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A Landscape-Based Ecological Classification System for River Valley Segments in Michigan's Upper Peninsula

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Abstract.–I developed a classification system for streams in Michigan's Upper Peninsula (UP) using a landscape-based approach that was originally developed for Lower Peninsula (LP) Michigan streams. Multiple linear regression, cluster analysis, and graphical techniques were used to examine stream attribute data (stream size, temperature, hydrology, gradient, water chemistry, valley type, fish community, and connectivity to one of the Great Lakes) and watershed attributes (surficial geology, land use, elevation, expected groundwater flow) to develop classification categories. Stream segments were classified based on examination of watershed characteristics and known relationships between these characteristics and stream attributes. I classified a total of 81 UP river systems into 596 discrete segments. Classified stream segments ranged from 0.4 to 187 km long and represented a broad range of stream types. Classifications used for UP rivers were modified from those developed for LP streams for water temperature, stream hydrology, stream gradient, and fish community because of substantial differences between UP and LP rivers. The UP VSEC system should be helpful to resource managers as a communication and learning tool as they manage UP stream resources. Efforts should now be directed to combining the UP and LP classifications into a single statewide stream classification system. This would provide resource managers statewide with a valuable tool for understanding and managing Michigan's stream resources.

Research directed at gaining a better understanding of the factors influencing Michigan's stream habitats and fish communities in the Lower Peninsula (LP) resulted in the development of a river classification framework termed Valley Segment Ecological Classification (VSEC) (Seelbach et al. 2006; Wehrly et al. 2006; Zorn et al. 2002). The VSEC system classifies river valley segments according to expected streamflow regime, temperature regime, fish community composition, etc. The classification process places breakpoints between adjacent river valley segments where significant change occurs in the river network (e.g., a major tributary junction, change in channel gradient and sinuosity, change in surficial geology). The VSEC system of classification is based on relationships between watershed characteristics and stream attributes. The VSEC process relies on catchment-scale attributes (e.g., surficial geology, land use, gradient) and mathematical models to assign attributes to stream segments. For example, multiple linear regression models were developed for LP rivers and these models were used to predict stream temperature from surficial geology, maximum daily air temperature, riparian shading, etc. (Wehrly et al. 2006).

Classifying streams according to discrete attributes helps our understanding of rivers as systems and can be used to enhance communication about stream resources. The original development of the VSEC system did not include Upper Peninsula (UP) rivers in part because the physical, climatic, and zoogeographic setting in the UP was recognized as being very different from the LP. This study was undertaken with the objective of developing a VSEC system based on data from UP streams and then classifying streams into ecological units.

The theory underlying VSEC and the process of classifying stream segments has been well described in various reports and publications (Seelbach et al. 2006; Seelbach and Wiley 1997; Wiley and Seelbach 1997). Therefore, this report will focus on the extension of VSEC to UP streams and will highlight the differences detected between UP and LP streams. The specific objectives of this study were 1) to extend and, when necessary, modify the LP VSEC system to rivers of the UP; 2) to use variables and models for UP streams to delineate and classify river valley segments into distinct types; 3) to determine composition of UP river fish communities from historic data and electrofishing surveys; and 4) to classify UP river fish communities into distinct types.

Approach and Methods

Development of the classification system for UP streams followed the approach and methods used to classify LP streams (Seelbach et al. 2006) and so will be only briefly described here. The classification process followed five steps.

Step 1 was the selection of stream attributes that were deemed important for identifying ecological units. The attributes used for the LP included catchment size, hydrology, water chemistry, water temperature, valley character, channel character, and fish assemblages (Seelbach et al. 2006). Because the ecological processes in UP catchments were expected to be similar to LP streams, I used the same attributes for the UP VSEC system.

Step 2 was the selection of key maps and the definition of rules used to define stream segment boundaries. Map layers used in LP stream classification included elevation, land use/land cover, surficial geology, hydrology (stream and lake features), and predicted groundwater velocity (derived from slope and surficial geology). In addition to the map layers listed, I used a map of glacial drift (earth and rocks which have been transported by moving ice) thickness and a bedrock geology map. Rules used to define stream segment boundaries were the same as those used in LP river classification. Segment boundaries were defined by major junctions in the stream network, major changes in slope, channel character, geologic boundaries, changes in groundwater supply, and changes in land cover patterns. Often, changes in one feature used to delineate segment boundaries were closely tied to changes in other features. For example, when a river channel crossed a geologic boundary there was typically a change in expected groundwater supply.

Step 3 was the development of classification categories for the attributes identified in Step 1. Categories used for the LP classification were defined in Seelbach et al. (2006). New categories I developed for UP streams were based on examination of data from UP streams and will be detailed below.

Step 4 was the definition of assignment rules for the attributes used in the classification. Assignment rules followed relationships identified during data analysis. For example, streams that drained catchments of medium and coarse textured glacial till or sand and gravel outwash were classified as cold based on the multiple linear regression (MLR) results.

Step 5 was the development of the computerized databases and geographic information system (GIS) maps that were used to store, retrieve, and display information on stream-segment boundaries and attributes. The databases and maps produced during the classification process can be queried to produce groupings of streams by common attributes.

Although the methods I used to classify UP streams were similar to those used for the LP, the classification scheme developed for the UP differed in some important attributes, including hydrology, stream temperature, gradient, and fish community classifications. Streams in the UP had different precipitation patterns, surficial geology, topography, and fish communities.

The following codes were developed to classify UP stream segments. Differences between UP and LP codes are highlighted and reasons for the differences are outlined.

Hydrology Codes

I examined United States Geological Survey (USGS) streamflow records, expressed as flow exceedence curves, for gauged UP streams and developed codes for classifying streamflow patterns. To facilitate comparisons among streams, flow data were expressed as cubic meters per second per square kilometer of drainage area ($m^3 \cdot s^{-1} \cdot km^{-2}$) (Figure 1). My initial examination of streamflow data for UP streams included a graphical comparison to streamflow data for LP streams. One obvious difference noted between UP and LP streamflows was the substantially higher 10% exceedence (flood) flow in many UP streams. This difference between UP and LP streamflow regimes was due primarily to the high snowfall and attendant high spring runoff from snowmelt in UP rivers (Figure 2). The difference could also be attributed to dissimilarity in the thickness of the glacial drift between the two peninsulas and contrasts in stream gradients. Drift thickness is less in the UP than in the LP (Farrand and Bell 1984) and this means there is less water-holding capacity in most UP catchments. As a result, most UP streams are surface-water dominated. In addition, stream gradient in many areas of the UP is higher than in the LP and therefore water travels through these UP catchments more rapidly than in the LP. Because of these differences between UP and LP streamflow regimes, I developed a new set of hydrology classifications for UP rivers.

I classified the hydrology of UP stream segments according to 11 classifications. These hydrology classifications were independent of catchment size (discharge data standardized as m^3/km^2) and can be broadly divided into stream water sources that are primarily either groundwater or surface runoff. Further subdivision of these broad classifications was based on flow patterns that appeared to be linked primarily to the precipitation pattern (snowfall, Figure 2) and the catchment gradient. Hydrology codes and definitions are:

Groundwater Source

GS Extremely high groundwater input and very high base flow (90% exceedence flow greater than 0.015 $m^3 \cdot s^{-1} \cdot km^{-2}$) with very little surface runoff, watershed characterized by deep sand deposits and high gradient (e.g., Cherry Creek, Marquette County)

G2 Good groundwater inputs with little surface runoff, moderate base flow (90% exceedence flow ~ 0.006 $m^3 \cdot s^{-1} \cdot km^{-2}$) and low peak flow (10% exceedence flow ~0.016 $m^3 \cdot s^{-1} \cdot km^{-2}$), deep coarse glacial deposits and outwash, low gradient (e.g., Iron River, Iron County)

G3 Good groundwater inputs with little surface runoff, high base flow (90% exceedence flow ~ 0.008 $m^3 \cdot s^{-1} \cdot km^{-2}$) and moderate peak flow (10% exceedence flow ~ 0.024 $m^3 \cdot s^{-1} \cdot km^{-2}$), deep coarse glacial deposits, relatively high snowfall and moderate gradient (e.g., Carp River, Marquette County)

Surface-water Source

S1A Moderate groundwater input and moderate surface runoff (90% exceedence flow ~ 0.005 $m^3 \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.020 $m^3 \cdot s^{-1} \cdot km^{-2}$), relatively shallow coarse glacial drift above bedrock and also relatively impervious material, relatively low snowfall (e.g., East Branch Ontonagon River, Ontonagon County)

S1B Moderate groundwater input and moderate surface runoff, moderate base flow and peak flow (90% exceedence flow ~ 0.005 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.024 $m^{3} \cdot s^{-1} \cdot km^{2}$), shallow mixed glacial drifts, low gradient, high snowfall (e.g., Manistique River, Schoolcraft County)

