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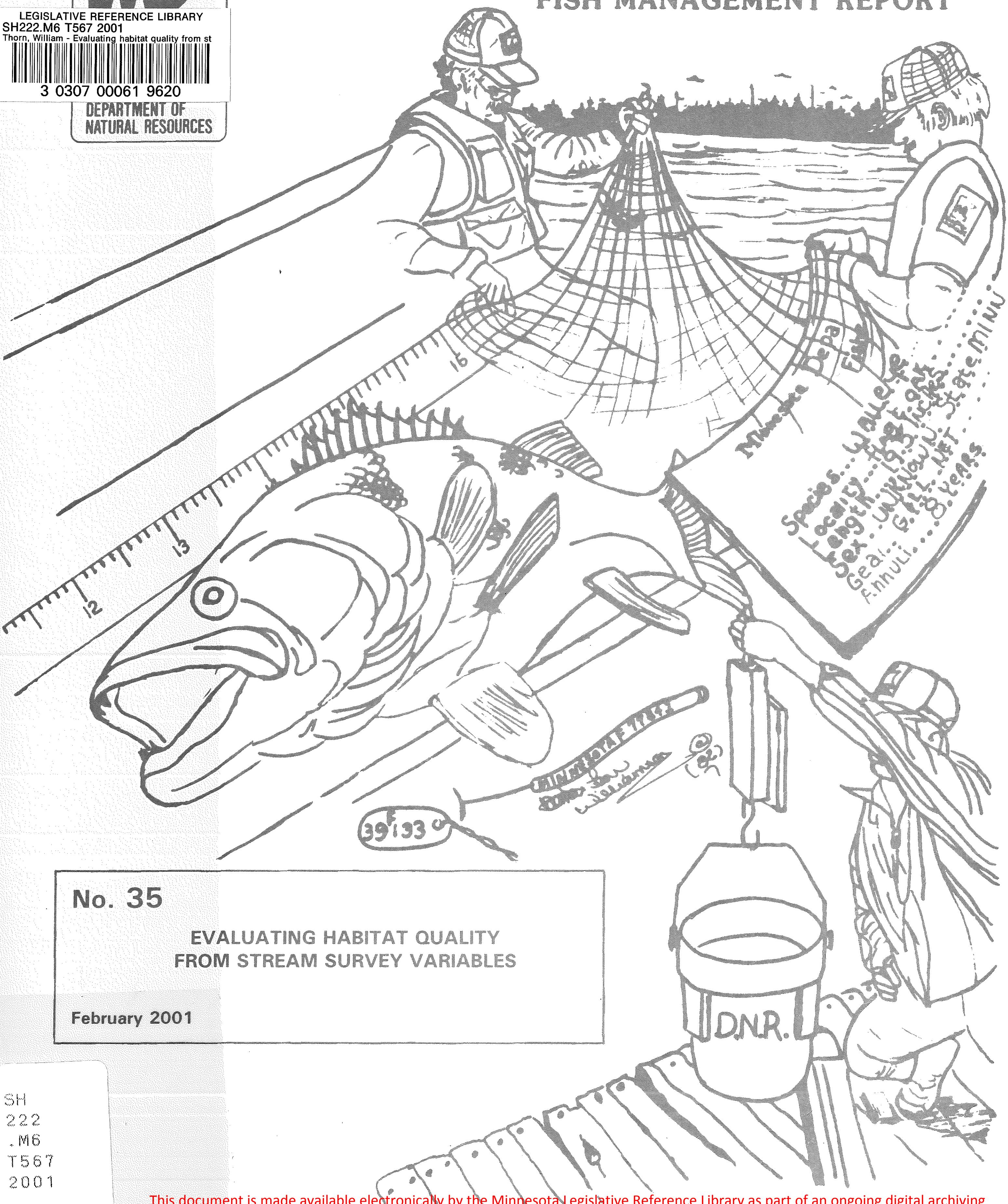

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EVALUATING HABITAT QUALITY FROM STREAM SURVEY VARIABLES

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EVALUATING HABITAT QUALITY FROM STREAM SURVEY VARIABLES

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Abstract– We developed indices of habitat quality for Minnesota rivers and streams from habitat variables recorded in stream surveys. Indices are described for trout streams, smallmouth bass streams, and large and small warmwater streams. We identified the range of indices that may be classified as poor, fair, good, or excellent habitat, suggested management options for these classes, and discussed some uses of these measures of habitat quality.

Introduction

Biologists of the Minnesota Department of Natural Resources (MNDNR) need a method to quantify habitat quality for rivers and streams. A quantitative method would allow comparison of streams, identification of important habitat variables, and classification of habitat quality for fisheries management. In Minnesota, biologists have evaluated habitat most frequently with qualitative observations to reduce time; however, this method was not always successful (Thorn 1990; Bushong and Anderson 1996; Thorn and Anderson 1999; MNDNR unpublished report). Three other methods of evaluating habitat quality are less frequently used. Habitat quality has been estimated from trout biomass in coldwater streams (MNDNR 1993; Thorn et al. 1997), but reliability of the method has not been verified and may be limited because of large natural fluctuations in fish abundance (Van Horne 1983). Habitat quality has been evaluated from the failures of stocked fish to survive (MNDNR unpublished reports; Thorn and Anderson 1999), but this method is very time-consuming and cannot be widely applied. Habitat quality has been estimated indirectly from models that predict fish abundance from measured habitat variables (Wesche 1976; Binns and Eiserman 1979; Thorn 1988). One such model has been validated for regional use (Thorn 1992a); however, the necessary habitat variables are not all measured in standard stream surveys, and would be time-consuming to measure. A more general method to evaluate habitat quality based on stream survey data (MNDNR 1978) was needed.

