should cause a corresponding decrease in variability of the adventitious tributary's flow regime (Platts 1979).

Other information provided solely by stream order may also be misleading, especially when a stream receives inflow from numerous streams of lower order magnitude. The resultant increase in discharge and possible temperature effects are not accounted for by the Horton (1945) classification. Minshall et al. (1985) hypothesized that potential impacts of an adventitious tributary may be determined by its size, riparian land use, and trophic structure. These factors may alter the fish community structure. A study by Osborne & Wiley (1992) on two warmwater watersheds in Illinois found that fish species richness was lower in headwater streams compared to adventitious tributaries and found no significant difference in species richness between adventitious tributaries and the proximal mainstreams. However, headwater streams and adventitious tributaries exhibited the greatest similarity in species composition (Osborne & Wiley 1992).

Differences in fish assemblages of adventitious and headwater streams may also occur due to abiotic differences. In Osborne & Wiley's (1992) study, no difference in slope gradient was found between headwater streams and adventitious tributaries in two warmwater river systems. This may partially explain the similarity in species composition. In coldwater river systems, however, decreases in both slope gradient and hydrological variation, and increases in temperature, are typically associated with increasing stream order (Cummins 1977; Platts 1979; Vannote 1980). Therefore, adventitious streams are more likely to drain regions of lower slope gradient than headwater streams in the same watershed. Because fish species richness is significantly and negatively correlated with hydrologic variability (Horwitz 1978; Platts 1979; Gorman 1986; Poff & Allan 1995), low gradient adventitious streams should have relatively higher species richness. Studies have shown that species richness is positively correlated with stream size and maximized in fifth- or sixth-order streams (Gorman & Karr 1978; Platts 1979; Beecher et al. 1988; Fairchild et al. 1998). Thus, it is likely that fish species richness would be increased in adventitious tributaries relative to headwater streams due to the proximity of a species-rich midreach.

Differences in fish assemblages due to abiotic factors may also occur on a temporal basis. Ibbotson et al. (1994) found fish species richness in low- to mid-order streams to vary over time spans as short as one month. Compared to headwater streams, adventitious streams may exhibit greater temporal dynamics in terms of fish species richness and density for several reasons. The greater level of habitat heterogeneity found in most headwater streams is usually coupled with a greater stability of fish assemblages compared to lowland streams (Gorman 1986). Because midreach streams are subject to the most extreme seasonal temperature fluctuations (Cummins 1977; Vannote 1980), adventitious tributaries may provide thermal refuges for coldwater fish when the mainstream water temperatures approach intolerable extremes. Adventitious tributaries may also be used seasonally for spawning by midreach-dwelling fish, thereby increasing the density and species richness at certain times each year (Gorman 1986; Osborne & Wiley 1992). A decrease in species richness in adventitious streams would be expected during low-flow events, such as a drought or a seasonal dry period, which would cause the fish to temporarily relocate to the midreach, thereby decreasing species richness and abundance (Gorman 1986; Osborne & Wiley 1992).

The distribution of fish taxa classified as tolerant, intermediate, or intolerant to environmental degradation may differ in adventitious streams when compared to headwater streams. Studies have demonstrated that riparian agricultural activities may degrade habitat through increased sedimentation (Karr 1981; Walser & Bart 1999), nutrient addition (Cooke et al. 1995), and addition of toxic chemicals associated with pesticide use (Loehr 1974; Johnson 1986; Cuffney et al. 2000). A study by Walser & Bart (1999) found that a significant positive relationship existed between agricultural use and sedimentation in mainstem reaches of a watershed due to the lower slope gradient, but not in the higher gradient headwater reaches. Therefore, low-gradient adventitious tributaries to a mainstem are also likely to be negatively impacted by agricultural land use, resulting in decreased numbers of intolerant species. The water quality may decrease to a level that renders adventitious streams unsuitable for intolerant fish species, thereby allowing tolerant and intermediate tolerant fish to dominate.

Changes in water quality associated with agricultural land use may also be reflected in the macroinvertebrate community composition. Indices of Biotic Integrity (IBI's) have been widely used to assess the quality of streams through examination of the presence and abundance of macroinvertebrates (Kerans & Karr 1994; Whiles et al. 2000) and fish (Leonard & Orth 1986; Steedman 1988; Lydy et al. 2000). However, Berkman et al. (1986) found that macroinvertebrates were more sensitive than fish as indicators of habitat perturbation in streams impacted by agricultural practices. Based on these IBI's, rapid bioassessment protocols have been developed for use in the Midwestern U.S. (Michigan Department of Environmental Quality 1997; Barbour et al. 1999). Other IBI's include EPT (Ephemeroptera, Plecoptera, and Trichoptera) abundance, and the ratio of Chironomidae abundance to EPT abundance (Merritt & Cummins 1996a).

Goals and Objectives

The goal of this project is to examine the role of adventitious tributaries in a watershed and to compare these streams to headwater streams of the same order designation within the watershed. Associated with this goal, I developed four hypotheses related to the fish communities. I first hypothesized that fish species richness is greater in adventitious tributaries than in headwater tributaries due to the connectivity with the mainstem. Second, I hypothesized that the fish species composition in adventitious streams would show greater similarity to the proximal mainstem than to headwater streams. Third, I hypothesized that adventitious streams would have a greater abundance of tolerant fish species than headwater streams. Finally, I hypothesized that adventitious streams would exhibit greater temporal fluctuations in fish species richness during the summer months than headwater streams. I also developed two hypotheses with respect to the macroinvertebrate communities. First, I hypothesized that the IBI scores would be lower for adventitious streams due to negative impacts of agriculture and urbanization. Second, I hypothesized that the loss of streamside vegetation associated with these land uses would create a more autotrophic situation in adventitious streams that would be reflected in the macroinvertebrate composition as a decrease in shredders and an increase in grazers. The specific objectives of this study were to:

(1) Characterize and compare the fish species richness and relative abundance in three second-order headwater streams, two second-order adventitious streams, and the fifth-order mainstem of the Pine River in Alcona County, Michigan.

(2) Using similarity indices, compare the fish species assemblages among these three stream types.

(3) Determine and compare the proportion of fish classified as tolerant, intermediate, and intolerant between these stream types.

(4) Examine and compare the temporal dynamics of the fish community composition in each of these streams from May to August.

(5) Characterize and compare the invertebrate community composition in each of these stream types for consistency with the River Continuum Concept.

(6) Using Indices of Biotic Integrity (IBI's), compare the macroinvertebrate community compositions in each of these three stream types as bioindicators of stream water quality.

(7) Characterize and compare habitat parameters such as stream width, depth, discharge, substrate composition, in-stream temperature, and meso-habitat composition (i.e. riffle, run, pool, etc.) in each of these types.

Study Area

The Pine River, a tributary of the AuSable River, is located in the northeastern region of Michigan's lower peninsula (Figure 1). The Pine River consists of five major branches: the South Branch, West Branch, East Branch, VanEtten Creek, and the Pine River mainstem. Approximately 95% of this watershed is located within the southeast region of Alcona County. Shortly after flowing south into Iosco County, the Pine enters VanEtten Lake, a recreational impoundment formed by a small bottom-release dam at the south end of the lake. The Pine continues its southerly flow until it reaches the AuSable River, approximately 3 kilometers downstream from VanEtten Dam.

Approximately one-half of the land drained by the Pine River is contained in the Huron National Forest. Most of the South and West Branches are contained within the forest boundary. Land use within the Huron National Forest is primarily dedicated to recreational activities, including camping, hunting, fishing, and hiking. The headwaters of the South Branch are found in a management area reserved for the Kirtland warbler, a federally listed endangered bird species, and are protected against development. The East Branch, VanEtten Creek, and Pine River mainstem lie east of the forest boundary. Here, the land use is largely for agricultural purposes.

The Pine River was chosen for my research because it is the subject of an ongoing habitat assessment for salmon and steelhead by myself, doctoral candidate Brad Thompson, and our advisor Daniel Hayes. The habitat data that we collect will be used to create a model for predicting the number of juvenile salmon and steelhead that the Pine River could support if fish passage is created at VanEtten Dam.

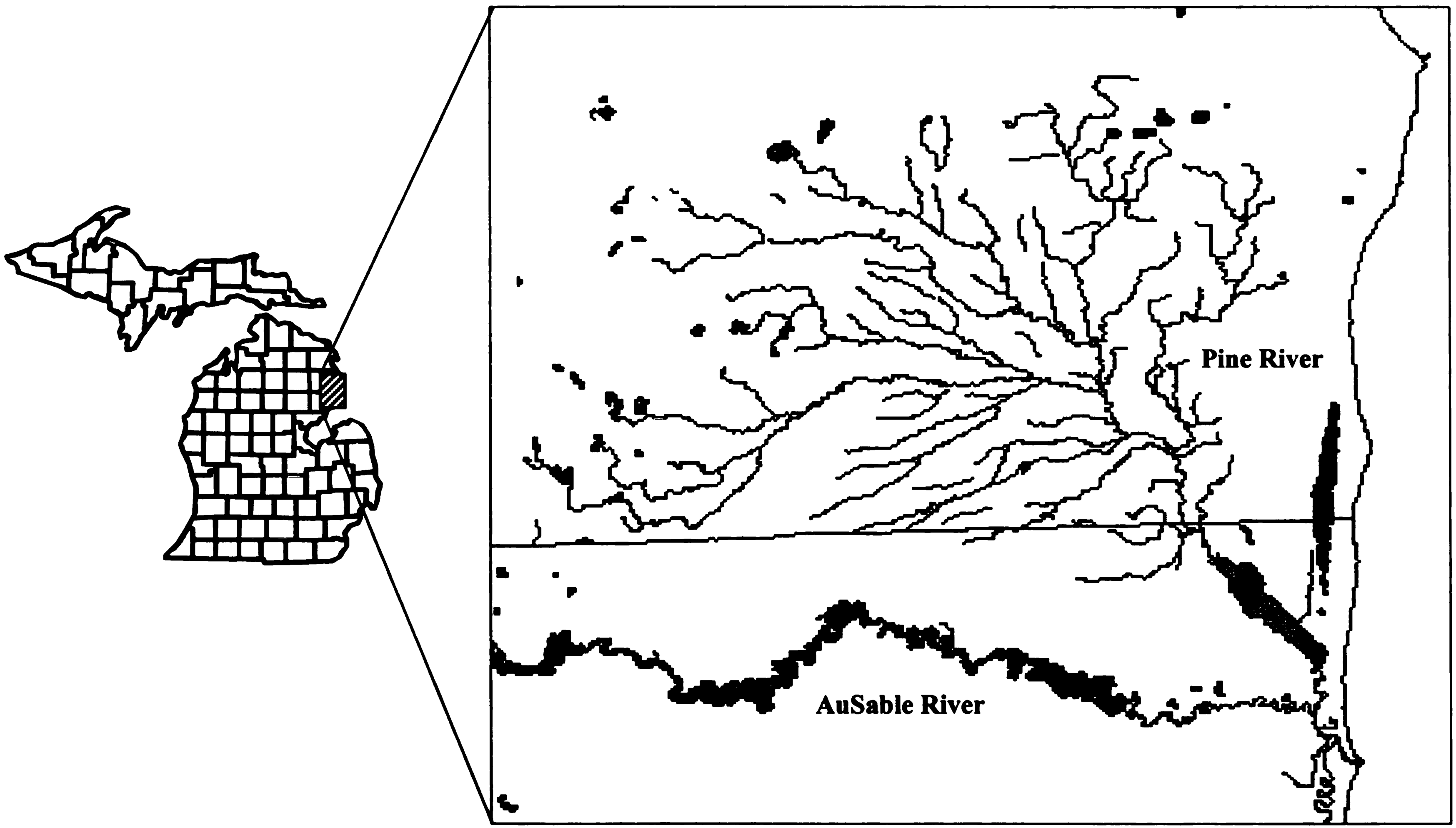

Figure 1. Location of the Pine River in Alcona and Iosco Counties, Michigan.

Stream order was determined from U.S. Geological Survey maps (scale 1:24,000). Two second-order adventitious tributaries to the Pine River mainstem were chosen for the purpose of this research: Hill Creek and an unnamed creek (hereafter referred to as Unnamed Creek). These were chosen because they are the only second-order adventitious tributaries to the fifth-order mainstem of the Pine River. Three second-order non-adventitious headwater tributaries were chosen for this research: McGillis Creek, McDonald Creek, and VanderCook Creek. The criteria used for selection of these streams were road access, spatial distribution within the watershed, and connectivity with streams differing by no more than one order designation.

Two sites separated by a minimum of one hundred meters were chosen for sampling purposes within each stream (Table 2). Each site consisted of a seventy-five meter section of stream, marked at each end to ensure month-to-month sampling consistency. Site selection for all second-order streams was determined by availability of access. For each of these streams, only one road crossing was available. Thus, one site was selected upstream of the road and one site was selected downstream, with the exception of UnNamed Creek. UnNamed Creek attains second-order status approximately five meters upstream from Cruzen Road, the only adequate access point. Thus, both sites were selected downstream from the road crossing. Sites were selected in the Pine River mainstem a short distance upstream from the confluence with each of the adventitious tributaries, Hill Creek and UnNamed Creek.

Table 2. Summary of study sites by stream name, stream order, and stream type.

Site #	Stream Name	Stream Order	Stream Type
1	McDonald Creek	2	Headwater
2	McDonald Creek	2	Headwater
3	McGillis Creek	2	Headwater
4	McGillis Creek	2	Headwater
5	VanderCook Creek	2	Headwater
6	VanderCook Creek	2	Headwater
7	Hill Creek	2	Adventitious
8	Hill Creek	2	Adventitious
9	UnNamed Creek	2	Adventitious
10	UnNamed Creek	2	Adventitious
11	Pine River	5	Mainstem
12	Pine River	5	Mainstem

Materials and Methods

Fish Collection

Fish were sampled at all sites during the first full week of May, June, July, and August of 2000. Blocknets with a ¼-inch mesh were placed at the downstream and upstream end of each site to prevent fish from migrating into or out of the site during sampling. A backpack-mounted DC electrofishing unit with a single anode probe was employed to sample fish in all 2nd order sites. For the larger and deeper 5th order sites, a barge-mounted DC electrofishing unit with 2 anode probes was employed. We used a three-pass depletion method to collect fish from each site. All passes were initiated at the downstream end of the site, working in an upstream direction. Captured fish were held in a water-filled bucket or cooler and aerated with a battery-powered unit. After each pass, all fish collected were identified to species, counted, and released downstream of the site. Uncertain fish identifications were retained in a 10% formalin solution for subsequent verification in the lab.

Additional data were included from fish sampling efforts conducted in 1999 on several branches of the Pine River. A backpack electrofishing unit was used in three 3rd order sites on the East Branch, a 3rd order site on the South Branch, and a 3rd order site on VanEtten Creek. The barge-mounted electrofishing unit was used to sample fish on a 4th order site in the South Branch, 4th order site in the West Branch, and a 5th order site in the Main Branch.