S1C Moderate groundwater input and moderate surface runoff, moderate base flow and high peak flow (90% exceedence flow ~ 0.005 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.035 $m^{3} \cdot s^{-1} \cdot km^{-2}$), shallow mixed glacial drifts, high gradient, high snowfall (e.g., Trap Rock River, Houghton County)

S2A Moderate groundwater input and moderate surface runoff, low moderate base flow and peak flow (90% exceedence flow ~ 0.003 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.019 $m^{3} \cdot s^{-1} \cdot km^{-2}$), shallow mixed glacial drifts, low gradient, low snowfall (e.g., Sturgeon River, Delta County)

S2B Moderate groundwater input and moderate surface runoff, low base flow and moderate peak flow (90% exceedence flow ~ 0.003 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.026 $m^{3} \cdot s^{-1} \cdot km^{-2}$), shallow mixed glacial drifts, low gradient, high snowfall (e.g., Tahquamenon River, Luce County)

S3A Very little groundwater and high surface runoff, low base flow and high peak flow (90% exceedence flow ~ 0.001 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.032 $m^{3} \cdot s^{-1} \cdot km^{-2}$), thin glacial deposits over bedrock, high snowfall, high gradient (e.g., Washington Creek, Isle Royale)

S3B Relatively little groundwater and relatively high surface runoff, low base flow and moderate peak flow (90% exceedence flow ~ 0.001 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.022 $m^{3} \cdot s^{-} \cdot km^{-2}$), mixed glacial deposits and thin glacial tills over bedrock, low snowfall, moderate gradient (e.g., Ford River, Delta County)

S4 Very little groundwater and high surface runoff, very low base flow and high peak flow (90% exceedence flow ~ 0.0003 $m^{3} \cdot s^{-1} \cdot km^{-2}$, 10% exceedence flow ~ 0.034 $m^{3} \cdot s^{-1} \cdot km^{-2}$), medium textured tills and thin glacial deposits over bedrock, low snowfall, moderate gradient (e.g., Tenmile Creek, Menominee County)

Water Chemistry Codes

The water chemistry codes used to classify UP streams were identical to those used for LP stream segments (Seelbach et al. 2006). Water chemistry classifications for UP streams were assigned based on evaluation of catchment surficial geology, bedrock geology, and land use/land cover. I also used water chemistry data collected by Michigan Department of Environmental Quality (DEQ) personnel and United States Environmental Protection Agency (EPA) data to verify and correct the original classifications.

Streams in the UP were generally less productive than LP streams and water chemistry among UP streams was less variable than LP streams. Therefore, water chemistry classifications for UP stream segments were limited to three types:

OS Oligotrophic Soft (low nutrients and alkalinity, total alkalinity < 135, $NO_2 + NO_3 < 100$ ppb).

OH Oligotrophic Hard (low nutrients and high alkalinity, total alkalinity > 135, $NO_2 + NO_3 < 100$ ppb).

M Mesotrophic (moderate nutrients, $NO_2 + NO_3$ 100-700 ppb, total alkalinity >135).

Water Temperature Codes

Water temperature data were collected from UP streams using electronic temperature loggers that recorded temperature multiple times each day. Loggers were generally programmed to record temperature once each hour and loggers were deployed in early spring and retrieved one year later. Temperature data analysis included plotting temperature by date for the entire collection period, calculating stream maximum summer temperature, and determining summer daily temperature range. I followed the methods developed by Wehrly et al. (1999) and used multiple linear regression (MLR) analysis to examine potential relationships between stream temperature and watershed characteristics. Streams were then classified based on the watershed characteristics that were meaningful in the MLR models.

Water temperature codes used for classifying UP streams were the same as used for LP streams and are defined below. Although the temperature codes used for UP and LP streams were identical, the temporal pattern of stream temperature in the UP was different than for LP streams. Wehrly et al. (1999) noted that the month of July was the period of warmest stream temperatures in the LP and used stream temperature data for the first three weeks of July to summarize LP stream temperature characteristics. However, UP streams typically reached their highest summer temperature near or shortly after the summer solstice (~June 21) and gradually cooled throughout the remainder of the summer. This suggests that direct sunlight may be more important than maximum air temperature in determining the timing of summer maximum stream temperature in UP streams. In support of this, MLR models for LP streams included maximum air temperature as a significant predictor variable (Wehrly et al. 2006). However, MLR models for UP streams did not include maximum air temperature (Table 1). Because UP streams reach the summer maximum temperature earlier than LP streams, UP stream data were summarized for the period 24 June-21 July. Temperature summaries produced using these methods represent the average or chronic temperature that fish and other biota are exposed to and are a better predictor of fish community composition than acute maximum temperature.

I also summarized stream temperature data differently than the method used for LP streams. Temperature data for LP streams were summarized using the maximum and minimum recorded temperatures for each of the first three weeks of July (July1-21) and calculating average stream temperature as the average of the three weekly maximum and minimum values. Average stream temperature for UP streams was calculated as the average temperature for the period using all the available data. Average stream temperatures calculated using this method were slightly lower (<1° C) than average temperatures calculated using the methods of Wehrly et al. (2006).

I also calculated stream temperature range differently than the method used for LP rivers. Wehrly et al. (2006) calculated stream temperature range as the average difference of the weekly maximum and minimum temperatures for each of the first three weeks of July. Average temperature range for UP streams was calculated as the average of the daily differences between maximum and minimum temperatures. Average temperature ranges calculated using this method were approximately half of the daily range values calculated by the methods of Wehrly et al. (2006). Therefore, classifications for daily temperature range were adjusted to account for this difference. Wehrly et al. (2003) used cutoff values for daily temperature range of 6° and 10° C to classify streams as stable, moderately stable, or highly variable. I used 3° and 5° C as the cutoff values (Figure 3). Temperature codes used to classify UP streams were:

C Cold, mean temperature less than 19° C
K Cool, mean temperature between 19° and 22° C
W Warm, mean temperature greater than 22° C
S Low diurnal variation, daily temperature variation less than 3° C
M Moderate diurnal variation, daily temp variation between 3° and 5° C
H High diurnal variation, daily temperature variation greater than 5° C

Valley/Channel Character

Stream valley gradients were classified directly from USGS topographic maps. I determined the vertical drop of the stream channel over the horizontal length of the stream by measuring the length of the stream channel between adjacent elevation contours where those contours crossed the stream channel. Stream channel gradient measures were standardized to m/km.

Codes used to classify valley and channel character were similar to those used for LP stream classification (Seelbach et al. 2006) but because gradients in some UP catchments were greater than any measured for LP, streams I added two additional gradient classifications ("High" and "Very High").

Valley gradient codes were:

Very low	gradient less than 0.75 m/km
Low	gradient between 0.75 and 1.88 m/km
Moderate	gradient between 1.88 and 3.75 m/km
High	gradient between 3.75 and 7.50 m/km
Very high	gradient greater than 7.50 m/km

Valley character codes were:

AU	Alluvial unconfined
AS	Alluvial sporadically confined
GU	Glacial unconfined
GC	Glacial confined

Fish Species Association Codes

Stream fish community data were collected from streams across the UP using either backpack or tow-barge electrofishing equipment. At each survey location, block nets were placed at the upstream and downstream boundary of the reach and three-pass depletion electrofishing was used to sample the fish community. Sampled stream segments were at least 100 m long and included at least one pool, riffle, and run habitat. An attempt was made to capture all observed fish, regardless of species, and fish from each pass were held in a live cage until processing after the last pass was completed. Fish were identified to species, counted, and batch weighed by species. Data were then used to calculate fish abundance and biomass per unit area of stream (Zippin 1958).

I developed fish species association codes for UP streams using the cluster analysis methods developed by Zorn et al. (2002). Standardized (Z-distribution) fish biomass data were clustered using complete linkage and the Pearson correlation coefficient distance measure. The resulting cluster dendogram was inspected and clusters were determined visually based on known aspects of individual species' biology and its proximity to other species in the dendogram.

