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SUMMER HABITAT ASSOCIATIONS OF LARGE BROWN TROUT IN SOUTHEAST MINNESOTA STREAMS[1]

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Abstract.--We evaluated summer habitat use of large brown trout *Salmo trutta* (TL > 380 mm) in pools and stream reaches of southeast Minnesota to test an earlier summer habitat model, to identify other important variables, and to develop a habitat quality classification to guide large trout management. We collected 224 large trout in 126 of 581 pools in 41 stream reaches during 2003 and 2004. The probability (P2) that a large brown trout was present in a pool was positively associated with the presence of water deeper than 90 cm, instream rock, overhead bank cover, and woody debris in a logistic regression model. Similarly, large trout abundance in pools was best predicted with a Poisson regression model with four variables (area of water deeper than 60 cm, length of overhead bank cover, pool width, and area of instream rock). Streambank riprap was not significantly associated with either large trout presence or abundance in pools. Large trout abundance in stream reaches increased linearly with mean P2-value, which explained 54% of the variation among study reaches. We categorized habitat quality of stream reaches into four classes based on mean P2-values. In large streams (>0.43 m^3/s), with poor to fair habitat quality, habitat management should increase water deeper than 90 cm, instream rock, overhead bank cover, and woody debris. Habitat management for large trout in smaller streams (<0.43 m^3/s) is more complex and may simply be more limited. Managers may have to recognize the limited biological potential in these systems and prioritize large trout management objectives to larger streams.

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Introduction

Large brown trout *Salmo trutta* (TL > 380 mm) are of high value to some anglers who request specific management actions to produce greater abundance and catch of large trout. Managers know that mean abundance of adult trout in southeast Minnesota streams increased from 139/km during 1970-1979 to 702/km during 1991-2001 (405%), and that mean abundance of large trout increased from 3/km to 6/km (100%; Thorn et al. in review). However, some anglers are convinced that abundance of large trout declined, perhaps because the proportion of large trout caught had declined or the slower rate of increase for large trout was less noticeable. This discrepancy has lead to requests for more protective fishing regulations and special habitat rehabilitation features. The success or failure of management actions may depend on the abundance of high quality habitat for large trout within a stream reach. For example, special regulations to reduce angling mortality may not produce more large trout if habitat quality is poor.

Large brown trout move through streams seasonally and select pools with appropriate habitat. Large brown trout often move extensively during spring and fall, but are relatively sedentary, using small home areas, often limited to a single pool, during winter and summer (Bachman 1984; Clapp et al. 1990; Meyers et al. 1992; Burrell et al. 2000). Seasonal movements are likely due to spawning migrations and movement between winter and summer habitats. During summer, large brown trout often select the deepest pools with abundant cover, especially overhead cover (Heggenes 1988; Greenberg et al. 2001; Diana et al. 2004). Pool depth and an abundance of complex covers, such as woody debris and undercut banks, are believed to provide more energetically profitable stream positions due to velocity reductions, decrease intraspecific competition through visual isolation, and provide protection from avian and mammalian predators (Bjornn and Reiser 1991; Sundbaum and Näslund 1998; Greenberg et al. 2001). Although some brown trout exhibit nighttime foraging movements through multiple pools, typically returning to daytime resting locations near cover in their original pool (Clapp et al. 1990; Diana et al. 2004), other brown trout exhibit a complete absence of diel movement during summer (Bunnell et al. 1998).

To evaluate the potential of a stream for large trout management in southeast Minnesota, fisheries biologists investigated trout abundance, growth potential, habitat quality, and trout harvest (MNDNR 2000). Biologists have estimated abundance in most streams and evaluated factors related to growth potential (Dieterman et al. 2004). Evaluations of habitat quality and harvest of large trout from standard creel surveys, however, are less certain. A standardized method of measuring and classifying habitat quality for large brown trout may enable fish managers to identify streams where instream habitat improvement or regulations would be most likely to succeed. Development of such a habitat quality classification first requires identification of habitat features used by large brown trout.

A pool-scale habitat model and subsequent reach-scale habitat quality classification for large brown trout were proposed for southeast Minnesota (Thorn and Anderson 1993; Thorn and Anderson 2001a), but rigorous testing of such models is required for confident management application (Rabeni 1992). Thorn and Anderson (1993) determined important habitat features influencing presence/absence (P/A) of large brown trout in pools in southeast Minnesota streams. They found that the probability (P-value) of finding a large brown trout in a pool was positively related to the presence of water deeper than 60 cm and presence of four cover types: woody debris, instream rock, overhead bank cover, and stream bank riprap. As more cover types were added to a pool, the probability a large trout would be present increased. Thorn and Anderson (2001a) recommended using quartiles based on P-values (as summarized in Table 8 of Thorn and Anderson 1993), to classify habitat quality in stream reaches as poor, fair, good, or excellent for large brown trout. First, each pool in the reach is assigned a P-value based on Table 8 in Thorn and Anderson (1993). Then the quartile (<0.25, 0.25 – 0.49, 0.50 – 0.74, >0.75) with the largest number of pools (i.e., mode) and the overall mean P-value for all pools were used to determine the habitat quality class for the reach. For example, habitat quality of Diamond Creek was classified as good because the P-value for 61% of the pools in the reach and the mean P (0.55) for all pools in the reach were both in the third quartile. However, J. Weiss (personal observation) found little agreement with the mean and modal P-values for 721 pools in 13 stream reaches. Although adding cover to a pool typically increased the P-value, several combinations of cover types when added to another specific cover type reduced the estimated probability (see Table 8 in Thorn and Anderson 1993). Because such negative interactions seem unlikely, it is assumed that some model terms were poorly estimated due to sampling noise or collinearity problems in the initial study.

