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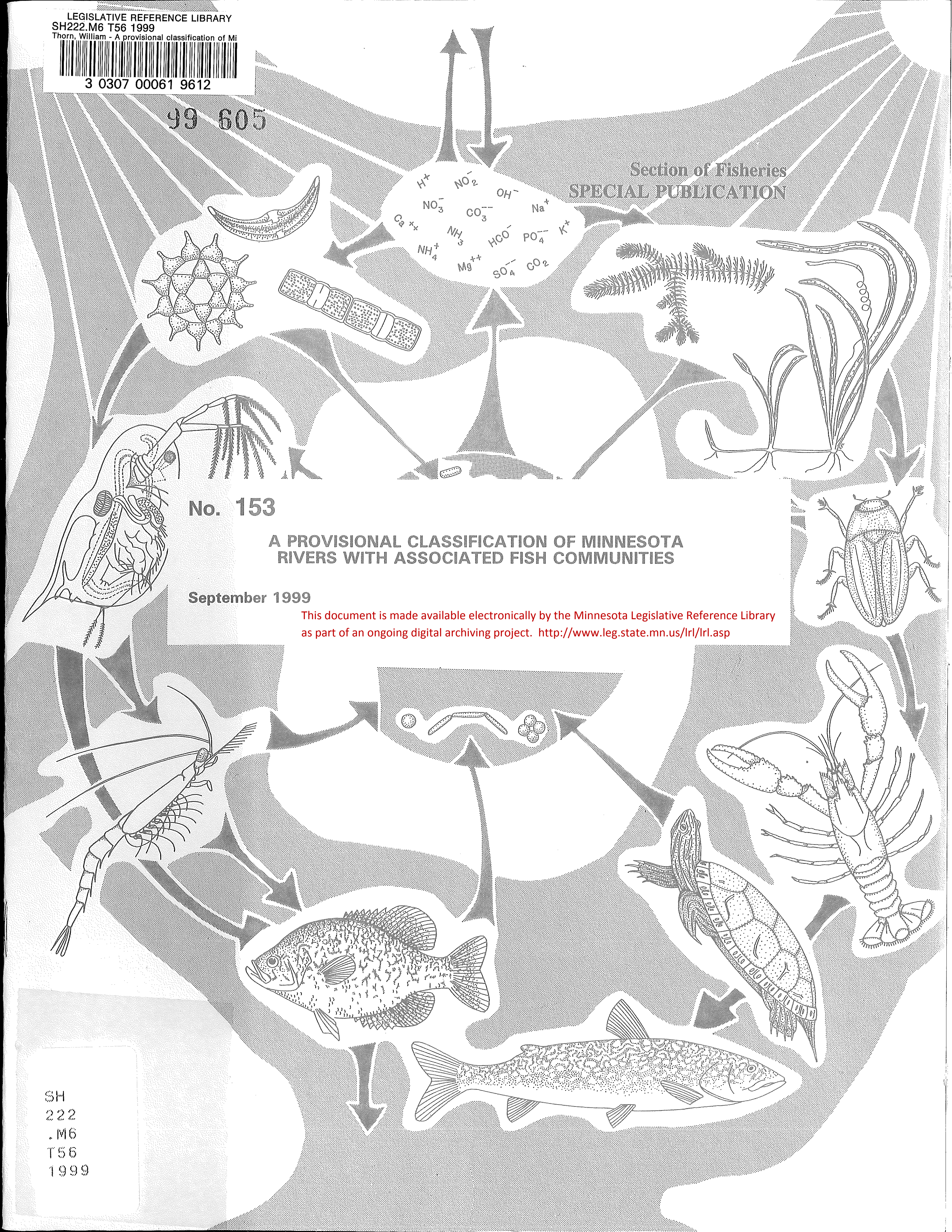

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A PROVISIONAL CLASSIFICATION OF MINNESOTA RIVERS WITH ASSOCIATED FISH COMMUNITIES

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A PROVISIONAL CLASSIFICATION OF MINNESOTA RIVERS WITH ASSOCIATED FISH COMMUNITIES[1]

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Abstract--We classified 1,038 Minnesota river and stream reaches into 19 classes based on physical and chemical variables recorded in stream surveys. Ten classes of coldwater streams were distinguished by productivity, stream morphology, size, gradient, and measures of degradation. However, surveys were not available for warmwater streams in all watersheds of Minnesota. The nine provisional classes of warmwater streams were distinguished by morphology, size, and measures of degradation. We also describe the fish species most prevalent in each class. We discuss the use of this classification system for fisheries management, stream rehabilitation, and ecological monitoring of coldwater streams and most southern Minnesota warmwater rivers and streams.

Introduction

Growing recognition of the value of riverine fishes and their sensitivity to environmental degradation has prompted the Minnesota Department of Natural Resources (MNDNR) to take a more active role in management of these resources. Lakes have had a greater fisheries management priority than streams in Minnesota. For example, the MNDNR has surveyed about 80% of the 5,000 managed fish lakes, and about 40% of Minnesota rivers and streams (H. Drewes, MNDNR, personal communication). The 3,000 miles of coldwater steams have a long history of management, while management of the 12,000 miles of warmwater rivers has been rare. Rivers and streams support at least 114 fish species and MNDNR fisheries managers want to conserve these resources. Platts (1980) suggested the development of a fishery habitat classification system was an important step to improving fisheries management in streams, and fisheries managers prefer classifications linking habitat to fish community structure and productivity (Leach and Herron 1992).

For Minnesota waters, Cunningham and Anderson (1992) discussed the need for ecological classifications to develop management plans, and to identify and communicate

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management methods for various environmental situations. Classification systems have guided MNDNR fishery management in lakes for many years (Eddy 1938; Moyle 1946, 1956; Schupp 1992). The most recent ecological classification, based on physical and chemical habitat variables recorded in lake surveys (Schupp 1992), allows MNDNR fisheries managers to analyze resources and past management, and formulate community-based fishery management plans. A similar ecological classification system for rivers and streams should enhance community-based fishery management plans, and incorporate the ecosystem-based management initiative recently adopted by MNDNR. Therefore, this study compiles many of the MNDNR stream survey records, classifies streams based on available physical and chemical variables, describes the associated fish communities, and discusses some applications of this classification for stream management planning and ecosystem-based management. Ours is a provisional classification because the stream survey records do not yet provide complete coverage of the state, and because we encourage other uses of the data.

Methods

Our data sources were paper copies of MNDNR stream survey reports (MNDNR 1978). The number of physical variables in a survey varies according to morphology (pool, riffle, run, other) and substrates (10 possible types for each morphological unit). A complete survey could record from 30 to over 60 physical variables. Twenty chemical variables could be recorded, but nearly all reaches had incomplete records of chemical variables. We selected 13 physical, one chemical, and one ecological classification variable for computerization (Table 1). These were chosen because similar variables have been used for classifica-

Table 1. Variables from stream surveys (MNDNR 1978) used to classify Minnesota rivers and streams.