Fish species association codes for UP streams were substantially different from those developed for LP streams, primarily due to zoogeographic differences in species diversity between LP and UP streams (Scott and Crossman 1973; Smith 1990; Page and Burr 1991). For example, in their analysis of LP stream fish data, Zorn et al. (2002) analyzed abundance data and developed their fish community classification system based on the 69 most commonly occurring species captured in LP streams. However, stream sampling throughout the UP from 1996 through 2004 (46 sites) using methods comparable to those employed by Zorn et al. (2002) resulted in the capture of only 46 species of fish (Table 2, Appendix 1). The maximum number of species captured at any one site was 21 and average species diversity across all sites was 11. Of the 46 species captured, only 30 were deemed common enough (captured at five or more sites) to include in development of fish species codes. Data analysis identical to that of Zorn et al. (2002) yielded 6 fish species association codes for UP streams (Figure 4) whereas 17 codes were developed for LP streams (Zorn et al. 2002). Because large rivers were underrepresented in the data set used to develop codes for UP streams, I added an additional code (Redhorse) to use for classifying large-river fish communities. This allowed for the classification of large UP rivers that were not sampled during the course of this study. Fish species association codes and species included in each group, with species listed in bold used in classification database were:

Rock bass, fathead minnow, bluntnose minnow, northern logperch
Longnose dace, fantail darter, burbot, blackside darter
White sucker, western blacknose dace, pearl dace
Creek chub, Johnny darter, smallmouth bass, central mudminnow, black bullhead, common shiner, hornyhead chub, pumpkinseed, yellow perch, northern pike
Brook trout, mottled sculpin, rainbow trout, brook stickleback
Brown trout, northern redbelly dace, slimy sculpin, coho salmon, blacknose shiner
Redhorse, walleye, smallmouth bass, lake sturgeon

GIS Data

The GIS data used in this study were from a variety of sources. I used the U. S. Environmental Protection Agency's 1:100,000 scale RF3 reach files as the basic hydrography data layer. These digital maps were processed and stream reaches classified using the Reach Indexing Tool program (Research Triangle Institute, Research Triangle Park, North Carolina). The surficial geology data layer was derived from Farrand and Bell (1984), land use data were derived from 1997-2001 Landsat Thematic Mapper imagery, and topography data were derived from 1:24,000 scale USGS topographic maps. The bedrock geology data layer was derived from a 1987 bedrock geology map produced by the Geologic Survey Division of the Michigan Department of Environmental Quality. All GIS data listed above were available from the Michigan Geographic Data Library (http://www.mcgi.state.mi.us/mgdl/?action=thm). Climate data (air temperature and precipitation) layers were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center.

Results and Discussion

I classified valley segments from a total of 81 river systems (defined as having an outlet to one of the Great Lakes) in the UP (Table 3). Each of the 81 classified river systems represented a single watershed except for the river system labeled "Potato River group." The "Potato River group" represents a total of 13 rivers that drain directly to Lake Superior between the Ontonagon and Mineral rivers in Ontonagon County. These rivers all originate in and flow over a lacustrine clay and silt plain. All of these streams are therefore flashy, surface-water driven systems that were classified as a group because they are all approximately the same size and have the same characteristic fish communities, temperature regimes, flow patterns, etc. The remaining 80 classified river systems represented a range of catchments from small Great Lakes tributaries (e.g., Black River, Mackinaw County) to large watersheds with numerous tributaries and sub-catchments (e.g., Ontonagon River). These 80 river systems were classified into 596 distinct valley segments ranging in length from 0.4 km to 187 km with the longest valley segments in the larger river systems.

Stream size for each classified segment was expressed as link and d-link number. Link number is the sum of the number of first order tributaries upstream of the classified segment and d-link number is the link number of the downstream segment that the classified segment joins. Classified UP streams were generally small to moderate sized and had short drainage paths to the Great Lakes (Figure 5).

Average link number for UP streams was 19 and 82% of the classified stream segments had link numbers less than 30. The maximum link number was 784 (Menominee River). In comparison, the maximum and average link numbers for LP rivers were 492 and 195 respectively (Seelbach et al. 2006).

Most (75%) UP streams were characterized as primarily surface-water source streams with low base flow (Figure 6). However, a few streams do have abundant groundwater resulting from deep, porous surficial deposits. Examples include Cherry Creek in Marquette County and the Fox River in Luce County. In addition, because of the heavy snowfall in the UP and the resultant high spring runoff (Figure 2), the 10% exceedence flows (peak flows) for UP streams were generally much higher than for LP Michigan rivers.

Dams and waterfalls have limited the amount of stream habitat accessible to Great Lakes resident fishes. Great Lakes access is limited to 43% of the total length of streams classified. Streams systems that are open to access by Great Lakes fishes are generally smaller than those that are inaccessible.

Stream gradients ranged from very low (<0.75 m/km) to very high (7.50 m/km) among UP valley segments and most streams (70%) were very low to moderate gradient (Figure 7). The eastern half of the UP is generally flatter than the western half and eastern streams are generally low and moderate gradient. Streams in the western half of the UP are also mostly low and moderate gradient systems but some of the streams that drain to Lake Superior were classified as high or very high gradient streams.

The majority (83%) of classified stream segments in the UP were classified as alluvial unconfined channels (free to meander within their floodplains). The remaining streams were classified as confined or sporadically confined (by bedrock) alluvial channels or as glacial meltwater channels that ranged from unconfined to confined.

Water chemistry of UP streams was primarily classified as oligotrophic and soft. Exceptions were some streams of the eastern UP and the streams of the Escanaba River, Ford River, and Cedar River watersheds. These streams were more productive and, not surprisingly, were catchments where agricultural land use was common.

Temperature classifications for UP streams ranged from cold to warm but the majority of streams were classified as cool (46%) or cold (45%; Figure 8).

Diurnal temperature fluctuation classifications were moderately stable for 83% of UP streams. Of the remaining streams, 16% were classified as stable and 1% were classified as having high daily temperature variation. Because most streams remain cold or cool during summer and exhibit moderate daily temperature variation they are able to support salmonids. Although salmonids were captured from most streams sampled, only 38% of the valley segments were classified as either brown trout or brook trout dominated fish communities (Figure 9). However, brook trout was the most commonly captured and abundant salmonid in UP streams and represented the greatest biomass of all species captured (Table 2). The remaining 62% of valley segments were classified primarily as creek chub, longnose dace, redhorse, rock bass, or white sucker communities. Large rivers represent a small percentage of stream resources in the UP and this was reflected in the fish community classifications—only 22 valley segments (4%) were classified as redhorse communities.

As noted in the introduction, Seelbach et al. (2006) provided a thorough discussion of the advantages, uses, limitations, and weaknesses of the VSEC system developed for the LP. Briefly, the advantages of the VSEC system include its value as a communications and learning tool. Fisheries managers in Michigan have been using the LP VSEC system for several years now and agree that the scale of classified reaches matches their needs for communication with the public. In addition, the classifications generally agree with their prior experiences and expectations of the rivers they manage. The system has also helped managers better understand the processes that shape the physical and biotic setting in rivers. By linking stream characteristics to catchment variables, the VSEC system promotes this understanding. The primary weakness of the VSEC system and classification systems in general, is that it imposes artificial boundaries on stream systems. These boundaries between adjacent river segments imply a distinct change in stream character when in reality the changes occur gradually over some stream distance. Therefore, the VSEC system places data that exist over a continuum into distinct categories and some information is necessarily "lost" in the process.

The VSEC system developed for UP streams was based on less extensive field sampling effort than in the LP. In developing the LP VSEC, Seelbach et al. (2006) used fish community and stream temperature data collected from hundreds of sites across the LP. I was able to use stream temperature data from 99 sites widely distributed across the UP, but fish community data were only available from 46 sites. Fish community sites covered the range of surficial geology, temperature, and land use conditions found in the UP and were widely distributed across the peninsula. However, the relatively small fish community sample size means it is likely that species were underrepresented in the data set or that unique communities were not sampled. The accuracy of the fish community classifications will improve in the future as more fish community data are collected and analyzed. I recommend that efforts be focused on more extensive fish community sampling as part of routine stream surveys.

The stream classification systems developed reflect the differences between habitat and biotic conditions in the LP and UP. The two classification systems can be valuable tools to enhance our understanding and management of stream resources across the state. In addition, the VSEC system can be used to plan future sampling and survey efforts. The VSEC system is being used by survey planners as part of Fisheries Division's new Status and Trends sampling program.

With the development of the UP VSEC classification system, all of the major streams and many smaller stream systems within the state have now been classified. However, because the upper and lower peninsula systems were developed in separate efforts, there are two VSEC systems in existence. The next logical step in the stream classification process for Michigan would be to merge the UP and LP stream classification databases into a single, statewide classification system. Combining the two databases and maps would provide a comprehensive overview of the stream resources in Michigan and would help fisheries managers and the public develop a better understanding of the diverse stream resources in the state. Combining the two systems would be relatively simple for some attributes (e.g., gradient, water chemistry) but may require additional modeling, data analysis, and code development for other attributes (e.g., fish communities, hydrology).

The database tables and maps produced from this study were stored electronically in ArcView 3.2 format and are available upon request from the author, Michigan Department of Natural Resources, Marquette Fisheries Station, 484 Cherry Creek Road, Marquette, MI (telephone 906 249 1611). The large volume of possible map combinations and the size of the databases make it impractical to include them in this report. Examples of VSEC maps and data tables for the LP are provided in Seelbach et al. (2006) and the same types of maps and data tables are now available for UP streams.