To verify the importance of the habitat features originally determined by Thorn and Anderson (1993), we applied their earlier P/A model to an independent dataset. We developed new models relating habitat features to large brown trout P/A and abundance in pools, and abundance in stream reaches. From these results, we developed a revised reach-scale habitat quality classification to guide management for large brown trout in southeast Minnesota streams (MNDNR 2000). The goal of this revised classification is to classify habitat in stream reaches into poor, fair, good or excellent habitat classes, and then relate these categories to large trout abundance. Specific objectives were to: (1) test the original pool-scale P/A model of Thorn and Anderson (1993) with an independent data set; (2) develop a new pool-scale P/A model with a newer and larger dataset; (3) develop a pool-scale large trout abundance model; (4) develop a reach-scale large trout abundance model; and (5) develop a habitat quality classification and relate these classes to large trout abundance.

Methods

We selected 41 study stations within stream reaches that represented the range of physical habitat conditions for southeast Minnesota trout streams. Study stations were assumed to represent stream reach conditions and are hereafter referred to simply as reaches. Study reaches usually included 10-15 pools, and no more than 25% of reaches had instream habitat that had been rehabilitated since 1970. Although channel morphology of these streams varied, separate pools were easily identified in most streams by riffles between them. A few pools were delineated by a reduction in depth, not by coarse substrate. We sampled from mid-July through the first week in October in 2003 and 2004.

Pool-scale

To test the original model of Thorn and Anderson (1993), we estimated large trout abundance and recorded the presence of the same five summer cover variables (overhead bank cover, riprap, instream rocks, woody debris, and water deeper than 60 cm) in each pool in 20 study reaches sampled in 2003 and 6 reaches in 2004. We made upstream electrofishing passes through each pool until no large trout were captured. The estimate of large trout for the pool was the sum of all large trout captured. In most streams, trout were sampled with a towed electrofishing barge with two or three handheld anodes. In the few pools that were not completely wadable, biologists floated in bellyboats. In one stream, we used two barges and five electrodes. In small streams, the sampling gear was one or two backpack electrofishers. Using the instream cover data and Table 8 in Thorn and Anderson (1993), we calculated the P-values (the expected probability of finding at least one large trout) for each pool.

To develop pool-scale P/A and abundance models for large brown trout, we also measured the abundance of 13 important summer covers for large trout in each pool for all 20 study reaches sampled in 2003 and for 6 study reaches sampled in 2004. We considered overhead bank cover longer than 0.6 m, deeper than 0.15 m, and wider than 0.3 m would provide cover for large trout. Overhanging grass was considered overhead bank cover when wider than 0.7 m. We measured overhead bank cover by length (L_{obc}), area (OBC), and as length of overhead bank cover per thalweg length of each pool (L_{obc}/T). Crevices in riprap provided cover for large trout. The area of cover from riprap (RR) was calculated by multiplying the length of riprap by either 0.1, 0.25, or 0.5 depending on how many crevices were available above the streambed for cover (0.1 = few crevices), and this value by 0.3 m to represent the average width of riprap extending into stream banks. Hayes and Jowett (1994) found instream rocks that were at least 0.027 m^2 in diameter provided cover for drift-feeding brown trout, but when larger boulders were available, brown trout used them almost exclusively. We deemed instream rocks covering areas greater than 0.225 m^2 would provide cover for large brown trout in our study streams. Thus, area of cover from instream rocks (IR) was estimated in increments of 0.225 m^2 (1.5 m long X 0.15 m wide), and summed for each pool. White (1996) reviewed numerous fish habitat studies and concluded that woody debris generally provided cover when larger than 0.20 m^2. However, White (1996) acknowledged that larger wood sizes may be necessary to provide cover for larger fishes or in larger stream systems. We considered woody debris to provide cover for large brown trout when it covered an area of stream at least 0.45 m^2 and we estimated this cover type (DEB) in increments of this area (1.5 m X 0.3 m). The area of water deeper than 60 cm (D60) was calculated from its length and average width. When more than one deep-water area was present in a pool, each area was measured and all areas were summed for the pool. An alternative used in some larger pools was the placement of transects at regular intervals to record the width of each water depth at each transect, calculating the length of each water depth and average width from transect data, and multiplying length times mean average width to estimate area. We similarly estimated the area of water deeper than 90 (D90), 120 (D120), and 150 (D150) cm. We also measured thalweg length (T), width (W), and area (Area) of each pool.

For our first objective, testing the pool-by-pool P/A habitat model of Thorn and Anderson (1993), we first calculated a P-value for each pool based on the presence of four types of cover and water deeper than 60 cm. If this P-value was greater than 0.5 (i.e., greater than a 50% chance that a large trout should be present), we predicted that pool should have a large trout present. If the P-value was less than 0.5 we predicted that large brown trout should be absent from that pool. Actual P/A of a large brown trout in each pool was determined from electrofishing results. We then compared the predicted P/A to the observed P/A with a classification table and chi-square test of association (Hatcher and Stepanski 1994). A significant chi-square test ($P \leq 0.05$) would indicate that the model-predicted data were associated with observed data, indicating an accurate model.