Macroinvertebrate Collection

Macroinvertebrates were sampled in late May 2000, mid-August 2000, and early January 2001 to seasonally represent larval instars of different insect groups. We followed the protocol described by the Michigan Department of Environmental Quality's (1997) Procedure 51. Equal sampling effort was given to all habitat types (i.e. pools, riffles, and runs). Organisms were collected from silt, sand, gravel, cobble, leaf packs, submerged vegetation, and woody material by sweeping with a D-frame net, kicking substrate material upstream of the net, and by hand-picking with forceps. All organisms captured at each site were placed in a 5-gallon bucket to form a single composite sample. The composite sample was rinsed through a sieve with a 1-mm mesh and large organic and inorganic debris fragments were removed. The remaining sample containing the organisms was then placed in a white enamel counting pan filled approximately half full with water. 100 organisms were removed from the sample with forceps and placed in a 95% ethanol solution for subsequent identification in the lab. Identification of the organisms was determined at the taxonomic level described by Appendix H of Procedure 51 (Michigan Department of Environmental Quality 1997) and summarized in Table 3. Organisms were also classified by functional feeding groups (i.e. shredders, grazers, predators, and collectors) according to Merritt and Cummins (1996a) and Pennak (1989).

Habitat Data Collection

Within each site, geomorphic habitat units were classified as pools, riffles or runs (Simonson et al. 1993). Habitats classified as pools were deeper than average, had a slow water velocity, and an unbroken water surface. Riffle habitats were shallow, had a higher water velocity, and a turbulent water surface. Habitats classified as runs had an

Table 3. Level of taxonomic identification used in the Procedure 51 (Michigan Department of Environmental Quality 1997).

Phylum	Class	Order	Level of Taxonomic Identification	Primary Key Used
Nematomorpha			Phylum	Pennak (1989)
Annelida	Oligochaeta		Class	Pennak (1989)
Annelida	Hirudinea		Class	Pennak (1989)
Arthropoda	Crustacea		Order	Pennak (1989)
Arthropoda	Arachnoidea		Order	Pennak (1989)
Arthropoda	Insecta	Collembola	Order	Merritt & Cummins (1996)
Arthropoda	Insecta	All others	Family	Merritt & Cummins (1996)
Arthropoda	Mollusca		Family	Pennak (1989)

intermediate and uniform depth, moderate flow velocity, and an unbroken water surface. Habitat units were delineated by starting at the downstream endpoint of each site and measuring in an upstream direction. A measuring tape was used to measure the length of each habitat unit to the nearest meter. Woody material was visually estimated as a percentage of total area for each habitat unit.

To characterize the habitat, transects were set up by extending a measuring tape across the width of the stream at several positions within each site. In all 2nd order sites, transects were located by extending a measuring tape across the width of the stream at the downstream endpoint and midpoint of each habitat unit. Additionally, transects were positioned at the upstream end of each site. To characterize the more homogeneous 5th order sites, transects were set up at 0, 25, 50, and 75 meters from the downstream endpoint. Data recorded at each transect included stream width, velocity, substrate, temperature, and geographic coordinates. Stream width was determined by reading the measuring tape and recording the width to the nearest 0.1-meter. Stream velocity was measured with a Marsh-McBirney® Model 2000 flow meter at 20-cm intervals across the stream width in all 2nd order sites and at 1-m intervals in all 5th order sites. Substrate was characterized by performing a pebble count (Wolman 1954) using a modified Wentworth (Cummins 1962; Harrelson et al. 1994) classification (Table 4) across all transects. In all 2nd order sites, 25 substrate particles were measured at each transect, while 50 substrate particles were measured in the wider 5th order sites. The latitude and longitude of each transect was determined using a Garmin® GPS 12XL Global Positioning System unit. A staff gauge was installed in each stream and measured weekly for hydrologic variation. Bank stability, bank vegetation, and streamside cover in each site were evaluated using

Table 4. Modified Wentworth (Cummins 1962; Harrelson et al. 1994) scale used for substrate size classification.

Size Value	Description	Size Range (mm)
1	Clay	<2 (visual)
2	Silt	<2 (visual)
3	Sand	<2
4	Fine gravel	2-4
5	Medium gravel	4-8
6	Coarse gravel	8-16
7	Small pebble	16-32
8	Medium pebble	32-48
9	Large pebble	48-64
10	Small cobble	64-128
11	Medium cobble	128-192
12	Large cobble	192-256
13	Small boulder	256-512
14	Medium boulder	512-1024
15	Large boulder	1024-2048
16	Very large boulder	>2048
17	Organic material	Any (visual)

metrics described in the Michigan Department of Environmental Quality's (1997) Procedure 51.

The temperature regime in each stream was determined by installing Onset® Optic Stowaway digital temperature recorders approximately 20 m upstream of each site. To ensure that these units remained submerged, they were attached to concrete reinforcement bars that were driven into the stream substrate. The temperature recorders were programmed to record the stream temperature at 2-h intervals from May 2000 until May 2001.

Data Analysis

All data manipulations and statistical tests were performed using SAS® Version 8 (SAS Institute 1999) software. Results were considered significant at α (Type I error) values of 0.05 for all tests. All pairwise comparisons were performed with a Kramer (1956) modification of Tukey's (1953) studentized range test as recommended by Day and Quinn (1989) for ecological data with unequal sample sizes.

Fish species richness was compared using a Mixed GLM with stream type as the main effect of interest, month as a blocking factor, and stream as a random effect. Least Squares Means (LSM) were used to obtain point estimates for mean species richness by type and these were compared using a Tukey-Kramer studentized range test.

Fish communities in each stream and stream type were compared using two indices of similarity, Sϕrenson's (1948) QS and Morisita's (1959) Γ (as modified by Horn 1966). Sϕrenson's index of similarity is based on species presence/absence and is calculated as:

$$QS = 2C / (A + B), \qquad [1]$$

where QS is the index of similarity, A is the number of species in one stream or stream type, B is number of species in another stream or stream type, and C is the number of species common to both streams or stream types. Values for QS may range from 0 to 1 with values of 0 indicating no species overlap and values of 1 indicating identical fish species composition.

Horn's (1966) modification of Morisita's (1959) Γ is based on relative abundance of each species and is calculated as:

$$\Gamma = \frac{2\Sigma\, p_{ij}\, p_{ik}}{\Sigma\, p^2_{ij} + \Sigma p^2_{ik}} \qquad [2]$$

where Γ is the index of similarity, p_{ij} and p_{ik} are the relative abundance of the *i*th species in the *j*th and *k*th stream or stream type. Values for Γ may range from 0 to 1 with values of 0 indicating no species overlap and values of 1 indicating identical proportions of species composition.

The proportion of fishes classified as tolerant, intermediate, and intolerant (Michigan Department of Environmental Quality 1997; Barbour et al. 1999) was calculated for each site. The vectors of proportions were arcsine-transformed and statistically compared using Multivariate Analysis of Variance (MANOVA; SAS Institute 1999) to determine if the tolerance designations of the fish community differed between stream types. When MANOVA indicated a significant difference in the vectors, a GLM was used to evaluate the differences in proportions of individual tolerance categories.

Month-to-month variability in fish community composition was assessed for each stream and stream type using Sϕrenson's (1948) QS and Morisita's (1959) Γ (as modified by Horn 1966) indices of similarity. QS values were calculated as in Equation 1, where A is the number of fish species present in one month, B is the number of fish species present in another month, and C is the number of fish species common to both months for a given stream or stream type. Γ values were calculated as in Equation 2, where p_{ij} and p_{ik} are the relative abundance of the *i*th species in the *j*th and *k*th month.

The proportion of macroinvertebrate functional feeding groups (collectors, grazers, shredders, and predators)(Merritt & Cummins 1996a; Pennak 1978) was calculated for each site. These proportions were arcsine-transformed and analyzed using a Mixed General Linear Model with stream type as the main effect of interest and month as a blocking factor.

The proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) were calculated for each site and sampling event (month). In addition, the ratio of Chironomidae to EPT was calculated for each site and month. These data were analyzed using a Mixed General Linear Model with stream type and month as the main effects of interest and stream as a random effect.

The macroinvertebrate community was evaluated following the procedures for the Northern Lakes and Forest (NLF) ecoregion as described in the Update of GLEAS Procedure 51 Metric Scoring and Interpretation (Michigan Department of Environmental Quality 1996) for the Procedure 51 (Michigan Department of Environmental Quality 1997). The nine invertebrate metrics that were scored for each site and stream are summarized in Table 5. For each metric, a score of +1, 0, or –1 was assigned as follows:

+1 = community performing better than average condition for "excellent" sites in the NLF ecoregion;

0 = community performing at or within minus two standard deviations of the average condition for "excellent" sites in the NLF ecoregion;

-1 = community performing at less than minus two standard deviations of the average condition for "excellent" sites in the NLF ecoregion.

Metric scores were then totaled for each site or stream by sampling month. Because there are nine metrics, scores could range from –9 to +9. Total scores are interpreted as follows:

≤ -5	Poor;
-4 to –1	Tending Toward Poor;
0	Neutral, no tendency toward Excellent or Poor;
1 to 4	Tending Toward Excellent;
≥ 5	Excellent.

Total scores in the range of –4 to +4 are deemed acceptable under Michigan Department of Environmental Quality (1996) Water Quality Standards.

Invertebrate functional feeding groups were used to index stream ecosystem attributes according to Merritt & Cummins (1996b). The ratio of scrapers to shredders plus total collectors was used to indicate the trophic status of a stream. Elevated numbers of scrapers relative to shredders and collectors indicate increased dietary reliance on periphyton from primary production, while increased proportions of shredders and collectors relative to scrapers indicate increased loading of allochthonous coarse particulate organic matter (CPOM) as the primary food source. In general, values greater than 0.75 imply an autotrophic state, while values less than 0.75 imply a heterotrophic state (Merritt & Cummins 1996b).

Table 5. Macroinvertebrate metrics used for calculations of Procedure 51 (Michigan Department of Environmental Quality 1997).

(1) **Total Taxa** – the total number of taxa identified according to Table 3;

(2) **Mayfly Taxa** – the total number of families in the order Ephemeroptera present;

(3) **Caddisfly Taxa** – the total number of families in the order Trichoptera present;

(4) **Stonefly Taxa** – the total number of families in the order Plecoptera present;

(5) **% Mayfly Composition** – ratio of individuals in the order Ephemeroptera to total number of organisms;

(6) **% Caddisfly Composition** – ratio of individuals in the order Trichoptera to the total number of organisms;

(7) **% Contribution of the Dominant Species** – ratio of individuals in the most abundant taxon to the total number of organisms;

(8) **% Isopods, Snails, & Leeches** – ratio of individuals in the order Isopoda and classes Gastropoda and Hirudinea to the total number of organisms;

(9) **% Surface Dependent** – ratio of individuals dependent on obtaining oxygen directly from the atmosphere to the total number of organisms.

The ratio of shredders to total collectors was used as a measure of allochthonous CPOM to fine particulate organic matter (FPOM) (Merritt & Cummins 1996b). Elevated proportions of shredders relative to collectors (>0.25) indicate a greater association of the benthic invertebrate community with the riparian system, while elevated proportions of collectors (<0.25) indicate a benthic invertebrate community reliant on upstream processing of organic material.

The amount of FPOM in transport (TFPOM) relative to that stored in the benthos (BFPOM) was indicated by calculating the ratio of filtering collectors to gathering collectors (Merritt & Cummins 1996b). Elevated proportions of filtering collectors relative to gathering collectors (>0.50) may indicate high levels of TFPOM, while elevated proportions of gathering collectors relative to filtering collectors (<0.50) are indicative of high levels of BFPOM.

The in-stream channel stability was indicated by calculating the ratio of scrapers and filtering collectors to shredders and gathering collectors (Merritt & Cummins 1996b). Elevated proportions of scrapers and filtering collectors (>0.50) indicate that stable substrates are not limiting, while elevated proportions of shredders and gathering collectors (<0.50) indicate low substrate stability.

Proportions of habitat types (i.e. riffles, runs, and pools) were calculated for each site by dividing the total length of each habitat type by the length of each site (i.e. 75 m). A general linear model (GLM) was then applied to the length proportions at each site using stream type (i.e., headwater, adventitious, mainstem) as the main effect of interest and site as a blocking factor. Least squares means (LSM) were used to obtain point estimates for parameter values, accounting for imbalance in sample sizes of habitat data.

For each site, average stream width, depth, woody material, and velocity were calculated. A GLM was then applied to these data for comparison using stream type as the main effect of interest and site as a blocking factor. Least Squares Means were used to obtain point estimates for each parameter of interest, accounting for imbalance in these data.

The values from the modified Wentworth scale (Table 4) for substrate material correspond to size ranges for inorganic material (values 1 through 16). The corresponding classification for organic material (17), however, is a descriptive term for substrate consisting of wood, leaves, etc. regardless of size. Therefore, organic substrate was treated separately using a Generalized Linear Model (GLIM; Nelder & Wedderburn 1972) assuming a binomial (organic vs. inorganic) distribution of error terms with stream type as the main effect of interest and stream as a blocking factor. The inorganic substrate composition was then analyzed using a Generalized Linear Model (GLIM; Nelder & Wedderburn 1972) assuming a multinomial distribution of error terms with stream type as the main effect of interest and stream as a blocking factor. Least Squares Means were used to calculate point estimates and standard errors for inorganic substrate material.

Mean daily temperatures were calculated for May through August, the period of fish sampling, for each site. Using these data, the mean summer temperatures for each stream were analyzed using a General Linear Model with stream type as the main effect of interest and site as a blocking factor.

Results

Fish Community Analysis

Species Richness

A total of 40 species of fish were captured in the Pine River watershed during the study (Table 6). We captured 33 fish species in the mainstem, 23 species in the adventitious streams, and 13 species in the headwater streams over the four-month study period. An average of 3.8 species of fish were present at each site in the headwater streams, 9.3 at each site in the adventitious streams, and 23.3 in the mainstem sites. Significant differences in fish species richness were detected between the stream types ($P<0.0001$). Using a Tukey's adjustment, a significant difference in species richness was detected for all pairwise comparisons of stream types ($P<0.02$).

When data from five third-order, two fourth-order, and two additional fifth-order sites were included, the number of species present showed a general increase with increasing stream order in non-adventitious streams (Figure 2). Furthermore, the species richness in the adventitious sites is above the mean for the non-adventitious second-order streams in this trend.

Spatial Variability

Sϕrensen's QS values for all pairwise comparisons of individual streams ranged from 0 to 0.75 (Appendix C). Generally, the mainstem was more similar to the adventitious streams ($QS \geq 0.43$) than to the headwater streams ($QS \leq 0.28$)(Appendix C). On average, adventitious streams had a higher degree of similarity to the mainstem ($QS=0.48$) than to the headwater streams ($QS=0.28$)(Table 7). Morisita's Γ values for all pairwise

Table 6. Fish species present, tolerance values, and number captured in each stream type.

Common name	Scientific Name	Tolerance	Adventitious	Headwater	Mainstem	Total
Creek Chub	*Semotilus atromaculatus*	Tolerant	791	615	221	1627
Mottled Sculpin	*Cottus bairdii*	Intolerant	19	617	100	736
Blacknose Dace	*Rhinichthys atratulus*	Tolerant	267	264	200	731
Brook Trout	*Salvelinus fontinalis*	Intolerant	0	528	11	539
Central Mudminnow	*Umbra limi*	Tolerant	413	104	18	535
Johnny Darter	*Etheostoma nigrum*	Intermediate	40	1	356	397
Blackside Darter	*Percina maculata*	Intermediate	30	0	210	240
Logperch	*Percina caprodes*	Intermediate	4	0	112	116
White Sucker	*Catostomus commersoni*	Tolerant	20	0	73	93
Channel Darter	*Percina copelandi*	Intolerant	4	0	53	57
Green Sunfish	*Lepomis cyanellus*	Tolerant	32	0	25	57
Rock Bass	*Ambloplites rupestris*	Intermediate	0	0	51	51
Common Shiner	*Luxilus cornutus*	Intermediate	4	6	38	48
Brook Stickleback	*Culaea inconstans*	Intermediate	40	0	0	40
Northern Hogsucker	*Hypentelium nigricans*	Intolerant	0	0	25	25
Yellow Perch	*Perca flavescens*	Intermediate	0	0	22	22
Northern Redbelly Dace	*Phoxinus eos*	Intermediate	15	2	0	17
Rainbow Darter	*Etheostoma caeruleum*	Intermediate	3	5	8	16
Golden Shiner	*Notemigonus crysoleucas*	Tolerant	11	0	1	12
Northern Brook Lamprey	*Ichthyomyzon fossor*	Intolerant	0	0	11	11
Rainbow Trout	*Oncorhynchus mykiss*	Intolerant	0	0	10	10
Bluntnose Minnow	*Pimephales notatus*	Tolerant	0	0	9	9
Hornyhead Chub	*Nocomis biguttatus*	Intolerant	9	0	0	9

Table 6 (cont.).