A database with 13 stream survey variables for 553 coldwater (trout) reaches and 536 warmwater reaches was recently compiled for classification of Minnesota rivers and streams (Thorn and Anderson 1999). Working from this database, we developed a matrix similar to that of Simonson et al. (1994) to show how variables may be assigned scores, and how aggregate scores may quantify habitat quality in Minnesota rivers and streams. Simonson et al. (1994) measured habitat quality to compare habitat quality for fish among

Wisconsin streams. They measured seven variables for small streams (<32.8 ft wide) and five variables for small to medium rivers (>32.8 ft wide). Their matrices cannot be used to evaluate habitat in Minnesota rivers and streams because all their variables are not measured in Minnesota stream surveys.

Our primary objectives were to develop indices of habitat quality for Minnesota rivers and streams from variables in the Minnesota stream classification database, to classify habitat based on these indices, and to recommend management by habitat quality class. Indices of habitat quality that are related to fish abundance would further help biologists evaluate fish abundance, prepare management objectives, and evaluate management efforts. A presumably predictable relationship exists between habitat quality and fish abundance (Rabeni 1992). Our secondary objective was assess the assumption that as habitat quality increases, so does abundance and biomass.

Methods

Most coldwater streams are in northeast and southeast Minnesota (Figure 1) and have a long history of stream surveys (Thorn and Anderson 1999). The northeast brook trout data set contained coldwater stream reaches of stream classes 1-3 in the Lake Superior watershed with brook trout present or with brook trout present in tributaries. Brown trout are present in very few of these streams. Trout abundance in these streams may be limited by productivity, water temperature, and flow. The southeast data set of stream reaches in stream classes 6-10 was divided into coldwater streams with brook trout, and with brown trout, rainbow trout, or no trout present. Trout abundance in many of these steams is limited by adult habitat.

Most warmwater streams in the stream classification database were in agricultural, southern Minnesota. Warmwater streams in Minnesota do not have a long history of management and many have not been surveyed (Thorn and Anderson 1999). We divided these stream reaches into three data sets: streams less than and greater than 32.8 ft wide (Simonson et al. 1994), and a smallmouth bass data set that included all warmwater streams with smallmouth bass present, regardless of stream size.

Other studies have evaluated habitat from variables similar to some in the stream classification database (e.g. Binns and Eiserman 1979; Raleigh et al. 1986; Simonson et al.1994). We selected variables that had been informative in other studies and that we could score from 1- 4, and developed matrices of variables and variable abundance similar to Simonson et al. (1994). The abundance of some variables (e.g. erosion, shade, stream width, and percent pool area) was scored directly from survey data, and values for other variables (e.g. percent fine substrate, width:depth ratio, cover, and pool type) must be calculated from the survey data before scoring. If the reach contained more than one sampling station, we calculated a reach average. Scores for all variables were summed for a measure of habitat quality.

Frequency distributions of habitat quality measurements were tabulated and then partitioned to classify habitat quality as poor, fair, good, and excellent. We assumed that good and excellent habitat quality would not be abundant because of habitat degradation.

Only for the southeast and northeast coldwater streams could we assess the assumption fish abundance increases as habitat quality increases. Estimates of fish abundance are not required in Minnesota stream surveys, and fish sampling is not standardized. Managers have estimated trout abundance in most southeast trout streams several times since 1970 (MNDNR file data) and in some northeast stream surveys. Therefore, we used correlation analysis to assess the relationship between habitat quality and trout biomass. In southeast trout streams, we used the biomass estimate from the year of survey or the year nearest the survey. Brown trout biomass has fluctuated during 1970-1999 (MNDNR unpublished data); and most streams were surveyed during 1975-1981 and 1985-1993, periods of low (mean of 45.7 lbs/a) and increasing (mean of 95.4 lbs/a)

