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A River Valley Segment Classification of Michigan Streams Based on Fish and Physical Attributes

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Abstract.—Water resource managers are frequently interested in river and stream classification systems to generalize stream conditions and establish management policies over large spatial scales. We used fish assemblage data from 745 river valley segments to develop a two-level, river valley segment–scale classification system of rivers and streams throughout Michigan. Regression tree analyses distinguished 10 segment types based on mean July temperature and network catchment area and 26 segment types when channel gradient was also considered. Nonmetric multidimensional scaling analyses suggested that fish assemblages differed among segment types but were only slightly influenced by channel gradient. Species that were indicative of specific segment types generally had habitat requirements that matched segment attributes. A test of classification strength using fish assemblage data from an additional 77 river valley segments indicated that the classification system performed significantly better than random groupings of river valley segments. Our classification system for river valley segments overcomes several weaknesses of the classifications previously used in Michigan, and our approach may prove beneficial for developing classifications elsewhere.

Rivers and streams exhibit remarkable complexity in their physicochemical and biological features, even within regions such as hydrologic units (Griffith et al. 1999) or ecoregions (Omernik 2003). This complexity results from rivers flowing long distances across landscapes composed of diverse surficial geology, bedrock geology, landscape topography, and land cover types. This complicates the understanding, assessment, and management of lotic systems because it can prevent the generalization of conditions across systems. As a result, water resource managers are often interested in developing river and stream classifications to summarize stream conditions and management policies across large spatial regions, and to assist in communicating about the consequences of management policies (Hawkins et al. 2000; Seelbach et al. 2006; Williams et al. 2007).

Stream and river classifications are useful for many aspects of water resource management. Uses include (1) the identification of strata for monitoring programs to improve the precision of habitat and biological measurements (Hughes et al. 2000; Hayes et al. 2003), (2) the development and selective application of stream health indices (e.g., indices of biotic integrity) to increase their sensitivity for detecting disturbances (Fausch et al. 1990; Lyons et al. 1996), (3) the derivation of a framework for protecting instream flows (Anonymous 2006), (4) determination of the capacity of streams to support fish stocks (Stanfield et al. 2006; Brewer et al. 2007) and for the selective application of policies to protect fish stocks (Wright 1992; Williams et al. 2007), and (5) the identification of reference streams (i.e., streams that have been minimally affected by human disturbance) (Robertson et al. 2006; Wang et al. 2008).

One of the first attempts at developing a regional classification for streams and rivers was made in the late 1990s by Seelbach et al. (2006). That classification system (hereafter referred to as SCS) was developed for Michigan's Lower Peninsula to improve understanding of ecological patterns within and among rivers and how landscape processes influence streams and rivers. The SCS was developed based on current stream condition; thus, the SCS accepted that a certain degree of human disturbance had occurred across the landscape (Seelbach et al. 2006). The SCS was developed using river valley segments as the classification unit. River valley segments are spatially adjacent sections of streams and rivers that are relatively homogenous in hydrologic, limnologic, geomorphic, and biotic characteristics (Frissell et al. 1986; Maxwell et al. 1995; Seelbach et al. 2006). One reason why river valley segments are

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considered useful in stream classifications is because their sizes are considered appropriate for many types of fishery and water resource management decisions (Fausch et al. 2002; Seelbach et al. 2006; Wang et al. 2006). River valley segment types for the SCS were identified by qualitatively characterizing the physicochemical and biological attributes of the segments, and then combining the attribute classes to form the different segment types. The SCS has been widely used for fisheries and water resource management in Michigan. Examples include the identification of spawning and rearing habitat for several Great Lakes fish species and evaluation of the sensitivity of rivers to nutrient, sediment, and thermal disturbances (Seelbach et al. 2006). Approaches similar to the SCS have been used to develop stream and river classifications in Missouri (Sowa et al. 2007), Ohio (Covert et al. 2001), Ontario (B. Kilgour and L. Stanfield, unpublished report), Michigan's Upper Peninsula (Baker 2006), and elsewhere in the Great Lakes basin (Higgins et al. 1998).

Despite its wide use, the SCS does have several recognized weaknesses (Seelbach et al. 2006). One weakness concerns the manner by which habitat types were identified by combining qualitatively characterized physicochemical and biological attributes of the river valley segments. Although this approach to identifying classification habitat types is not unique to the SCS, defending the classification results can nevertheless prove difficult because of the subjectivity involved in creating the attribute classes. Additionally, simply combining the attribute classes to form the classification habitat types does not allow for possible interactions among classification variables. Such interactions have been found to be important determinants of fish distributions in streams (Kwak 1988; Todd and Rabeni 1989; Muhlfeld and Marotz 2005; Wehrly et al. 2007). An additional weakness of the SCS is that river valley segments were delineated by expert opinion, whereby aquatic ecologists used a geographic information system (GIS) to view river network maps in relation to landscape theme maps and then manually drew river valley segment boundaries based on their knowledge of what factors affected instream physicochemical and biological features. This approach to identifying river valley segments can be tedious to implement, difficult to defend, and makes updating or transferring classifications difficult. Because of these and other associated weaknesses, the SCS was considered a preliminary classification of Michigan rivers and streams that would require future refinement and modifications (Seelbach et al. 2006). In particular, reducing the subjectivity involved in developing the classification process was considered crucial for improving the defensibility of the classification system.

The purpose of this research was to develop an improved river valley segment classification of Michigan rivers and streams to overcome some of the weaknesses of the SCS. Our objective was to develop a robust statewide classification system that summarizes segment types based on observed physicochemical and fish assemblage attributes among streams and rivers.

Methods

River valley segment database.—We developed our classification of Michigan rivers and streams using the database of river valley segments developed by Brenden et al. (2008) from the 1:100,000 scale National Hydrography Data set (NHD; USGS 2007). In that work, river valley segments were identified by spatially constrained clustering using several landscape and river channel attributes calculated for each NHD stream reach: $\log_e$ transformed network catchment area, percentage nonforested wetland land cover in network catchments, percentage lacustrine surficial geology in local catchments, percentage moraine surficial geology in local catchments, mean local catchment slope, predicted mean July stream temperature (T. Brenden, unpublished data), and predicted $\log_e$ transformed 90th-percentile flow yield (P. Seelbach, unpublished data). The attribution of NHD stream reaches with these variables is described in Brenden et al. (2006). Brenden et al. (2008) found that river valley segments identified with a similarity threshold of 0.60 resulted in the most homogenous segments and had good agreement with a previously completed expert-opinion delineation of river valley segments. Thus, we used the river valley segments identified with this threshold value as the classification units for this study.