Pumpkinseed	*Lepomis gibbosus*	Intermediate	1	0	8	9
Smallmouth Bass	*Micropterus dolomieu*	Intermediate	0	0	9	9
Silver Lamprey	*Ichthyomyzon unicuspis*	Intermediate	0	0	8	8
Pearl Dace	*Margariscus margarita*	Intermediate	0	5	1	6
Black Bullhead	*Ameiurus melas*	Intermediate	1	1	3	5
Iowa Darter	*Etheostoma exile*	Intermediate	1	4	0	5
River Chub	*Nocomis micropogon*	Intolerant	0	5	0	5
Spottail Shiner	*Notropis hudsonius*	Intermediate	5	0	0	5
Bluegill	*Lepomis macrochirus*	Tolerant	0	0	4	4
Brown Trout	*Salmo trutta*	Intolerant	1	0	3	4
Chinook Salmon	*Oncorhynchus tshawytscha*	Intolerant	0	0	4	4
Northern Pike	*Esox lucius*	Intermediate	1	0	1	2
Black Crappie	*Pomoxis nigromaculatus*	Intermediate	0	0	1	1
Emerald Shiner	*Notropis atherinoides*	Intermediate	1	0	0	1
Golden Redhorse	*Moxostoma erythurum*	Intermediate	0	0	1	1
Largemouth Bass	*Micropterus salmoides*	Intermediate	0	0	1	1
Silver Redhorse	*Moxostoma anisurum*	Intermediate	0	0	1	1
		Total	1713	2157	1599	5469

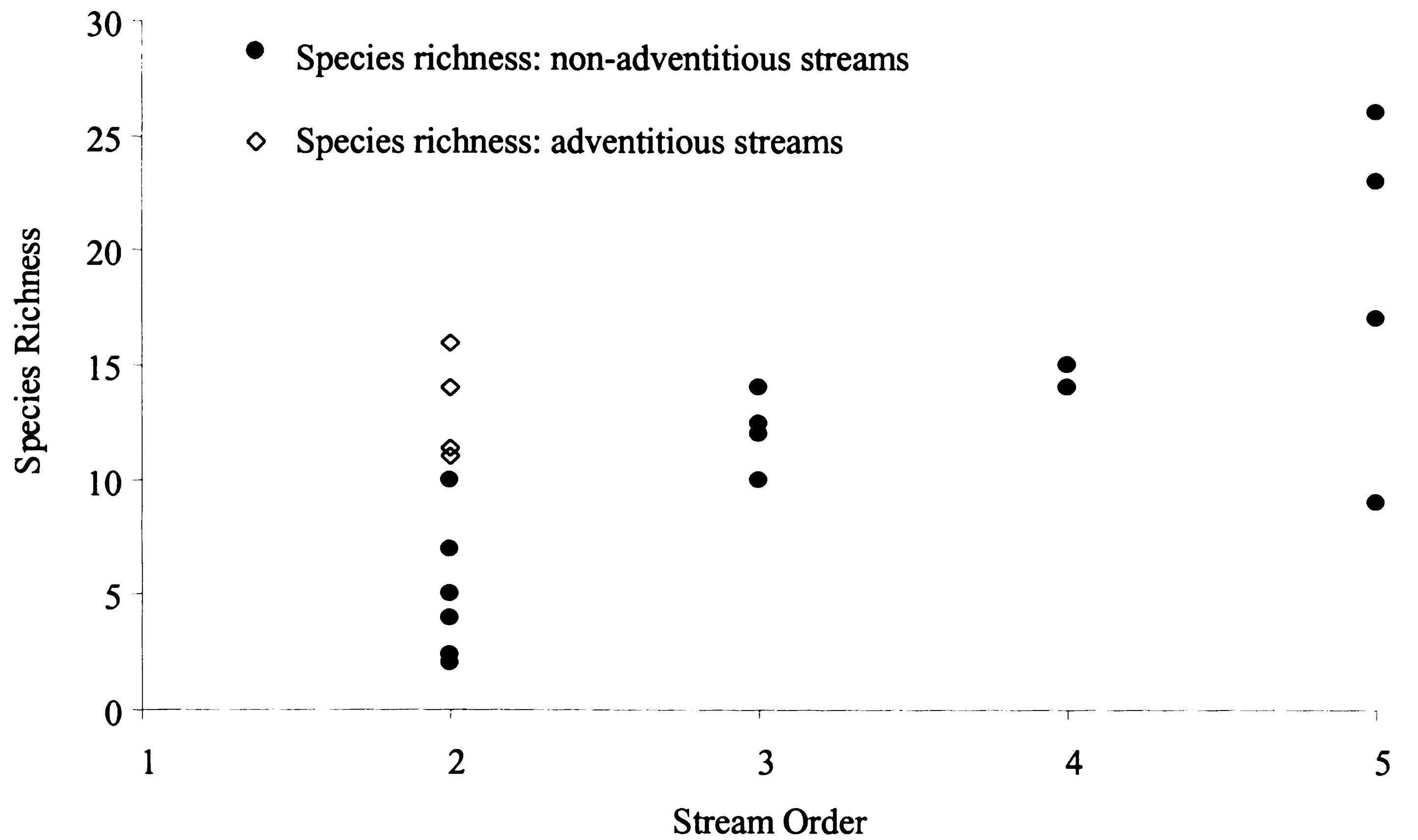

Figure 2. Fish species richness by stream (includes additional data from third-, fourth-, and fifth-order sampling efforts).

comparisons of streams ranged from 0.00 (no similarity) to 0.96 (Appendix C). Table 8 shows that the average Morisita's Γ values were higher for comparisons of adventitious streams to the mainstem (Γ=0.48) than to headwater streams (Γ=0.30).

Similarity indices were calculated comparing each adventitious stream to its mainstem reference site (Table 9). The similarity values for comparison of Unnamed Creek to mainstem Site #11 were moderately high whether based on species presence/absence (QS=0.49) or relative abundance (Γ=0.56). The similarities between Hill Creek and mainstem Site #12 showed a different trend, however. The similarity of species overlap was moderately high (QS=0.49) while similarity based on relative abundance was lower (Γ=0.25).

Tolerance

The tolerance proportions were similar across all stream types (Figure 3). The greatest proportion of fish species present across all stream types were classified as intermediate tolerance, with fewer intolerant and tolerant species (Figure 3). When viewed by relative abundance, however, a high proportion of tolerant fish dominated the fish communities of adventitious streams (Figure 4). A high proportion of intolerant fish dominated the fish communities of headwater streams (Figure 4). The mainstem had a more even distribution of tolerance classifications, with high numbers of intermediate tolerant fish, and fewer numbers of tolerant and intolerant fish (Figure 4).

The proportion of intermediate tolerant fish was higher for the mainstem compared to headwater streams (P=0.0002) and adventitious streams (P=0.0043). Adventitious streams had a higher proportion of intermediate tolerant fish compared to headwater streams (P=0.0462). Although the differences visually appear to be large (Figure 4), no

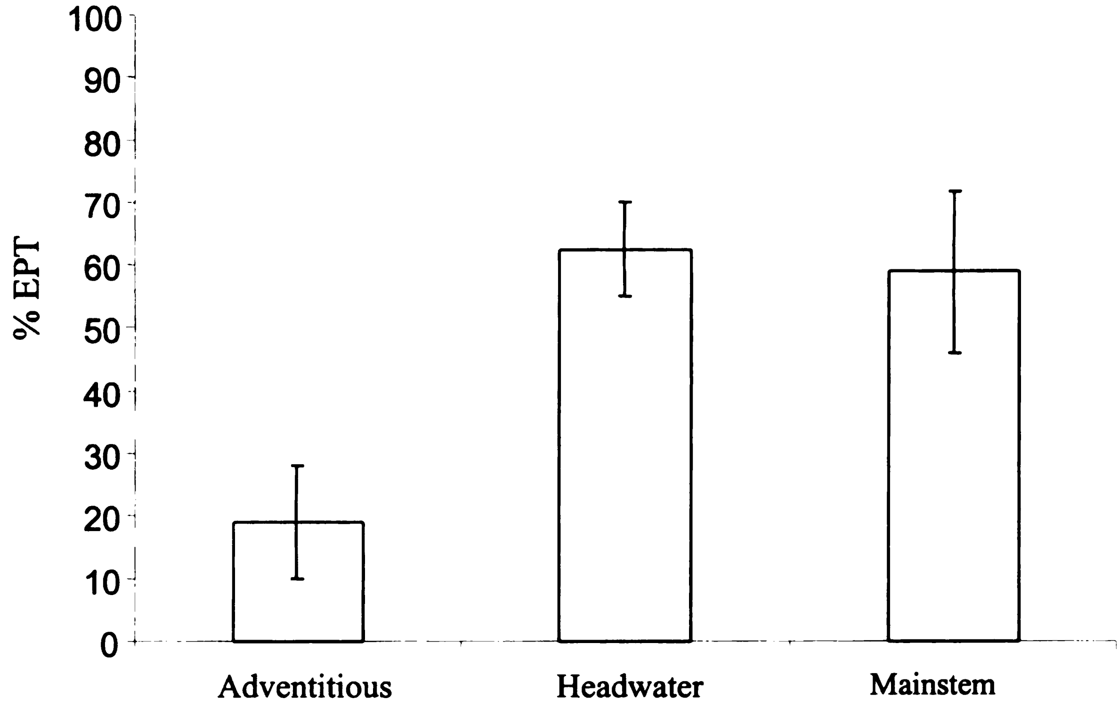

Figure 7. Percent composition (± approximate 95% confidence intervals) of Ephemeroptera, Plecoptera, and Trichoptera (EPT) by stream type.

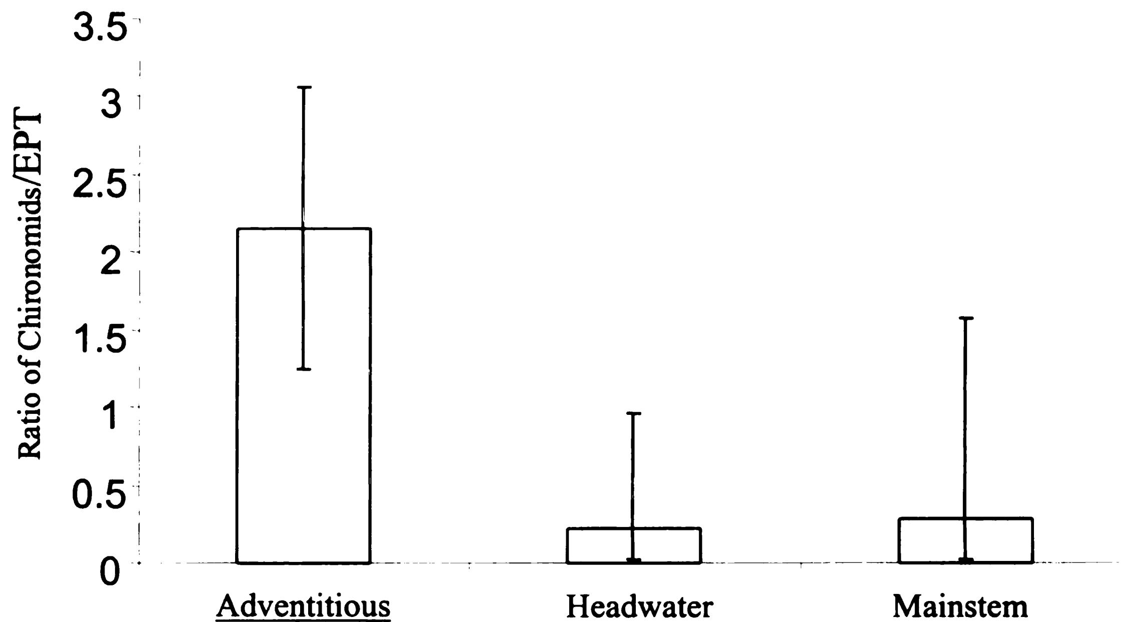

Figure 8. Ratio (± approximate 95% confidence intervals) of Chironomidae to Ephemeroptera, Plecoptera, and Trichoptera (EPT) by stream type.

Table 9. Similarity of fish species composition in adventitious streams to Pine River mainstem reference sites using Sϕrensen's (1948) QS and Morisita's (1959) Γ indices (as modified by Horn 1966).

	Sϕrensen's	Morisita's
Unnamed Creek-Site #11	0.49	0.56
Hill Creek-Site #12	0.49	0.25

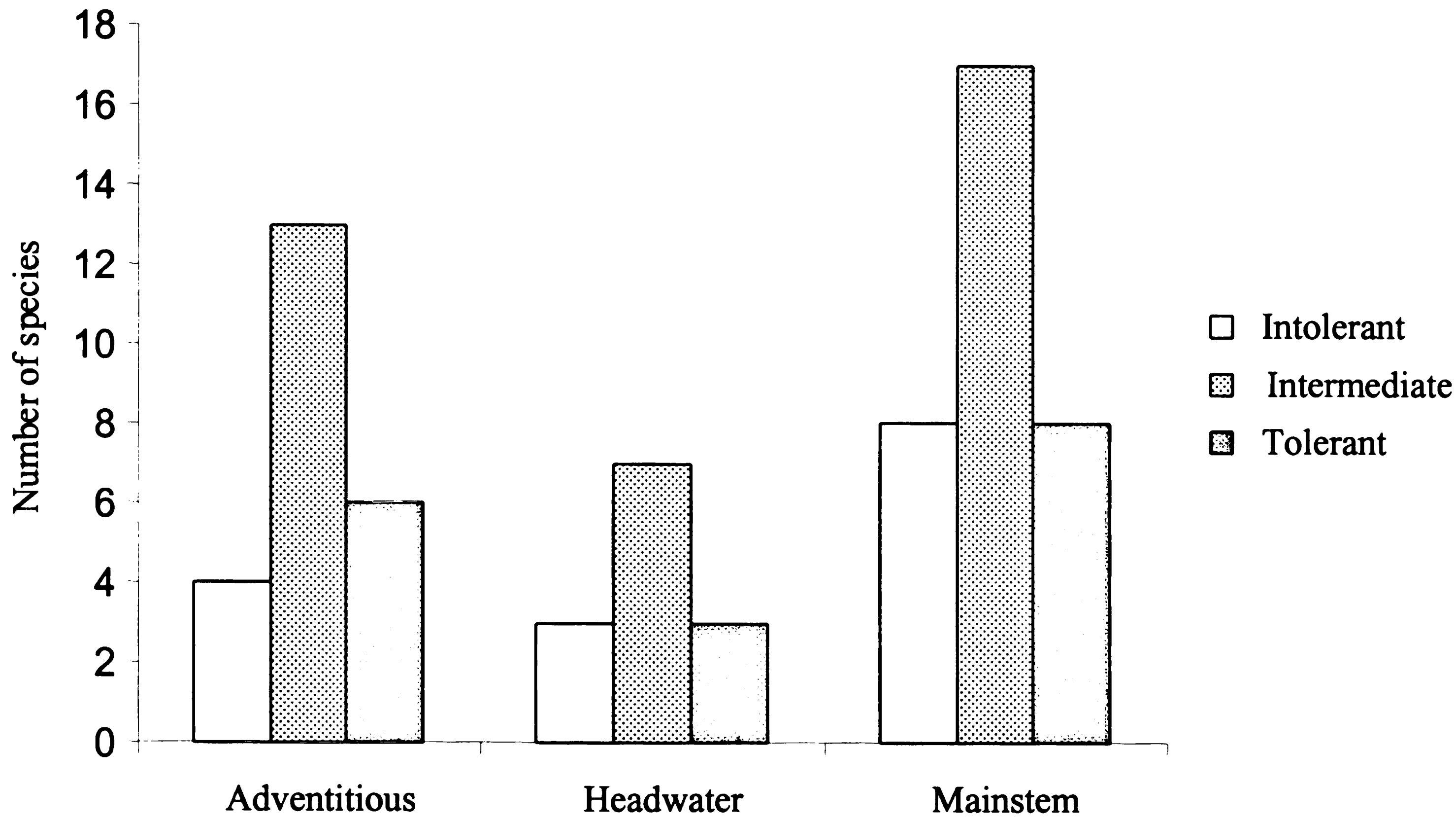

Figure 3. Number of fish species in each tolerance category by stream type.