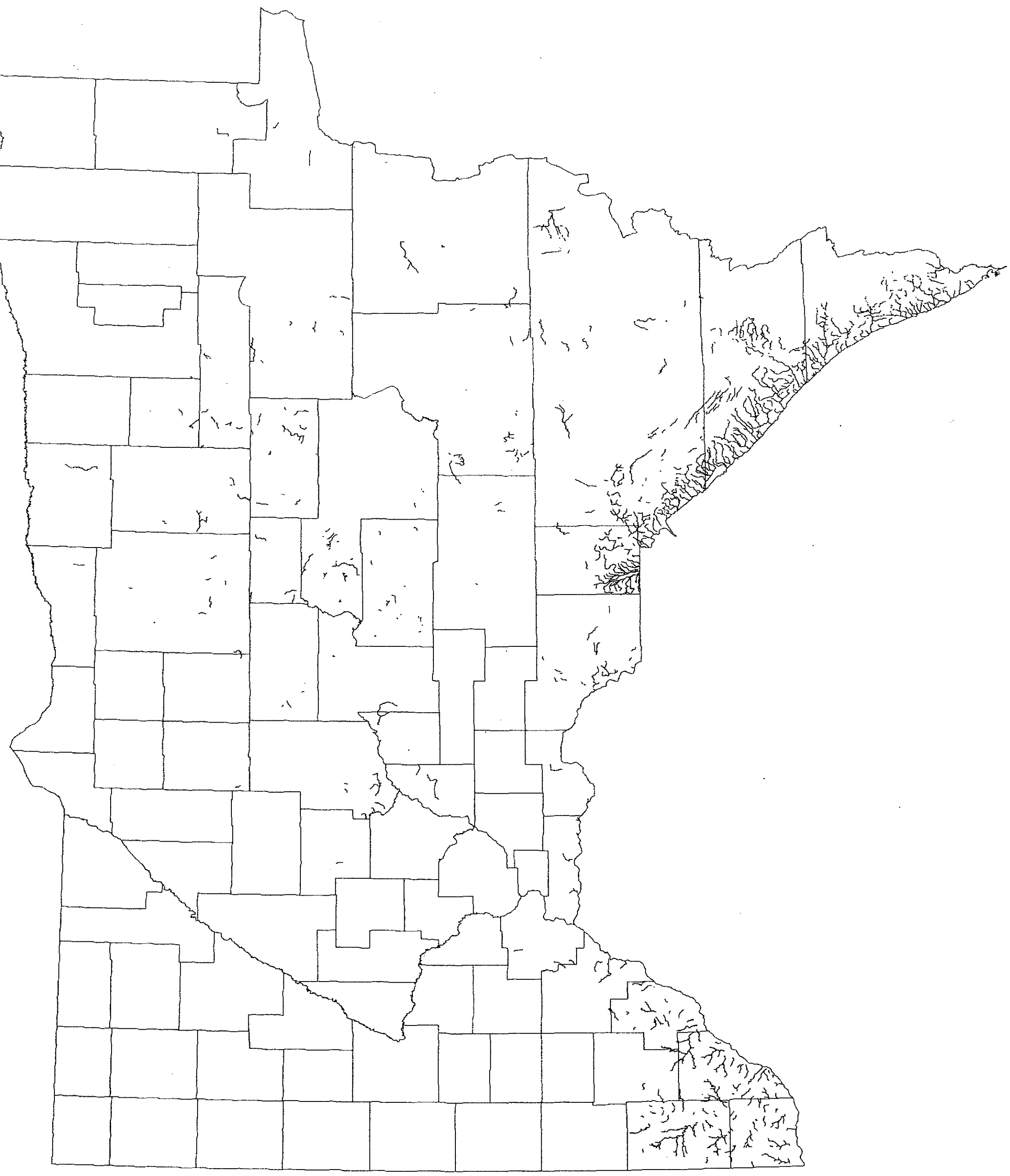

Figure 1. Distribution of designated trout streams in Minnesota.

biomass, respectively. Trout biomass was more stable during 1994-99 (mean of 112.8 lbs/a), and we multiplied biomass for streams surveyed during 1975-1981 by 2.5 and for streams surveyed during 1985-1993 by 1.2. Because larger brown trout have some different habitat requirements than smaller trout (Thorn and Anderson 1993), we also correlated habitat quality with abundance of brown trout longer than 300 mm and longer than 380 mm. For northeast brook trout streams, when population estimates were not included in the survey, we estimated abundance and biomass from survey data. For streams with two electrofishing passes, we used the two-pass depletion formula of Platts et al. (1983); and for streams with one electrofishing pass, we used a catchability coefficient calculated from data supplied by T. Close (MNDNR, personal communication). We used an average weight of 0.1 lb for adults to calculate biomass when weights were not recorded in the survey. We also assessed the accuracy of the biomass ranges assigned to classes of habitat quality by MNDNR (1993) and Thorn et al. (1997). If the mean biomass for our classes of habitat quality fell within the range assigned to that class of habitat quality by MNDNR (1993) and Thorn et al. (1997), their ranges of biomass were reasonable approximations of biomass expected for that class of habitat quality.

Results

Our matrix to estimate habitat quality for coldwater streams was based on 8 variables and a 0-32 scale (Table 1). The index of habitat quality calculated from the statewide coldwater database should be used for coldwater streams not in northeast or southeast

Table 1. Stream habitat variables and assigned scores for measuring habitat quality for trout (BKT = brook trout, BNT = brown trout).

	Score			
Variable	1	2	3	4
Shade[a]	0-25%		>75%	26-75%
Pool area BKT[b]	0%	<35%	>65%	35-65%
BNT[c]	0%	<25%	25-50% >75%	51-75%
Mean pool type[d]	0-1.5	1.6-2.5	2.6-3.5	>3.5
Fine substrates[e]	>60%	21-60%	10-20%	<10%
Cover[d]	0-6	7-12	13-18	19-24
Stream bank erosion[d]	Severe	Moderate		Light
Stream width[f]	<7 ft >75 ft	7-11.5 ft 51-75 ft	11.6-17.4 ft 23-50 ft	17.5-22 ft
Width:depth ratio (WD)[e]	>25	16-25	8-15	<8

[a]Ranges of measurements from MNDNR (1978), and scores adapted from Raleigh et al. (1986)
[b]Modified from Raleigh (1982)
[c]Modified from Raleigh et al. (1986)
[d]Modified from MNDNR (1978). Each pool in the survey station was rated as A, B, C, and D, and we assigned values of 4,3,2, and 1, respectively, for calculating a mean pool type. Five cover types (log jams - LJ , boulder - B, overhead cover - OC, undercut banks - UB, and instream vegetation - IV) are recorded in surveys, and are rated as scarce (1), occasional (2), and frequent (3). We calculated cover (C) for trout from: $C = 2LJ + 2B + OC + 2UB + IV$. The cover variables weighted by 2 provide year around cover for stream fish, and the other two variables are most abundant only in summer. The description of erosion is from the survey.
[e]From Simonson et al. (1994). Fine substrates is the sum of the percentages of silt, sand, clay, muck, detritus, and marl recorded in the stream survey; and coarse substrates is the sum of the percentages of ledge rock, boulder, rubble and gravel. The width:depth ratio was calculated from average width and average depth.
[f]Binns and Eiserman (1979)