Then, we repeated the logistic regression modeling analysis of Thorn and Anderson (1993), although without the complication of sub-sampling of pools without large trout, to see whether the same habitat variables were important as main effects. Prior to model building, we fit and plotted generalized additive models (GAM; SAS Institute Inc. 2001) for each independent variable to ascertain logit linearity (Hosmer and Lemeshow 1989). If logits were not linear with raw data, we transformed variables and reassessed linearity with GAMs. We initially tested the full range of cover variables originally tested by Thorn and Anderson (1993) for significant associations with large trout P/A in pools. However, the D120 and D150 variables were omitted because the coefficients were unstable, likely because of rarity. We used purposeful and stepwise forward approaches to determine the subset of variables and interaction terms to include in the final habitat selection model. For stepwise forward approaches, we used *P* values chosen to enter and remove variables of 0.15 and 0.20, respectively (Thorn and Anderson 1993). Models were also evaluated for significance with a log-likelihood test for the overall model; the Wald chi-square statistic, which compares the individual slope coefficients to see if they differ from zero (i.e., no effect); and an adjusted generalized R^2 (Hosmer and Lemeshow 1989; Nagelkerke 1991; Menard 1995).

For our third objective, we developed a pool-scale model relating trout abundance in pools to habitat variables using Poisson regression. We started by running a full model with all 13 habitat variables with the general linear modeling procedure in Statistical Analysis Systems software (McCullagh and Nelder 1989). However, the D120 and D150 variables were again omitted because of unstable coefficients. We then assessed the significance of each habitat variable as a main effect with a chi-square test, and manually removed non-significant variables until we developed a final model (SAS Institute Inc. 1999). The final model was assessed with a goodness-of-fit test for the overall model, a Wald χ^2 statistic which tested the significance of individual slope coefficients, and a log-likelihood χ^2 statistic comparing one model to another (SAS Institute Inc. 1999).

Reach scale

To develop a reach-scale model of factors associated with large brown trout abundance, our fourth objective, we recorded data for 37 variables from 20 stream reaches in 2003. Although we had initially intended to validate this 2003 reach-scale model with data collected in 2004 (i.e., only those variables necessary to validate the 2003 model), new results prompted development of a revised reach-scale model (see Results below). Consequently, all reach-scale variables were not measured for 15 of the 21 reaches sampled in 2004. We measured length, width, mean depth, estimated substrates, and calculated area of each pool and riffle in the reach following methods in MNDNR (1978). Trout cover (as described above), pool type, bank erosion, percent aquatic vegetation, and percent pool bank shade were also measured or estimated in each pool (MNDNR 1978). We then calculated reach totals or means from these individual pool and riffle measurements (MNDNR 1978). We measured gradient and discharge, calculated the width:depth ratio, recorded sinuosity from the latest stream survey, and calculated stream class (Thorn and Anderson 1999) and habitat quality class (Thorn and Anderson 2001a). Abundance and biomass of smaller trout in the reach was recorded from previous electrofishing surveys. We included five GIS watershed variables for each reach (drainage basin area, watershed slope, land use, minimum soil permeability, and K factor of the Universal Soil Loss Equation). Minimum soil permeability and the K factor of the Universal Soil Loss Equation are indicators of the susceptibility of soils in the watershed to erosion (USDA 1991). Large trout abundance in the reach, the dependent variable, was the sum of abundance in all pools in the reach, and converted to density (number per km). We culled reach-scale variables following methods in Dieterman and Galat (2004) because we had more predictor variables, 37, than stream reach replicates (N=20) in 2003. Individual reach-scale variables significantly related ($P < 0.05$) to abundance of large brown trout in reaches were first identified with univariate linear regression models. Variables not significantly related were culled. To reduce problems of collinearity in final multiple model building steps, Pearson's rank correlations were then used to identify which remaining variables were correlated. Multiple regression models were then developed by manually entering and removing variables until the best model; based on significance, variation explained, and lack of collinearity was achieved.

Habitat Quality Classification

Our fifth objective was to develop a reach-scale habitat quality classification for large brown trout in southeast Minnesota streams. If a reach model relating abundance directly to habitat (i.e., reach-scale mean P-value) was developed, quartiles of mean P-values or other cut points might be used to classify habitat as poor, fair, good, or excellent. Our preferred criteria for an adequate reach-scale habitat classification, was that large trout abundance differed significantly among habitat classes. At a minimum, large trout abundance must differ between poor-fair and good-excellent habitat groupings to guide selection of reaches requiring instream habitat rehabilitation following MNDNR (2000). We used trout abundance information from this study as an initial test of abundance differences among our proposed habitat classes, but recognize the tautological nature of using trout abundance data to both develop a reach-scale model and subsequently test for differences among proposed habitat classes from this model. We acknowledge that additional data should be collected to better test our classifications. Finally, extensive habitat degradation in the region (Thorn et al. 1997; Thorn and Anderson 2001a) should result in a proposed classification scheme with few reaches rated as good or excellent habitat if our study reach selection was a true representation of southeast Minnesota streams. We ranked stream reaches from highest to lowest P-value and visually interpreted potential breaks between poor, fair, good, and excellent habitat quality classes. Then we used Kruskal-Wallis and Wilcoxon two-sample tests to test whether large trout abundance differed significantly ($P < 0.05$) among these proposed habitat classes.

Results

We electrofished 580 pools in 41 stream reaches in 2003 and 2004, and collected 224 large brown trout (0.39/pool) from 126 of the pools (22% of pools). Multiple large trout were collected in 46 pools, with a maximum of 11 in one pool. During 1991-1992, Thorn and Anderson (1993), electrofished 511 pools in 21 stream reaches and collected 157 trout (0.31/pool) in 107 pools (21% of pools). Multiple large trout were sampled in 28 pools, and the maximum was 6.