Variable	Abbreviation	Number of sites
% pool	Pool	1,114
% riffle	Riffle	1,114
% run	Run	1,114
Width (feet)	AveW	1,114
Depth (feet)	AveD	1,114
Width:Depth[a]	WD	1,114
Flow (cubic feet/second)	Flow	1,050
Gradient (feet/mile)	Grad	1,104
Sinuosity	Sinu	1,103
% fines[b]	Fines	1,114
Bank erosion[c]	Ero	1,114
Shade[d]	Shade	1,114
Cover[e]	Cover	1,093
Alkalinity (ppm)	Alk	692[f]
Ecological classification	CW,WW[g]	1,114

[a] Mean width/mean depth (wetted width and depth under low flow conditions)
[b] Sum of sand, silt, clay, and muck
[c] 1 = light, 2 = moderate, 3 = severe
[d] 1 = light = 0-25% shaded, 2 = moderate = 26-75% shaded, 3 = heavy =>75% shaded
[e] Sum of ratings (1 = scarce, 2 = occasional, 3 = frequent) for each type of cover (log jams, overhanging vegetation, undercut banks, instream vegetation, boulders)
[f] Sample size was increased to 1,114 based on alkalinity at other sites in the same stream or watershed.
[g] cw = coldwater, ww = warmwater

tion of streams and rivers (Hudson et al. 1992), records for these variables were most complete, or they could be calculated from survey variables (width:depth ratio (WD); fine substrates). These variables and the absence/presence of fish species were compiled from stream surveys completed between 1978 and 1996. Data from surveys of southeast Minnesota streams completed during 1975-77 were included if missing data could be found or estimated.

Maxwell et al. (1995) concluded that stream reaches should be the basic strata for collecting and storing river and stream data, and assessing habitat quality. The stream reach is the basis of MNDNR stream surveys and management plans. Also, in MNDNR stream surveys, some variables we selected (gradient, sinuosity) are recorded only for the reach, and some are not always recorded for all sampling stations in a reach (alkalinity, flow). When more than one station in a reach was sampled, a mean for the reach was calculated from the station data. The initial data base included 1,134 stream reaches (Table 2).

Temperature is a common stream classification variable (Hudson et al. 1992; Lyons 1989). However, selecting a representative temperature from the stream survey was difficult. Therefore, we separated coldwater and warmwater stream reaches for analysis based on the ecological classification of the reach (Minnesota Department of Natural Resources 1978). Class I (trout) streams were considered coldwater streams, and Classes II-IV (warmwater game fish, warmwater feeder, and rough fish-forage fish) were warmwater streams. Class V (intermittent) streams were assigned to cold or warmwater groups based on the ecological classification of the stream into which they flowed.

Minnesota DNR fisheries managers have used chemical variables to characterize lake productivity for many years (Schupp 1992). In stream surveys, the most available productivity variables were alkalinity, total phosphorus, and total dissolved solids. However, all three variables were not routinely sampled in each stream reach, and preliminary analysis showed redundancy of the three variables when available. Therefore, we used alkalinity to represent productivity. To increase the sample size for alkalinity from 692 to all the stream reaches, we applied the measurement from a single station to all stream reaches for the spring-fed, coldwater streams because small, spring-fed streams are chemically stable (Hynes 1972), and applied stream averages and watershed averages to the remaining reaches without alkalinity measurements. In general, alkalinity of Minnesota waters increases from northeast to southwest (Moyle 1956).

We classified streams by a multivariate analysis of one chemical and 13 physical variables (Table 1), with separate analyses of the coldwater and warmwater reaches. Eliminating reaches with missing data, reduced the total number of reaches for analysis to 1,038. Each variable was examined by summary statistics, histograms, and correlations with other variables. Distributions of physical variables were normalized with natural logarithms $(x+1)$ (Lyons 1989), and chemical variables with square roots (Schupp 1992). Because the variables were somewhat redundant, we calculated principal component scores to reduce the dimensions of the analyses. Principal components analyses (PCA) of the correlation matrices showed that five components explained 71% of the variance among 564 coldwater stream reaches and 72% of the variation among 474 warmwater stream reaches. The standardized component scores for each data set were analyzed with k-means cluster analysis (CA) to propose stream classes. The final number of classes was determined by requiring class sizes ≥ 10, and by examination of reclassification rates in discriminant function analysis. We used the original 14 variables, not PC scores, to reclassify streams, because the resulting discriminant functions would be simpler to use in classifying new locations.

We analyzed the occurrence (presence/absence data) of fish species in three ways to further describe the stream classes. Our species data base started with 1,104 records. It was reduced to 1,038 when combined with

Table 2. Distribution of 1,134 Minnesota river and stream reaches in the classification data base by ecoregion, instream flow region, and watershed.[a]

	Coldwater	Warmwater
Ecoregion		
Northern Minnesota Wetlands	0	20
Northern Lakes and Forests	225	148
North Central Hardwood Forests	77	80
Driftless Area	147	20
Western Corn Belt Plains	119	236
Northern Glaciated Plains	7	44
Red River Valley	1	10
Instream Flow Regions[b]		
Southeast Dissected (1)	256	108
Southwest Till Plains (2)	17	201
Red River Valley (3)	10	24
Central Lakes (4)	80	53
St. Croix Delta (5)	41	97
Crow River (6)	6	28
Superior Uplands (7)	115	6
Border Lakes (8)	5	1
Northern Peatlands (9)	29	29
Metro (10)	17	11
Watershed[c]		
St. Louis River (1)	4	5
Lake Superior (2)	120	6
Rainy Lake (3)	5	1
Little Fork River (4)	13	4
Big Fork River (5)	0	0
Lake of the Woods (6)	0	2
Mustinka-Bois de Sioux (7)	0	4
Otter Tail River (8)	9	6
Buffalo River (9)	0	2
Wild Rice River (10)	0	0
Red Lake River (11)	1	12
Middle River (12)	0	0
Two Rivers (13)	0	2
Roseau River (14)	0	0
Mississippi Headwaters (15)	36	49
Crow Wing River (16)	24	6
Crow River (17)	0	9
Rum River (18)	1	1
Mississippi-Sauk (19)	37	36
Big Stone Lake (20)	0	12
Pomme de Terre River (21)	0	8
Lac Qui Parle (22)	3	12
Chippewa River (23)	0	11
Yellow Medicine (24)	0	4
Redwood River (25)	2	1
Cottonwood River (26)	3	12
Blue Earth River (27)	0	36
Minnesota-Hawk Creek (28)	0	2
Lower Minnesota (29)	12	23
Kettle River (30)	31	66
Snake River (31)	1	31
Lower St. Croix River (32)	10	0
Metropolitan (33)	1	2
Cannon River (34)	13	53
Zumbro River (35)	28	81
Root River (36)	215	29
Cedar River (37)	3	26
Des Moines River (38)	4	0
Rock River (39)	0	4

[a]Includes 96 stream reaches in data base with missing data that were not used for classification.
[b]From Olson et al. 1988.
[c]Watershed name and number (MNDNR 1978).

the physical variable data base. In surveys that did not differentiate between species of sculpin (*Cottus* spp.), we listed the more common species, slimy sculpin for spring-fed streams in southeast Minnesota, and mottled sculpin for Lake Superior tributaries (Becker 1983; Eddy and Underhill 1974). Scientific names of the 50 most common species are listed in Table 3. First, as a simple description of the fish commonly found in each stream class, we tabulated the percent of reaches where each species was present in a stream class, and listed those present in 40% or more of the reaches of that class. Second, we reduced the 114 species recorded in stream surveys to a more manageable 50 by dropping species found in less than 5% of the stream reaches (Table 3), and described which species tended to be associated with each other by a PCA of the presence/absence data. The PCA was calculated for the correlation matrix, components having eigenvalues > 1 were retained, and a varimax rotation was performed. Third, we used the mean PC scores as an index of suitability of the stream class for those species having high loadings on each component. All statistical analyses were done with SYSTAT (Wilkinson 1988).