Minnesota, and the index of habitat quality for brook trout should be used for those few streams with nonanadromous rainbow trout (Table 2). Mean habitat quality for brook trout (17.9) in southeast streams was significantly less (t -test, $P < 0.01$) than in northeast streams (20.9). In southeast streams, more than 80% of the streams have poor and fair habitat quality; and in northeast streams, 45% of the streams have poor and fair habitat quality (Table 3). In southeast streams, three variables (pool type, cover, and fine substrates) most influenced habitat quality; and in northeast streams, two variables (cover and pool type) were most influential (Table 4).

For southern Minnesota warmwater streams, we developed matrices (Table 5) for estimating habitat quality from 6 variables and a 0-24 scale in streams with smallmouth bass (Table 6), and from 5 variables and a scale 0-28 for streams smaller than 30 feet wide and a scale of 0-32 for streams larger than 30 feet wide. In streams with smallmouth bass and in smaller warmwater streams, fair habitat quality was most common (Table 7). In larger streams, abundance of streams with poor (33%), fair (29%), and good (29%) habitat quality was similar. In streams with smallmouth bass, habitat quality was most influenced by pool substrates, cover, and

Table 2. Frequency distribution of habitat quality measurements in streams for brook trout in Minnesota (BKT_{MINN}), southeast Minnesota (BKT_{SE}), and northeast Minnesota (BKT_{NE}); and brown trout in Minnesota (BNT_{MINN}) and southeast Minnesota (BNT_{NE}).

	Number				
Habitat quality	BKT_{MINN}	BKT_{SE}	BKT_{NE}	BNT_{MINN}	BNT_{SE}
4					
5					
6					
7					
8					
9					
10					
11	1				
12	2			4	2
13	7	2		6	5
14	21	4	1	18	10
15	30	5	2	34	17
16	49	10	2	39	26
17	57	13	3	60	23
18	72	12	12	69	24
19	80	12	11	79	23
20	73	8	19	73	18
21	40	4	6	54	13
22	61	5	17	45	10
23	31	1	16	37	4
24	16	1	9	21	2
25	7		3	8	0
26	3		2	3	0
27	3		1	2	1
28				1	
29					
30					
31					
32					
Mean	18.6	17.7	20.9	18.7	17.9
Total	553	77	104	553	178

Table 3. Ranges of habitat quality measures for habitat quality class and percent (%) stream reaches in each class for brook trout in Minnesota streams (BKT_{MINN}) and in southeast and northeast Minnesota streams (BKT_{SE}, BKT_{NE}), and brown trout in Minnesota streams (BNT_{MINN}) and southeast Minnesota streams (BNT_{SE}).

	Habitat quality class							
	Poor	%	Fair	%	Good	%	Excellent	%
BKT_{MINN}	<18	30	18-20	41	21-23	24	>23	5
BKT_{SE}	<18	44	18-20	42	21-23	13	>23	1
BKT_{NE}	<18	8	18-20	37	21-23	36	>23	19
BNT_{MINN}	<17	18	17-20	51	21-24	28	>24	3
BNT_{SE}	<17	33	17-20	50	21-24	16	>24	1

coarse substrates (Table 8). In smaller warmwater streams, habitat quality was most influenced by habitat diversity, coarse substrates, and cover. In larger warmwater streams, habitat quality was most influenced by fine substrates, erosion, and pool area.

Our measures of habitat quality were correlated with trout biomass in southeast streams, but not northeast streams (Figure 2). In the southeast streams, habitat quality for brook trout and brown trout was correlated with biomass ($r^2 = 0.124$ and 0.214, $P < 0.01$). In the northeast streams, habitat quality and brook trout biomass were not correlated ($r^2 = 0.034$, $P > 0.05$). Habitat quality in southeast streams was also correlated with abundance of brown trout longer than 12 in ($r^2 = 0.166$, $P < 0.01$), but not with abundance of brown trout longer than 15 in ($r^2 = 0.007$, $P > 0.05$).

The mean biomass for most classes of habitat quality in southeast streams was within the range suggested for that class of habitat quality. For southeast brook trout streams, Thorn et al. (1997) suggested biomass ranges of <25, 25-75, 75-150, and >150 lbs/a for poor, fair, good, and excellent habitat quality, respectively. Actual mean biomass for these classes was 41 (n =34), 59 (n = 32), 82 (n =10), and 231 (n =1) lbs/a. For southeast brown trout streams, MNDNR (1993) listed biomass ranges of <50, 50-100, 100-200, and >200 lbs/a for the four classes of habitat quality. Actual mean biomass for the four classes was 30 (n =57), 57 (n =86), and 116 (n =28), and 280 (n =1) lbs/a. For northeast streams, MNDNR (1993) listed biomass ranges of <10, 10-30, 30-50, and >50 lbs/a for poor, fair, good, and excellent habitat quality, respectively; and actual means were 4 (n =5), 47 (n =22), 22 (n =21), and 7 lbs/a (n =1).