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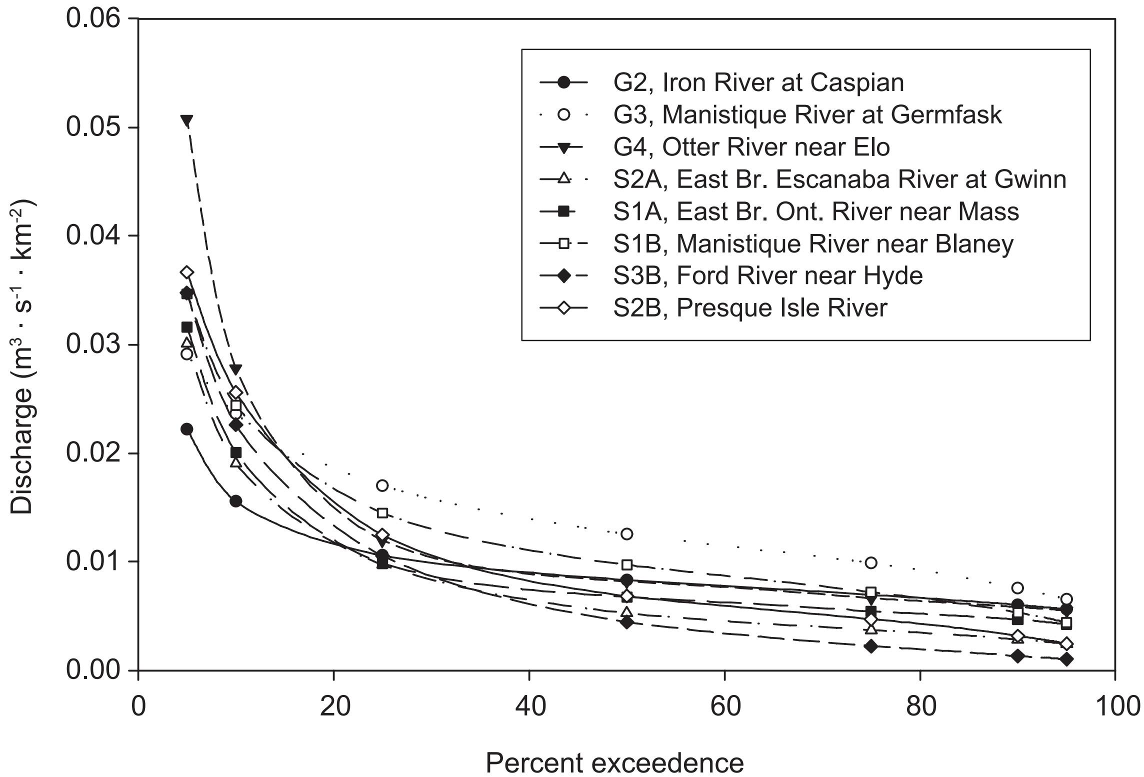


Figure 1.–Flow exceedence curves representing the range of stream-flow patterns present in Upper Peninsula rivers. Streams that are dominated by groundwater inputs have codes beginning with G and streams that are surface water dominated have codes beginning with S. See text for code definitions.

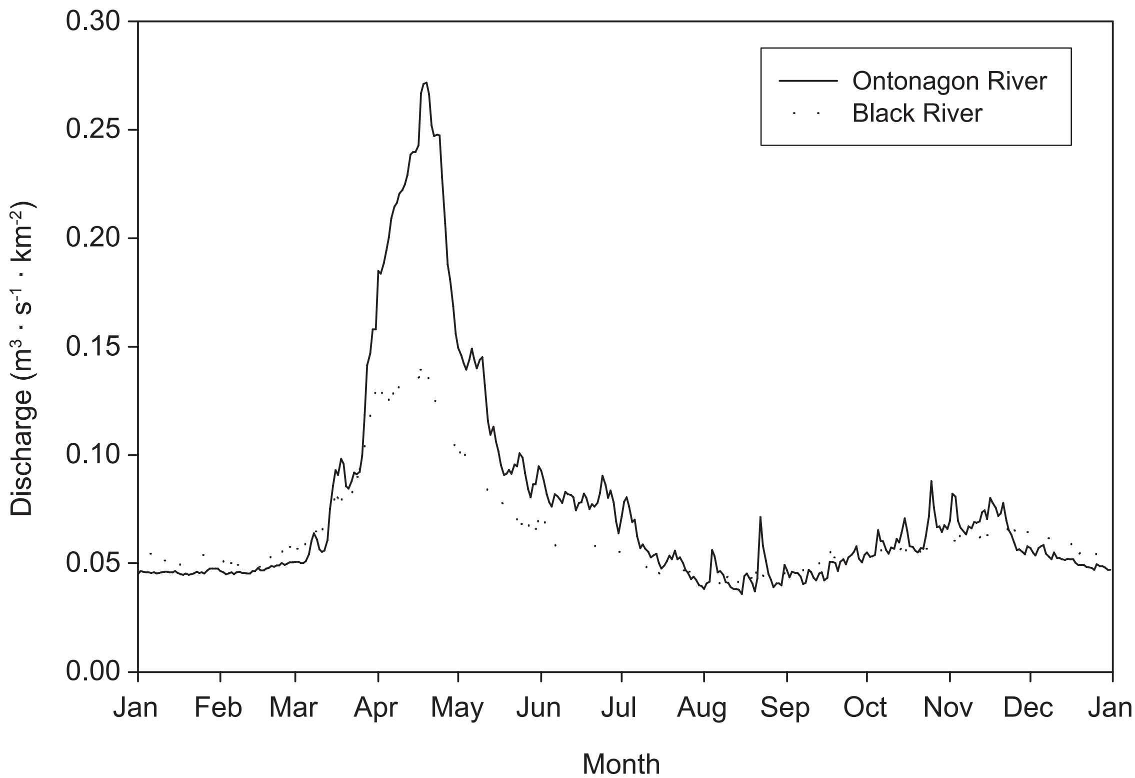


Figure 2.–Average daily discharge of a typical Upper Peninsula river (Ontonagon River, solid line) and a typical Lower Peninsula river (Black River, Cheboygan County, dashed line).

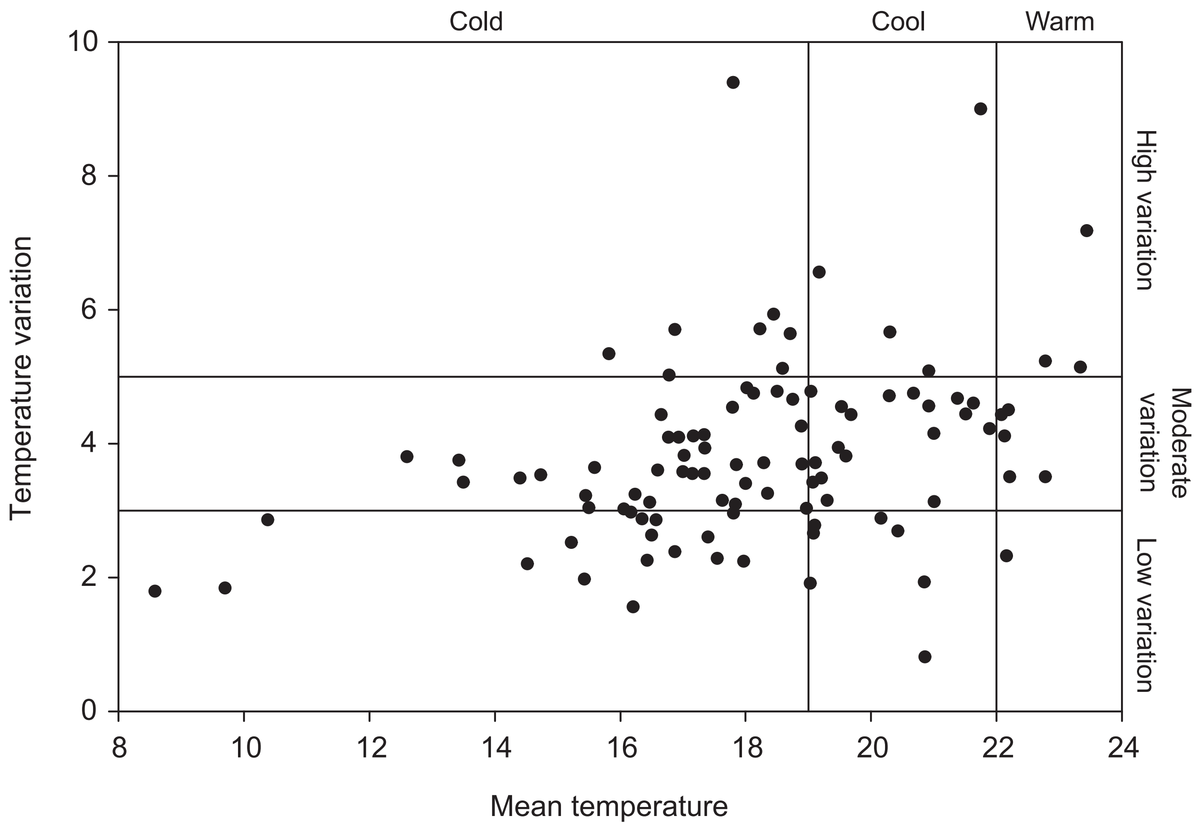


Figure 3.–Summer mean temperature (C) and temperature variation data for Upper Peninsula streams.