River and Stream Classification

We grouped Minnesota rivers and streams into 19 classes by cluster analysis (Tables 4 and 5). Classes 1-10 are coldwater classes, and classes 11-19 are warmwater classes. Because of the limited distribution of coldwater streams in Minnesota (Eddy and Underhill 1974), and the long history of coldwater stream surveying, our classification should represent the coldwater resource in Minnesota. However, warmwater streams and rivers in Minnesota have not been representatively sampled (Table 2), and therefore, this classification system for warmwater streams is provisional until a more representative number of streams is surveyed.

The 10 coldwater classes included 3 soft-water (mean alkalinity < 100 mg/l) classes and 7 hard-water (mean alkalinity ≥100 mg/l) classes. These classes were described by size (mean width and flow), morphology, gradient, and several variables that may measure habitat degradation (cover, bank erosion, % fine substrate, and WD). The three soft-water classes all had a mean of 16% fine substrates and gradient > 50 ft/mi. The seven hard-water classes were divided into two moderately productive classes (mean alkalinity 100-200 mg/l), and five very productive classes (mean alkalinity > 200 mg/l). All hard-water classes had low gradient (< 50 ft/mi).

Our nine warmwater stream classes were separated by morphology and size, and all warmwater classes were low gradient. Warmwater streams could not be classified by alkalinity because our data base included only 16 soft-water stream reaches from forested, northern Minnesota. Therefore, the nine warmwater classes represented rivers and streams in agricultural, southern Minnesota. The largest rivers (i.e. Minnesota, Mississippi, Red, Rainy, St. Croix) were not entered into our data base and were not classified. These largest rivers require individual management.

All stream classes could not be distinguished by one or several unique and common fish species (Table 6). In the 10 coldwater classes, trout were common (present in ≥40% of streams in class) in 8 classes, were moderately common in 2 classes (present in 30-38% of the streams), while several other species (white sucker, creek chub, blacknose dace, longnose dace, and brook stickleback) were common in many classes. Although white sucker, cyprinids, and northern pike were common in most warmwater streams, some warmwater classes could be characterized by common species. Common species in Classes 13, 17, and 18 were mostly cyprinids. Class 15 was uniquely described by walleye and large catostomids. No cyprinids were common in Class 12. Classes 12 and 14 had the fewest common species (4), and Class 16 had the most (20).

In addition to identifying common species in each class, we also identified 12 sets of species that were correlated with each other, but were weakly correlated with the presence

Table 3. Abbreviations and common and scientific names for the 50 fish species present at more than 5% of the stream reaches.

Abbreviation	Common name	Scientific name
ABL	American brook lamprey	*Lampetra appendix*
BKT	Brook trout	*Salvelinus fontinalis*
BNT	Brown trout	*Salmo trutta*
RBT	Rainbow trout	*Oncorhynchus mykiss*
CNM	Central mudminnow	*Umbra limi*
NOP	Northern pike	*Esox lucius*
BMS	Bigmouth shiner	*Notropis dorsalis*
BND	Blacknose dace	*Rhinichthys atratulus*
BNM	Bluntnose minnow	*Pimephales notatus*
BRM	Brassy minnow	*Hybognathus hankinsoni*
CAP	Common carp	*Cyprinus carpio*
CRC	Creek chub	*Semotilus atromaculatus*
CSH	Common shiner	*Luxilus cornutus*
CSR	Central stoneroller	*Campostoma anomalum*
FHM	Fathead minnow	*Pimephales promelas*
FND	Finescale dace	*Phoxinus neogaeus*
HHC	Hornyhead chub	*Nocomis biguttatus*
LND	Longnose dace	*Rhinichthys cataractae*
NRD	Northern redbelly dace	*Phoxinus eos*
PRD	Pearl dace	*Margariscus margarita*
SFS	Spotfin shiner	*Notropis spilopterus*
SDS	Sand shiner	*Notropis stramineus*
SRD	Southern redbelly dace	*Phoxinus erythrogaster*
WTS	White sucker	*Catostomus commersoni*
NHS	Northern hog sucker	*Hypentelium nigricans*
SLR	Silver redhorse	*Moxostoma anisurum*
GLR	Golden redhorse	*Moxostoma erythrurum*
SHR	Shorthead redhorse	*Moxostoma macrolepidotum*
BLB	Black bullhead	*Ameiurus melas*
YEB	Yellow bullhead	*Ameiurus natalis*
STC	Stonecat	*Noturus flavus*
TPM	Tadpole madtom	*Noturus gyrinus*
BUB	Burbot	*Lota lota*
BST	Brook stickleback	*Culaea inconstans*
MTS	Mottled sculpin	*Cottus bairdi*
SMS	Slimy sculpin	*Cottus cognatus*
BLC	Black crappie	*Pomoxis nigomaculatus*
BLG	Bluegill	*Lepomis macrochirus*
GSF	Green sunfish	*Lepomis cyanellus*
LMB	Largemouth bass	*Micropterus*
PMK	Pumkinseed sunfish	*Lepomis gibbosus*
RKB	Rock bass	*Ambloplites rupestris*
SMB	Smallmouth bass	*Micropterus dolomieu salmoides*
BSD	Blackside darter	*Percina maculta*
FTD	Fantail darter	*Etheostoma flabellare*
IOD	Iowa darter	*Etheostoma exile*
JND	Johnny darter	*Etheostoma nigrum*
LGP	Logperch	*Percina caprodes*
WAE	Walleye	*Stizostedion vitreum*
YEP	Yellow perch	*Perca flavescens*

Table 4. Mean values of physical and chemical variables in 19 classes of Minnesota rivers and streams. The number of stream reaches in each class is in parentheses. There are 564 coldwater and 474 warmwater reaches.

Variable	Class 1 (71)	2 (47)	3 (30)	4 (44)	5 (28)	6 (50)	7 (62)	8 (86)	9 (69)	10 (77)
Ecological Classification[a]	CW	CW	CW	CW	CW	CW	CW	CW	CW	CW
Pool (%)	46.16	29.94	16.10	90.93	4.14	45.12	30.21	66.14	66.16	81.75
Riffle (%)	53.14	70.02	68.53	9.07	17.36	24.60	39.42	30.97	24.67	17.18
Run (%)	0.70	0.04	15.37	0.00	78.50	30.28	30.37	2.90	9.17	1.07
Average width (ft)	10.15	6.68	32.95	13.23	9.29	11.63	6.26	10.65	26.29	15.63
Average depth (ft)	0.61	0.35	0.99	1.41	1.24	0.95	0.65	0.69	1.27	0.86
Width/depth	17.73	21.08	33.66	9.97	7.50	12.22	10.45	16.86	21.83	20.47
Flow (cfs)	2.10	0.76	29.76	5.60	6.43	5.92	2.32	2.54	19.91	7.49
Gradient (feet/mile)	85.47	187.36	75.07	14.31	12.80	26.18	46.12	38.46	18.23	23.20
Sinuosity	1.32	1.19	1.32	1.40	1.18	1.90	1.31	1.62	1.64	1.34
Fines (%)	15.61	16.30	15.87	77.80	84.71	56.98	64.97	46.29	46.71	74.86
Cover	10.20	6.06	6.63	8.18	5.93	9.58	6.11	7.09	8.94	3.61
Bank erosion	1.18	1.26	1.10	1.11	1.14	2.02	1.31	2.64	1.93	2.05
Shade	2.65	2.19	1.53	1.98	1.68	1.90	1.98	1.92	1.75	1.78
Alkalinity	92.11	85.43	72.07	135.30	201.50	254.54	214.98	250.67	188.49	253.56