Discussion

Fisheries biologists evaluate habitat during stream management planning (MNDNR 1993). Our index and classification of habitat quality allows biologists to evaluate stream habitat from variables commonly measured in stream surveys. The measurement of habitat quality should enhance historic reviews, the choosing of achievable and measurable objectives, the selection of the most appropriate management technique for stream management plans, and evaluation of management efforts. We will give examples from coldwater streams.

A stream management plan includes a review of the history of the stream. As an example of showing habitat changes over time, we measured habitat quality for brown trout in East Beaver Creek and compared variable scores from three stream surveys. Habitat quality improved from fair (17) in 1946 to good (21) in 1954 because of changes in pool area (2 to 4) and pool type (2 to 4), and to excellent (25) in 1985 because of increases in cover (2 to 4) and shade (1 to 4). Biomass increased from 63 kg/ha of stocked trout in 1945 to >200 kg/ha of wild trout during 1984-89.

Table 4. Means for physical variables in poor, fair, good, and excellent habitat quality for Minnesota streams with brook trout (BKT_{MINN}) and brown trout (BNT_{MINN}), southeast Minnesota streams with brook trout (BKT_{SE}) and brown trout (BNT_{SE}), and northeast Minnesota streams with brook trout (BKT_{NE}). See text for definitions of variables. Letters indicate significant difference ($P < 0.05$) among habitat quality ratings (i.e., means without a similar letter are different).

Habitat quality	Erosion	Shade	Cover	% pool area	Pool type	% fine substrate	Width(ft)	WD
				BKT_{MINN}				
Poor	2.2[a]	1.7[a]	8.5[a]	53[a]	1.4[a]	66[a]	13.2[a]	17.5[a]
Fair	1.6[b]	2.1[b]	11.4[b]	51[a]	1.9[b]	48[b]	13.9[a]	17.1[a]
Good	1.4[c]	2.2[b]	14.4[c]	54[a]	2.6[c]	34[c]	14.3[a]	17.0[a]
Excellent	1.1[c]	2.1[b]	16.8[d]	54[a]	3.1[d]	23[c]	16.3[a]	15.7[a]
				BKT_{SE}				
Poor	2.4[a]	1.9[a]	8.7[a]	68[a]	1.5[a]	58[a]	8.6[a]	13.2[a]
Fair	2.3[a]	2.1[a]	11.0[a]	62[a]	2.0[b]	45[a]	9.8[a]	14.2[a]
Good	2.3[a]	2.0[a]	9.7[a]	52[a]	2.6[b]	9[b]	8.9[a]	14.0[a]
Excellent								
				BKT_{NE}				
Poor	1.9[a]	1.5[a]	7.8[a]	20[a]	0.6[a]	6[ab]	23.6[a]	36.9[a]
Fair	1.2[b]	2.0[ab]	11.7[b]	34[ab]	1.9[b]	18[a]	15.6[a]	24.2[ab]
Good	1.2[b]	2.3[b]	15.5[c]	42[a]	2.4[c]	6[b]	10.6[a]	20.1[b]
Excellent	1.1[b]	2.2[ab]	15.9[c]	40[a]	3.0[d]	9[ab]	15.3[a]	17.9[b]
				BNT_{MINN}				
Poor	2.3[a]	1.6[a]	7.8[a]	53[a]	1.3[a]	70[a]	13.8[a]	18.4[a]
Fair	1.7[b]	2.0[b]	10.9[b]	52[a]	1.9[b]	51[b]	13.6[a]	17.1[a]
Good	1.3[c]	2.2[c]	14.5[c]	54[a]	2.6[c]	35[c]	14.1[a]	16.5[a]
Excellent	1.0[bc]	2.0[abc]	17.1[c]	55[a]	3.3[d]	22[c]	17.9[a]	15.7[a]
				BNT_{SE}				
Poor	2.5[a]	1.6[a]	7.6[a]	76[a]	1.6[a]	72[a]	16.5[a]	20.8[a]
Fair	2.3[ac]	1.9[b]	11.0[b]	67[a]	2.0[b]	55[b]	14.8[a]	16.3[b]
Good	1.8[b]	2.2[b]	15.3[c]	69[a]	2.4[c]	41[c]	19.5[a]	17.6[ab]
Excellent	1.0[ab]	2.0[ab]	19.0[c]	70[a]	3.1[bc]	8[bc]	18.0[a]	20.3[ab]

Table 5. Stream habitat variables and assigned scores for measuring habitat quality for streams with smallmouth bass, and for large (>30 ft wide) and small (<30 ft wide) warmwater streams.

	Score			
Variable	1	2	3	4
		Smallmouth Bass		
Pool area[a]	0%	<25%	25-50% >75%	51-75%
Mean pool depth[b]	No pools	<3 ft	>15 ft	3-15 ft
Coarse substrates[e]	<15%	15-44%	45-65%	>65%
Dominant pool substrate[b]	No pools	Sand/silt/	Pebbles bedrock	Gravel/ boulder
Cover[d]	0-6	7-12	13-18	19-24
Stream width[b]	<20 ft	20-25 ft	>50 ft	26-50 ft
		Large Warmwater Streams[c]		
Stream bank erosion (x)[c]	Severe		Moderate	Light
Maximum thalweg depth (2x)[c]	<2 ft	2-3 ft	3.1-4.5 ft	>4.5 ft
Habitat diversity[e](x)[c]	Riffles/runs or pools >90%	Riffles/runs 71-90% 10-29%	Riffles/runs 61-70% 30-39%	Riffles/runs 40-60%
Coarse substrate (2x)[c]	<15%	15-44%	45-65%	>65%
Cover[d] (2x)[c]	0-3	4-7	8-11	12-15
		Small Warmwater Streams[c]		
Stream bank erosion (1.5x)[c]	Severe		Moderate	Light
Pool area (x)[c]	<10% >90%	10-29% 71-90%	30-39% 61-70%	40-60%
Width:depth ratio (1.5x)[c]	>25	16-25	8-15	<8
Fine sediments (1.5x)[c]	>60%	21-60%	10-20%	<10%
Cover[d] (1.5x)[c]	0-3	4-7	8-11	12-15