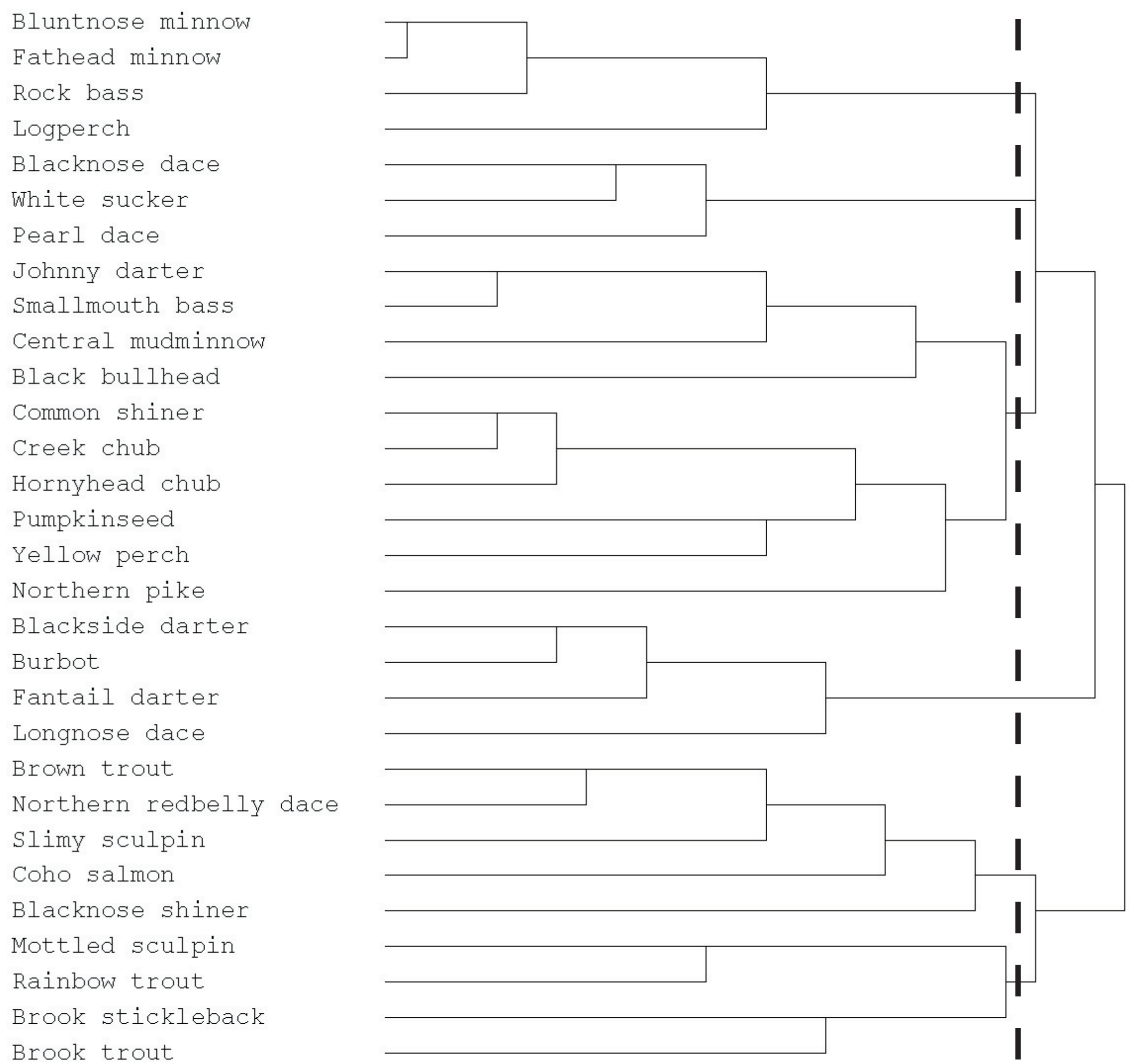


Figure 4.–Fish species hierarchical cluster analysis results using complete linkage and Pearson correlation coefficient analysis. Data from 46 sites sampled across Upper Peninsula were included in analysis. Dashed vertical line indicates cut point used to define fish clusters.

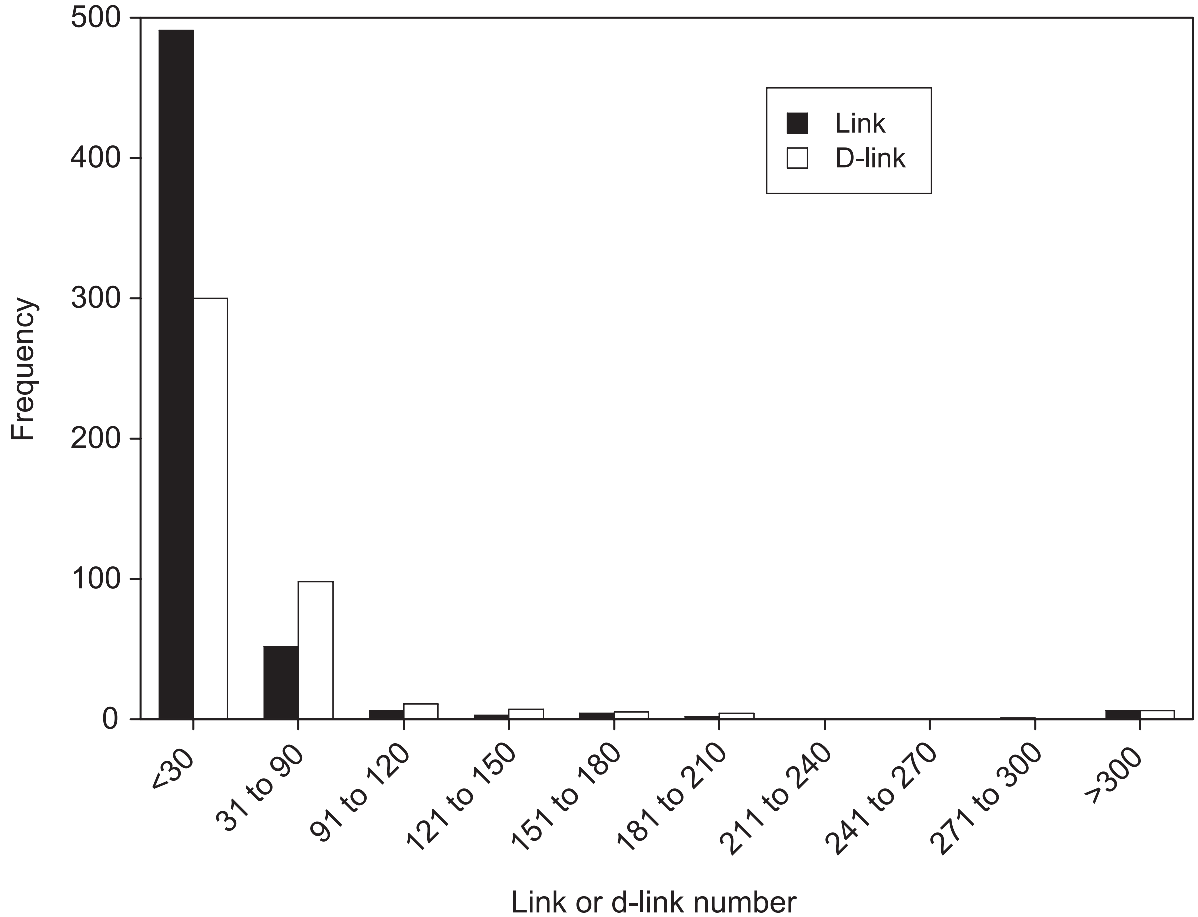
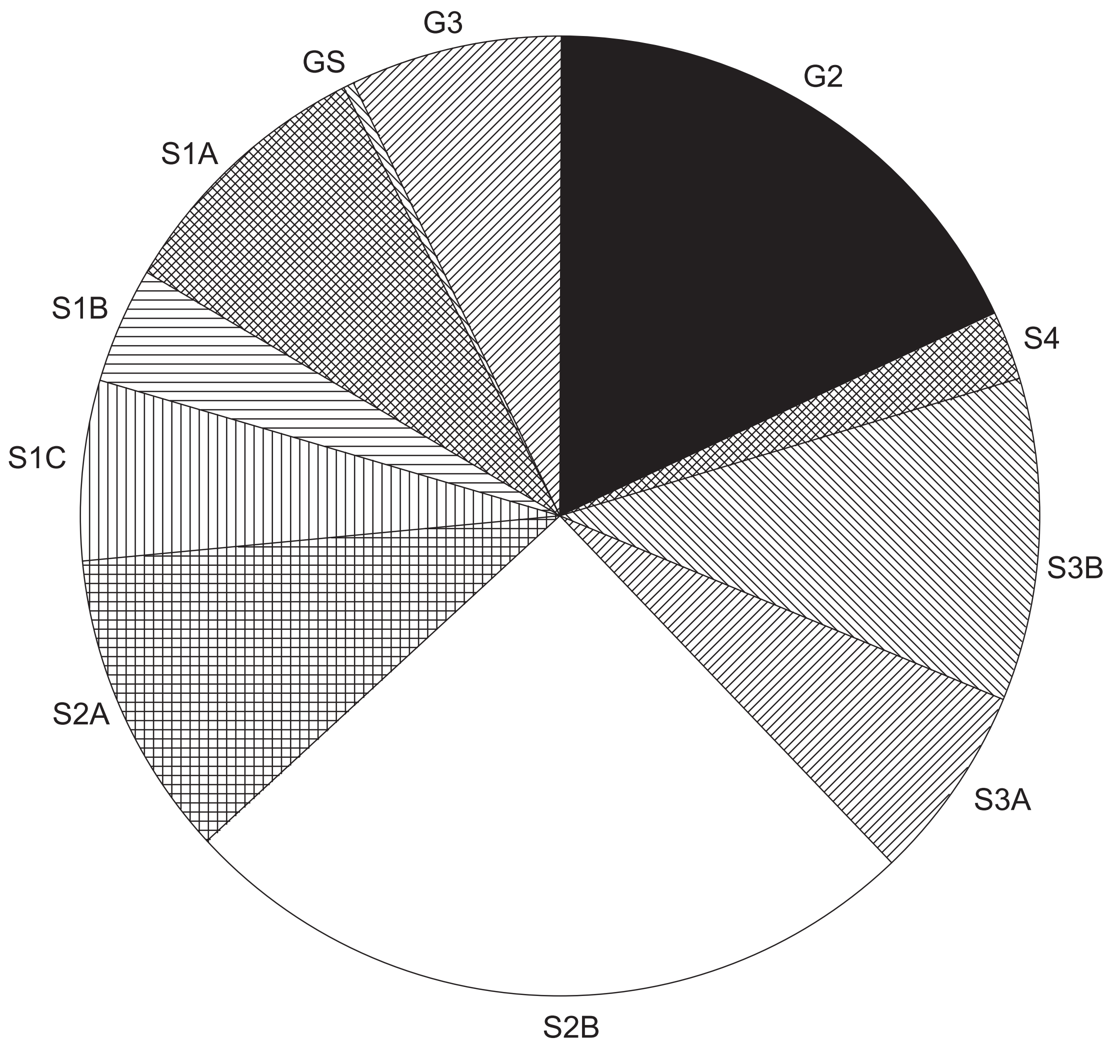