Our range of values for many habitat variables in 2003 and 2004 was greater than in 1991-1992 (Table 1). We selected streams to represent the range of regional stream conditions (Appendix Tables A1-A5), but Thorn and Anderson (1993), selected stream reaches known or expected to contain large trout. For example, the reach of Badger Creek in 2003 was characterized by no riffles, pools distinguished by thalweg crossover and sand "dunes," and abundant overhead bank cover from overhanging grass on both stream banks (L_{obc}/T of 162.3% for the reach). In 1991-1992, such a stream reach was not sampled. Without the Badger Creek data, mean percentage of overhead bank cover in pools without a large trout would decrease from 3.4% to 2.7%. Also, in pools with large trout, the mean percentage of pools with riprap was 0.34 in 1991-1992 and 0.12 in 2003-2004 (Table 1).

Pool scale

The Thorn and Anderson (1993) model based on the presence of five cover variables was informative about the presence/absence of large brown trout in pools in this study ($\chi^2 = 47.63$, df = 1, P < 0.001). The mean P-value for pools with a large trout (0.484) was 43% greater (t- test, $P < 0.01$) than the mean P-value for pools without a large trout (0.276). Overall, the model correctly predicted P/A in 70% of the 580 pools sampled (Table 2). However, the model had a high Negative Predictive Value, correctly predicting absence in 333 of 384 pools (87%), and a lower Positive Predictive Value, correctly predicting presence in 75 of 196 pools (38%).

In the newer dataset, presence of a large brown trout in a pool was positively associated with the presence of water > 90 cm deep, instream rock, overhead bank cover, and woody debris, with two negative interaction terms (Table 3). All four cover variables in the final model had been transformed to presence/absence values because responses were not linear on the logit scale. The six-term model was significant (log likelihood $\chi^2 = 112.75$, df = 6, $P < 0.0001$), explained 40.8% of the variation in these data, and included some main effects originally identified by Thorn and Anderson (1993) (e.g., woody debris and overhead bank cover). Although the interaction terms were negative, they were small relative to the main effects, thus for any set of cover types present, the addition of another cover type increased the predicted probability of large trout presence. This avoids a problematic aspect of the Thorn and Anderson (1993) model, where addition of another cover type did not always increase predicted probabilities.

Some cover types originally included in the Thorn and Anderson (1993) model (e.g., riprap, pool length, and water deeper than 60 cm), were not associated with large trout P/A in these newer data. Area of water deeper than 60 cm was tested in our multiple model development because it was significantly associated with large trout presence in our univariate general additive models. However, area of water deeper than 60 cm and the presence/absence of water deeper than 90 cm were nested and highly correlated prompting inclusion of only one of these terms. We retained the presence/absence of D90 in our multiple regression model because the model with D60 only explained 28.1% of the variation in these data and provided a poorer fit to the data

Table 1. Mean and range of variabl es in pools with and without brown trout (BNT) > 380 mm TL in southeast Minnesota streams, 1991-1992 and 2003-2004.

		Pools with BNT > 380 mm				Pools without BNT > 380 mm			
		Mean		Mean		Mean		Range	
Variable	Abbreviation	1991-92	2003-04	1991-92	2003-04	1991-92	2003-04	1991-92	2003-04
Length (m)	T	62.41	60.46	9.1-228.8	8.5-220.0	42.73	40.54	6.7-144.9	2.1-213.00
Area (m^2)	Area	457.40	424.48	21.8-2608.3	29.75-1980.0	314.00	248.58	26.4-1428.0	10.0-1810.50
Width (m)	W	6.55	6.64	2.3-18.9	2.1-15.0	6.47	5.38	1.8-14.0	1.6-19.1
Area overhead bank cover (%)	OBC	1.78	2.78	0.0-27.7	0.0-35.52	0.91	3.38	0.0-14.0	0.0-98.68
Area debris (%)	DEB	0.94	0.97	0.0-8.4	0.0-26.71	0.89	0.38	0.0-10.5	0.0-15.59
Area riprap (%)	RR	0.34	0.12	0.0-6.9	0.0-2.28	0.09	0.11	0.0-2.1	0.0-2.29
Area instream rocks (%)	IR	0.79	0.17	0.0-2.0	0.0-1.19	0.13	0.15	0.0-1.1	0.0-4.00
Length overhead bank cover (m)	L_{obc}	5.48	10.46	0.0-122.0	0.0-178.0	2.30	5.88	0.0-27.0	0.0-145.0
Length overhead bank cover/ thalweg length (%)	L_{obc}/T	12.27	20.78	0.0-125.0	0.0-172.0	7.45	16.42	0.0-75.0	0.0-179.0
Area deeper than 60 cm (%)	D60	19.27	20.45	0.0-91.0	0.0-73.56	12.25	5.17	0.0-62.7	0.0-54.49
Area deeper than 90 cm (%)	D90	4.34	6.22	0.0-59.5	0.0-51.36	3.31	0.73	0.0-39.7	0.0-32.72
Area deeper than 120 cm (%)	D120	0.81	0.92	0.0-13.5	0.0-15.71	1.09	0.14	0.0-26.1	0.0-19.67
Area deeper than 150 cm (%)	D150	0.16	0.01	0.0-9.5	0.0-0.92	0.39	0.00	0.0-18.4	0.0-0.00

Table 2. Accuracy of pool-scale logistic regression models developed from 1991-1992 (Thorn and Anderson 1993; Table 8) for predicting presence/absence of large brown trout (> 380 mm TL) in pools in 2003 and 2004, based on presence/absence of five cover variables, in southeast Minnesota streams. For the proportion of pools, the first number is the observed number and the second number is the predicted number. For example, the first value (75/196) shows that large trout were predicted to be present in 196 pools but were observed present in only 75 of these 196 pools.