[a]Lyons et al. (1988), Thorn and Milewski (1994), Thorn and Anderson (1999)
[b]Edwards et al. (1983)
[c]Simonson et al. (1994). Fine substrates were the sum of the percentages of silt, sand, clay, muck, detritus, and marl. Coarse substrates were the sum of the percentages of ledge rock, boulder, rubble and gravel. The width/depth ratio was calculated from average width and average depth. Simonson et al. (1994) assigned more points in the same class to some variables than for others. For example, he gave 12 points to excellent bank stability and 25 points to excellent thalweg depth for small to medium rivers; we doubled the score for thalweg depth (2x).
[d]Modified from MNDNR (1978). Pool types in the surveys were rated as A, B, C, and D, and assigned values of 4,3,2, and 1, respectively, for calculating a mean pool type. Five cover types (log jams - LJ , boulder - B, overhead cover - OC, undercut banks - UB, and instream vegetation - IV) are recorded in surveys, and are rated as scarce (1), occasional (2), and frequent (3). We calculated cover (C) for smallmouth bass streams from: C = 2LJ +2B + OC + 2UB +IV. The cover variables weighted by 2 provide year around cover for smallmouth bass, and the other two variables are most abundant in summer. For large and small warmwater streams, cover variables were not weighted.
[e]Modified from pool:riffle ratio

Table 6. Frequency distribution of habitat quality measurements for streams with smallmouth bass (SMB), large warmwater streams (WW_{LARGE}), and small warmwater streams (WW_{SMALL}). Maximum habitat quality is 24 for smallmouth bass, 32 for large warmwater streams, and 28 for smaller warmwater streams.

Habitat quality	Number		
	SMB	WW_{LARGE}	WW_{SMALL}
4			
5			
6			
7			5
8	1		
9	1		17
10	2		43
11	2	1	10
12	4	1	28
13	6	6	63
14	13	4	37
15	12	12	17
16	12	2	18
17	10	15	22
18	10	7	15
19	7	23	16
20	3	5	4
21	1	38	21
22	0	20	2
23	1	24	
24		11	
26		12	
27		8	
29		1	
30		2	
31		1	
32			
Mean	15.6	21.6	13.8
Total	85	216	320

Table 7. Ranges of habitat quality measures for habitat quality class and percent (%) stream reaches in each class for smallmouth bass (SMB) streams; and large warmwater streams (WW_{LARGE}) and small warmwater streams (WW_{SMALL}).

	Habitat quality class							
	Poor	%	Fair	%	Good	%	Excellent	%
SMB	<14	19	14-16	43	17-19	32	>19	6
WW_{SMALL}	<11.5	24	11.5-15	45	15.5-19	22	>19	9
WW_{LARGE}	<20	33	20-22	29	23-26	29	>26	9

Table 8. Means for physical variables in poor, fair, good, and excellent habitat quality for Minnesota streams with smallmouth bass, and large (width>30 ft) and small(width<30 ft) warmwater streams. See text for definitions of variables. Letters indicate significant difference (P <0.05) among habitat quality ratings (i.e., means without a similar letter are different).

	Dominant pool substrate	Cover	% pool area	Mean pool depth	% coarse substrate	Width (ft)
			Smallmouth bass			
Poor	1.7a	7.7^{a}	60^{a}	1.5^{a}	23^{a}	40^{a}
Fair	2.2^{b}	10.7^{b}	78^{a}	2.4^{b}	40^{b}	73^{a}
Good	2.9^{c}	12.9^{bc}	59^{a}	2.5^{b}	67^{c}	64^{a}
Excellent	3.8^{d}	17.0^{c}	70^{a}	2.1^{ab}	82^{c}	37^{a}

	Erosion	Maximum thalweg depth	Habitat diversity	% coarse cover substrate	Cover
			Large Warmwater streams		
Poor	1.7^{a}	4.4^{a}	30^{a}	20^{a}	4.9^{a}
Fair	1.5^{ab}	5.6^{ab}	35^{ab}	44^{b}	6.9^{b}
Good	1.3^{b}	6.1^{b}	50^{b}	57^{c}	8.1^{c}
Excellent	1.2^{b}	6.7^{b}	54^{c}	80^{d}	8.5^{c}

	Erosion	Pool area	WD	% fine substrate	Cover
			Small Warmwater streams		
Poor	2.1^{a}	82^{a}	19.1^{a}	84^{a}	4.1^{a}
Fair	1.5^{b}	66^{b}	14.0^{a}	67^{b}	6.3^{b}
Good	1.2^{c}	54^{c}	14.5^{a}	56^{c}	6.8^{b}
Excellent	1.1^{c}	50^{c}	11.1^{a}	45^{d}	7.4^{b}

We suggest that the measurement of habitat quality and the variables of habitat quality be used as achievable and measurable objectives, and for evaluating instream habitat management and watershed management. Habitat management should improve some variables and habitat quality. Instream habitat management should increase cover and decrease bank erosion. Watershed management should decrease width, width:depth ratio, and amount of fine substrates. We suggest that habitat quality for trout should be excellent (>24) after habitat improvement. In Diamond Creek after improvements, cover was not abundant (2) and habitat quality was good (23). The more intensive addition of cover in pools (Thorn 1988) would have increased the cover score to 4, and habitat quality to excellent (25).