Figure 5.–Frequency histogram of link and d-link numbers for river valley segments in Michigan's Upper Peninsula. Link number is the sum of the first order tributaries upstream and d-link number is the link number of the tributary at the downstream junction.



GS Extremely high groundwater (GW) input and very high base flow (BF) with very little surface runoff (SR), watershed characterized by deep sand deposits and high gradient

G2 Good GW inputs with little SR, moderate BF and low peak flow (PF), deep coarse glacial (GL) deposits and outwash, low gradient

G3 Good GW inputs with little SR, high BF and moderate PF, deep coarse GL deposits, relatively high snowfall and moderate gradient

S1A Moderate GW input and moderate SR, relatively shallow coarse GL drift above bedrock and also relatively impervious material, relatively low snowfall

S1B Moderate GW input and moderate SR, moderate BF and PF, shallow mixed GL drifts, low gradient, high snowfall

S1C Moderate GW input and moderate SR, moderate BF and high PF, shallow mixed GL drifts, high gradient, high snowfall

S2A Moderate GW input and moderate SR, low moderate BF and PF, shallow mixed GL drifts, low gradient, low snowfall

S2B Moderate GW input and moderate SR, low BF and moderate PF, shallow mixed GL drifts, low gradient, high snowfall

S3A Very little GW and high SR, low BF and high PF, thin GL deposits over bedrock, high snowfall, high gradient

S3B Relatively little GW and relatively high SR, low BF and moderate PF, mixed GL deposits and thin glacial tills over bedrock, low snowfall, moderate gradient

S4 Very little GW and high SR, very low BF and high PF, medium textured tills and thin GL deposits over bedrock, low snowfall, moderate gradient

Figure 6.–Proportional representation of hydrology codes for river valley segments in Michigan's Upper Peninsula.