Model prediction	Proportion of pools	Percentage of pools
Correct predictions		
Large trout present where predicted to be present	75/196	38%
Large trout absent where predicted to be absent	333/384	87%
Incorrect predictions		
Large trout absent where predicted to be present	121/196	62%
Large trout present where predicted to be absent	51/384	13%
Overall correct classification	408/580	70%

Table 3. Estimated coefficients, standard errors (SE), and Wald χ^2-statistic testing for significance of the individual coefficients for a multiple logistic regression model predicting presence/absence of brown trout > 380 mm TL in southeast Minnesota streams, 2003-2004.

Variable	Coefficient	SE	Wald χ^2	$P > \chi^2$
Constant	-4.097	0.518	62.39	<0.0001
OBC (0=absent, 1=present)	1.616	0.492	10.76	0.0010
IR (0=absent, 1=present)	2.327	0.604	14.85	0.0001
DEB (0=absent, 1=present)	0.774	0.322	5.74	0.0165
D90 (0=absent, 1=present)	3.040	0.472	41.43	<0.0001
OBC x IR	-1.254	0.639	3.84	0.0498
IR x D90	-1.315	0.629	4.36	0.0368

(Hosmer and Lemeshow (1989) Goodness of Fit Test, $\chi^2 = 26.02$, df = 7, $P = 0.0005$). Because this model differed from Thorn and Anderson's, for contrast to their Table 8 we calculated the predicted probability of a large trout being present for pools with all possible combinations of cover and renamed this pool scale index the P2-Value (Table 4).

Large brown trout abundance in pools was significantly associated with four variables: area of water deeper than 60 cm, length of overhead bank cover, pool width, and area of instream rock (Table 5). Together, these four variables explained about 26% of the deviance (i.e., variation) in large trout abundance in pools. Area of water deeper than 60 cm and 90 cm were both significantly associated with our large trout variable again. However, we retained D60 in our multiple Poisson model

Table 4. Probability (new P2-value**)** of finding a large brown trout in pools with various combinations of the presence=1 or absence="blank" of four habitat variables found to be significantly associated with presence/absence of large brown trout in pools in southeast Minnesota streams.

Variables				
DEB	OBC	IR	D90	P2-value
		No Cover		
				0.016
		1 cover type		
1				0.034
	1			0.077
		1		0.145
			1	0.257
		2 cover types		
1	1			0.153
	1	1		0.196
1		1		0.269
1			1	0.429
		1	1	0.488
	1		1	0.636
		3 cover types		
1	1	1		0.346
	1	1	1	0.578
1		1	1	0.674
1	1		1	0.791
		4 cover types		
1	1	1	1	0.748

Table 5. Estimated coefficients, standard errors (SE), and χ^2-statistic testing for significance of the individual coefficients for a pool-scale multiple Poisson regression model testing for associations between habitat variables and abundance of brown trout > 380 mm TL in pools in southeast Minnesota streams, 2003-2004.

Variable	Coefficient	SE	χ^2	$P > \chi^2$
Constant	-1.982	0.210	88.85	<0.0001
D60 (m^2)	0.006	0.001	77.59	<0.0001
OBC_L (m)	0.013	0.002	42.67	<0.0001
W (m)	0.075	0.029	6.76	0.0093
IR (m^2)	0.245	0.099	6.39	0.0115

because it explained more deviance than comparable models with D90. For example, in univariate models, D60 explained 20% of the deviance, whereas D90 only explained 13%. Overhead bank cover, instream rock, and a water depth variable were similarly selected in our P/A model, and help corroborate our findings of pool-scale variables influencing large trout.

Reach scale

Large trout abundance in this study ranged from 0.0–30.7/km, and mean abundance was 8.5/km in 2003, 6.1/km in 2004, and 7.2/km for both years. Mean density of large trout in the 20 streams used for model development in this study, was 12.9/ha and ranged from 0.0 to 43.5/ha (Appendix Table A1).

Large trout abundance (number/km) was positively related to mean P2-value, discharge, mean depth, trout biomass, and watershed basin area in univariate regressions. However, all variables were significantly correlated with each other except for mean depth with discharge, trout biomass, and basin area (Table 6), suggesting coefficient estimates would be unstable if other predictor variables besides mean P2-value were added. Mean P2-value alone explained 54% of the variation in large brown trout abundance among the 20 reaches sampled in 2003 plus an additional 6 reaches where sufficient data were collected in 2004 to calculate a reach-scale mean P2-value ($y = -3.57 + 51.83x$, with $\sigma^2\ y|x = 41.50$, and $P < 0.0001$; Figure 1).

Habitat Quality Classification

We ranked the 26 stream reaches from highest to lowest P2-value, and visually interpreted potential breaks between poor, fair, good and excellent habitat classes (Table 7). Based on these data, we propose the lower bounds for these classes be 0.0, 0.15, 0.30, and 0.50, respectively. Large brown trout abundance differed significantly among the four habitat quality classes (Kruskal-Wallis test $\chi^2 = 14.14$, df = 3, $P = 0.003$). The Wilcoxon two-sample test showed that abundance was significantly different between most pairwise comparisons, except fair and excellent habitat quality classes (Z-statistic = 1.39, $P = 0.081$) or between good and excellent classes (Z-statistic = 0.50, $P = 0.308$). This was likely because of small sample size as only two reaches had excellent habitat quality using this method.