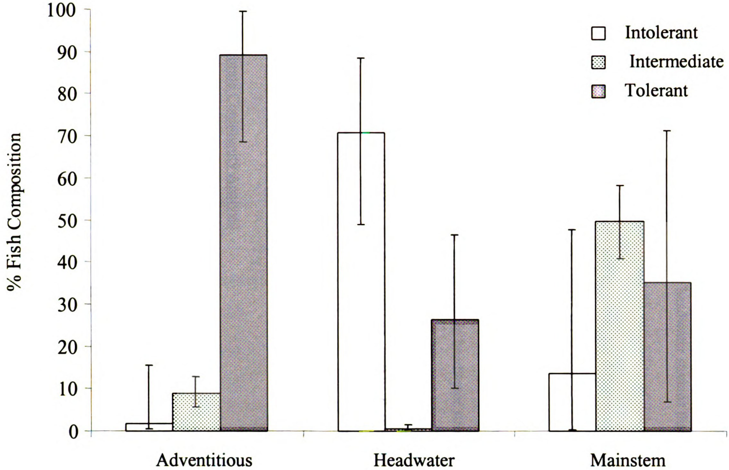

Figure 4. Percent composition (± approximate 95% confidence intervals) of fish abundance in each tolerance category by stream type.

differences were detected between stream types for the proportions of intolerant species ($P \geq 0.0824$) or tolerant species ($P \geq 0.1510$) due to the high variability within stream types.

Temporal Variability

Average month-to-month QS values were high for all stream types (Table 10). Using a Tukey's adjustment, QS values were higher for headwater streams than for adventitious streams ($P=0.007$) indicating higher month-to-month variability of fish species presence in adventitious streams compared to headwater streams. No differences were detected between the mainstem and headwater streams ($P=0.834$) or between the mainstem and adventitious streams ($P=0.157$).

Average month-to-month Γ values were variable, ranging from moderately high in adventitious streams to very high temporal similarities in headwater streams (Table 11). Using a Tukey's adjustment, Morisita's Γ values were lower for adventitious streams than for headwater streams ($P<0.0001$) and the mainstem ($P=0.019$), indicating higher month-to-month variability of fish abundance in adventitious streams compared to headwater streams and the mainstem. No significant difference was detected between the mainstem and headwater streams ($P=0.565$).

Macroinvertebrate Community Analysis

A total of 52 aquatic macroinvertebrate taxa were collected during the study (Table 12). The Pine River mainstem had the highest richness overall, with 34 taxa present. Little variation in taxa richness existed between the second-order streams, ranging from 25 (VanderCook Creek and Unnamed Creek) to 29 (Hill Creek)(Appendix G). The most common taxa present in all streams were the families Chironomidae (non-biting midges)

Table 10. Average of month-to-month similarities within each stream type using Sϕrensen's (1948) QS index.

	May-Jun	May-Jul	May-Aug	Jun-Jul	Jun-Aug	Jul-Aug	Average	SE
Adventitious	0.76	0.68	0.63	0.67	0.65	0.64	0.67	0.04
Headwater	0.79	0.82	0.79	0.83	0.93	0.89	0.84	0.03
Mainstem	0.88	0.81	0.76	0.78	0.79	0.84	0.80	0.06

Table 11. Average of month-to-month fish community similarities within each stream type using Morisita's (1959) Γ index (as modified by Horn 1966).

	May-Jun	May-Jul	May-Aug	Jun-Jul	Jun-Aug	Jul-Aug	Average	SE
Adventitious	0.52	0.60	0.76	0.63	0.50	0.70	0.62	0.05
Headwater	0.91	0.89	0.92	0.97	0.98	0.98	0.94	0.04
Mainstem	0.93	0.74	0.53	0.79	0.50	0.76	0.71	0.07

Table 12. Macroinvertebrate taxa present and percent composition for each stream type over all sites and months.

Phylum	Class	Family	Adventitious	Headwater	Mainstem
Annelida	Hirudinea	-	0.1	0.2	0.3
Annelida	Oligochaeta	-	0.3	0.6	0.0
Arthropoda	Arachnoidea	-	0.9	0.2	0.2
Arthropoda	Crustacea	-	15.3	10.9	7.7
Arthropoda	Insecta	-	0.1	0.1	0.0
Arthropoda	Insecta	Aeshnidae	1.4	1.5	0.7
Arthropoda	Insecta	Athericidae	0.0	0.0	0.7
Arthropoda	Insecta	Baetidae	0.3	2.7	1.5
Arthropoda	Insecta	Baetiscidae	0.0	0.0	1.5
Arthropoda	Insecta	Belostomatidae	0.6	0.0	0.0
Arthropoda	Insecta	Brachycentridae	0.3	9.5	0.3
Arthropoda	Insecta	Calopterygidae	2.0	0.8	1.0
Arthropoda	Insecta	Chironomidae	23.7	11.2	13.5
Arthropoda	Insecta	Cordulegastridae	0.0	1.4	0.2
Arthropoda	Insecta	Corixidae	0.8	0.0	2.2
Arthropoda	Insecta	Corydalidae	0.3	1.4	1.2
Arthropoda	Insecta	Dixidae	3.3	0.0	0.0
Arthropoda	Insecta	Dytiscidae	3.1	0.1	0.3
Arthropoda	Insecta	Elmidae	0.7	0.2	3.7
Arthropoda	Insecta	Ephemerellidae	7.5	14.3	9.3
Arthropoda	Insecta	Ephemeridae	0.0	0.0	3.8
Arthropoda	Insecta	Gerridae	1.0	1.6	1.7
Arthropoda	Insecta	Glossosomatidae	0.9	3.7	3.0
Arthropoda	Insecta	Gomphidae	0.0	0.3	0.0
Arthropoda	Insecta	Gyrinidae	0.4	0.2	0.0
Arthropoda	Insecta	Helicopsychidae	0.0	0.6	0.0
Arthropoda	Insecta	Heptageniidae	0.0	4.5	21.8
Arthropoda	Insecta	Hydropsychidae	2.2	5.6	7.2
Arthropoda	Insecta	Isonychiidae	0.0	0.0	2.2
Arthropoda	Insecta	Leptophlebiidae	2.3	2.4	0.0
Arthropoda	Insecta	Libellulidae	1.2	0.0	0.0
Arthropoda	Insecta	Limnephilidae	3.8	6.8	1.0
Arthropoda	Insecta	Metretopodidae	0.1	0.0	2.0
Arthropoda	Insecta	Molanidae	0.1	0.0	0.0
Arthropoda	Insecta	Nemouridae	0.0	6.8	0.0

Table 12 (cont.).

Arthropoda	Insecta	Perlidae	0.3	0.5	2.0
Arthropoda	Insecta	Perlodidae	0.0	1.8	1.7
Arthropoda	Insecta	Philopotamidae	1.0	1.0	0.0
Arthropoda	Insecta	Pleidae	3.0	0.0	0.3
Arthropoda	Insecta	Polycentropodidae	0.2	0.4	0.0
Arthropoda	Insecta	Psephenidae	0.0	0.1	0.0
Arthropoda	Insecta	Pteronarcidae	0.0	0.4	0.5
Arthropoda	Insecta	Sialidae	0.2	0.7	0.0
Arthropoda	Insecta	Simuliidae	12.5	3.8	4.0
Arthropoda	Insecta	Stratiomyidae	0.0	0.3	0.0
Arthropoda	Insecta	Tabanidae	0.1	0.3	0.2
Arthropoda	Insecta	Taeniopterygidae	0.0	1.3	1.0
Arthropoda	Insecta	Tipulidae	1.2	1.2	1.7
Mollusca	Gastropoda	Bithyniidae	4.3	0.0	0.0
Mollusca	Gastropoda	Lymnaeidae	4.5	0.6	1.2
Mollusca	Pelecypoda	Unionidae	0.3	0.1	0.7
Nematomorpha	-	-	0.0	0.1	0.0
		n=	**1200**	**1800**	**600**

and Ephemerellidae (mayflies), and the class Crustacea (primarily amphipods and crayfish).

The composition of macroinvertebrate functional feeding groups varied among stream types (Figure 5). Collectors were the most abundant group in all three stream types, but the proportion of collectors were significantly higher in adventitious than in headwater streams (P=0.0145). The proportion of predators varied little between stream types, ranging from 11.3% in headwater streams to 15.5% in adventitious streams. The proportion of grazers varied among types and was higher in the mainstem than both adventitious streams (P=0.0103) and headwater streams (P=0.0053). The proportion of shredders was highest in headwater streams relative to adventitious streams (P=0.0004) and the mainstem (P=0.0031).

The proportion of functional feeding groups varied over time (Figure 6). No interactions between stream type and month were detected for any of the function feeding groups ($P \geq 0.0550$), implying similar seasonal patterns among stream types. Collector abundance was highest in adventitious streams over all three sampling events, yet was only significantly higher than headwater streams in January (P=0.0004). Collectors reached peak abundance in January across all stream types. The proportion of predators decreased from August 2000 to minimum values in January 2001 for all three stream types ($P \leq 0.0390$). The proportion of predators in adventitious streams and the mainstem was greatest in August while headwater streams peaked in May. Grazer abundance in the mainstem was higher than in second-order streams over all three sampling events, yet was significantly so only in May ($P \leq 0.0030$). The proportion of shredders was the highest in headwater streams over all three sampling events. However, significant

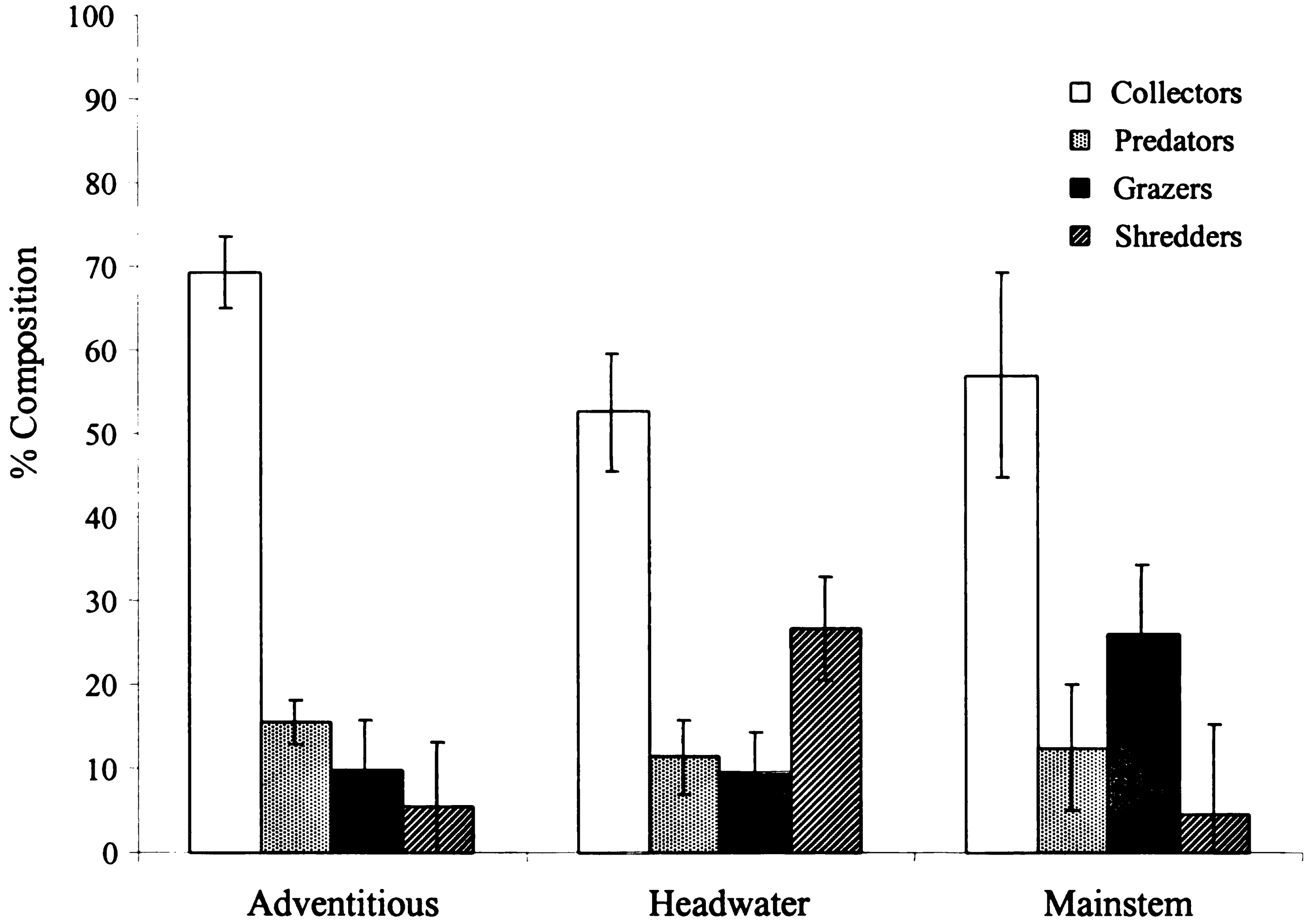

Figure 5. Percent composition (± approximate 95% confidence intervals) of invertebrate functional feeding groups by stream type.