Fish data.—We obtained fish assemblage data for 745 of the river valley segments identified by Brenden et al. (2008) from the Michigan Department of Natural Resources (MDNR) Fish Collection and Michigan Rivers Inventory databases (Seelbach and Wiley 1997; Figure 1). These databases include fish collections made throughout the state with several sampling techniques, including boat, backpack, tow-barge electrofishing, and rotenone sampling. A partial list of the species collected during this sampling is found in Table A.1 in the appendix. We limited our use of data to collections made from 1980 to 2004. From these data, we calculated the relative abundances (number of individuals/100 m stream length) of species collected at each of the sampling locations. Because of likely differences in sampling efficiency among the collection methods, we transformed the relative abundance data to a 0–1 scale using a Hellinger transformation (Legendre

FIGURE 1.—Streams in Michigan for which data were obtained from the Department of Natural Resources Fish Collection and Michigan Rivers Inventory databases to develop a statewide river valley segment classification.

and Gallagher 2001), which maintained the Euclidean distances among fish abundances within individual sampling locations. A few of the river valley segments had multiple records of fish collections, in which case we calculated the mean of the transformed relative abundances so that only a single measure of abundance for each species occurred for each river valley segment.

We developed six categories of species associations (SA I–VI) that represented distinct thermal, hydrological, and other physicochemical characteristics of Midwestern U.S. rivers based on scientific literature (Lyons et al. 1996, 2001; Zorn et al. 2002; Wang et al. 2003) and professional knowledge. Some of the species associations included fish that were believed to be either relatively abundant or absent within particular types of streams, while other associations only included fish that were believed to be abundant within particular stream types (Table 1). Species associations V and VI included fish that were listed for a few of the other species associations; thus, the associations were not necessarily independent. Because of the connection between rivers and the Great Lakes in Michigan, drastically different lake-influenced fish assemblages can occur within large rivers depending on habitat conditions. Species associations V and VI were developed primarily to help distinguish among these different types of large river habitats. The similarity with some of the other species associations was a result of the migratory behavior of many Great Lakes fishes.

We used Kendall's coefficient of concordance to test

TABLE 1.—Fish species associations (SAs; see text for details) used in developing the level-1 classification of Michigan river valley segments. Asterisks indicate species that were not significantly associated with the other species in the group and were subsequently deleted.

SA I, high abundance	SA II, high abundance	SA II, low abundance	SA III, high abundance	SA III, low abundance
Brook trout	Blacknose dace	Brook trout	Bluntnose minnow	Black bullhead
Brown trout	Burbot	Brown trout	Brook stickleback	Black crappie
Coho salmon	Longnose dace	Coho salmon	Central mudminnow	Bowfin
Rainbow trout	Mottled sculpin	Rainbow trout	Central stoneroller	Brook trout
Slimy sculpin	Northern redbelly dace*	Slimy sculpin	Creek chub*	Brown trout
	Pearl dace		Fathead minnow	Burbot
	Southern redbelly dace		Johnny darter	Channel catfish
			White sucker	Coho salmon
				Flathead catfish
				Grass pickerel
				Largemouth bass
				Mottled sculpin
				Northern pike
				Northern redbelly dace
				Pearl dace
				Rainbow trout
				Rock bass
				Slimy sculpin
				Smallmouth bass
				Southern redbelly dace
				Walleye
				White crappie

whether the high-abundance species identified for SA I–VI (Table 1) were significantly co-occurrent (Legendre 2005). As suggested by Legendre (2005), we first conducted an overall test of concordance for all high-abundance species identified for the species associations. If this overall test was rejected, we then conducted individual tests of the high-abundance species for each of the species associations. Significance of the concordance tests was determined by Monte Carlo randomizations ($n = 1{,}000$). A Holm (1979) correction was used to protect the experimentwise error rate of the individual association tests (Legendre 2005). If a species was not significantly associated with the other species listed for the species association, it was removed from the group. We did not test the concordance of the low-abundance species as these included a mixture of fishes that would not necessarily be expected to occupy similar streams. After testing the concordance of the species associations, single measures of fish abundance for the associations were calculated by summing the transformed relative abundances for all the high-abundance species and subtracting the transformed relative abundances for all low-abundance species (where appropriate).

Development of the river valley segment classification.—Our classification of Michigan river valley segments was developed using July stream temperature, catchment area, and stream gradient as the classification variables. These attributes were calculated for the segments by weighted-averaging of the reach measurements. Weights were calculated by dividing segment length by reach length. We used these variables for our classification because they formed a major component of the SCS, and we were interested in maintaining some congruence with this earlier classification system. Furthermore, these variables are known integrators of stream network position, catchment surficial geology and soil characteristics, landscape topography, land cover, and local riparian conditions (Wang et al. 2003, 2006). Thus, we believed that classifications developed from these attributes would be useful for generalizing a variety of habitat and biological stream features.

Our river valley segment classification consisted of two nested levels (level 1 and level 2). Level 1 was intended to index hydrologic and thermal differences among the river valley segments, while level 2 was intended to index geomorphologic differences among the segments. Development of the level-1 classification system was a multi-step process in which differences in fish abundance in SA I–VI were related to differences in July stream temperature and catchment area using regression trees. In the first step of the level-1 classification, we used multivariate regression tree analysis (De'ath 2002) to relate differences in fish abundance in SA I–IV to differences in July stream temperature and catchment area. In the second step of the level-1 classification, we conducted additional regression tree analyses on two of the habitat types

TABLE 1.—Extended.

SA IV, high abundance	SA V, high abundance	SA VI, high abundance
Black crappie	Brook trout	Alewife
Black redhorse	Brown trout	Bigmouth buffalo
Channel catfish	Chinook salmon	Black buffalo
Flathead catfish	Coho salmon	Channel catfish
Freshwater drum	Rainbow trout	Flathead catfish
Gizzard shad		Freshwater drum
Golden redhorse		Gizzard shad
Greater redhorse		Longnose sucker
Quillback		Quillback
Shorthead redhorse		White bass
Silver redhorse		White perch
Walleye		
White crappie		

(medium rivers and large rivers) that were identified in the first step. For medium rivers, a univariate regression tree was used to relate differences in fish abundance in SA V to differences in catchment area and July stream temperature. For large rivers, we used a multivariate regression tree to relate differences in fish abundances in SA V and VI to differences in catchment area and July stream temperature. Regression tree sizes were determined by cross validation ($n = 10$) and trees were constructed using a complexity parameter of 0.01. For the first step, regression trees were constructed using a minimum bucket size of 20. For the second step, we reduced the minimum bucket size to five because of the fewer number of river valley segments for this part of the classification process.

For the level-2 classification, we subdivided the level-1 river valley segment types using channel gradient. Because of insufficient sample sizes, we were unable to use the existing fish assemblage data to assist in identifying the stream gradient classes. Instead, we simply used the following gradient classes to identify our level-2 segment types: very low gradient (<0.00076%), low gradient (0.00076–0.0019%), and moderate to steep gradient (≥0.0019%). These same stream reach gradient classes were used in the SCS of Michigan stream and rivers, and have been used in other stream classifications developed for the Great Lakes region (Higgins et al. 1998).