Discussion

Annear et al. (2004) identified five riverine components as influencing the structure and function of riverine systems: hydrology, geomorphology / physical habitat, water quality, connectivity / energy sources, and biotic interactions. Numerous studies have found relationships between these factors and one or more age- or size-groups of brown trout in streams (e.g., Mesick 1995; Eklöv et al. 1999; Lobón-Cerviá 2004). Results from this study suggest physical habitat and hydrology are important factors limiting large trout abundance in southeast Minnesota streams. In particular, the cover types identified here should be considered as necessary, but not sufficient conditions for a stream to support high densities of large trout. Large trout abundance is generally lower in streams in southeast Minnesota than in other upper Midwest states (Figure 2). For example, mean number of large brown trout/km was lowest in southeast Minnesota compared with other Midwest states. However, the mean number of large brown trout in southeast Minnesota, expressed as number/ha, was only slightly lower than the mean number/ha in coldwater streams in the Black Hills in South Dakota, but higher than mean number/ha in Michigan (Figure 2). These patterns suggest additional regional features may be important.

Our findings confirm several physical habitat features identified by Thorn and Anderson (1993) as being important to large brown trout during summer, but not all of them. Overhead bank cover, instream rocks, and woody debris were significant predictors of large trout presence in a pool in both studies. Presence of deep water, as either D90 in the present study or D60 in the previous study, was also identified. Similarly, our Poisson abundance model selected overhead bank cover, instream rocks, and deeper water, as represented by D60. Pool width was also significantly associated with large trout abundance in pools. Greater pool widths may

Table 6. Pearson's correlation matrix for reach-scale variables significantly related to abundance of large brown trout (No./km) following univariate linear regressions. Data were collected from coldwater streams in southeast Minnesota in 2003 and 2004. Values presented are correlation coefficients (*r*), with probabilities in parentheses.

Variable	Large trout abundance	Mean P2-value	Discharge	Mean depth	Trout biomass (all sizes)
Mean P2-value	0.81 (< 0.001)				
Discharge	0.70 (< 0.001)	0.73 (<0.001)			
Mean depth	0.52 (0.016)	0.60 (0.005)	0.40 (0.078)		
Trout biomass (all sizes)	0.52 (0.018)	0.64 (0.002)	0.56 (0.010)	0.33 (0.150)	
Basin area	0.44 (0.047)	0.54 (0.013)	0.65 (0.001)	0.30 (0.185)	0.46 (0.038)

Table 7. Length, number of pools , mean P2-value (a proposed index to habitat quality), and large brown trout (≥ 380 mm TL) abundance (No./km) estimates for 26 stream reaches sampled in southeast Minnesota used to develop a reach-scale habitat quality (HQ) classification to guide large trout management. Lower bounds for habitat classes are at mean P2-values 0.0, 0.15, 0.30, and 0.50.

Stream reach	Year	Reach length (km)	No. Pools	Trout abundance	Mean P2-value	H Q Class
Miller Cr.	2003	0.99	15	1.00	0.039	Poor
Daley Cr. – unimproved	2003	0.55	16	0.00	0.047	Poor
Watson Cr. – upper	2004	0.85	16	0.00	0.063	Poor
Ferguson Cr.	2003	0.32	15	3.14	0.092	Poor
Crooked Cr. – North Fork	2003	0.87	13	1.15	0.104	Poor
Badger Cr.	2003	0.65	14	1.55	0.117	Poor
Big Springs Cr.	2003	0.49	15	0.00	0.146	Poor
Wisel Cr.	2003	1.47	18	2.72	0.146	Poor
Lynch Cr.	2004	0.93	16	5.81	0.164	Fair
Money Cr.	2003	0.48	15	6.23	0.175	Fair
Pine Cr. – unimproved	2004	1.05	14	3.78	0.176	Fair
Daley Cr. – improved	2003	0.47	15	2.10	0.189	Fair
Thompson Cr. – upper	2004	0.82	17	0.94	0.195	Fair
Money Cr. – West Branch	2003	0.45	15	4.40	0.196	Fair
Root Rv. – South Branch	2003	0.72	11	1.38	0.208	Fair
West Beaver Cr.	2003	0.82	16	9.72	0.223	Fair
Etna Cr.	2003	0.53	18	22.64	0.233	Fair
Pine Cr. – New Hartford	2003	1.24	14	12.30	0.243	Fair
Spring Valley Cr.	2003	0.87	15	13.74	0.302	Good
Root Rv. – South Fork	2003	1.02	14	1.96	0.308	Good
Rush Cr. – unimproved	2004	0.53	9	24.16	0.337	Good
Bee Cr.	2003	0.75	10	7.07	0.358	Good
Main Beaver Cr. – upper	2003	0.75	14	18.80	0.364	Good
Rush Cr. – improved	2003	0.89	13	28.22	0.432	Good
Main Beaver Cr. – lower	2003	0.65	8	30.77	0.513	Excellent
Pine Cr. – improved	2004	1.00	14	8.24	0.514	Excellent