Some fisheries biologists use the Index of Biotic Integrity (IBI) for stream health to help evaluate habitat. Our index of habitat quality may evaluate habitat better than the IBI in streams with brook trout and brown trout. Brook trout abundance is an important coldwater IBI metric and low abundance may show poor stream health (Lyons et al. 1996; Mundahl and Simon 1998) but in many southeast Minnesota streams, brook trout abundance and distribution was limited by wild brown trout abundance (Thorn and Ebbers 1997). In an improved reach of West Indian Creek, habitat quality was excellent (27); but the IBI was just fair to good (N. Mundahl unpublished

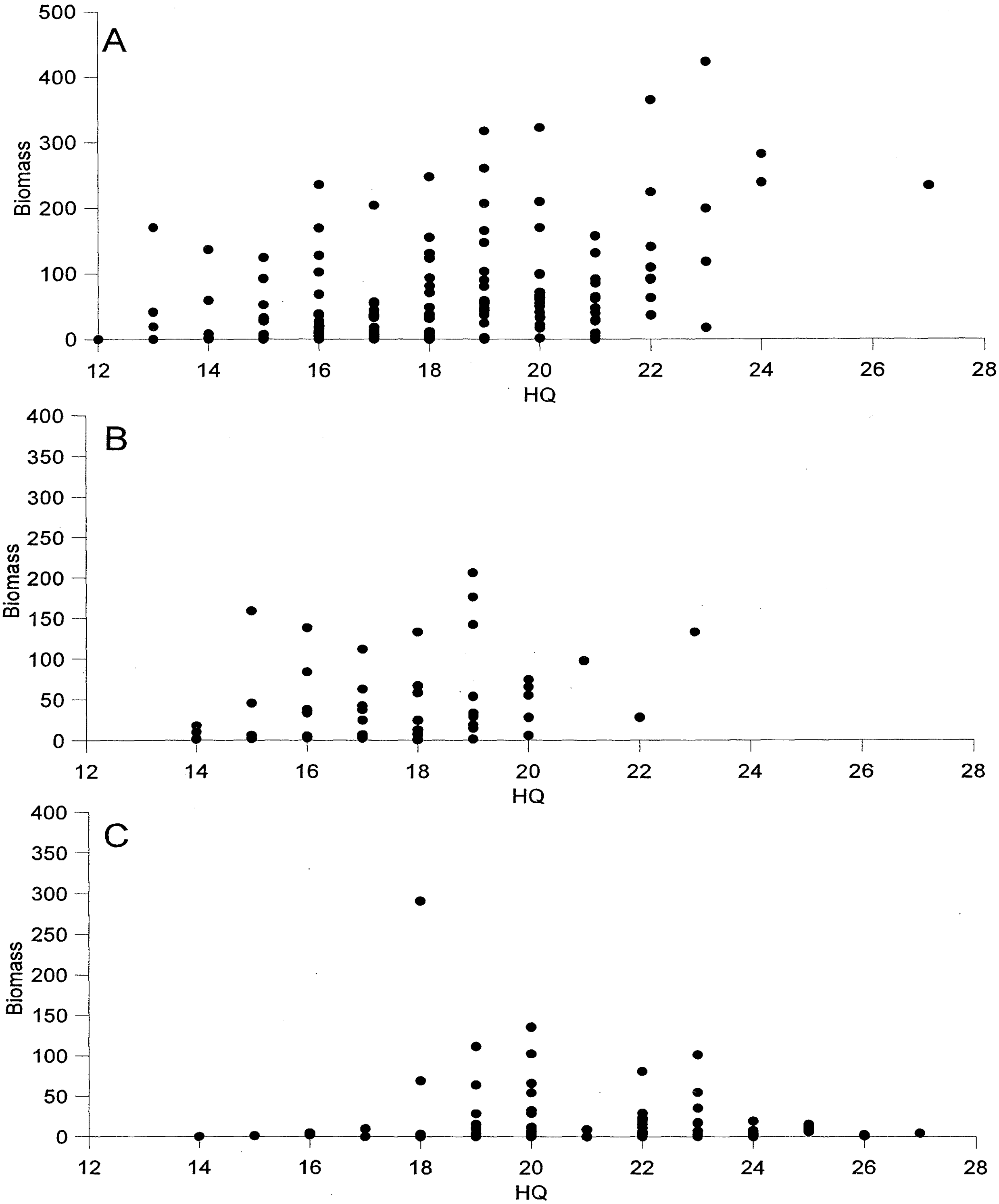

Figure 2. Scatter plots of habitat quality (HQ) and biomass (lbs/a) for brown trout (A) and brook trout (B) in southeast Minnesota streams, and brook trout in northeast Minnesota streams (C). Brown trout biomass is adjusted as explained in Methods.

report) because abundant brown trout in the improved reach limited the downstream migration of brook trout from the headwaters and brook trout abundance.