Correspondence among fish assemblages and river valley segment types.—After developing our river valley segment classification, we used nonmetric multidimensional scaling (NMDS) based on Bray–Curtis distances to summarize the patterns in fish assemblage structure for the river valley segments. A three-dimensional NMDS solution was used to facilitate interpretation of the ordination results. Up to 100 random restarts were used with the NMDS analyses to help find the best solution. All fish species included in the original fish assemblage data set were used. After the NMDS solution was obtained, we tested for differences in segment scores among the level-1 and level-2 river valley segment types using multivariate analysis of variance (MANOVA). If the overall MANOVA tests were statistically significant, we then conducted separate univariate analysis of variance (ANOVA) tests of the segment scores for each NMDS dimension (Heino et al. 2002).

Indicator species analysis (Dufrêne and Legendre 1997) was used to identify whether individual fish species discriminated among the river valley segment types. Indicator species analysis consists of calculating an index value that is a function of species specificity and fidelity for a segment. The index value of a species for a particular class is at a maximum when all individuals of the species occur at all segments of one class only (Legendre and Legendre 1998). Monte Carlo randomizations ($n = 1{,}000$) were used to determine the statistical significance of the indicator values for each species. All fish species included in the original fish assemblage data set were used.

Test of classification strength.—To test the strength of our classification system, we obtained fish abundance data from an additional 77 river valley segments in Michigan. These additional sampling data were obtained from the MDNR Fish Collection Database and were from sampling collections made between 2005 and 2007, which were not included in the classification-development data set. Roughly half of the river valley segments in this verification data set were segments that had not been sampled previously, while the remaining river valley segments in the verification data set had been sampled previously and were part of the data used to develop the classification system. As a result, the data used to test the classification strength were not entirely independent from the data used to develop the classification system and some level of similarity could be expected. River valley segment types for the verification data set were identified using the attribute splits identified from our stream and river classification. Similarities in fish assemblages among the resulting river valley segment types were calculated using the Bray–Curtis coefficient. We then calculated the mean fish assemblage similarities within each river valley segment type (W_i),

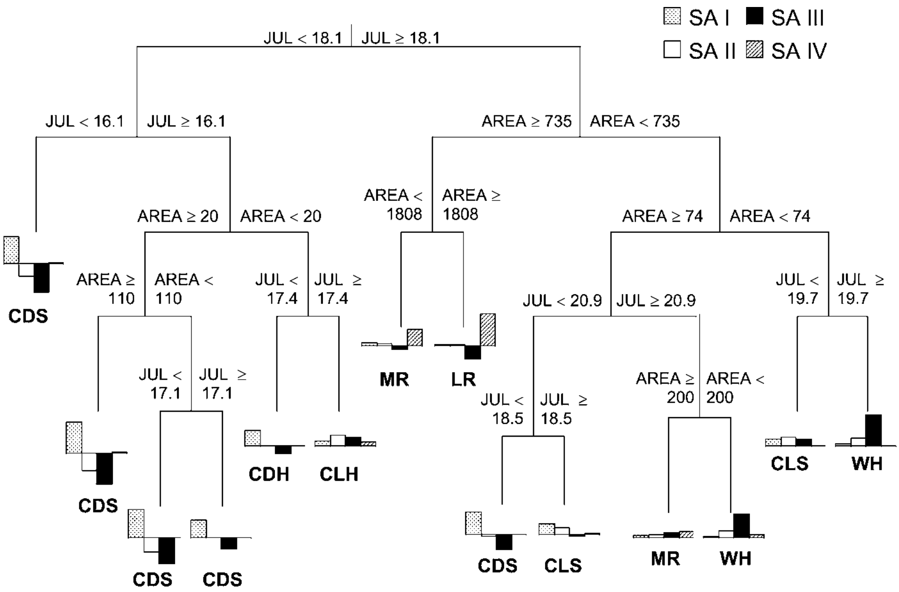

FIGURE 2.—Multivariate regression tree showing the results of the initial level-1 classification of Michigan river valley segments. The bar chart below each node presents the mean abundances of species associations (SAs) I–IV (see text). Segment types were determined from both environmental features and SA abundances. Abbreviations are as follows: CDH = cold headwater, CDS = cold stream or river, CLH = cool headwater, CLS = cool stream, WH = warm headwater, MR = medium river, LR = large river, JUL = mean July stream temperature (°C), and AREA = network catchment area (km^2).

the overall weighted mean within-river valley segment type similarity ($\bar{W}$), and the mean between-river valley segment type similarity ($\bar{B}$) based upon our classification results. The ratio of $\bar{B}$ and $\bar{W}$ provides an overall measure of strength of the developed classification system (Van Sickle 1997; Van Sickle and Hughes 2000). Ratios close to 1 are indicative of poor classifications, while ratios substantially less than 1 are indicative of strong classifications. We determined the statistical significance of the classification strengths using randomization tests (n = 1,000; Van Sickle 1997).

Results

Tests of Species Association Concordance

The overall test of species concordance was rejected ($W = 0.052$, $P = 0.001$), indicating that at least one of the high-abundance species identified for the species associations was concordant with at least one of the other species. The individual species association tests indicated that southern redbelly dace was not significantly associated with the other species identified for SA II ($W = 0.141$, $P = 0.407$). Similarly, creek chub was not significantly associated with the other species identified for SA III ($W = 0.110$, $P = 0.940$). As a result, creek chub and southern redbelly dace were removed from these species associations. The summed Hellinger-transformed relative abundances for the species associations fell into the following ranges: 0–1.92 (SA I), −1.86 to +1.47 (SA II), −2.18 to +1.69 (SA III), 0–1.85 (SA IV), 0–1.86 (SA V), and 0–1.25 (SA VI).

Classification Results

The first step of the level-1 classification partitioned 14 groups of river valley segments based on differences in abundance of SA I–IV (Figure 2). The resulting regression tree indicated that abundances of a few of the species associations were affected by an interaction between July stream temperature and catchment area (Figure 2). For example, SA I was the most abundant assemblage at July stream temperatures less than 17.4°C. It also was the most abundant association at temperatures as warm as 18.5°C for segments with catchment areas between 74 and 735 km^2. Similarly, SA III was the most abundant association when catchment areas were less than 74 km^2 and July stream temperatures were warmer than 19.7°C; it was also the most abundant species association at catchment areas between 74 and 201 km^2 and July stream temperatures warmer than 20.9°C. Based upon the attribute partitions identified by multivariate regression tree and the resulting changes in abundance of the species associations, we identified seven river valley segment types