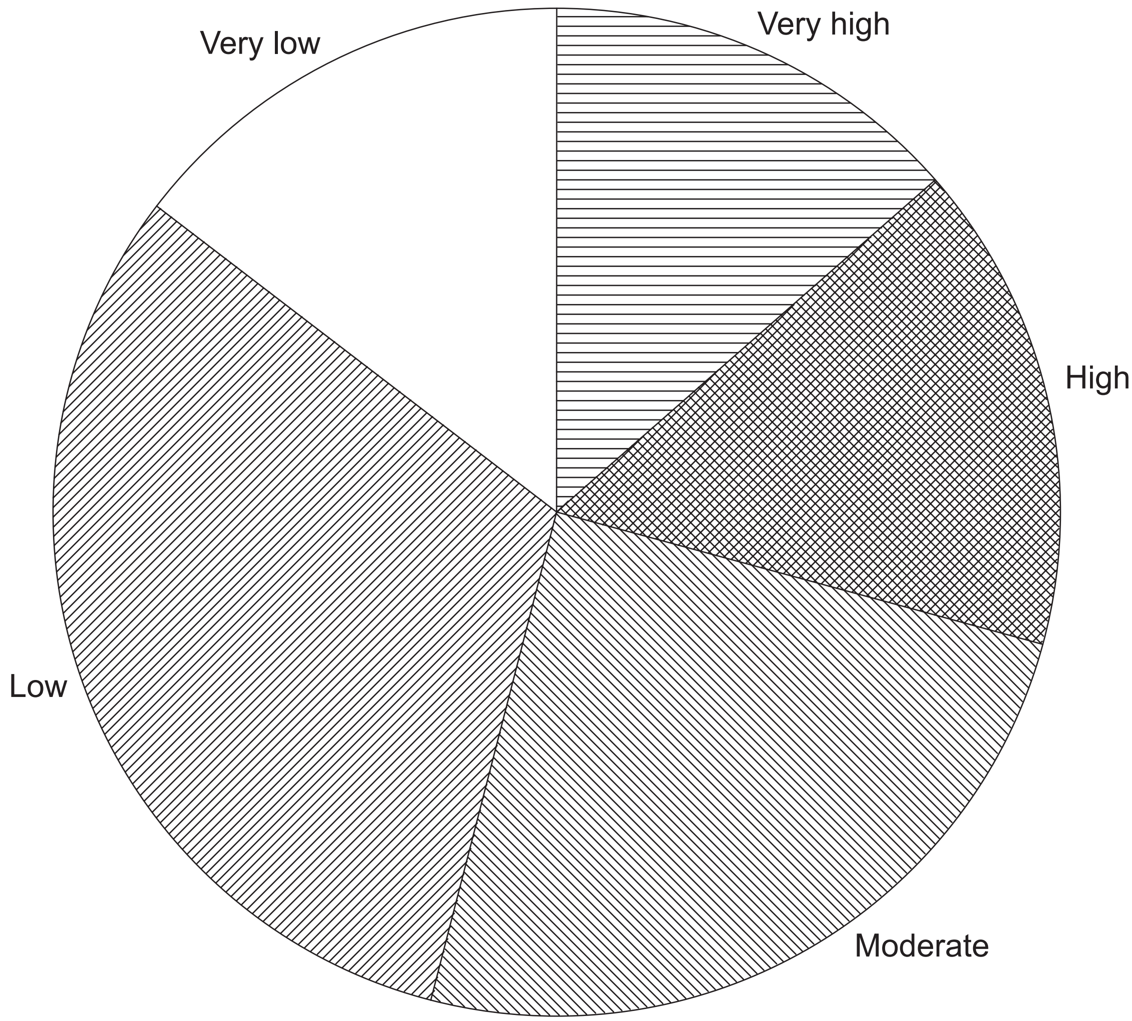
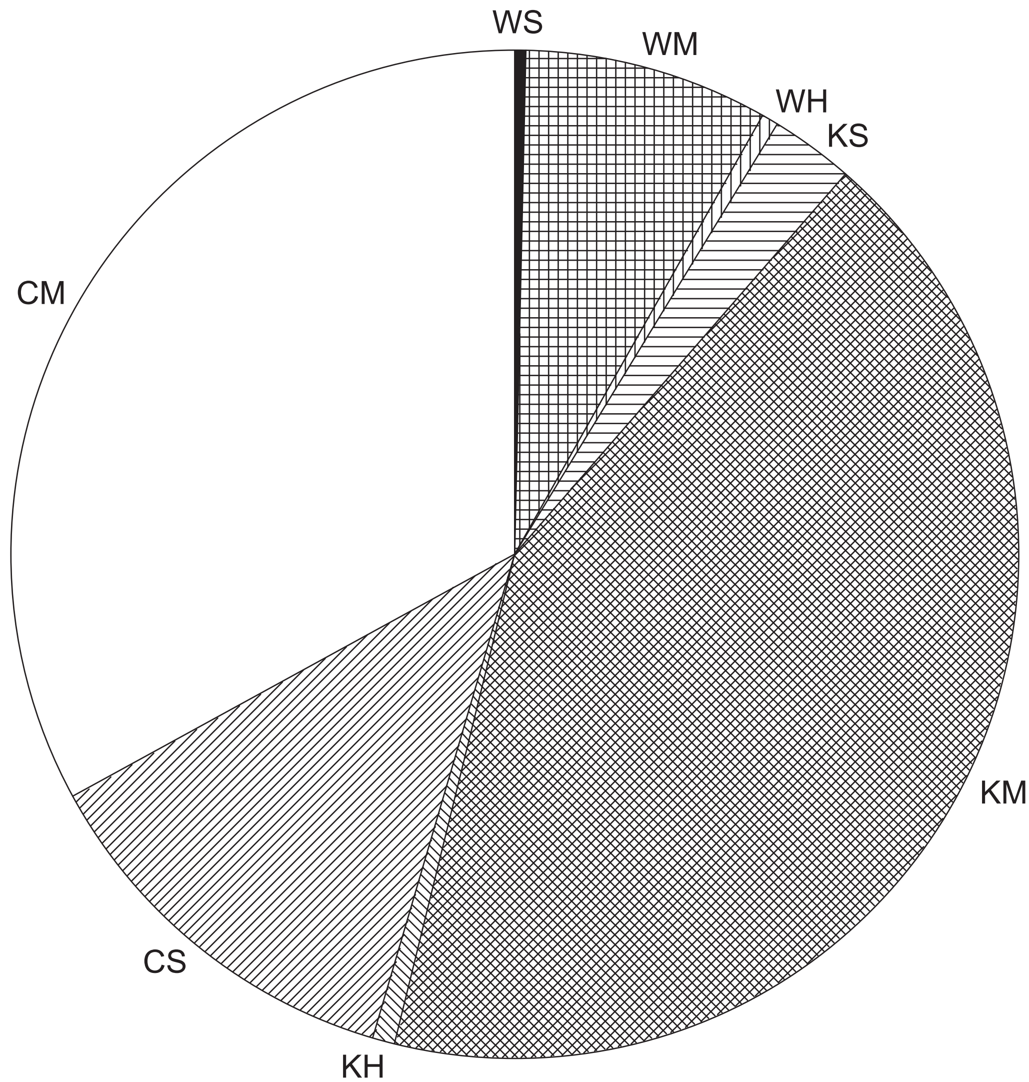


Figure 7.–Proportional representation of valley gradient codes for river valley segments in Michigan's Upper Peninsula.



C Cold, mean temperature less than 19° C
K Cool, mean temperature between 19° and 22° C
W Warm, mean temperature greater than 22° C
S Low diurnal variation, daily temperature variation less than 3° C
M Moderate diurnal variation, daily temp variation between 3° and 5° C
H High diurnal variation, daily temperature variation greater than 5° C

Figure 8.–Proportional representation of water temperature codes for river valley segments in Michigan's Upper Peninsula.

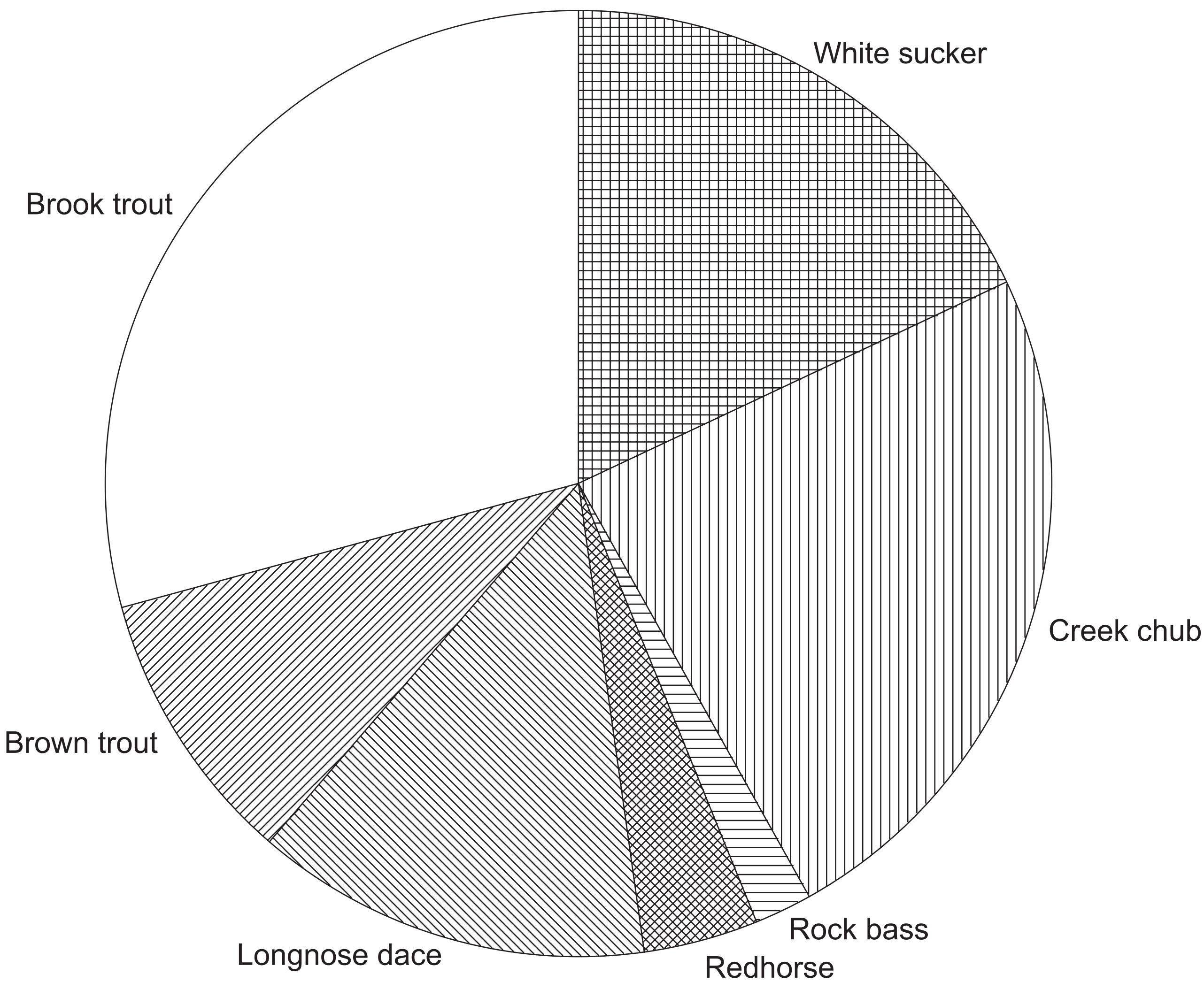


Figure 9.–Proportional representation of fish species association codes for river valley segments in Michigan's Upper Peninsula.

Table 1.–Generalized multiple linear regression model (R^2=0.61) relating average stream temperature to reach- and catchment-scale habitat attributes for Upper Peninsula streams. Model is of the general form: $\ln(Y) = \text{constant} + B_1\ln X_1 + B_2\ln X_2 + B_3\ln X_3 \ldots B_n\ln X_n$.