Variable	Class 11 (29)	12 (35)	13 (64)	14 (53)	15 (59)	16 (66)	17 (114)	18 (26)	19 (28)
Ecological Classification[a]	WW	WW	WW	WW	WW	WW	WW	WW	WW
Pool (%)	20.07	5.71	53.37	92.77	90.20	75.95	82.03	19.39	20.79
Riffle (%)	47.24	2.06	45.24	4.89	8.20	19.56	16.57	28.85	11.96
Run (%)	32.69	92.23	1.39	2.34	1.60	4.49	1.61	51.77	67.25
Average width (ft)	67.90	44.85	23.76	23.99	83.87	37.55	12.37	8.05	51.77
Average depth (ft)	1.98	2.53	0.90	2.00	1.98	1.35	0.88	1.01	2.47
Width/depth	35.41	17.63	25.89	13.14	44.51	28.00	15.87	8.55	22.09
Flow (cfs)	115.46	71.75	12.40	11.62	87.92	44.08	3.07	4.70	120.01
Gradient (feet/mile)	11.88	4.19	24.48	7.02	3.79	6.66	14.39	29.23	5.17
Sinuosity	1.39	1.52	1.47	1.43	1.42	2.12	1.49	1.38	2.39
Fines (%)	18.72	76.05	37.74	86.19	66.19	61.68	73.23	66.68	57.19
Cover	6.66	7.06	7.19	8.66	4.68	6.62	4.01	5.46	9.11
Bank erosion	1.17	1.34	1.19	1.08	1.37	2.34	1.78	1.50	1.89
Shade	1.35	1.34	2.11	1.45	1.26	1.66	1.70	1.89	1.46
Alkalinity	141.52	207.69	134.70	113.45	200.27	265.01	251.58	234.23	215.14

[a] CW = cold-water; WW = warmwater

Table 5. Discriminant functions to classify stream reaches. See Table 1 for variable abbreviations.

Stream class	Variable coefficients[a]														
	Alk	Aved	Avew	Cover	Ero	Fines	Flow	Grad	Pool	Riffle	Run	Shade	Sinu	WD	Constant
1	1.29	116.61	-36.17	3.08	3.00	8.42	-2.66	14.62	9.34	8.87	1.78	7.63	94.41	55.32	-212.76
2	1.27	125.11	-42.18	1.91	2.81	8.54	-2.75	15.78	8.50	8.89	1.56	5.88	86.79	61.09	-202.16
3	1.25	111.51	-30.43	2.00	1.74	8.32	-0.64	14.73	5.98	8.62	2.86	4.38	87.18	54.99	-195.88
4	1.35	124.06	-36.57	2.60	1.95	10.15	-2.70	13.06	9.41	6.63	1.12	6.32	89.64	54.14	-196.20
5	1.61	116.39	-32.78	2.07	1.82	10.19	-3.18	12.90	2.60	5.80	4.11	3.94	81.82	50.24	-165.12
6	1.99	106.66	-31.58	3.26	4.54	10.23	-2.31	14.02	9.27	9.46	4.48	5.58	115.35	49.09	-239.10
7	1.79	109.48	-33.63	2.09	2.23	10.64	-2.97	14.66	8.47	9.16	4.28	4.81	93.25	51.05	-201.38
8	1.92	111.84	-34.40	2.53	6.25	10.14	-2.77	14.61	9.86	9.29	2.38	5.76	103.18	53.83	-231.91
9	1.72	113.98	-32.76	2.89	3.97	9.86	-0.53	13.87	9.80	8.88	2.91	5.71	101.25	54.13	-231.74
10	1.94	114.49	-34.45	1.40	3.67	10.50	-1.85	14.39	9.93	7.96	1.63	5.09	86.20	55.82	-208.76
11	0.98	64.12	-17.19	0.79	4.62	14.66	-2.31	10.45	3.20	3.49	3.57	3.91	57.55	35.01	-137.68
12	1.19	68.27	-17.82	0.97	5.71	21.55	-3.20	10.91	1.20	2.36	5.86	4.35	63.38	33.07	-167.89
13	0.95	66.15	-20.71	1.06	5.08	18.29	-3.19	10.43	5.68	3.99	2.04	4.70	64.84	37.20	-159.04
14	0.89	70.80	-22.02	1.35	5.34	20.74	-3.60	9.16	6.18	2.87	1.86	3.55	63.77	35.89	-159.91
15	1.26	66.13	-18.15	0.50	5.58	19.97	-2.76	9.29	6.48	3.34	1.84	3.24	57.71	37.28	-167.79
16	1.33	65.48	-20.13	1.04	8.71	20.48	-2.89	9.23	6.43	3.95	2.49	4.15	79.79	36.06	-191.66
17	1.35	68.27	-21.81	0.55	6.76	20.69	-3.72	9.78	6.51	3.62	2.32	3.49	65.18	36.71	-168.03
18	1.18	61.08	-17.05	0.73	5.78	21.44	-3.42	11.97	3.35	3.41	5.70	4.31	64.81	29.67	-160.47
19	1.09	66.99	-19.58	1.37	7.58	21.32	-2.18	10.61	3.56	3.43	5.71	4.59	85.78	33.78	-197.92

[a]See Methods for variable transformation before classification

Table 6. The most prevalent fish species in each stream class. The percent of sites at which each species was found is in parentheses. Species abbreviations are identified in Table 2.

Stream class

1	2	3	4	5	6	7	8	9	10	11	12
BKT(67)	RBT(53)	WTS(63)	CNM(70)	WTS(59)	CRC(82)	BST(68)	CRC(86)	WTS(75)	WTS(86)	WTS(64)	WTS(69)
BND(67)		BKT(60)	WTS(63)	CNM(52)	WTS(78)	CRC(60)	WTS(82)	CRC(80)	BND(77)	NOP(60)	NOP(66)
CRC(64)		LND(60)	BND(58)	CRC(44)	BND(67)	BKT(58)	BND(79)	BND(76)	CRC(75)	LND(52)	CNM(40)
BST(45)		CRC(53)	CRC(58)	BST(41)	BST(59)	WTS(47)	BNT(70)	LND(76)	BNT(51)	RKB(52)	BLB(40)
RBT(40)		CSH(47)	BST(51)		BNT(53)	CNM(45)	CSR(66)	BNT(74)	LND(51)	JND(52)	YEP(40)
		BND(43)	JND(44)		BKT(53)		LND(63)	JND(58)	JND(42)	CSH(49)	
		MTS(40)			JND(53)		BST(61)	BKT(52)	CSR(40)	BLB(44)	
					FHM(49)		BKT(59)	CSR(45)		CAP(40)	
					CSR(47)		JND(51)	CSH(45)			
					CSH(41)		FHM(47)	SMS(41)			

13	14	15	16	17	18	19
CRC(73)	CNM(71)	WTS(84)	WTS(91)	WTS(81)	CRC(69)	WTS(88)
WTS(73)	WTS(67)	NOP(61)	BNM(77)	CRC(78)	WTS(69)	NOP(73)
JND(60)	NOP(52)	CAP(59)	CRC(77)	JND(63)	FHM(55)	CSH(73)
CSH(56)	CSH(50)	SHR(54)	CSH(71)	FHM(59)	CNM(48)	CRC(65)
BND(52)	CRC(46)	CSH(51)	CAP(68)	BND(59)	BND(45)	HHC(62)
CNM(51)		GLR(49)	FHM(66)	CSR(58)	JND(45)	JND(62)
BST(40)		WAE(46)	JND(66)	CSH(58)	CSH(41)	YEP(58)
		JND(44)	CSR(60)	BNM(50)		SHR(54)
		YEP(44)	GSF(58)	BMS(48)		CAP(50)
		NHS(41)	BMS(57)			FHM(50)
		BLB(41)	GLR(52)			BND(50)
		RKB(41)	BND(51)			
			NHS(49)			
			BSD(49)			
			BLB(48)			
			HHC(45)			
			RKB(45)			
			SHR(43)			
			NOP(42)			
			SDS(40)			

or absence of species in other components or sets (Table 7). Three sets were associated with coldwater species (PC3 - finescale dace and pearl dace, PC6 - trout, and PC10 - slimy sculpin). The nine sets of warmwater species were more complex. Three sets each contained a major game fish (PC1 - smallmouth bass, PC5 - other centrarchids, PC8 - walleye). A forage fish set (PC2) had seven cyprinids, two darters, and white sucker. Five other sets (PC4, 7, 9, 11, and 12) contained 1-3 species with high loadings.