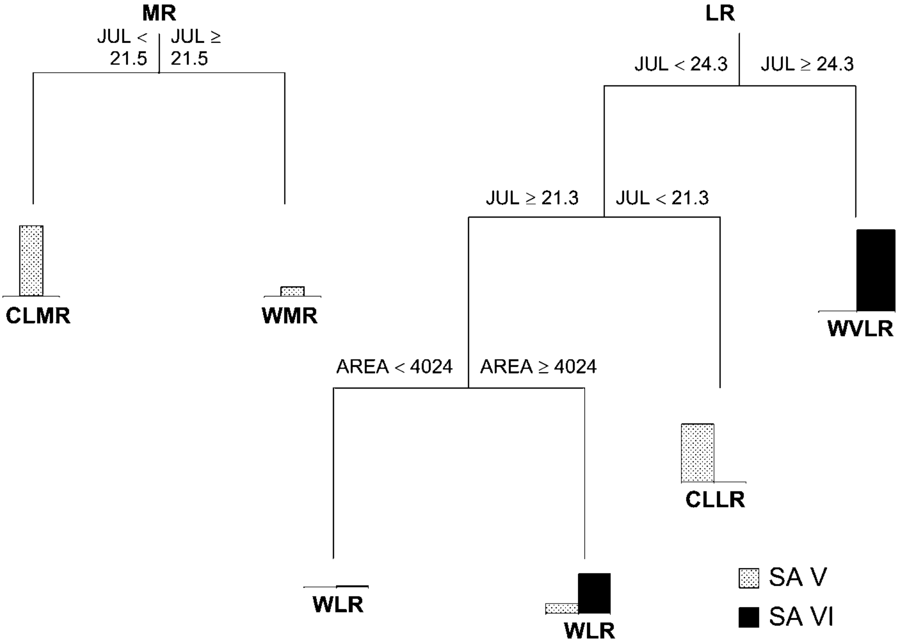

FIGURE 3.—Regression tree showing the results of the level-1 classification of the medium-river (MR) and large-river (LR) habitat types identified in the initial level-1 classification of Michigan river valley segments. Abbreviations are as follows: CLMR = cool medium river, WMR = warm medium river, CLLR = cool large river, WLR = warm large river, WVLR = warm very large river, JUL = mean July stream temperature (°C), and AREA = network catchment area (km^2). See Figure 2 for additional details.

from the first step of the level-1 classification: cold headwater (CDH), cold stream or river (CDS), cool headwater (CLH), cool stream (CLS), warm headwater (WH), medium river (MR), and large river (LR) (Figure 2).

In the second step of the level-1 classification, the univariate regression tree analysis of the abundance of SA V in relation to July stream temperature and catchment area subdivided medium rivers into two classes (Figure 3). At July stream temperatures cooler than 21.5°C, there was a greater abundance of SA V than at warmer temperatures. Based on this temperature value, we split medium rivers into cool medium river (CLMR) and warm medium river (WMR) types. The multivariate regression-tree analysis of abundances of SA V and VI in relation to July stream temperature and catchment area subdivided the large river category into four groups (Figure 3). The first partition occurred at 24.3°C, with a greater abundance of SA VI occurring at warmer temperatures. The next partition occurred at 21.3°C, with a greater abundance of SA V occurring at cooler temperatures. At temperatures between 21.3°C and 24.3°C, an additional partition occurred at catchment areas of 4,023 km^2, with larger areas resulting in similar abundances of SA V and VI, and smaller surface areas resulting in low abundances of both species associations (Figure 3). Based upon these partitions, we split the large river class into cool large river (CLLR), warm large river (WLR), and warm very large river (WVLR) segment types. Because of the low abundance of both SA V and SA VI for the partition identified at water temperatures between 21.3°C and 24.3°C and catchment areas of greater than and less than 4,024 km^2, we simply consolidated these partitions into the WLR river valley segment type (Figure 3).

Altogether, 10 river valley segment types were identified from the level-1 classification. For the 745 river valley segments with available fish assemblage data, the number of river valley segments assigned to the different level-1 segment types ranged from 6 (cool large river) to 242 (cold stream or river) (Table 2). When the level-1 attribute partitions were used to identify classes for Michigan's statewide data set of river valley segments, the number of river valley segments assigned to the habitat types ranged from 27 (warm very large river) to 6,876 (cold stream or river; Table 2). Approximately 70% of all river valley segments in Michigan were classified as cold stream or river, cool stream, or warm headwater segment

TABLE 2.—Frequency of segment types resulting from the level-1 classification of Michigan river valley segments for segments for which fish assemblage data were available and statewide.

Habitat type	Fish sites	Statewide
Cold headwater	59	3,217
Cold stream or river	242	6,876
Cool headwater	20	1,670
Cool stream	175	4,295
Warm headwater	107	1,920
Cool medium river	33	180
Warm medium river	68	235
Cool large river	6	43
Warm large river	27	105
Warm very large river	8	27

types. Geographically, cold headwater and stream or river segment types occurred predominantly in the upper and northern Lower Peninsulas of Michigan, while warm headwater segment types occurred predominantly in the southeastern part of the state (Figure 4).

Combining the three stream gradient classes with the level-1 segment types resulted in 30 possible level-2 segment types. When the level-2 attribute partitions were applied to the 745 river valley segments with available fish assemblage data, at least one river valley segment was assigned to 16 of the level-2 segment types (Table 3). The number of river valley segments assigned to the each of the level-2 habitat types ranged from 1 (cool medium river–low gradient) to 186 (cold stream or river–very low gradient). When the level-2 habitat attribute partitions were applied to the statewide data set of Michigan river valley segments, at least one river valley segment was assigned to 26 of the level-2 segment types (Table 3). The number of river valley segments assigned to the segment types ranged from 1 (cool large river–moderate to steep gradient) to 4,081 (cool stream–very low gradient) (Table 3). No river valley segments were assigned to the cool medium river–moderate to steep gradient, cool large river–low gradient, warm very large river–low gradient, or warm very large river–moderate to steep gradient types. A few of the river valley segment types, such as the warm very large river–moderate to steep gradient class, were unlikely to occur in Michigan given the geographic and