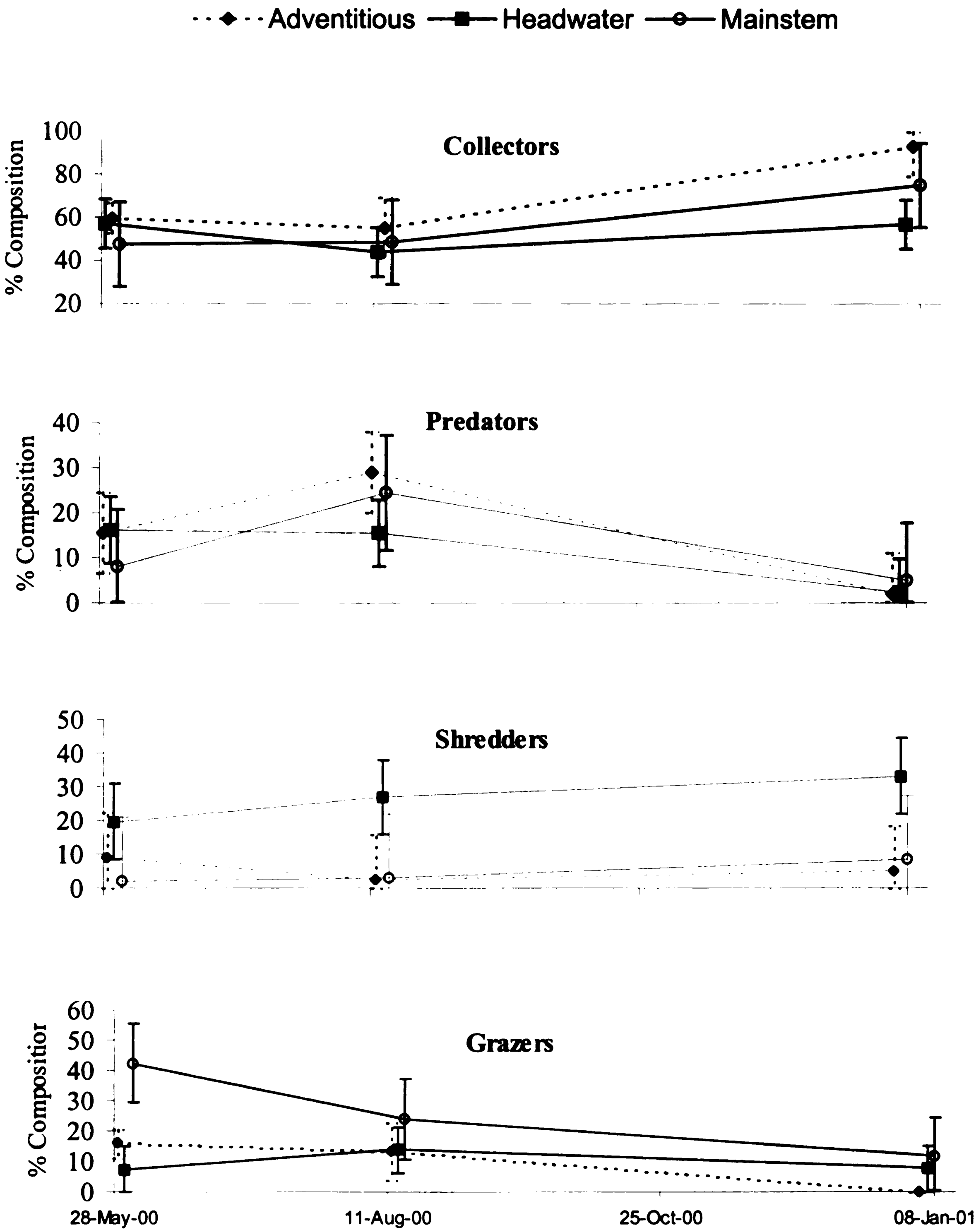

Figure 6. Change in composition of macroinvertebrate functional feeding groups over sampling period.

differences were only detected in Fall ($P \leq 0.0398$) and January ($P \leq 0.0350$). No significant month-to-month differences in shredder abundance were detected for any stream type ($P \geq 0.0972$).

The mean proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) varied among the three stream types over all sampling events (Figure 7). These three invertebrate orders accounted for more than half of all organisms collected in headwater streams (62%) and the mainstem (59%), yet accounted for about 19% of the organisms collected in adventitious streams. The proportion of EPT in adventitious streams was significantly lower than that of headwater streams ($P<0.0001$) and the mainstem ($P<0.0001$). No difference in EPT proportion was detected ($P= 0.6299$) between headwater streams and the mainstem. No interactions between stream type and month were detected ($P=0.5295$) indicating similar seasonal patterns in EPT abundance. In addition, no differences in month of sampling were detected ($P=0.5715$).

The mean ratio of Chironomidae to EPT was highly variable for all stream types (Figure 8). In adventitious streams, chironomids outnumbered EPT. In headwater streams and the mainstem, chironomids were much less abundant than EPT. No interaction between stream type and month were detected ($P=0.2760$). In addition, no difference in month of sampling was detected ($P=0.3609$). Differences in stream type were significant only for comparisons of adventitious and headwater streams ($P=0.0065$). The difference between adventitious streams and the mainstem was not significant ($P=0.0594$), and no difference was detected between headwater streams and the mainstem ($P=0.9959$).

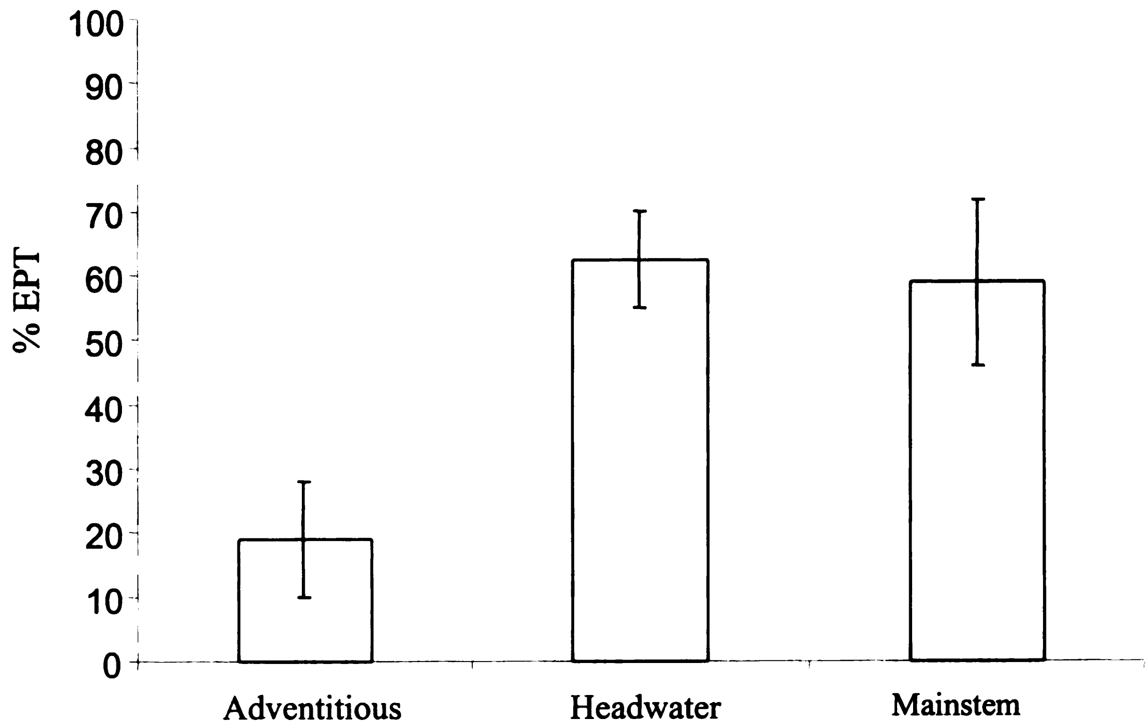

Figure 7. Percent composition (± approximate 95% confidence intervals) of Ephemeroptera, Plecoptera, and Trichoptera (EPT) by stream type.

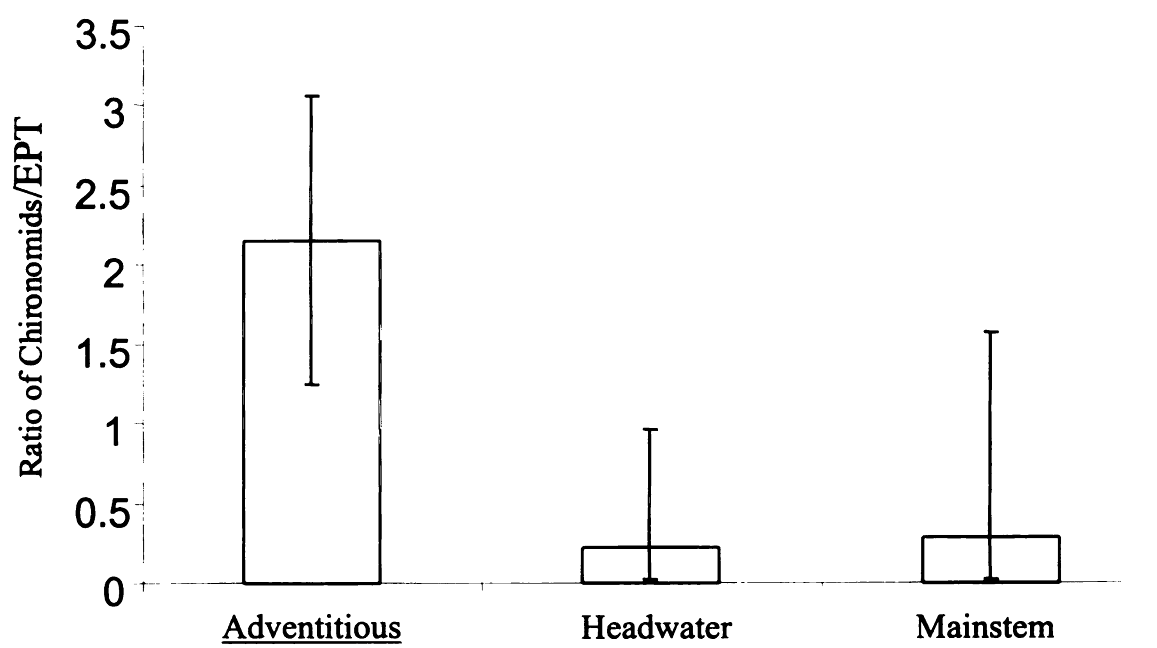

Figure 8. Ratio (± approximate 95% confidence intervals) of Chironomidae to Ephemeroptera, Plecoptera, and Trichoptera (EPT) by stream type.

The invertebrate metric scores were variable among the stream types (Table 13). Mean values for adventitious streams were generally low, indicating a tendency toward poor water quality (Michigan Department of Environmental Quality 1996). The values for headwater streams were moderately high, indicating a tendency toward high water quality. The Pine River mainstem had the highest and most consistent invertebrate metric scores (5) over all three sampling periods and indicate excellent water quality. Values for all stream types were within the range deemed acceptable (-4 to +4) for Michigan Water Quality Standards (Michigan Department of Environmental Quality 1996).

Trophic status (P:R), represented by the ratio of scrapers to shredders and total collectors, varied seasonally over all stream types (Table 14). In May, all second-order sites tended toward a heterotrophic condition (<0.75), while the fifth-order mainstem indicated an autotrophic condition (>0.75). August values were variable, with the mainstem, a headwater stream (McGillis Creek), and an adventitious stream (Unnamed Creek) tending toward an autotrophic condition and the remaining streams tending toward a heterotrophic state. Values for January were the lowest, with all streams tending toward a heterotrophic state.

The ratio of coarse particulate organic matter to fine particulate organic matter (CPOM/FPOM), represented by the ratio of shredders to total collectors, varied among stream types (Table 15). Values were generally highest for headwater streams across all months, indicating increased input of allochthonous material relative to adventitious streams and the mainstem. The mainstem and adventitious streams were generally low (<0.25), indicative of systems dependent on fine particulate organic matter.

Table 13. Mean invertebrate metrics based on Procedure 51 (Michigan Department of Environmental Quality 1997) scores for each stream type by month.

Month	Adventitious	Headwater	Mainstem
May	0.00	4.33	5
August	-1.50	2.67	5
January	-0.50	3.67	5
Annual Average	**-0.67**	**3.56**	**5**

Table 14. Mean monthly and annual values for River Continuum Concept ratios of photosynthesis to respiration (P:R) for each stream type. Values above 0.75 indicate production in excess of respiration (autotrophic condition).

Month	Adventitious	Headwater	Mainstem
May	0.24	0.11	0.86
August	0.36	0.25	0.47
January	0.00	0.09	0.14
Average	**0.20**	**0.15**	**0.49**

Table 15. Mean monthly and annual values for River Continuum Concept ratios of coarse particulate organic matter (CPOM) to fine particulate organic matter (FPOM) for each stream type. Values above 0.25 indicate riparian dominated streams.

Month	Adventitious	Headwater	Mainstem
May	0.15	0.34	0.04
August	0.04	0.69	0.06
January	0.05	0.68	0.11
Average	**0.08**	**0.57**	**0.25**

Table 16. Mean monthly and annual values for River Continuum Concept ratios of fine particulate organic matter in transport (TFPOM) to that stored in the benthos (BFPOM) for each stream type. Values above 0.50 indicate increased suspended organic material in transport.

Month	Adventitious	Headwater	Mainstem
May	2.34	0.14	0.38
August	0.18	0.78	0.31
January	1.16	0.38	0.52
Average	**1.22**	**0.46**	**0.41**

Table 17. Mean monthly and annual values for River Continuum Concept ratios for channel stability for each stream type. Values above 0.50 indicate that stable substrates are not limiting.

Month	Adventitious	Headwater	Mainstem
May	2.52	0.24	1.69
August	0.72	0.86	1.12
January	0.27	0.33	0.67
Average	**1.17**	**0.48**	**1.16**

The ratio of fine particulate organic matter in transport (TFPOM) to that stored in the benthos (BFPOM), represented by the ratio of filtering collectors to gathering collectors, varied among stream types and months (Table 16). The fifth-order mainstem had more moderate and consistent values seasonally than second-order adventitious and headwater streams. In May, values for all but one stream were below 0.50, indicative of high loads of FPOM in transport relative to that stored in the benthos. The value for Unnamed Creek was approximately 4.50, possibly due to invertebrate community responses to increased FPOM in suspension from high annual springtime flows. In August and January, values for all streams were more moderate.

The in-stream channel stability, represented by the ratio of scrapers and filtering collectors to shredders and gathering collectors, varied among stream types and months (Table 17). The values for adventitious streams were above the reference point (0.50) for all months except January, indicating high channel stability. Values for headwater streams exceeded the reference point only in August only, but on average indicated moderate channel stability. The mainstem was above the reference point for all months, indicating high channel stability.

Habitat Analysis

The proportion of habitat types (i.e. riffle, run, pool) varied among stream types (Table 18). Pools comprised approximately 26% of the length of sites in adventitious streams, followed by headwater streams (15%) and the mainstem (13%). Riffles comprised approximately 28% of the length in the mainstem, but made up little of the proportion of length in adventitious (5%) and headwater (2%) streams. Runs comprised the largest proportion of length in all stream types with headwater streams containing the

Table 18. Mean (± 1SE) of habitat conditions and standard errors for each stream type.