Dependent variable	Independent variables	Coefficient
Average stream temperature (°C)	Constant	6.50
	Watershed area (km^2)	0.68
	90% exceedence flow ($m^3 \cdot s^{-1} \cdot km^{-2}$)	-482.31
	Mean minimum air temp. (°C)	0.50
	% glacial outwash	-0.34
	% water within 4 km of stream	1.02
	Longitude	0.58
	Reach gradient (m/km)	-0.63
	% end moraine [a] of fine till	-0.84

[a] End moraines are irregular ridges of glacial sediments that form at the margin or edge of a glacial ice sheet.

Table 2.–Biomass data for fish species captured in Upper Peninsula stream fish community surveys (n=46) from 1997 through 2004. Fish species are listed in descending order by mean biomass value (minimum biomass = 0 for all species). Species without an association code were not included in the analysis due to low occurrence. SD = standard deviation.

	Biomass (g/ha)			
Fish species	Mean	Maximum	SD	Association code
Brook trout	11844.4	119897.1	23185.4	Brook trout
White sucker	4553.9	48497.9	9341.0	White sucker
Mottled sculpin	3712.6	15841.4	4399.5	Brook trout
Creek chub	2469.8	24706.4	5183.7	Creek chub
Longnose dace	2133.1	20613.5	4242.6	Longnose dace
Rainbow trout	1941.4	12896.7	3960.2	Brook trout
Central mudminnow	1520.8	16385.3	2956.6	Creek chub
Western blacknose dace	1518.3	8717.3	2564.8	White sucker
Hornyhead chub	1358.1	14470.5	3165.8	Creek chub
Common shiner	1209.1	16113.4	3377.6	Creek chub
Rock bass	915.3	11177.1	2170.7	Rock bass
Slimy sculpin	712.9	8223.2	1965.7	Brown trout
Burbot	670.8	8540.4	1713.2	Longnose dace
Northern pike	667.4	17383.4	2744.0	Creek chub
Brown trout	563.7	12977.2	2150.2	Brown trout
Black bullhead	350.5	6102.5	1261.7	Creek chub
Bluntnose minnow	345.5	10661.8	1611.3	Rock bass
Northern hog sucker	333.1	7357.6	1464.2	
Johnny darter	322.0	2495.9	517.8	Creek chub
Yellow perch	317.1	4549.3	841.1	Creek chub
Longnose sucker	257.3	11837.0	1745.3	
Brook stickleback	249.3	4266.8	789.3	Brook trout
Lake chub	229.2	10542.7	1554.4	
Northern logperch	218.6	2335.9	553.8	Rock bass
Blackside darter	207.8	2544.4	507.3	Longnose dace
Pumpkinseed	196.5	3114.5	583.9	Creek chub
Fantail darter	170.7	3040.8	583.7	Longnose dace
Trout-perch	144.4	5220.9	793.2	
Smallmouth bass	136.3	2803.6	493.7	Redhorse
Coho salmon	120.8	2254.0	393.2	Brown trout
Largemouth bass	89.6	3403.3	507.6	
Pearl dace	47.1	894.0	164.6	White sucker
Muskellunge	44.6	2049.7	302.2	
Northern redbelly dace	43.4	675.6	131.0	Brown trout

Table 2.–Continued.

Fish species	Biomass (g/ha)			Association code
	Mean	Maximum	SD	
Lamprey (adults and ammocoetes)	33.3	970.2	150.0	
Yellow bullhead	19.3	889.1	131.1	
Mimic shiner	18.0	483.3	81.2	
Bluegill	8.4	305.1	45.6	
Fathead minnow	5.8	163.7	24.9	Rock bass
Brassy minnow	5.5	255.2	37.6	
Black crappie	4.4	203.4	30.0	
Blacknose shiner	4.0	82.0	13.8	Brown trout
Chinook salmon	3.7	172.1	25.4	
Iowa darter	1.9	88.7	13.1	
Golden shiner	1.7	77.4	11.4	
Rosyface shiner	1.6	73.1	10.8	

Table 3.–Summary of Upper Peninsula stream systems classified into valley segments and which river systems were sampled for data used in developing the classification system. An "X" in a column indicates data were collected for the parameter at one or more locations within the named river system.

	Parameter measured			
Classified river system	Water temperature	Hydrology	Water chemistry	Fish community
Anna River	X		X	X
Au Train River	X		X	X
Bark River				
Big Garlic River				
Big Iron River	X	X		X
Black Creek				
Black River (Gogebic County)	X	X		X
Black River (Mackinaw County)	X			X
Boston Creek				
Brevoort River	X			X
Carp River (Mackinaw County)	X		X	
Carp River (Marquette County)	X	X	X	X
Carp River (Ontonagon County)				
Cedar River				
Charlotte River				X
Chocolay River	X			X
Compeau Creek				
Days River	X		X	X
Dead River	X		X	X
Eagle River				
East Sleeping River	X		X	
Elm River	X			X
Escanaba River	X	X	X	X
Falls River				
Firesteel River				
Fishdam River	X			X
Flintsteel River				
Ford River	X	X	X	X
Gratiot River	X			
Graveraet River				
Harlow Creek			X	
Huron River	X			
Hurricane River			X	
Iron River (Marquette County)	X		X	X
Laughing Whitefish River	X			X
Little Carp River				
Little Elm River				

Table 3.–Continued.

Classified river system	Parameter measured: Water temperature	Hydrology	Water chemistry	Fish community
Little Garlic River	X		X	
Little Huron River				
Little Iron River				
Little Munuscong River	X			X
Little Two Hearted River	X			
Manistique River	X	X	X	X
Menominee River	X	X	X	X
Milakokia River				
Millecoquins River	X			
Mineral River				
Miners River	X			
Misery River				
Montreal River (Keweenaw County)	X			X
Montreal River (Gogebic County)				
Mosquito River				
Munuscong River			X	
Ogontz River				
Ontonagon River	X	X	X	X
Pike River				
Pilgrim River				
Pine River	X	X	X	X
Potato River group	X		X	
Presque Isle River	X	X	X	
Rapid River	X			X
Ravine River	X			X
Rock River (Alger County)	X			X
Rock River (Mackinaw County)				
Salmon Trout River (Houghton County)	X		X	X
Salmon-Trout River (Marquette County)	X			X
Sand River	X			X
Shelldrake River	X			
Silver River	X			
Slate River				
Sturgeon River (Houghton/Baraga County)	X	X	X	X
Sturgeon River (Delta County)	X	X	X	X
Sucker River	X			

Table 3.–Continued.

Classified river system	Parameter measured			
	Water temperature	Hydrology	Water chemistry	Fish community
Tacoosh River	X			X
Tahquamenon River	X	X		
Tobacco River	X		X	
Trap Rock River	X	X		X
Traverse River				
Two Hearted River	X			X
Waiska River	X			
Whitefish River	X		X	

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Appendix 1.–Common and scientific names of fishes captured from UP streams.

Common name	Scientific name
Black bullhead	*Ameiurus melas*
Black crappie	*Pomoxis nigromaculatus*
Blacknose shiner	*Notropis heterolepis*
Blackside darter	*Percina maculata*
Bluegill	*Lepomis macrochirus*
Bluntnose minnow	*Pimephales notatus*
Brassy minnow	*Hybognathus hankinsoni*
Brook stickleback	*Culaea inconstans*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Burbot	*Lota lota*
Central mudminnow	*Umbra limi*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Common shiner	*Luxilus cornutus*
Creek chub	*Semotilus atromaculatus*
Fantail darter	*Etheostoma flabellare*
Fathead minnow	*Pimephales promelas*
Golden shiner	*Notemigonus crysoleucas*
Hornyhead chub	*Nocomis biguttatus*
Iowa darter	*Etheostoma exile*
Johnny darter	*Etheostoma nigrum*
Lake chub	*Couesius plumbeus*
Lampreys (adults and ammocoetes)	*Petromyzon marinus and Ichthyomyzon* sp.
Largemouth bass	*Micropterus salmoides*
Longnose dace	*Rhinichthys cataractae*
Longnose sucker	*Catostomus catostomus*
Mimic shiner	*Notropis volucellus*
Mottled sculpin	*Cottus bairdii*
Muskellunge	*Esox masquinongy*
Northern hog sucker	*Hypentelium nigricans*
Northern logperch	*Percina caprodes*
Northern pike	*Esox lucius*
Northern redbelly dace	*Phoxinus eos*
Pearl dace	*Margariscus nachtriebi*
Pumpkinseed	*Lepomis gibbosus*
Rainbow trout	*Oncorhynchus mykiss*
Rock bass	*Ambloplites rupestris*
Rosyface shiner	*Notropis rubellus*
Slimy sculpin	*Cottus cognatus*
Smallmouth bass	*Micropterus dolomieu*
Trout-perch	*Percopsis omiscomaycus*
Western blacknose dace	*Rhinichthys obtusus*
White sucker	*Catostomus commersonii*
Yellow bullhead	*Ameiurus natalis*
Yellow perch	*Perca flavescens*