These sets of species are most likely to be found in certain classes (Table 8). Streams in Class 16 should be most suitable for the smallmouth bass component (PC1), and streams in Classes 15 and 19 should be most suitable for the walleye component (PC8). Classes 1, 2, 3, 4, 5, and 7 commonly have fewer cyprinids (PC2) than other coldwater classes. The wide range of mean values for the trout component (PC6) shows that these classes differ in the number of species of trout present. We expected a principal component to include brook trout and slimy sculpin from southeast Minnesota streams. Although this did not happen, probably because of reduced distribution of the sculpin, the scores for the trout (PC6) and slimy sculpin components (PC10) were similar for the classes with streams in southeast Minnesota (6, 7, 8, 9, 10). Therefore, streams in these classes that have habitat quality for trout may be suitable for slimy sculpin.

Stream Class 1

Streams of this soft-water, coldwater class were small (width < 10 ft) to medium sized (width 10-20 ft), had moderate gradient (50-100 ft/mi), and little apparent degradation (1:1 pool/riffle morphology, very good cover, heavy shade, little bank erosion, and few fine substrates). Seventy percent of the stream reaches in this class were in the forested Lake Superior watershed, and all but one were upstream from the natural fish barriers near their mouths in Lake Superior. Only five species were common, including introduced brook trout and steelhead.

Stream Class 2

This soft-water, coldwater class includes small streams (width < 10 ft) with riffle morphology, light bank erosion, high gradient (> 100 ft/mi), moderate cover, and low sinuosity. Of the 79% of the streams in this class that were in the Lake Superior watershed, 89% are direct tributaries to Lake Superior, and most were found downstream of the natural fish barrier. Rainbow trout was the only common fish species, and brook trout were moderately common. The mean score for PC2 showed poor suitability for cyprinids.

Stream Class 3

The soft-water streams in this class were large for coldwater streams (width > 20 ft), and had riffle morphology, moderate gradients, light bank erosion, a high WD, and moderate cover. A majority of the stream reaches were in the Lake Superior watershed. Seven fish species were common, including brook trout.

Stream Class 4

This widely distributed class was present in 15 different watersheds, and included soft-water and hard-water streams. The medium sized streams (width 10-20 ft) in this coldwater class had 9:1 pool/ riffle morphology, a low mean WD, moderate-good cover, and light bank erosion. Although this class included many of the streams within the native brook trout range of east-central Minnesota, trout were not common - only found in 37% of the streams - and the mean score for PC6 was negative. This is the most suitable class for finescale dace and pearl dace (PC3).

Stream Class 5

The hard-water streams in this coldwater class were small (< 10 ft) to medium sized (width 10-20 ft) with light bank erosion, low WD and sinuosity, poor cover, and abundant fine substrates. Most streams were in north-central Minnesota, and were outside the

Table 7. Loadings (>0.50) for fish species in 12 principal components. Species abbreviations are identified in Table 2.

	Principal Component											
Species	1	2	3	4	5	6	7	8	9	10	11	12
NHS	0.74											
GLR	0.71											
SMB	0.70											
STC	0.59											
RKB	0.53											
CSR		0.73										
JND		0.68										
CRC		0.67										
BND		0.62										
WTS		0.61										
BNM		0.57										
CSH		0.56										
SRD		0.55										
BMS		0.54										
FTD		0.54										
FND			0.76									
PRD			0.74									
BSD				0.60								
BLG					0.68							
LMB					0.68							
PMK					0.65							
YEP					0.60							
BLC					0.52							
RBT						0.70						
BKT						0.57						
BNT						0.57						
LND						0.50						
IOD							0.79					
SHR								0.68				
SLR								0.66				
WAE								0.65				
SFS								0.60				
BUB									0.73			
LGP									0.52			
SMS										0.73		
TPM											0.71	
YEB											0.64	
BLB												0.62
GSF												0.58
CAP												0.57

Table 8. Mean fish principal component scores of 10 coldwater stream classes (1-10) and 9 warm water classes (11-19). Table 7 identifies the species which load heavily on each of the principal components. Separate PCAs were done on coldwater and warmwater streams.

Stream	Mean score on fish principal component											
Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
1	-0.228	-0.641	0.358	-0.370	-0.196	0.983	0.049	-0.213	-0.322	-0.129	-0.156	0.089
2	-0.101	-1.036	0.068	-0.449	-0.248	0.797	-0.252	-0.326	-0.471	-0.664	0.001	0.140
3	-0.243	-0.422	-0.012	-0.386	-0.007	1.032	-0.196	-0.267	0.685	-0.231	0.147	0.350
4	-0.270	-0.300	0.932	-0.151	-0.014	-0.253	0.038	-0.390	0.052	0.167	-0.214	0.167
5	-0.358	-0.700	0.125	-0.105	-0.069	-0.018	0.500	-0.315	0.122	-0.280	-0.087	0.014
6	-0.317	0.380	0.045	-0.032	-0.066	0.441	0.158	-0.149	-0.224	0.486	-0.255	-0.167
7	-0.298	-0.482	0.414	0.025	-0.267	-0.114	0.114	-0.258	-0.209	0.146	-0.202	-0.289
8	-0.306	0.615	-0.313	-0.176	-0.314	0.512	-0.053	-0.002	-0.244	0.542	-0.295	-0.655
9	0.344	0.308	-0.115	0.086	-0.006	1.138	0.126	-0.303	0.385	0.805	0.004	0.018
10	-0.484	0.242	-0.463	-0.002	-0.283	0.093	-0.136	-0.065	0.058	0.376	-0.457	-0.068
11	0.513	-0.397	-0.354	-0.259	0.551	-0.230	0.050	0.587	0.856	-0.076	0.684	-0.039
12	-0.052	-0.719	-0.345	0.390	0.295	-0.552	0.019	0.424	0.286	-0.256	0.682	-0.272
13	0.351	0.118	0.389	-0.190	0.174	-0.434	-0.073	-0.279	0.534	-0.025	-0.088	0.193
14	-0.055	-0.473	0.552	-0.198	0.690	-0.655	0.144	-0.452	0.049	0.146	0.483	0.290
15	0.604	-0.198	-0.167	0.447	0.666	-0.324	-0.443	1.474	0.041	-0.076	0.127	0.133
16	1.029	0.462	-0.162	0.875	-0.278	-0.379	-0.034	0.512	-0.428	-0.254	0.478	0.626
17	-0.056	0.690	-0.217	0.095	-0.158	-0.636	-0.271	-0.366	-0.328	-0.463	-0.020	-0.209
18	-0.357	-0.167	-0.115	0.182	-0.118	-0.548	0.454	-0.113	0.012	-0.151	-0.170	-0.223
19	0.110	0.323	-0.437	-0.148	0.385	-0.480	1.450	1.083	0.503	-0.366	0.335	0.447

native brook trout range. Only four nongame fish species were common. Introduced brook trout and brown trout were present in 30% of the streams of this class.