	Headwater	**Adventitious**	**Mainstem**
% Pool by Length	14.7 ± 2.5	26 ± 4.4	13.3 ± 13.3
% Riffle by Length	1.8 ± 1.8	5.3 ± 4.1	28 ± 28
% Run by Length	83.6 ± 2.6	68.7 ± 1.4	58.7 ± 41.3
% Woody Cover	22.2 ± 3.2	21.4 ± 3.4	3.1 ± 6.1
Mean Width (m)	2.44 ± 2.3	2.1 ± 0.25	17.7 ± 0.38
Mean Depth (cm)	14.45 ± 1.4	13.35 ± 1.5	35.9 ± 2.2
Mean Velocity (m/s)	0.09 ± 0.012	0.05 ± 0.01	0.16 ± 0.02
Mean Summer Temperature (°C)	13.5 ± 0.04	16.6 ± 0.04	16.7 ± 0.06

highest average proportion (84%) followed by adventitious streams (69%) and the mainstem (59%). The high standard error in the mainstem is accounted for by the fact that the downstream site was comprised entirely of a single run (Appendix A). Across stream types, the average lengths of habitat units within a type were not significantly different ($P=0.0702$).

The proportion of estimated woody material varied between the different stream types ($P=0.0211$). The main branch had significantly less woody material ($P<0.05$, Tukey's studentized range test) than headwater and adventitious streams, yet no difference was found between headwater and adventitious streams ($P=0.9855$, Tukey's studentized range test).

Differences in habitat conditions were apparent among stream types. Average width ($P<0.0001$, GLM), depth ($P<0.0001$, GLM), and water velocity ($P<0.0001$, GLM) differed between the three stream types. The fifth order mainstem had a significantly higher average width (17.3m; $P<0.0001$) than the second order headwater (2.4m) and adventitious (2.1m) streams. However, Tukey's analysis detected no significant difference between the headwater and adventitious stream widths ($P=0.6524$). Similarly, the mainstem had a significantly greater average depth (35.9cm; $P<0.0001$) than the headwater (14.5cm) and adventitious (13.4cm) streams. No difference in depth was found between headwater and adventitious streams ($P=0.8616$). The mainstem had the highest average velocity (0.16m/s) followed by the headwater (0.09m/s) and adventitious (0.05m/s) streams. All pairwise comparisons of velocity were found to be significant ($P<0.05$).

Substrate material varied among the three stream types (Figure 9). Organic material composed approximately 34% of the substrate in adventitious streams, 29% in headwater streams, but only 5% in the mainstem. Significant differences were detected for the percent composition of organic material between the three stream types ($P<0.0001$). When the mainstem sites were excluded from the analysis, adventitious streams were found to have a greater proportion of organic material ($P=0.0086$) than headwater streams. Headwater streams had an average inorganic substrate size of 2.8, composed primarily of sand (56%) and silt (15%). Adventitious streams had an average inorganic substrate size of 2.6 and were composed primarily of silt (39%) with lesser amounts of clay, sand, gravel, and pebbles. The mainstem had an average inorganic substrate size of 3.4 and was composed primarily of sand (71%) with some clay, silt, gravel, pebbles, and cobble. No difference was detected in mean substrate size between adventitious and headwater streams ($P=0.2206$, Tukey's studentized range test), however these stream types had smaller mean substrate sizes than the mainstem ($P\leq0.0057$, Tukey's studentized range test).

The staff gauge readings followed similar trends for all stream types (Figure 10). The headwater streams were generally the most hydrologically stable, followed by the adventitious streams, and the mainstem. A series of heavy rainfalls in early June caused the readings for the mainstem and adventitious streams to fluctuate more dramatically than the headwater streams. Much of the remainder of the sampling period was dry resulting in stable staff gauge readings. Another series of showers occurred in early August, primarily affecting the mainstem stream levels.

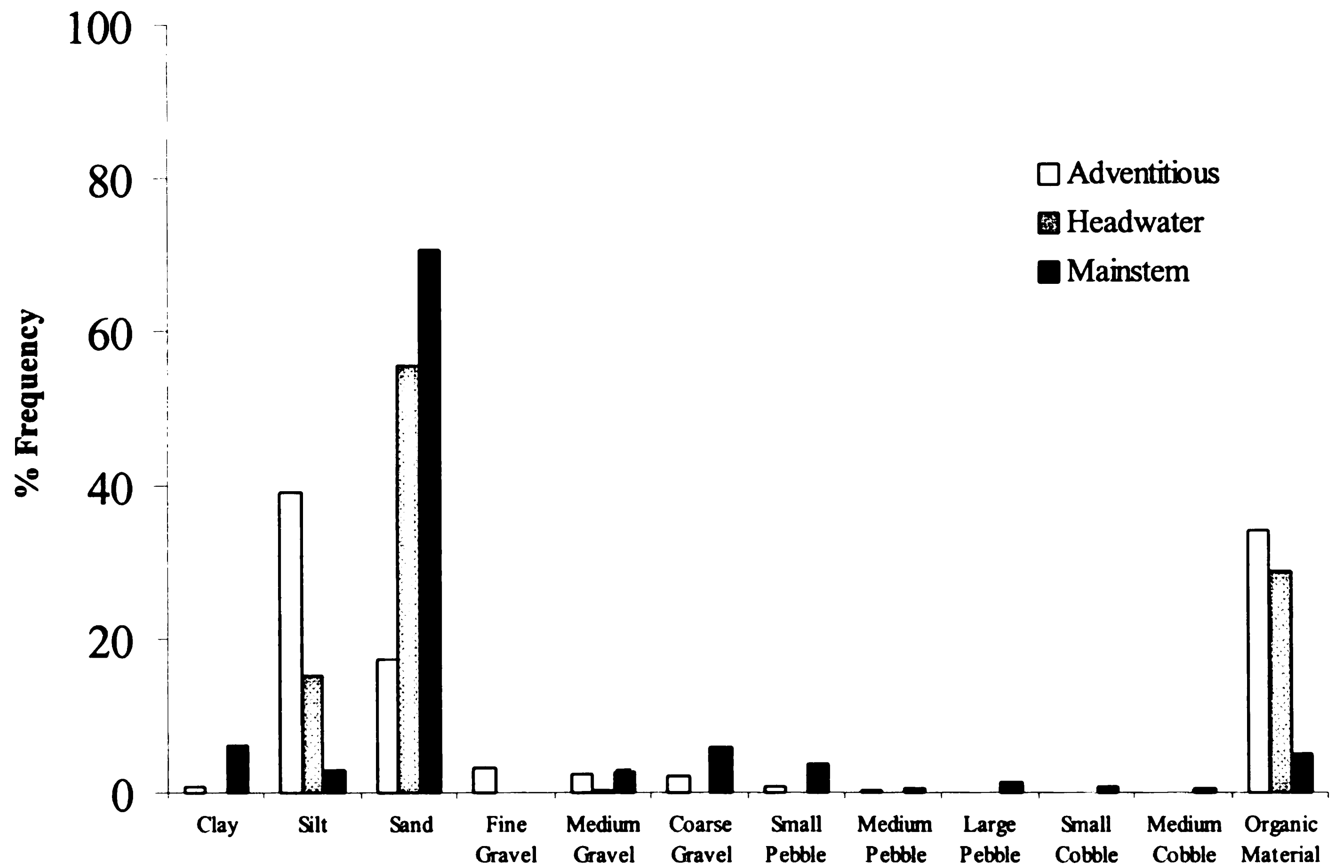

Figure 9. Frequency of substrate sizes by stream type.

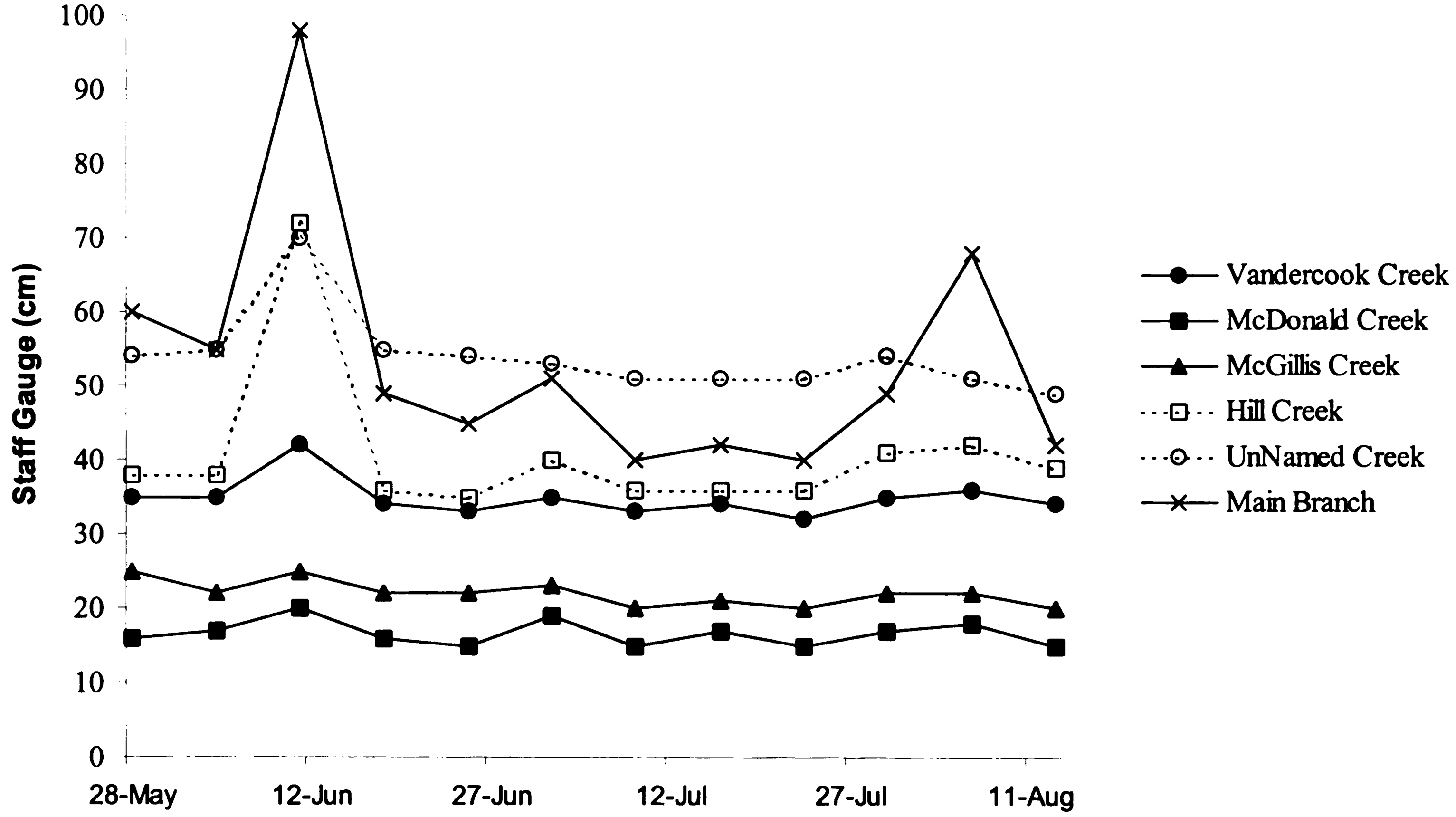

Figure 10. Weekly staff gauge readings for each stream.

The average temperature during the summer months ranged from 13.5°C for the headwater streams to 16.6°C for the adventitious streams and 16.7°C for the mainstem. Using a Tukey's Studentized Range Test, no significant difference was found between the mainstem and adventitious streams ($P=0.6958$). However, as a group, the headwater streams were significantly colder than the mainstem ($P<0.0001$) and adventitious streams ($P<0.0001$). Although the headwater streams were cooler on average than the adventitious streams and mainstem, all three stream types followed similar trends in temperature fluctuations (Figure 11) indicating that temporal variation in these streams was largely driven by local weather conditions. McGillis Creek, a headwater stream, was the warmest stream in the study (mean summer temp=17.4°C), followed by the adventitious streams Hill Creek (16.8°C) and Unnamed Creek (16.7°C), the Pine River mainstem (15.1°C), and the remaining headwater streams McDonald Creek (12.5°C), and VanderCook Creek (11.5°C)(Appendix A).

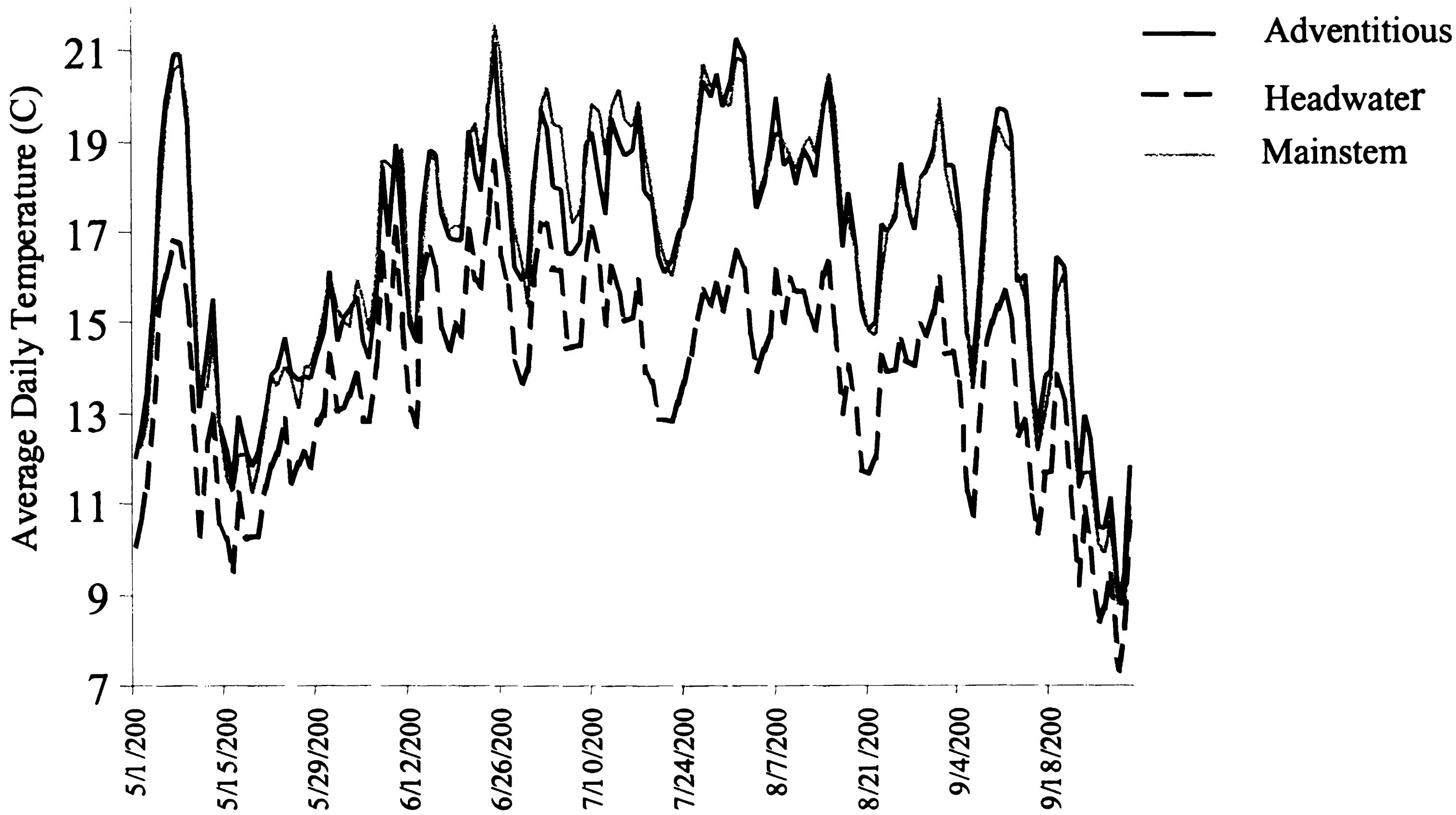

Figure 11. Average daily temperature by stream type during the summer months.