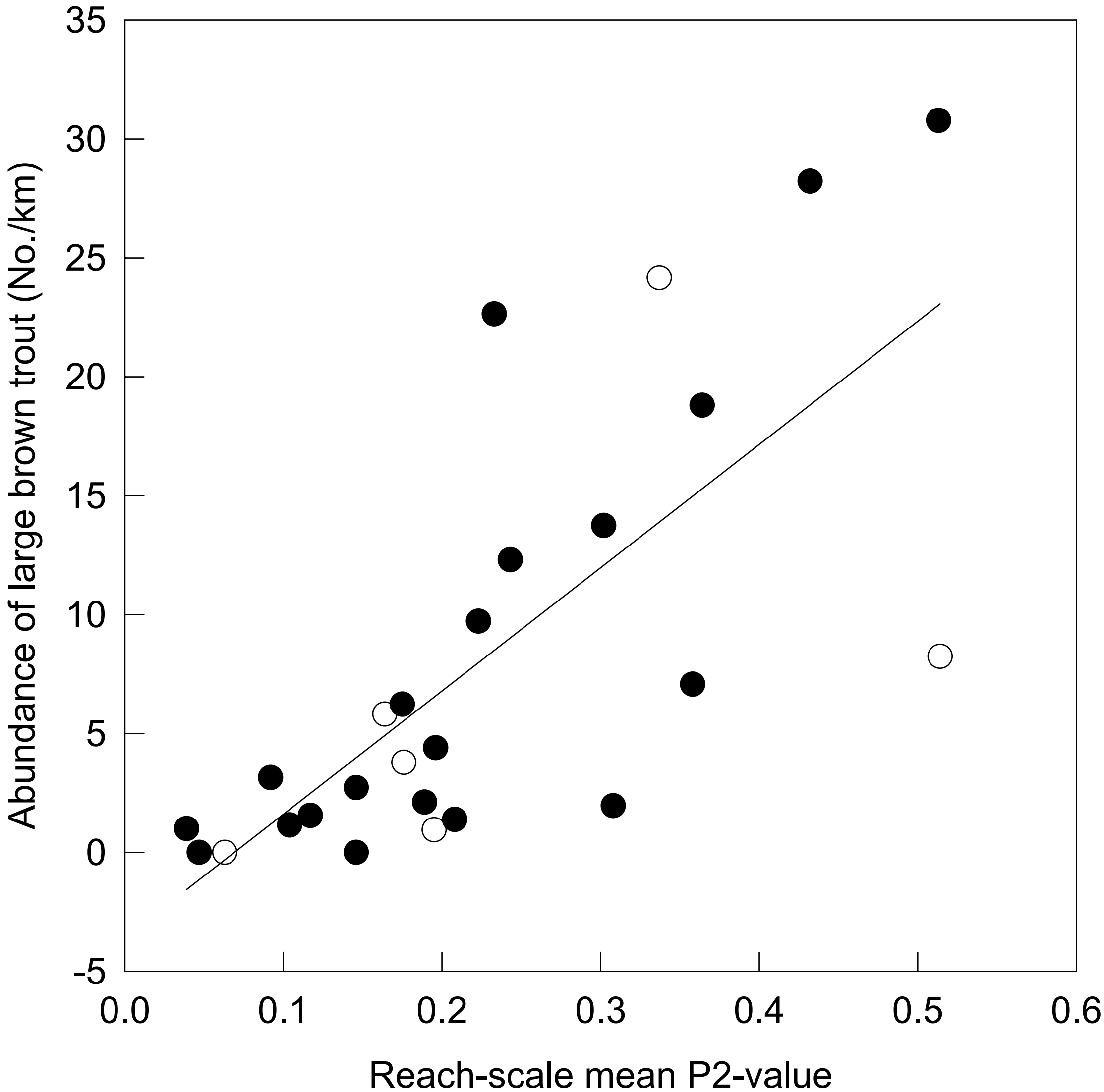

Figure 1. Relationship between mean P2-values, an index to habitat quality, and abundance of brown trout > 380 mm TL in 20 stream reaches sampled in 2003 (filled circles) and 6 reaches sampled in 2004 (open circles) in southeast Minnesota.