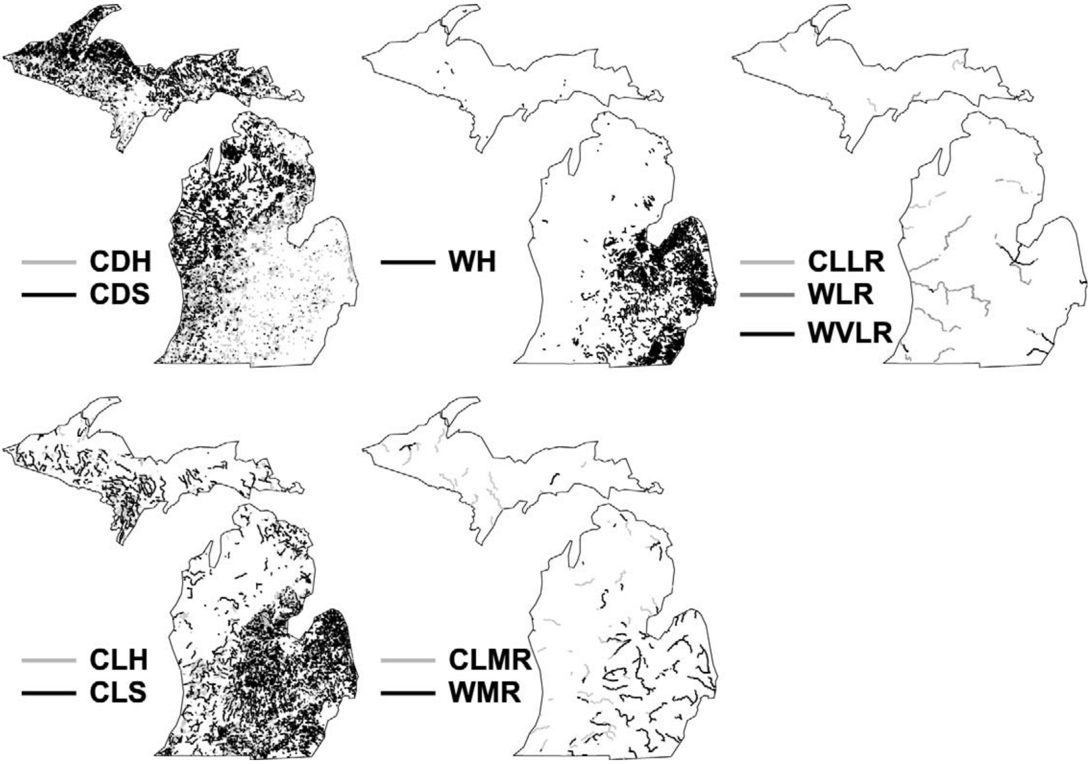

FIGURE 4.—Geographical distribution of level-1 segment types for Michigan river valley segments. Abbreviations are as follows: CDH = cold headwater, CDS = cold stream and river, CLH = cool headwater, CLS = cool stream, WH = warm headwater, CLMR = cool medium river, WMR = warm medium river, CLLR = cool large river, WLR = warm large river, and WVLR = warm very large river.

climatic conditions within the state, although such segment types may occur in other regions.

Correspondence among Fish Assemblages and River Valley Segment Types

The three-dimensional NMDS ordination of the fish assemblage data set resulted in an overall stress value of 17.4. The Pearson correlation coefficient between the resulting three-dimensional ordination distances and the original dissimilarities was 0.82, indicating that the NMDS ordination did have fairly good agreement with the original data.

An overall difference in NMDS segment scores for the level-1 segment types was observed ($F = 48.22$; df $= 27, 2{,}141$; $P < 0.001$). Individual tests of differences in segment scores among the level-1 segment types for each NMDS dimension were also significant ($P \leq 0.003$ for NMDS dimensions 1–3). Based on plots of the level-1 segment type centroids in relation to the NMDS species scores, cold headwater segment types appeared to be most closely associated with cyprinids such as northern redbelly dace, while cold stream or river segment types were more closely associated with species such as mottled sculpin and brook trout (Figure 5). Cool headwater and cool stream segment types were closely associated with species such as creek chub, central mudminnow, and white sucker (Figure 5). Johnny darter was closely associated with warm headwaters, while northern pike was closely associated with cool medium rivers. The warmer and larger segment types were more closely associated with species such as smallmouth bass, golden redhorse, alewife, and channel catfish (Figure 5).

An overall difference in NMDS segment scores for the level-2 segment types also was found ($F = 32.12$; df $= 45, 2{,}160$; $P < 0.001$). Individual tests of differences in segment scores among the level-2 segment types for the NMDS dimensions also were significant ($P < 0.001$ for NMDS dimensions 1–3). Based on plots of the level-2 segment type centroids in relation to species scores, there was not a substantial separation in fish assemblages among the gradient classes for the segment types. For example, the cool headwater gradient class centroids clustered together in each NMDS dimension, as did the cold stream or river–very low gradient and low gradient segment types. Thus, one could expect to find very similar assemblages among these level-2 segment types (Figure 6).

Species with significant indicator values were identified for eight of the level-1 river valley segment types (Table 4). The number of species with significant indicator values for the segment types ranged from 2 (cold stream or river) to 14 (warm very large river). The species with the largest significant indicator values for the level-1 river valley segment types were brook trout (cold stream or river), creek chub (cool headwater), johnny darter (warm headwater), blackside darter (cool medium river), bluntnose minnow (warm medium river), silver redhorse (cool large river), smallmouth bass (warm large river), and freshwater drum (warm very large river).

TABLE 3.—Frequency of segment types resulting from the level-2 classification of Michigan river valley segments for segments for which fish assemblage data were available and statewide. Abbreviations are as follows: VLG = very low gradient, LG = low gradient, and MSG = moderate to steep gradient.

Habitat type	Fish sites	Statewide
Cold headwater–VLG	46	2,451
Cold headwater–LG	13	728
Cold headwater–MSG		38
Cold stream or river–VLG	186	3,812
Cold stream or river–LG	46	1,943
Cold stream or river–MSG	10	1,121
Cool headwater–VLG	18	1,462
Cool headwater–LG	2	205
Cool headwater–MSG		3
Cool stream–VLG	171	4,081
Cool stream–LG	4	199
Cool stream–MSG		15
Warm headwater–VLG	107	1,892
Warm headwater–LG		23
Warm headwater–MSG		5
Cool medium river–VLG	32	171
Cool medium river–LG	1	9
Warm medium river–VLG	68	231
Warm medium river–LG		2
Warm medium river–MSG		2
Cool large river–VLG	6	42
Cool large river–MSG		1
Warm large river–VLG	27	97
Warm large river–LG		2
Warm large river–MSG		6
Warm very large river–VLG	8	27

For the level-2 classification, species with significant indicator values were identified for only five of the river valley segment types (Table 5). The species with the largest significant indicator values for the level-2 habitat types were: white crappie (cool headwater–low gradient), blackchin shiner(cool stream–low gradient), rainbow trout (cool medium river–low gradient), silver redhorse (cool large river–very low gradient), and freshwater drum (warm very large river–very low gradient).