Stream Class 6

Streams in this coldwater class were small (< 10 ft) to medium sized (width 10-20 ft), > 50% fine substrates, good fish cover, and high sinuosity. Most streams were in southeast and north-central Minnesota, and were managed for trout. Ten species were common, including brook trout, brown trout, and cyprinids.

Stream Class 7

The hard-water streams of this coldwater class were small (< 10 ft), > 50% fine substrates, light bank erosion, moderate cover, and a low WD. This class was found throughout Minnesota, but was most common in southeast and central Minnesota. Only five species of fish were common, including brook trout. The streams in this class were most suitable for the blackside darter (PC4).

Stream Class 8

Streams in this hard-water, coldwater class were small (< 10 ft) to medium sized (width 10-20 ft), and had 2:1 pool/riffle morphology, severe bank erosion (erosion =3), moderate cover, and < 50% fine substrates. Most streams were in southeast Minnesota. The 10 common fish species included cyprinids, brook trout, and brown trout.

Stream Class 9

The large (width > 20 ft) hard-water streams in this coldwater class were described by 3:1 pool/riffle morphology, < 50% fine substrates, good cover, and high sinuosity. This class includes most of the larger trout streams of southeast Minnesota, and most stream reaches were in the Root River watershed of southeast Minnesota. Ten fish species were common, including brook trout, brown trout, and cyprinids. This is the only stream class where slimy sculpin were common and there was a high mean score for PC10.

Stream Class 10

Streams in this hard-water, coldwater class were intermediate in size (width 10-20 ft), and had a pool/riffle morphology of 4:1, > 75% fine substrates, and very low abundance of fish cover. Most streams were in southeast Minnesota, and seven fish species, including brown trout, were common.

Stream Class 11

This class of large, warmwater streams (width > 40 ft) was described by pool/riffle/run morphology, few fine substrates, light bank erosion, and little shade. These streams were most frequent in the northern one-half of the state. Eight species, including northern pike, were common. The mean score for PC1 shows moderate suitability for the smallmouth bass component, however, smallmouth bass were present in only 24% of the streams in the class. The mean score for PC8 shows moderate suitability for the walleye component, but they were present in only 12% of the streams in the class.

Stream Class 12

This class of large, warmwater streams (> 40 ft), had run morphology and light bank erosion. Most were in the Upper Mississippi River watersheds of central and north-central Minnesota. Only five fish species were common, and the low score for PC2 showed low suitability for cyprinids.

Stream Class 13

This class of medium sized, warmwater streams (width 15-50 ft), was characterized by a 1:1 pool/riffle morphology, < 50% fine substrates, and light bank erosion. The class was distributed throughout east-central, southeast, and north-central Minnesota. Seven fish species were common and did not include game fish.

Stream Class 14

The medium sized streams (width 15-40 ft) in this warmwater class had 9:1 pool/riffle morphology, good cover, and light bank erosion and shade. This class was found in the upper Mississippi River drainage and east-central Minnesota. Five fish species, including northern pike, were common in streams of this class.

Stream Class 15

The large streams in this warmwater class (width >40) ft) had 9:1 pool/riffle morphology, poor cover, and light bank erosion and shade. Most streams were in southern and east-central Minnesota. Twelve fish species, including walleye, were common, and the high score for PC8 showed this class to be most suitable for walleye. The mean score for PC1 shows moderate suitability for the smallmouth bass component, and smallmouth bass were moderately common (in 36% of the streams).

Stream Class 16

The medium sized warmwater streams (width 15-40 ft) of this class had 4:1 pool/riffle morphology, high sinuosity, and severe bank erosion. This class was found in agricultural southeast, south-central, and west-central Minnesota. More fish species were common in this class (20) than in any other class, and the mean score for PC1 identifies this class as the most suitable for the smallmouth bass component. Smallmouth bass were moderately common (in 31% of the streams). The mean score for PC8 indicates moderate suitability for the walleye component, but walleye were present only in 24% of the streams in the class.

Stream Class 17

The small streams of this warmwater class (width < 15 ft) were distinguished by 4:1 pool/riffle morphology and poor fish cover. Seventy-five percent of the reaches were in agricultural southeast and south-central Minnesota. Seven of the nine fish species that were common were cyprinds.

Stream Class 18

Streams of this warmwater class were small (width <15 ft) with a low WD ratio, poor fish cover, and light bank erosion. This class was widely distributed in agricultural Minnesota, and the seven common fish species did not include game fish.

Stream Class 19

This class of large warmwater streams (>40 ft) had run-dominated morphology and good fish cover. Most stream reaches were found in agricultural Minnesota. Eleven species were common, and the mean score for PC8 indicates this class is suitable for the walleye component. The mean score for PC7 identifies this class as most suitable for the Iowa darter.

Uses and Recommendations

This classification is recommended for use by managers in those regions of the state adequately represented in our stream survey data base. It should be applicable statewide to coldwater streams because of their limited distribution and long history of stream surveys. However, statewide application to warmwater streams is not recommended because of the limited number of stream surveys in parts of the state.

This classification distinguishes classes of rivers and streams with potential for recreational fisheries. Most streams in the 10 coldwater classes have potential for trout management. The trout species present in each class has been influenced by habitat degradation, stocking, and naturalization. Northern pike are common in streams of Classes 11, 12, 14, 15, 16, and 19. Streams in Classes 11, 15, and 16 have potential for smallmouth bass management while streams in Classes 11, 15, 16, and 19 have potential for walleye management.

It would be informative to compare trout growth rates, the extent of natural reproduction, and density among stream classes. The cyprinid component (PC2) may be an indicator of habitat degradation in coldwater streams, or an indicator of potential to support growth of large (piscivorous) trout or higher densities of trout. The cyprinid component may be useful for identifying streams where experimental regulations might have the best chance for producing large trout.

Managers need to consider habitat quality as a possible factor limiting the fishery before selecting management strategies. Habitat quality can be evaluated in a general way by examination of the stream class, and more specifically by comparing habitat variables to the means and quartiles of the stream class or a reference stream. Habitat variables that fall outside the inter-quartile range (Appendix Tables 1 and 2) may indicate poor habitat quality or suggest other limiting factors. Because habitat quality can rarely be completely assessed with physical and chemical variables (Fausch et al. 1990), the fish community data of Tables 6-8 should complement direct habitat evaluation. Fish component scores (Table 8) should be the best index of suitability for those species that have high loadings on one component (Table 7).

As an example, we reexamined habitat quality for smallmouth bass in a stream where a smallmouth bass fishery was reestablished above a dam (South Branch Middle Fork Zumbro River), and a stream where efforts to reestablish smallmouth bass above a dam failed (North Fork Zumbro River). Fishery mangers have assumed that smallmouth bass were native to both branches. Dams were built on both streams in the late 1800s. Agricultural, industrial and municipal pollution, and fish kills (Surber 1924; Moyle 1955) apparently exterminated the species above the dams in both streams. Self-sustaining smallmouth bass populations were sampled below the dams in 1974 in South Branch, and in 1982 in the North Fork. A limited review of the watershed history indicates that industrial and municipal pollution in South Branch was not as severe as in the North Fork (Surber 1924), and a 1980-1982 fisheries stream survey of the South Fork Middle Branch Zumbro River recommended reintroduction of bass above the dam because of suitable habitat. Moyle (1955) concluded that the 11 miles of the North Fork above the dam could provide habitat for smallmouth bass if pollution was eliminated, and survey reports in 1976-81 suggested that water and habitat quality were adequate for smallmouth bass management. Age-0 smallmouth bass were stocked in five years between 1982 and 1987. Assessments of these stockings found very low survival and only one naturally produced age-0 smallmouth bass. The 1993 assessment, done at a high stream stage, reported good habitat and no smallmouth bass, and questioned whether low or normal flow could provide smallmouth bass habitat. As a last attempt to establish smallmouth bass, adults were stocked above the dam near a site with good spawning habitat, adequate cover, and abundant forage. An assessment in 1996 found no survival of these fish. These unsuccessful stockings revealed habitat quality was inadequate for smallmouth bass above the dam in the North Fork, thereby contradicting the 1976-81 stream survey conclusions. The conclusion that habitat above the dam in the South Branch was suitable was validated by the successful stockings of smallmouth bass during 1983-87 that produced a reproducing population by 1995.