Discussion

Fish Community

As in previous studies relating stream order to fish species richness (Lotrich 1973; Gorman & Karr 1978; Platts 1979; Beecher et al. 1988; Fairchild et al. 1998), the non-adventitious sites sampled in this study clearly showed an increase in species richness with increasing stream order (Figure 2). The deviation from this trend in adventitious streams suggests that their connection with the species-rich mainstem and their warmer stream temperature increases species richness above what could be expected based on stream order alone. This is further illustrated by the observation that adventitious streams were more similar on average to the mainstem than were headwater streams, whether based on species presence/absence (Table 7) or relative abundance (Table 8). Furthermore, adventitious streams were more similar on average to the mainstem than they were to headwater streams (Tables 7, 8 and 9). This contradicts the Osborne & Wiley (1992) study, which found no difference in species composition between headwater and adventitious streams. However, no differences in slope gradient were detected in their study, regardless of tributary location within the Illinois watersheds.

Individual streams were generally more similar within stream types than across stream types. An exception to this, however, was McGillis Creek, which was more similar to adventitious streams than to its headwater counterparts. Based on Sϕrenson's QS values (Appendix B), McGillis Creek had more species in common with the adventitious streams (QS=0.34, 0.75) than with the other headwater streams (QS=0.27, 0.00). Based on Morisita's Γ values (Appendix C), it is clear that species common to McGillis Creek and the adventitious streams are present in high numbers (Γ=0.96, 0.74), while species common to McGillis Creek and McDonald Creek are present in low numbers (Γ=0.02). This suggests that factors beyond stream connectivity are influencing the composition of fish species in headwater streams.

As indicated earlier, McGillis Creek was the warmest of all streams during the study, while the other two headwater streams were the coldest. The species most frequently occurring in McGillis Creek, creek chubs (*S. atromaculatus*), blacknose dace (*R. atratulus*), and central mudminnows (*U. limi*), are species typically associated with warmwater systems and were also found in high abundance in the adventitious streams. Conversely, the species most frequently occurring in the other headwater streams, brook trout (*S. fontinalis*) and mottled sculpin (*C. bairdi*), are species typically associated with coldwater systems and were not captured in McGillis Creek. This reinforces the notion that temperature regime is an important factor, even more so than stream order, in determining a stream's fish assemblage (Paller 1994; Lyons et al. 1996). Furthermore, the species composition in McGillis Creek contrasts with the RCC's prediction that headwater streams are dominated by coldwater fish species.

Based on the distribution of fish tolerance classifications (Figure 3), most species present in each stream type were of intermediate tolerance, with relatively fewer tolerant and intolerant species present. When viewed by relative abundance (Figure 4), however, relatively few individuals of intermediate tolerance are present in adventitious and headwater streams. The majority of individual fish in adventitious stream populations were classified as tolerant, with few intermediate and intolerant individuals present. The majority of individual fish in headwater stream populations were classified as intolerant, with relatively fewer tolerant and intermediate individuals present. This supports the hypothesis that adventitious streams would have a greater abundance of tolerant fish species than headwater streams. In the mainstem, the proportion of individual fish was comprised primarily of individuals classified as intermediate, with fewer tolerant and intolerant individuals present. Lyons et al. (1996) found an increase in fish species richness and a shift from intolerant-dominated to tolerant-dominated fish assemblages following environmental degradation of several Wisconsin coldwater streams. The study suggested that declines in water quality associated with such land uses as agriculture may increase the average temperature and variability of the temperature, creating conditions unsuitable to intolerant coldwater fish species.

Based on month-to-month similarity indices, the fish species composition of adventitious streams was more variable in adventitious streams than headwater streams or the mainstem (Tables 10 and 11). This was consistent with the hypothesis that adventitious streams would show greater temporal variability compared to headwater streams. Søorenson's QS values for the adventitious streams were consistently lower than headwater streams for all month-to-month comparisons. This suggests that the species assemblage in adventitious streams generally changed throughout the summer, while the fish species assemblage in headwater streams remained more stable.

Morisita's Γ values were lower for adventitious streams (Γ=0.62) compared to headwater streams (Γ=0.94), further supporting the hypothesis that fish community composition in adventitious streams are more variable than headwater streams. This implies that fish communities of adventitious streams tend to be more variable in terms of species presence and their relative abundance across months. Conversely, the fish communities of headwater streams tend to be more stable in terms of species presence and relative abundance across months.

The fish community composition in headwater streams and the mainstem generally fit the predictions made by the River Continuum Concept (Table 1). Intolerant coldwater species, such as brook trout and mottled sculpin dominated two of the headwater streams. McGillis Creek, however, was dominated by tolerant species associated with warmwater systems. The mainstem was dominated by warmwater fish species of varying tolerance. The fish assemblages of adventitious streams, however, were not dominated by coldwater species as predicted by the RCC. In general, this study has found that shifts in tolerance classifications for fish may occur based on spatial location within a watershed. I would therefore propose that consideration be given to amending the RCC, based on further research, to include the element of fish tolerance.

Macroinvertebrate Community

The invertebrate metric scores for each stream type are consistent with the distribution of fish tolerance classifications. The Procedure 51 (Michigan Department of Environmental Quality 1997) invertebrate metric scores for adventitious streams were lower than scores for headwater streams across all sampling events (Table 13) and may indicate lower water quality in adventitious streams. The proportion of EPT (Figure 7), an indicator of stream water quality (Merrit & Cummins 1996a), was lower for adventitious streams than for headwater streams. Furthermore, the ratio of chironimids to EPT (Figure 8) was higher for adventitious streams relative to headwater streams. Overall, the results of the invertebrate metrics suggest that the water quality in adventitious streams may be unsuitable for intolerant fish and invertebrate species, while allowing tolerant species to thrive. Reductions in EPT proportions accompanied by increases in other, more tolerant, taxa have been documented in other studies of streams impacted by agricultural practices (Dance & Hynes 1980; Lenat 1984; Lenat & Crawford 1994).

The invertebrate composition in headwater streams and the mainstem also fit the predictions made by the RCC, while adventitious streams did not. Collectors were the most abundant functional feeding group across all stream types. As expected, shredders were the second most abundant group in headwater streams due to increased inputs of allochthonous organic material (Vannote et al. 1980). In the mainstem, grazers were the second most abundant group due to an increased forage base of periphyton from primary production. In adventitious streams, however, shredders were the least abundant functional feeding group, suggesting that riparian input of organic material is limited. Furthermore, functional feeding groups in adventitious streams were the most homogeneous of the stream types. Delong & Brusven (1998) found that, in watersheds heavily impacted by agricultural use, invertebrate communities were relatively homogeneous, dominated by species tolerant of agricultural non-point source pollution, and were comprised of few shredders throughout the longitudinal stream continuum.

Various ratios of invertebrate functional feeding groups were used to characterize the trophic status and amount of coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM) for the stream types (Table 14). These ratios give a general indication of stream ecosystem attributes based on functional feeding group abundance as a response to food resource availability (Merritt & Cummins 1996b). Heterotrophic streams, dependent on inputs of allochthonous material, would be expected to have a low ratio of scrapers and shredders to total collectors. The headwater streams in this study had the lowest average score (0.15) for this ratio. However, the adventitious streams did not score much higher (0.20). McGillis Creek consistently scored the highest for headwater streams, indicating a greater tendency toward autotrophy. Unnamed Creek, which had very little vegetative canopy, consistently scored the highest over all sampling events for the adventitious streams and even approached the reference point for autotrophy (0.75) during the summer sampling period. The mainstem sites scored the highest for this ratio (0.49), indicating that it is more autotrophic in nature. These scores are in general agreement with the predictions made by the River Continuum Concept (Table 1).

As expected, the ratio of shredders to total collectors indicated a high loading of CPOM associated with riparian vegetation in headwater streams (Table 15). Conversely, the mainstem scored much lower, indicating an increased loading of FPOM from upstream processes. These results support the RCC's predictions that headwater invertebrate communities are dependent on input of allochthonous organic material (CPOM), while mid-order invertebrate communities are dependent on algae from primary production and FPOM derived from upstream processing of CPOM (Vannote et al. 1980). However, scores for adventitious streams also indicated a high loading of FPOM. This may be due to a decrease in vegetative canopy, increased siltation from agricultural practices or urbanization, or a combination of the two. Minshall (1978) suggested that in headwater streams of "open" regions, input of allochthonous CPOM might be limited, in which case autochthonous carbon sources would predominate. Vannote et al. (1980) also suggested that small tributaries to larger streams might have localized impacts on carbon processing, dependent on the "volume and nature of the inputs." Lenat & Crawford (1994) found that suspended sediment yield and invertebrate collector abundance were increased in agricultural-impacted streams relative to forested headwater sites. The effects of agriculture practices in this region of the watershed may therefore contribute to the increased FPOM loading in the adventitious streams. This is further supported by the increased ratio of FPOM in transport (TFPOM) relative to that stored in the benthos (BFPOM) for adventitious streams (Table 16). Interestingly, McGillis Creek consistently scored the lowest for headwater streams and was below or near the reference point, indicating relatively high load of FPOM. This further reinforces the idea that agricultural practices may lead to inconsistencies with the RCC by increasing the amount of sediment in streams, while the associated loss of streamside vegetation may lead to a shift from systems dependent on allochthonous inputs to those dependent on autochthonous energy sources.

Habitat

Many of the in-stream habitat components were similar between headwater and adventitious streams. Measures of stream size (e.g., width and depth) and habitat units were similar. Inorganic substrate and physical structure provided by woody material were also similar. Therefore, these characteristics do not appear to be responsible for the differences in fish community structure.

Detectable differences in habitat attributes included the proportion of organic substrate, hydrologic stability, stream velocity, and summer stream temperature. The elevated proportion of organic sediments in adventitious streams may be the result of the agricultural land use in that region of the watershed. Walser & Bart (1999) found that sedimentation from agricultural practices was increased in mainstem reaches relative to forested headwater reaches. This may partially explain the greater composition of tolerant fish and decreased composition of intolerant fish in adventitious streams.

Based on stream velocity and staff gauge data, the hydrologic regime of headwater streams and adventitious were different. Compared to headwater streams, adventitious streams had slower stream velocities and exhibited greater hydrologic variability in response to precipitation events. A study by Poff & Allan (1995) found that fish assemblages in hydrogically variable streams were characterized by species associated with slow velocities and with affinities for low-order streams, including creek chubs (*S. atromaculatus*), central mudminnows (*U. limi*), and blacknose dace (*R. atratulus*). These were also the most abundant fish species that we found in adventitious streams and McGillis Creek, the slowest of the headwater streams.

On average, the temperature regime of adventitious streams was significantly warmer than that of headwater streams, which may also partially explain the higher mean fish species richness in adventitious streams. Interestingly, McGillis Creek was the warmest of all the streams studied (Appendix A) and had the greatest fish species richness of the headwater streams. Studies by Paller (1994) and Lyons et al. (1996) have demonstrated that warmwater streams exhibit greater fish species richness than coldwater streams, which may explain the relatively higher species richness in McGillis Creek compared to the other headwater streams.

Several factors, including groundwater and riparian vegetative shading, may have contributed to the cooler temperatures in headwater streams relative to adventitious streams. Although quantifying the groundwater regime was beyond the scope of this study, it is likely that groundwater upwelling contributed to the cooling effect on headwater streams because of the steep valley side, in headwater regions, producing a large head for groundwater inputs. Generally, the headwater sites were shaded by a denser canopy of vegetation than the adventitious streams, which may have also contributed to the cooler temperatures in headwater streams. Several studies have found an increase in stream temperature resulting from removal of streamside vegetative canopy (Schlosser 1982b; Platts & Nelson 1989; Weaver & Garman 1994; Hetrick et al. 1998). McDonald Creek and VanderCook Creek lie completely within the Huron National Forest and are largely shaded by a dense canopy of vegetation. While the McGillis Creek and Hill Creek sites were largely shaded by vegetation, portions of these streams flow through agricultural land with little or no canopy. In addition, the lands adjacent to these sites are used primarily for agriculture and are largely devoid of shading canopy. UnNamed Creek flows through a low-lying swampy area, with little vegetative canopy and these sites are almost entirely exposed to direct sunlight. The loss of streamside vegetation may also shift processes in low-order streams to an autotrophic state typically associated with mid-order streams (Vannote et al. 1980; Minshall et al. 1985). Schlosser (1982) documented shifts in invertebrate and fish communities resulting from removal of riparian vegetation. In addition, his study found an increase in invertebrate and fish biomass attributed to an increase in primary production.

Conclusions

Stream order designation alone did not account for differences in fish community in this study. Adventitious streams had greater fish species richness than headwater streams of the same order. The similarity in fish assemblage between adventitious streams and the mainstem lead me to conclude that the increase in species richness is largely due to the connectivity of these stream types. However, connectivity did not entirely account for the increase in species richness, as is evidenced by the increased fish species richness in the headwater stream McGillis Creek. Habitat conditions were similar among the headwater streams, with the exception of stream temperature. McGillis Creek was the warmest stream examined in this study and had the highest species richness among the headwater streams. Therefore, I conclude that connectivity and stream temperature are the primary factors accounting for species richness.

The high temporal variability in fish communities of adventitious streams combined with their similarity to the mainstem suggest that some fish species utilize these stream types interchangeably, possibly for reproductive purposes, food, or thermal refuge. Fisheries managers should therefore recognize the potential importance of adventitious streams to fish communities of mid-order streams.

Adventitious streams also had a greater proportion of tolerant fish compared to headwater streams, suggesting that the water quality was lower in adventitious streams. The increase in tolerant fish was probably due to several reasons, including agricultural impacts combined with greater flow instability, stream temperatures, and siltation in adventitious streams. Fisheries managers should realize that these impacts are typically associated with removal of riparian vegetation and may therefore be minimized by maintaining a vegetative buffer zone around these tributaries.

The lower IBI scores for macroinvertebrate communities further support the conclusion that the water quality is lower in adventitious streams. This may be primarily due to a high sediment load in transport, as indicated by the high ratio of TFPOM to BFPOM. The remaining RCC ratios for trophic status and CPOM/FPOM indicate that adventitious streams are more autotrophic in nature compared to headwater streams and are therefore an exception to the River Continuum Concept (Cummins 1977; Minshall 1978; Vannote et al. 1980).

This study was somewhat limited by time constraints and the low number of adventitious tributaries present in the Pine River watershed, which resulted in a relatively small number of streams sampled. Therefore, future research may involve larger watersheds with more adventitious streams and perhaps comparison across watersheds within a region. This research may serve to expand the scope of the River Continuum Concept and improve its practical use in management applications.

APPENDICES

Appendix A. Habitat conditions for each site sampled.

Site #	**1**	**2**		**3**	**4**		**5**	**6**	
Stream	McDonald Creek			McGillis Creek			VanderCook Creek		
Stream Type	Headwater			Headwater			Headwater		
Stream Order	2	2		2	2		2	2	
			Mean			Mean			Mean
% Pool	12.0	17.3	14.7	6.7	10.7	8.7	17.3	24.0	20.7
% Riffle	0.0	0.0	0.0	0.0	10.7	5.3	0.0	0.0	0.0
% Run	88.0	82.7	85.3	98.3	78.7	86.0	82.7	76.0	79.3
% Woody Material	15.0	13.2	14.1	16.7	21.5	19.1	38.1	28.6	33.4
Mean Width (m)	2.7	2.7	2.7	1.9	2.3	2.1	2.3	2.6	2.5
Mean Depth (cm)	14.1	12.9	13.5	12.3	9.6	10.9	17.9	16.9	17.3
Mean Velocity (m/s)	0.09	0.06	0.08	0.05	0.04	0.05	0.12	0.14	0.13
Mean Substrate Size Value	2.8	2.9	2.85	2.8	2.9	2.85	2.8	2.7	2.75
Mean Summer Temperature (°C)	12.1	13.0	12.6	17.5	17.3	17.4	12.1	11.0	11.6

Appendix A (cont.)