Verification of Habitat Types

None of the river valley segments included in our verification data set was classified as a cool headwater habitat. For all other level-1 river valley segment types, at least one river valley segment in our verification data set was assigned to the other class types. The number of river valley segments assigned to each of level-1

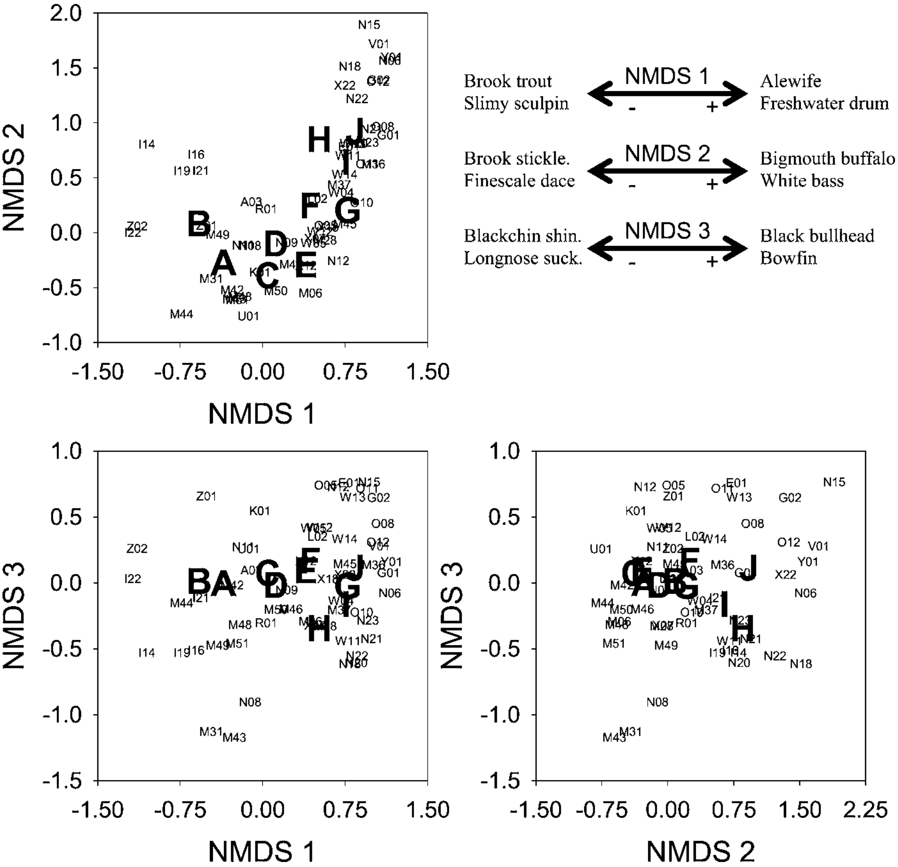

FIGURE 5.—Ordination from nonmetric multidimensional scaling (NMDS) analysis of fish assemblage structure for the river valley segments used to develop the Michigan stream and river classifications. Plotted are the weighted averages of species scores for the three NMDS dimensions and the centroids of the level-1segment type segment scores. Species codes are listed in the appendix. Species with large loadings on each of the NMDS axes are indicated in the upper right of the figure to assist in interpretation. Abbreviations are as follows: A = cold headwater, B = cold stream or river, C = cool headwater, D = cool stream, E = warm headwater, F = cool medium river, G = warm medium river, H = cool large river, I = warm large river, and J = warm very large river.

segment types ranged from 2 (cold headwater) to 27 (cold streams or rivers). Twenty-six of the river valley segments in the verification data set were classified as either cool large, warm large, or warm very large river segment types, which partly resulted from the initiation of a large river sampling program by MDNR in 2005.

The overall strength of our level-1 classification of river valley segments based on the additional fish assemblage data set was 0.41 ($\bar{B} = 0.13$, $\bar{W} = 0.32$). The randomization analysis indicated that our level-1 classification of the verification data set was significantly better than a simple random grouping of the river valley segments ($P < 0.001$). We were unable to test the strength of our level-2 classification, as too few river valley segments were assigned to some of the segment types to allow this method of testing.

Discussion

There is a long history of using classifications to simplify and organize the diverse physicochemical and biological characteristics of rivers and streams (Ricker 1934; Van Deusen 1954). Although development of stream and river classifications can be challenging, they are considered essential for regional management of streams and rivers (Seelbach et al. 2006). Classifications aid in the extrapolation of locational information to broader scales and provide a framework for organizing data and generalizing results to similar spatial units (Hudson et al. 1992; Maxwell et al. 1995). Classifications also provide a means for thinking and communicating about the physicochemical and ecological processes in streams and rivers (Bailey et al. 1978; Seelbach et al. 2006).

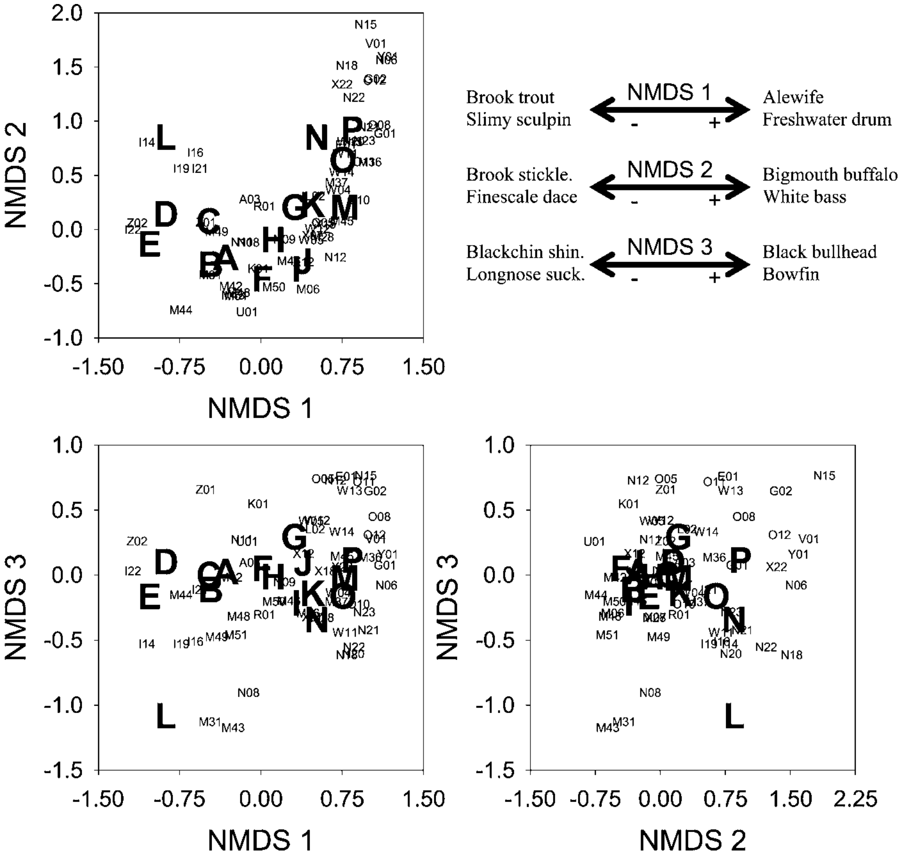

Figure 6.—Ordination from nonmetric multidimensional scaling (NMDS) analysis of fish assemblage structure for the river valley segments used to develop the Michigan stream and river classifications. Plotted are the weighted averages of species scores for the three NMDS dimensions and the centroids of the level-2 segment type segment scores. Abbreviations are as follows: VLG = very low gradient, LG = low gradient, MSG = moderate to steep gradient; A = cold headwater–VLG, B = cold headwater–LG, C = cold stream or river–VLG, D = cold stream or river–LG, E = cold stream or river–MSG, F = cool headwater–VLG, G = cool headwater–LG, H = cool stream–VLG, I = cool stream–LG, J = warm headwater–VLG, K = cool medium river–VLG, L = cool medium river–LG, M = warm medium river–VLG, N = cool large river–VLG, O = warm large river–VLG, and P = warm very large river–VLG. See Figure 5 for additional details.