Although we could not reclassify all stream reaches of both streams because of missing data, our stream classification indicated the South Branch reaches with smallmouth bass fell primarily in Class 16; those reaches in the North Fork proposed for bass management, in Class 15. Class 16 had the highest mean score for fish PC1 (1.03; the component on which smallmouth bass had a high loading) and Class 15 had a lower mean score (0.60). All five species with high loadings on fish PC1 were found in the South Branch, but only one, stonecat, was found in the North Fork. All four species that Lyons et al. (1988) identified as comprising the smallmouth bass assemblage in southwestern Wisconsin were found in the South Branch, but only one was found in the North Fork. Similarly, eight of nine species associated with smallmouth bass in southern Minnesota (Thorn and Milewski 1994) were present in the South Branch, but only one was found in the North Fork. Below the dam in each stream where smallmouth bass were present, at least five of eight species associated with smallmouth bass were present in each stream.

Thorn and Milewski (1994) found that stations with smallmouth bass in southern Minnesota rivers and streams were wider (44.6 ft vs. 21.0 ft) and deeper (1.3 ft vs. 1.0 ft); and had more riffles (23% vs. 17%), more coarse substrates (49.6% vs. 29.7%), and less silt (5.8% vs 21.0%) than stations without smallmouth bass. By those standards, habitat for smallmouth bass was better in the South Branch than in the North Fork. Gradients for smallmouth bass streams in Wisconsin ranged from 0.1-0.5% (Lyons 1991), with the gradient for the North Fork being slightly below this range. Sinuosity was greater in the South Branch and flow was more stable than in the North Fork, indicating the South Branch would sustain higher habitat quality. More variable flows and lower base flows can reduce habitat quality and contribute to the stressful environmental conditions that can reduce smallmouth bass populations (Lyons et al. 1989). For example, in southwest Wisconsin, Graczyk et al. (1993) reported two occasions of smallmouth bass mortality from dissolved oxygen concentrations <1 mg/l during drought flow (1988-99). In the North Fork, some survival of smallmouth bass was noted before the drought of 1988-99, but no smallmouth bass were sampled after the drought. During the early 1980s surveys of these 2 streams, mean flow in the North Fork reach was 43% less than in the South Branch, suggesting less deep water for cover.

Findings from several Wisconsin studies also substantiate that the South Branch has better habitat for smallmouth bass than does the North Fork. Lyons et al. (1988) and Lyons (1991) reported stream size to be important for smallmouth bass, and Lyons (1989) found smallmouth bass to be a species distinguishing small rivers (width 32.2-64.4 ft) but not creeks (width 9.6-32.2 ft). The average width of reaches proposed for smallmouth bass management in the North Fork was 31.0 ft, while the average width of the stations with smallmouth bass in South Branch was 45 ft. Smallmouth bass prefer substrate>40-45% rocks (Lyons et al. 1988; Lyons 1991). Coarse sediments averaged 32% in the North Fork and 62% in the South Branch.

The poor physical habitat for smallmouth bass and the variable flow in the North Fork are due to inherent watershed conditions. The basin of South Branch was about 20% larger than the North Fork. Lyons 1989 suggested that larger streams often have larger drainage basins. The greater sedimentation in the North Fork cannot be explained by land use because both watersheds were >90% agricultural. However, the soil erodibility factor, soil types, geomorphic regions, and soil slope classes suggest a greater erosion potential in the North Fork watershed. The South Branch has a higher gradient. Geomorphic region and aquifer materials may help account for the more stable flow in South Branch.

The coldwater classification may be used to select species for management, provide realistic fisheries objectives, and select candidate streams for special regulations or habitat improvements. In general, streams in Classes 1, and 3-8 should be managed for brook trout, streams in Classes 9 and 10 for brown trout, and streams in Class 2 for steelhead. Also, some of the larger streams of Class 9 in southeast Minnesota could be candidates for rainbow trout management to provide a diversity of fishing opportunities without harming wild sustainable fisheries. When productivity is inherently low (Classes 1-3), it may be unrealistic to expect high trout abundance of desirable sizes and popular fisheries. Streams in

Classes 6 and 9, and other streams in Classes 6-10 with habitat quality greater than the interquartile range, may provide the best candidate streams in southeast Minnesota for special regulations to produce more large brown trout (MNDNR 1997). The best candidates for habitat rehabilitation would be the degraded, medium size streams in Classes 5, 6, 8, and 10. Thorn et al. (1997) recommended evaluating habitat rehabilitation of degraded small and large streams for experimental learning. These would fall in Classes 5-8 and Class 9, respectively. Because stocking of brown trout has failed to establish sustainable fisheries in most northeast and east-central Minnesota streams, we discourage brown trout stocking in streams of Classes 1 and 3, where brook trout are naturalized, and in streams of Class 4, where brook trout are native. Candidate streams elsewhere in the state for brown trout stocking to provide fisheries should have moderate or good cover (Classes 6-9) for survival and growth, and no wild trout (Thorn et al. 1997). Streams in Classes 5 and 10 would be poor candidates for successful stocking because of poor cover.

Fisheries managers can also use this classification for the conservation and management of uncommon species or a larger fish assemblage. Four species of special concern to MNDNR were noted in our survey data base, and their habitat can be evaluated from this stream classification. This classification can guide the reintroduction of species within their native range. For example, the prevalence and distribution of the historic fish community (brook trout and slimy sculpin) in coldwater, spring-fed streams in southeast Minnesota has been reduced by habitat degradation (Eddy and Underhill 1974). Fishery managers have restored wild brook trout to 138 of 259 stream reaches (Thorn and Ebbers 1997). Slimy sculpin were present in only 57 of these 259 reaches, therefore, 81 stream reaches with wild brook trout are candidates for slimy sculpin reintroduction. Also, fish communities should benefit from habitat management for most game fish because game fish are typically top carnivores and represent an integration of stream conditions for the community (Rabeni 1993). For example, habitat features important for community health in Wisconsin coldwater streams are similar to those needed for trout (Simonson et al. 1994).

This classification can help prioritize, develop, and evaluate stream and habitat rehabilitation plans. An examination of classification variables should show which variables should be changed for rehabilitation. For example, in southeast Minnesota coldwater streams (Classes 7 - 10), values for the pool/riffle ratio, amount of fine substrates, and cover show that streams in Class 10 are the most degraded and, therefore, most in need of rehabilitation. Values in the upper quartile of the class or values in a target class can provide a measurable objective for planning and evaluating, and with a discriminant function worksheet managers can model the effects of changing variables. However, we do not recommend using our classification as the only tool in developing stream restoration plans. Managers need a more complete historical stream and watershed review than found in stream surveys; a more complete fluvial geomorphological analysis of stream conditions such as Gordon et al. (1992), Newbury and Gaboury (1993), and Rosgen (1996), and the inclusion of other resource agencies with stream expertise.