After habitat is evaluated and the objective determined, we recommend use of Table 9 for selecting management techniques for coldwater streams. For all streams, we generally do not recommend: 1) stocking fish to provide fisheries in streams with poor and fair habitat quality because stocked fish would have poor survival potential, 2) habitat management in streams with good and excellent habitat quality because benefits may be limited, and 3) regulations that restrict harvest to increase abundance in streams with poor and fair habitat quality because habitat may limit abundance. Also, we promote the evaluation of warmwater management because of abundant uncertainties.

We recommend our measure of habitat quality to evaluate unexplained failures and substantiate conclusions of past management. A restrictive harvest regulation on South Branch Whitewater River did not increase abundance of brown trout longer than 12 in from 96/mi to the objective of 330/mi (Thorn 1990). Because habitat quality was good (22) and forage was abundant, we concluded that excellent habitat quality (>24) probably was necessary to achieve the 247% increase in abundance. Most stocked brown trout did not survive in Hay Creek because of poor habitat (Thorn 1992b). We agree with that conclusion because habitat quality was just fair (17).

Correlations of habitat quality with trout biomass in southeast streams (Figure 2) suggest that this scoring system is reasonable and reliable in these streams because physical habitat limits abundance. The wedge-shaped variation in biomass relative to habitat variables (Figure 2A) shows that habitat limits biomass because the range of biomass increases as a function of the variable (Terrell et al. 1996), and that abundance fluctuates. Therefore, we do not recommend the sole use of biomass to evaluate habitat quality. For example, habitat quality in South Branch Whitewater River calculated from habitat variables of the 1977 stream survey was good (22). Habitat quality estimated from biomass ranged from poor (40 lbs/a) in the 1970s to good (135 (lbs/a) in the 1990s. Biomass of brown trout in southeast Minnesota was naturally increasing during the 1980s (MNDNR file data).

To evaluate habitat for large brown trout (longer than 15 in) in southeast Minnesota streams, we recommend use of Table 8 of

Table 9. Recommended management by Habitat Quality class for trout streams.

Poor Habitat Quality: When wild trout are present, habitat rehabilitation is usually recommended. When wild trout are not present, stocking may provide a limited fishery. Experimental regulations and stocking to increase abundance or change size structure are not usually recommended. Management by stocking and harvest could compromise effective population size of the wild population (Kapuscinski and Jacobson 1987).

Fair Habitat Quality: Management of the streams in this class is similar to those with poor Habitat quality. Habitat rehabilitation may not have to be as intensive, more fish can be stocked when wild trout are not present, and the need to protect effective population size is less likely. Experimental regulations are usually not recommended.

Good Habitat Quality: When wild trout are present, habitat rehabilitation may not be cost beneficial and stocking is unnecessary. Experimental regulations are a management option when exploitation is >50%. When wild trout are not present, rehabilitation of reproductive habitat should be explored. Until reproduction is successful, stocking will provide a fishery, and benefits from stocking may be increased by recycling fish with experimental regulations.

Excellent Habitat Quality: Management of streams in this class is similar to those with good Habitat quality. When wild trout are present, habitat improvement and stocking are not recommended. Experimental regulations on streams with high exploitation may be a management option. When wild trout are not present, the need for rehabilitating reproductive habitat should have management priority, and a stocked fishery may be enhanced with an experimental regulation.

Thorn and Anderson (1993). Our measurement of habitat quality was not correlated with abundance of large brown trout, and large trout have different habitat requirements than small trout (Thorn and Anderson 1993). From the presence of large trout cover types, the probability (P) for finding a large brown trout can be identified from Table 8 for each pool in the reach. The probabilities are divided into quartiles, and each P is assigned to a quartile. The quartiles are designated as classes of habitat quality (first quartile, 0.0 - 0.24 = poor; second quartile, 0.25-0.49 = fair; third quartile, 0.50-0.74 = good; and fourth quartile, >0.74 = excellent). The quartile that includes the largest number of pools and the mean P for all pools in the reach is the class of habitat quality of the stream reach. For example, habitat quality for large brown trout in Diamond Creek was good because P for 61% of the pools and the mean P (0.55) were in the third quartile. When one quartile does not include the largest number of pools and the mean P, evaluation of habitat quality is less certain.

Habitat quality can be misclassified from the incorrect identification of pools, riffles, and runs (Thorn and Anderson 1999) and the qualitative measurement of cover abundance. According to the definitions for morphology (MNDNR 1978), runs should not be abundant in most Minnesota trout streams. However, they were commonly recorded in surveys. For such streams, we suggest calculating percent pool area by subtracting percent riffle area from 100 percent. The Diamond Creek survey is an example of subjectivity of qualitative observations of cover abundance. This survey recorded abundant cover and numerous kinds of covers for a cover total of 22 and cover score of 4. During a field inspection, we recorded cover in each pool for the reach, and calculated a mean pool total of 7.4 for a cover score of 2. Our lower cover total was due to scarce or occasional undercut banks and boulders rather than the frequent occurrence recorded in the survey. We suggest that abundance of the five cover types be defined as scarce (in one pool in the station), occasional (in more than one pool in the station but not in all pools in the station), and frequent (in every pool in the station).

We urge MNDNR to appoint a stream survey work group (Thorn and Anderson 1999). This group could evaluate our indices of habitat quality for important warmwater species and work with the stream survey manual revision committee to assure the continued sampling of important variables.

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