Both physical (e.g., Hawkins et al. 1993; Rosgen 1994; Snelder and Biggs 2002) and biological (e.g., Naiman 1998; Seelbach et al. 2006) criteria have been used to classify rivers and streams. Using biological criteria to classify stream systems is appealing because stream ecosystems often are managed based on a supposed understanding of species distribution, community structure, and biotic function. Additionally, biological communities integrate physicochemical conditions across multiple temporal and spatial scales and hence can be sensitive indicators to environmental conditions. The difficulty in using biotic criteria to classify rivers and streams stems from such classifications being highly dependent on segment-specific biological data (Naiman et al. 1992), which are generally unavailable across large areas. As a result, classifications based on biological criteria can limit the generalization of stream conditions and management policies. Conversely, using physical criteria to classify streams has practical value for both science and management. Because physical habitat provides the template for evolution of organisms and organization of communities (Southwood 1977; Townsend and Hildrew 1994), physical attributes are considered adequate for developing biologically meaningful classifications (Frissell et al. 1986; Imhof et al. 1996). Additionally, the wide availability of GIS databases of landscape attributes (e.g., catchment area, surficial geology, landscape topography, and climate conditions) that control instream features, such as water temperature and discharge, make it possible to classify streams across large areas. However, the ecological relevance of

TABLE 4.—Indicator species for the segment types identified from the level-1 classification of Michigan rivers and streams. For habitat types with no statistically significant indicator species, the species with the largest indicator value (INDVAL) is given. For habitat types with statistically significant indicator species, those with the three largest indicator values are shown.

Segment type	Species	INDVAL	*P*-value
Cold headwater	Stickleback spp.	2.75	0.473
Cold stream and river	Brook trout	30.99	0.002
	Brown trout	17.56	0.026
Cool headwater	Creek chub	20.23	0.001
	Central mudminnow	18.28	0.023
	Blacknose dace	15.56	0.039
Cool stream	Northern brook lamprey	2.16	0.450
Warm headwater	Johnny darter	21.00	0.010
	Central stoneroller	20.08	0.011
	Green sunfish	18.16	0.024
Cool medium river	Blackside darter	21.90	0.009
	Rainbow darter	21.04	0.010
	Common shiner	17.69	0.044
Warm medium river	Bluntnose minnow	25.55	0.001
	Stonecat	21.04	0.010
	Spotfin shiner	18.00	0.018
Cool large river	Silver redhorse	53.61	0.001
	Shorthead redhorse	42.27	0.001
	Chinook salmon	37.65	0.001
Warm large river	Smallmouth bass	23.50	0.002
	Golden redhorse	21.15	0.012
	Sand shiner	15.44	0.018
Warm very large river	Freshwater drum	70.37	0.001
	Gizzard shad	67.97	0.001
	White bass	61.68	0.001

TABLE 5.—Indicator species for the segment types identified from the level-2 classification of Michigan rivers and streams. For segment types with no statistically significant indicator species, the species with the largest indicator value (INDVAL) is given. For habitat types with statistically significant indicator species, those with the three largest indicator values are shown. Abbreviations are as follows: VLG = very low gradient, LG = low gradient, and MSG = moderate to steep gradient.

Segment type	Species	INDVAL	*P*-value
Cold headwater–VLG	Lake chubsucker	2.90	0.484
Cold headwater–LG	Creek chubsucker	15.25	0.080
Cold stream or river–VLG	Brown trout	13.04	0.313
Cold stream or river–VLG	Coho salmon	10.83	0.207
Cold stream or river–MSG	Brook trout	25.18	0.084
Cool headwater–VLG	Creek chub	13.20	0.158
Cool headwater–LG	White crappie	39.88	0.021
	Tadpole madtom	38.77	0.042
	Northern brook lamprey	37.25	0.039
Cool stream–VLG	Longnose sucker	1.47	0.610
Cool stream–LG	Blackchin shiner	19.71	0.044
Warm headwater–VLG	Johnny darter	17.34	0.099
Cool medium river–VLG	Blackside darter	21.02	0.102
Cool medium river–LG	Rainbow trout	60.06	0.001
Warm medium river–VLG	Bluntnose shiner	21.35	0.104
Cool large river–VLG	Silver redhorse	45.55	0.024
	Shorthead redhorse	39.76	0.039
	Chinook salmon	30.85	0.044
Warm large river–VLG	Smallmouth bass	23.31	0.113
Warm very large river–VLG	Freshwater drum	70.37	0.001
	Gizzard shad	67.97	0.014
	White bass	61.68	0.008

river and stream classifications developed from physical criteria has not been widely tested (Thomson et al. 2004).

For our classification, we attempted to integrate both biological and physical criteria within a single classification process so that we could take advantage of the strengths of both classification approaches (Naiman et al. 1992). By basing the classification on physical criteria, we were able to classify all Michigan rivers and streams. Additionally, by using the differences in abundances of the species associations to identify our habitat type partitions, our river valley segment types should be sensitive integrators of environmental conditions. Although we could have developed a classification system based on a single species, we see several advantages in using groups of species to develop stream and river classifications. First, fishery managers are increasingly called upon to manage communities and ecosystems rather than single species (Cowx and Gerdeaux 2004). Additionally, species associations may be better integrators of environmental conditions because they are less subject to sampling error than are individual species (Legendre 2005). Groups of species may have larger structuring effects on other aquatic community levels; thus, classification systems based on species associations may be more relevant to environmental assessment. Furthermore, the variables used in our classification (network catchment area, July mean stream temperature, channel gradient) have also been found to affect distribution and abundance of macroinvertebrates (Weigel et al. 2003; Wang et al. 2007) and benthic algae (Dodds and Oakes 2004). Generalist species can complicate the use of species associations in stream classifications as they may cause substantial overlap in assemblages among different habitat types (Zorn et al. 2002). For this study, we purposefully avoided generalist species in hopes of improving sensitivity of the classification system.