The physical habitat variables and distribution of nongame fish species from this classification system should be included in ecological stream monitoring plans. Fishery biologists routinely monitor game fish abundance to evaluate trends and management efforts, but the distribution and abundance of other species (Moyle 1994; Fausch et al. 1990), and stream habitat (Conquest et al. 1994) should also be monitored. Although models that relate fish abundance and habitat variables suggest that habitat changes could be detected by monitoring only fish abundance, fish density should not be used as the sole biological indicator of habitat quality (Van Horne 1983; Minns et al. 1996). Also, detecting change is easier with physical variables than biological variables because they are less variable (Robison 1997).

In addition, we recommend that MNDNR-Fisheries create a stream survey work group to improve this classification for stream management. This group should use Table 2 to prioritize future survey efforts to include surveys from all Minnesota rivers and streams. We recommend a minimum of 10 stream surveys for each watershed (MNDNR 1978), and 50 for each instream flow region. The work group could periodically reclassify streams as classification is iterative and can be improved as our knowledge base increases (Hughes et al. 1994). This work group could also standardize fish sampling, evaluate the status of uncommon fish assemblages, and compile successful management efforts for each stream class.

To minimize the potential for misclassification, we recommend strict adherence to instructions in the stream survey manual (MNDNR 1978). From reviews of studies evaluating accuracy and precision of measuring habitat variables (Platts et al. 1983; Hogle et al. 1993; Roper and Scharnecchia 1995; Wang et al. 1996), we conclude that the identification of pools, riffles, and runs would be the most likely cause of misclassification.

Where a complete stream survey cannot be done to classify a stream reach, we suggest a quick classification method: 1) identify the stream reaches by the Phase I survey described in the stream survey manual; 2) identify reaches as coldwater or warmwater; 3) measure the 14 classification variables used in this study; and 4) enter these variables into the worksheet to identify stream classes using discriminant functions.

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Appendix Table 1. Coldwater stream class medians and intra-quartile ranges for classifications variables. See Table 2 for abbreviations.

	Class 1		Class 2		Class 3		Class 4		Class 5	
Variable	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
Pool	44	26-65	26	19-37	9	1-26	100	83-100	0	0-4
Riffle	56	35-73	74	63-81	63	51-86	0	0-15	0	0-21
Run	0	0-0	0	0-0	7	0-35	0	0-0	93	70-100
AveW	10	7-12	5	4-9	28	18-41	12	8-18	7	5-10
AveD	0.5	0.4-0.7	0.4	0.2-0.4	0.9	0.8-1.3	1.3	1.0-1.7	1.2	0.8-1.6
WD	17	14-22	17	12-26	30	21-44	10	7-12	7	5-10
Flow	1	1-3	1	0-1	21	7-51	3	2-5	4	2-9
Grad	64	42-90	209	58-292	42	20-106	9	5-18	11	5-20
Sinu	1.5	1.4-1.8	1.2	1.1-1.2	1.3	1.2-1.4	1.4	1.2-1.6	1.2	1.1-1.3
Fines	8	2-26	8	0-29	6	1-19	86	60-98	90	62-100
Cover	10	9-11	6	5-8	6.5	5-8	8	7-10	6	5-7.5
Ero	1	1-1	1	1-1	1	1-1	1	1-1	1	1-1
Shade	3	2-3	2	2-3	1	1-2	2	1-2	2	1-2
Alk	80	43-102	60	41-77	31	21-103	101	69-222	219	139-282

	Class 6		Class 7		Class 8		Class 9		Class 10	
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
Pool	44	26-63	26	15-50	72	55-82	72	58-80	85	70-94
Riffle	24	20-36	34	17-52	25	17-42	21	11-30	14	4-29
Run	22	8-46	30	7-49	0	0-2	3	0-11	0	0-0
AveW	10	7-14	6	4-10	10	8-14	25	21-31	12	9-19
AveD	0.8	0.7-1.0	0.6	0.5-0.8	0.7	0.5-0.9	1.2	1.0-1.4	0.8	0.5-1.0
WD	12	9-16	11	7-14	15	12-19	21	17-25	17	13-26
Flow	3	2-6	1	1-3	2	1-3	19	11-31	5	2-9
Grad	23	12-46	32	20-50	33	21-48	15	11-23	19	13-29
Sinu	1.7	1.6-2.1	1.3	1.2-1.4	1.5	1.4-1.8	1.6	1.4-1.9	1.3	1.1-1.5
Fines	58	37-76	70	51-87	45	27-68	46	27-67	76	58-93
Cover	9	8-11	6	5-8	7	6-8	9	8-11	3	2-4
Ero	2	1-3	1	1-1	3	2-3	2	1-2	2	1-2
Shade	2	1-2	2	2-2	2	1-2	2	1-2	2	1-2
Alk	248	235-269	248	145-275	248	246-263	245	145-248	253	248-268

Appendix Table 2. Warmwater stream class medians and intra-quartile ranges for classifications variables. See Table 2 for abbreviations.

Variable	Class 11		Class 12		Class 13		Class 14		Class 15	
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
Pool	9	0-19	0	0-1	54	36-73	100	95-100	95	78-100
Riffle	34	15-87	0	0-4	45	26-60	0	0-4	1	0-17
Run	32	4-65	100	93-100	0	0-0	0	0-0	0	0-0
AveW	54	40-86	27	19-54	17	10-36	21	12-31	73	49-110
AveD	1.6	1.4-2.5	2.3	1.7-3.0	0.8	0.6-1.2	1.6	1.3-2.3	1.8	1.4-2.5
WD	33	27-45	13	9-21	22	16-34	12	8-18	41	30-54
Flow	72	40-136	34	11-83	4	1-14	4	1-14	62	21-116
Grad	5	3-16	3	2-6	17	9-28	3	2-7	3	2-5
Sinu	1.4	1.2-1.6	1.4	1.3-1.6	1.4	1.2-1.6	1.4	1.2-1.6	1.4	1.2-1.5
Fines	11	3-23	80	61-99	31	22-55	91	74-100	63	48-89
Cover	6	5-8	7	6-9	7	5-9	9	8-10	5	3-7
Ero	1	1-1	1	1-2	1	1-1	1	1-1	1	1-2
Shade	1	1-2	1	1-2	2	2-3	1	1-2	1	1-2
Alk	166	55-218	219	166-251	103	55-235	98	40-142	228	100-263

Variable	Class 16		Class 17		Class 18		Class 19	
	Median	Range	Median	Range	Median	Range	Median	Range
Pool	82	65-91	83	70-99	21	9-45	9	2-25
Riffle	14	5-29	17	1-30	18	1-44	9	0-18
Run	0	0-7	0	0-0	45	21-67	78	58-88
AveW	34	19-48	.11	8-15	9	4-14	44	29-70
AveD	1.3	0.9-1.7	0.9	.06-1.0	0.9	0.6-1.5	2.3	1.8-3.0
WD	25	20-34	15	11-19	9	5-12	19	14-23
Flow	22	5-53	2	1-4	2	1-5	76	45-153
Grad	5	4-8	10	6-21	22	9-35	3	2-5
Sinu	2.1	1.8-2.4	1.4	1.3-1.7	1.4	1.2-1.7	2.2	2.0-2.8
Fines	63	47-78	78	56-91	62	50-83	58	49-73
Cover	6	5-8	4	3-5	7	3-8	9	7-10
Ero	2	2-3	2	1-2	1	1-2	2	1-3
Shade	2	1-2	2	1-2	2	1-2	1	1-2
Alk	260	230-291	251	228-290	252	207-290	241	150-278

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