Site #	7	8		9	10		11	12	
Stream	Hill Creek			UnNamed Creek			Pine River		
Stream Type	Adventitious			Adventitious			Mainstem		
Stream Order	2	2		2	2		5	5	
			Mean			Mean			Mean
% Pool	30.7	14.7	22.7	24.0	34.7	29.3	26.7	0.0	13.3
% Riffle	0.0	17.3	8.7	4.0	0.0	2.0	56.0	0.0	28.0
% Run	69.3	68.0	68.7	72.0	65.3	2.0	17.3	100	58.7
% Woody Material	31.7	35.0	33.3	0.7	18.4	9.5	4.3	2.0	3.1
Mean Width (m)	1.8	2.4	2.1	2.3	2.1	2.2	11.3	23.9	17.6
Mean Depth (cm)	13.6	17.8	15.9	10.6	17.7	14.5	29.1	43.8	37.9
Mean Velocity (m/s)	0.05	0.02	0.03	0.05	0.05	0.05	0.18	0.14	0.16
Mean Substrate Size Value	2.3	3.0	2.60	2.9	2.5	2.70	3.9	3.0	3.45
Mean Summer Temperature (°C)	17.0	16.7	16.85	16.7	16.8	16.75	15.1	15.2	15.15

Appendix B. Similarity of fish species composition across study streams using Sϕrensen's (1948) QS index.

	Hill	Unnamed	McDonald	VanderCook	McGillis	Pine River
Hill	\	0.55	0.25	0.10	0.34	0.54
Unnamed	0.55	\	0.21	0.00	0.75	0.43
McDonald	0.25	0.21	\	0.57	0.27	0.26
VanderCook	0.10	0.00	0.57	\	0.00	0.11
McGillis	0.34	0.75	0.27	0.00	\	0.28
Pine River	0.54	0.43	0.26	0.11	0.28	\

Appendix C. Similarity of fish species composition across streams using Morisita's (1959) Γ index (as modified by Horn 1966).

	Hill	Unnamed	McDonald	VanderCook	McGillis	Pine River
Hill	\	0.81	0.04	0.02	0.96	0.54
Unnamed	0.81	\	0.02	0.00	0.74	0.42
McDonald	0.04	0.02	\	0.96	0.02	0.18
VanderCook	0.02	0.00	0.96	\	0.00	0.13
McGillis	0.96	0.74	0.02	0.00	\	0.50
Pine River	0.54	0.42	0.18	0.13	0.50	\

Appendix D. Month-to-month fish community similarity within each stream using Sϕrensen's (1948) QS index.

	May-Jun	May-Jul	May-Aug	Jun-Jul	Jun-Aug	Jul-Aug	**Average**	SE
Hill	0.70	0.82	0.58	0.84	0.67	0.70	0.72	0.04
Unnamed	0.82	0.53	0.67	0.50	0.63	0.57	0.62	0.05
McDonald	0.75	0.86	0.86	0.89	0.89	1.00	0.87	0.03
VanderCook	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
McGillis	0.62	0.62	0.50	0.60	0.89	0.67	0.65	0.05
Pine River	0.88	0.81	0.76	0.78	0.79	0.84	0.80	0.02

Appendix E. Month-to-month fish community similarities within each stream using Morisita's (1959) Γ index (as modified by Horn 1966).

	May-Jun	May-Jul	May-Aug	Jun-Jul	Jun-Aug	Jul-Aug	**Average**	**SE**
Hill	0.86	0.65	0.96	0.86	0.85	0.63	0.80	0.06
Unnamed	0.19	0.54	0.57	0.39	0.14	0.77	0.43	0.06
McDonald	0.96	0.95	0.98	0.99	0.98	0.97	0.97	0.06
VanderCook	0.84	0.76	0.82	0.97	0.97	0.99	0.89	0.06
McGillis	0.93	0.95	0.94	0.95	0.97	0.99	0.96	0.06
Pine River	0.93	0.74	0.53	0.79	0.50	0.76	0.71	0.06

Appendix F. Fish species present, tolerance values, and number captured in each stream. Tol = Tolerant; Intol = Intolerant; Med = Intermediate tolerance.

Common name	Scientific Name	Tolerance	HC	McD	McG	MS	UN	VC	Total
Creek Chub	*Semotilus atromaculatus*	Tol	524	0	615	221	267	0	1627
Mottled Sculpin	*Cottus bairdii*	Intol	19	348	0	100	0	269	736
Blacknose Dace	*Rhinichthys atratulus*	Tol	119	24	240	200	148	0	731
Brook Trout	*Salvelinus fontinalis*	Intol	0	225	0	11	0	303	539
Central Mudminnow	*Umbr alimi*	Tol	136	1	103	18	277	0	535
Johnny Darter	*Etheosto manigrum*	Med	33	0	1	356	7	0	397
Blackside Darter	*Percina maculata*	Med	30	0	0	210	0	0	240
Logperch	*Percina caprodes*	Med	4	0	0	112	0	0	116
White Sucker	*Catostomus commersoni*	Tol	3	0	0	73	17	0	93
Channel Darter	*Percina copelandi*	Intol	0	0	0	53	4	0	57
Green Sunfish	*Lepomis cyanellus*	Tol	27	0	0	25	5	0	57
Rock Bass	*Ambloplites rupestris*	Med	0	0	0	51	0	0	51
Common Shiner	*Luxilus cornutus*	Med	3	0	6	38	1	0	48
Brook Stickleback	*Culaea inconstans*	Med	3	0	0	0	37	0	40
Northern Hogsucker	*Hypentelium nigricans*	Intol	0	0	0	25	0	0	25
Yellow Perch	*Perca flavescens*	Med	0	0	0	22	0	0	22
Northern Redbelly Dace	*Phoxinus eos*	Med	3	0	2	0	12	0	17
Rainbow Darter	*Etheostoma caeruleum*	Med	0	0	5	8	3	0	16
Golden Shiner	*Notemigonus crysoleucas*	Tol	11	0	0	1	0	0	12
Northern Brook Lamprey	*Ichthyomyzon fossor*	Intol	0	0	0	11	0	0	11
Rainbow Trout	*Oncorhynchus mykiss*	Intol	0	0	0	10	0	0	10
Bluntnose Minnow	*Pimephales notatus*	Tol	0	0	0	9	0	0	9
Hornyhead Chub	*Nocomis biguttatus*	Intol	8	0	0	0	1	0	9
Pumpkinseed	*Lepomis gibbosus*	Med	1	0	0	8	0	0	9
Smallmouth Bass	*Micropterus dolomieu*	Med	0	0	0	9	0	0	9
Silver Lamprey	*Ichthyomyzon unicuspis*	Med	0	0	0	8	0	0	8

Appendix F (cont.).

Pearl Dace	*Margariscus margarita*	Med		0	5	0	1	0	0	6
Black Bullhead	*Ameiurus melas*	Med		0	0	1	3	1	0	5
Iowa Darter	*Etheostoma exile*	Med		0	0	4	0	1	0	5
River Chub	*Nocomis micropogon*	Intol		0	0	5	0	0	0	5
Spottail Shiner	*Notropis hudsonius*	Med		5	0	0	0	0	0	5
Bluegill	*Lepomis macrochirus*	Tol		0	0	0	4	0	0	4
Brown Trout	*Salmo trutta*	Intol		1	0	0	3	0	0	4
Chinook Salmon	*Oncorhynchus tshawytscha*	Intol		0	0	0	4	0	0	4
Northern Pike	*Esox lucius*	Med		1	0	0	1	0	0	2
Black Crappie	*Pomoxis nigromaculatus*	Med		0	0	0	1	0	0	1
Emerald Shiner	*Notropis atherinoides*	Med		1	0	0	0	0	0	1
Golden Redhorse	*Moxostoma erythurum*	Med		0	0	0	1	0	0	1
Largemouth Bass	*Micropterus salmoides*	Med		0	0	0	1	0	0	1
Silver Redhorse	*Moxostoma anisurum*	Med		0	0	0	1	0	0	1
			Total	932	603	982	1599	781	572	5469

Appendix G. Macroinvertebrate taxa present and numbers sampled in each stream over all sites and months.

Phylum	Class	Family	McDonald	McGillis	VanderCook	Hill	Unnamed	Pine River	Total
Annelida	Hirudinea		0	2	1	0	1	2	6
Annelida	Oligochaeta		1	0	9	2	1	0	13
Arthropoda	Arachnoidea		2	1	0	0	11	1	15
Arthropoda	Crustacea		114	15	67	109	74	46	425
Arthropoda	Insecta		0	0	1	1	0	0	2
Arthropoda	Insecta	Aeshnidae	1	26	0	17	0	4	48
Arthropoda	Insecta	Athericidae	0	0	0	0	0	4	4
Arthropoda	Insecta	Baetidae	33	0	15	0	4	9	61
Arthropoda	Insecta	Baetiscidae	0	0	0	0	0	9	9
Arthropoda	Insecta	Belostomatidae	0	0	0	0	7	0	7
Arthropoda	Insecta	Brachycentridae	93	4	74	3	0	2	176
Arthropoda	Insecta	Calopterygidae	0	14	0	11	13	6	44
Arthropoda	Insecta	Chironomidae	49	79	74	144	140	81	567
Arthropoda	Insecta	Cordulegastridae	1	24	0	0	0	1	26
Arthropoda	Insecta	Corixidae	0	0	0	1	9	13	23
Arthropoda	Insecta	Corydalidae	0	25	0	4	0	7	36
Arthropoda	Insecta	Dixidae	0	0	0	24	15	0	39
Arthropoda	Insecta	Dytiscidae	1	1	0	6	31	2	41
Arthropoda	Insecta	Elmidae	0	3	0	5	3	22	33
Arthropoda	Insecta	Ephemerellidae	99	79	80	74	16	56	404
Arthropoda	Insecta	Ephemeridae	0	0	0	0	0	23	23
Arthropoda	Insecta	Gerridae	10	2	17	5	7	10	51
Arthropoda	Insecta	Glossosomatidae	20	27	20	11	0	18	96
Arthropoda	Insecta	Gomphidae	0	5	0	0	0	0	5
Arthropoda	Insecta	Gyrinidae	2	0	1	1	4	0	8
Arthropoda	Insecta	Helicopsychidae	0	11	0	0	0	0	11

Appendix G
(cont.).

Arthropoda	Insecta	Heptageniidae	9	72	0	0	0	131	212
Arthropoda	Insecta	Hydropsychidae	45	41	15	25	1	43	170
Arthropoda	Insecta	Isonychiidae	0	0	0	0	0	13	13
Arthropoda	Insecta	Leptophlebiidae	1	43	0	0	28	0	72
Arthropoda	Insecta	Libellulidae	0	0	0	2	12	0	14
Arthropoda	Insecta	Limnephilidae	23	36	63	31	15	6	174
Arthropoda	Insecta	Metretopodidae	0	0	0	0	1	12	13
Arthropoda	Insecta	Molanidae	0	0	0	1	0	0	1
Arthropoda	Insecta	Nemouridae	44	0	79	0	0	0	123
Arthropoda	Insecta	Perlidae	4	0	5	3	0	12	24
Arthropoda	Insecta	Perlodidae	2	0	31	0	0	10	43
Arthropoda	Insecta	Philopotamidae	18	0	0	12	0	0	30
Arthropoda	Insecta	Pleidae	0	0	0	0	36	2	38
Arthropoda	Insecta	Polycentropodidae	5	0	2	2	0	0	9
Arthropoda	Insecta	Psephenidae	0	1	0	0	0	0	1
Arthropoda	Insecta	Pteronarcidae	0	0	7	0	0	3	10
Arthropoda	Insecta	Sialidae	1	0	11	2	0	0	14
Arthropoda	Insecta	Simuliidae	9	58	2	65	85	24	243
Arthropoda	Insecta	Stratiomyidae	2	3	0	0	0	0	5
Arthropoda	Insecta	Tabanidae	0	0	5	1	0	1	7
Arthropoda	Insecta	Taeniopterygidae	3	9	12	0	0	6	30
Arthropoda	Insecta	Tipulidae	4	14	4	14	0	10	46
Mollusca	Gastropoda	Bithyniidae	0	0	0	0	52	0	52
Mollusca	Gastropoda	Lymnaeidae	4	4	3	22	32	7	72
Mollusca	Pelecypoda	Unionidae	0	1	0	2	2	4	9
Nematomorpha			0	0	2	0	0	0	2
		Total	600	600	600	600	600	600	3600

Appendix H. Invertebrate metric scores for each stream based on Procedure 51 (Michigan Department of Environmental Quality 1997). Stream names are abbreviated as follows: McD = McDonald Creek, McG = McGillis Creek, VC = VanderCook Creek, HC = Hill Creek, UN = Unnamed Creek, Pine = Pine River mainstem.

Month	Metric	McD	McG	VC	HC	UN	Pine
Jan	Total # of Taxa	0	0	0	0	-1	0
Jan	Total # of Mayfly Taxa	0	1	-1	-1	0	1
Jan	Total # of Caddisfly Taxa	0	0	0	0	-1	-1
Jan	Total # of Stonefly Taxa	1	0	1	0	-1	1
Jan	% Mayfly Composition	0	1	0	0	0	1
Jan	% Caddisfly Composition	0	0	0	0	0	0
Jan	% Dominant Taxon	1	1	0	0	-1	1
Jan	% Isopods, Snails, & Leeches	1	1	1	1	1	1
Jan	% Surface Dependent	1	1	1	1	1	1
	Totals	**4**	**5**	**2**	**1**	**-2**	**5**
May	Total # of Taxa	0	1	1	1	1	0
May	Total # of Mayfly Taxa	0	0	0	-1	0	1
May	Total # of Caddisfly Taxa	0	0	0	1	-1	0
May	Total # of Stonefly Taxa	0	-1	1	-1	-1	1
May	% Mayfly Composition	1	1	1	1	0	1
May	% Caddisfly Composition	1	0	0	0	0	0
May	% Dominant Taxon	0	1	0	1	-1	0
May	% Isopods, Snails, & Leeches	1	1	1	0	-1	1
May	% Surface Dependent	1	1	1	1	0	1
	Totals	**4**	**4**	**5**	**3**	**-3**	**5**
Aug	Total # of Taxa	0	0	0	1	1	0
Aug	Total # of Mayfly Taxa	0	0	-1	-1	0	1
Aug	Total # of Caddisfly Taxa	0	0	0	0	-1	0
Aug	Total # of Stonefly Taxa	0	-1	1	-1	-1	1
Aug	% Mayfly Composition	0	1	-1	0	-1	1
Aug	% Caddisfly Composition	1	0	1	0	-1	0
Aug	% Dominant Taxon	1	1	1	1	1	1
Aug	% Isopods, Snails, & Leeches	1	1	1	1	-1	1
Aug	% Surface Dependent	0	1	0	0	-1	0
	Totals	**3**	**3**	**2**	**1**	**-4**	**5**

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