Traditional approaches to classifying streams and rivers largely involved the creation of longitudinal zones that tied discontinua in biological assemblages to key physical factors, such as temperature, substrate, water depth, current velocity, and network position (Hawkes 1975; Hudson et al. 1992). More recently, greater emphasis has been placed on describing physical drainage (catchment, subcatchment) and channel (segment, reach, mesohabitat, microhabitat) units or habitat patches at a series of nested scales (i.e., hierarchical stream classifications) (Frissell et al. 1986; Tonn 1990; Maxwell et al. 1995; Snelder and Biggs 2002; Benda et al. 2004; Higgins et al. 2005; Sowa et al. 2007). Compared with a hierarchical classification, our approach is more simplistic and is more reflective of traditional classification approaches. However, it would be relatively straightforward to incorporate our classification results within a hierarchical stream classification that respects river drainage patterns, such as those described by Maxwell et al. (1995), Higgins et al. (2005), and Sowa et al. (2007).

As with all classifications, our approach to classifying Michigan river valley segments has strengths and weaknesses. A major strength is that it permits the generalization and mapping of habitat and biotic conditions across the state. River valley segment types were partly identified using a rigorous statistical approach (regression trees) that accommodates interactions among physical attributes and that can objectively discriminate attribute boundaries (De'ath and Fabricius 2000; De'ath 2002). The use of regression trees in developing stream classification is becoming increasingly common (Robertson et al. 2006; Sowa et al. 2007; Steen et al. 2008), and we believe this technique will ultimately make it easier to defend the resulting classifications. An additional strength of our classification is its simplicity. We classified all Michigan rivers and streams into one of 10 level-1 segment types and one of 30 level-2 segment types based on three physical variables: stream temperature, catchment area, and stream reach gradient. Despite its simplicity, the river valley segment types that were identified from the classification are precisely the types of habitats of interest to water resource and fisheries managers. For example, under the Clean Water Act, U.S. states are required to manage water quality more stringently in streams designated for coldwater uses, and being able to quickly and efficiently identify coldwater streams may be extremely beneficial for ensuring these habitats are protected.

The weaknesses of our classification include the placement of boundaries on attributes with truly continuous characteristics (Hawkins and Vinson 2000; Seelbach et al. 2006). An additional weakness is the inability to use our classification system to identify changes in rivers and streams from presettlement reference conditions. Like the SCS, our classification of Michigan rivers and streams uses current data and accepts that some degree of human disturbance has occurred across the landscape. As a result, our classification system is not appropriate for identifying reference streams or streams that have been most affected by human settlement. To develop such a classification, an approach where native fish or macroinvertebrate assemblages are related to variables not easily altered by humans would need to be employed (Van Sickle et al. 2004; Kilgour and Stanfield 2006). Another weakness of our approach is its reliance on predicted July stream temperatures as one of the classification variables. Stream thermal regime is considered extremely influential for fisheries management (Lyons et al. 1996) and environmental assessment and regulation (Wang et al. 2008); thus, there is a strong desire to incorporate stream temperatures within classification systems for streams and rivers. However, the use of model predictions may be a source of error causing misidentification of some habitat types.

We believe that this classification system is an improvement over those previously used in Michigan. Furthermore, we believe that the approaches used to develop this classification may prove beneficial for developing stream and river classifications elsewhere. The revised classification system integrates biotic and abiotic attributes and ultimately reduces subjectivity in classifying streams and rivers. It will be useful for generalizing stream conditions as well as establishing and justifying management policies over large spatial scales. However, all classification systems should be considered as hypotheses about ecosystem organization and function (Snelder and Biggs 2002). As a result, it is important for managers to evaluate the sensitivity of their decisions to possible classification inaccuracies and continually review classifications to correct errors that may have resulted.

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Appendix: Species Represented in the Study

TABLE A.1.—Fish species included in the data used to classify Michigan river valley segments. The codes pertain to Figures 5 and 6.

Species	Code	Species	Code
Alewife *Alosa pseudoharengus*	G01	Green sunfish *Lepomis cyanellus*	W05
Bigmouth buffalo *Ictiobus cyprinellus*	N15	Johnny darter *Etheostoma nigrum*	X12
Black buffalo *Ictiobus niger*	N16	Lake chubsucker *Erimyzon sucetta*	N12
Black bullhead *Ameiurus melas*	O05	Largemouth bass *Micropterus salmoides*	W12
Black crappie *Pomoxis nigromaculatus*	W14	Longnose dace *Rhinichthys cataractae*	M49
Black redhorse *Moxostoma duquesnei*	N20	Longnose sucker *Catostomus catostomus*	N08
Blackchin shiner *Notropis heterodon*	M31	Mottled sculpin *Cottus bairdii*	Z01
Blacknose dace *Rhinichthys atratulus*	M48	Northern pike *Esox lucius*	L02
Blackside darter *Percina maculata*	X18	Northern brook lamprey *Ichthyomyzon fossor*	A03
Bluntnose minnow *Pimephales notatus*	M45	Northern redbelly dace *Phoxinus eos*	M42
Bowfin *Amia calva*	E01	Pearl dace *Margariscus margarita*	M51
Brook stickleback *Culaea inconstans*	U01	Quillback *Carpiodes cyprinus*	N06
Brook trout *Salvelinus fontinalis*	I22	Rainbow darter *Etheostoma caeruleum*	X07
Brown trout *Salmo trutta*	I21	Rainbow trout *Oncorhynchus mykiss*	I19
Burbot *Lota lota*	R01	Rock bass *Ambloplites rupestris*	W04
Central mudminnow *Umbra limi*	K01	Sand shiner *Notropis stramineus*	M37
Central stoneroller *Campostoma anomalum*	M06	Shorthead redhorse *Moxostoma macrolepidotum*	N22
Channel catfish *Ictalurus punctatus*	O08	Silver redhorse *Moxostoma anisurum*	N18
Chinook salmon *Oncorhynchus tshawytscha*	I16	Slimy sculpin *Cottus cognatus*	Z02
Coho salmon *Oncorhynchus kisutch*	I14	Smallmouth bass *Micropterus dolomieu*	W11
Common shiner *Luxilus cornutus*	M28	Southern redbelly dace *Phoxinus erythrogaster*	M43
Creek chub *Semotilus atromaculatus*	M50	Spotfin shiner *Cyprinella spiloptera*	M36
Creek chubsucker *Erimyzon oblongus*	N11	Stonecat *Noturus flavus*	O10
Fathead minnow *Pimephales promelas*	M46	Tadpole madtom *Noturus gyrinus*	O11
Flathead catfish *Pylodictis olivaris*	O12	Walleye *Sander vitreus*	X22
Freshwater drum *Aplodinotus grunniens*	Y01	White bass *Morone chrysops*	V01
Gizzard shad *Dorosoma cepedianum*	G02	White crappie *Pomoxis annularis*	W13
Golden redhorse *Moxostoma erythrurum*	N21	White perch *Morone americana*	V03
Grass pickerel *Esox americanus*	L01	White sucker *Catostomus commersonii*	N09
Greater redhorse *Moxostoma valenciennesi*	N23		