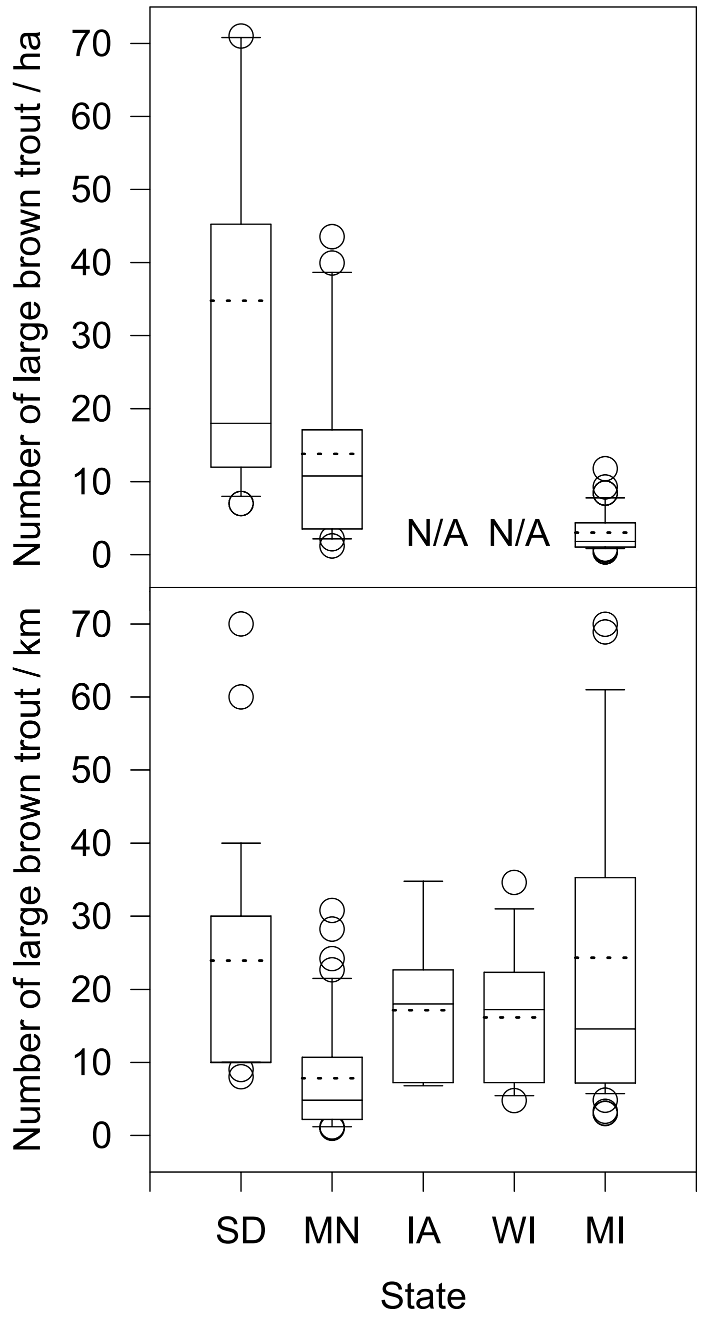

Figure 2. Modified box plots depicting large brown trout (≥ 380 mm TL) abundance in streams in five Midwestern states sampled between 2000 and 2004. Only streams where at least one large brown trout was captured were included. The solid line in each box is the median and the dashed line is the mean. N/A – Not available - stream widths not provided. N=47 for SD, 5 for IA, 13 for WI, 43 for MI, 38 for MN No./ha and 23 for MN No./km.

indicate a need for greater pool volume in addition to the presence of multiple cover types. Perhaps the presence of multiple cover types promoted presence in a pool by at least one large brown trout, but larger pools, as indicated by wider pool widths, promoted presence of multiple large trout. Streambank riprap was not significantly associated with either large trout presence or abundance in pools in the present study. Clearly, shallow pools with little cover do not provide habitat for large brown trout in southeast Minnesota streams. Larger and deeper pools with overhead bank cover, instream rock, and woody debris typically afford protection from predators (Bjornn and Reiser 1991), and may reduce intraspecific competition for space through visual isolation (Sundbaum and Näslund 1998).

The pool-scale model of Thorn and Anderson (1993), that predicted P/A of large trout in pools from the presence of five cover variables, was not very good at predicting presence, although it predicted absence well (Table 2). This indicated a need for redeveloping the pool-scale model with newer data. Because pools lacking the cover variables identified in Thorn and Anderson (1993) usually did not have large trout present, the presence of these covers was a partial requirement, but not the only requirement for large trout presence. If the pools failed to have most of these cover types present, then large trout were usually absent. If, however, the pools had the appropriate cover types, then large trout were present, but only 38% of the time. Other factors may have precluded large trout presence in the other 62% of pools with adequate covers present. The missing physical habitat factors may have been the greater pool depths (i.e., D90) identified in this study, some other unmeasured pool-scale factor, or a factor at a larger spatial scale, such as the reach scale. The low positive predictive value also suggests that the former model did not generalize well to new data, possibly because it was overparameterized. Finally, the method Thorn and Anderson (1993) used to select study streams and pools may have inflated the probabilities of finding large brown trout and slightly biased their model. Thorn and Anderson (1993) selected reaches known to have large brown trout to ensure an adequate sample size for model development. Also, they only measured physical habitat features in an equal number of pools where large trout were present or absent (i.e., as opposed to measuring habitat features in all pools large brown trout were absent from). Their approach may have inflated the likelihood of finding large trout overall. Thus, although the pool-scale model of Thorn and Anderson (1993) had some predictive value, we proceeded to develop new models based on new data measured across a wider range of stream types that were more representative of conditions in southeast Minnesota. We also included data from all pools sampled for large trout irrespective of whether a large trout was present in each pool or not.

Large spatial-scale factors, such as environmental differences among stream reaches, could have influenced large trout abundance and their pool selection, further explaining the low positive predictive value of the Thorn and Anderson (1993) model. A post-hoc analysis, that included a categorical factor for each stream reach sampled in our final pool-scale presence/absence model, indicated a significant stream-reach effect on pool-scale presence of large brown trout (log-likelihood ratio test comparing the final multiple logistic models with and without the stream-reach factor: $-2 \log L = 42.773$, $P < 0.025$). This supports the notion that some reach-scale factor(s) were important. Our reach-scale model found large trout abundance to be positively related to mean P2-value, strongly correlated with stream discharge (a hydrology factor), and with watershed area (Table 6). The latter two variables indicate that larger streams have more large brown trout. Stream discharge in late summer was not selected in our final reach-scale model, because it was strongly correlated with the new mean P2-values. This may be because our new P2-value index included D90 and larger streams with greater late summer low flows would likely have a greater frequency of D90 present in pools. Thorn and Anderson (1999) developed a classification scheme for rivers and streams across Minnesota. They speculated that coldwater streams in Class 9 might be some of the best candidates for large brown trout management. Streams in Class 9 were generally the largest coldwater streams with low flow wetted widths exceeding 6 m. Our findings of strong reach-scale positive correlations between large trout abundance and discharge and positive pool-scale associations with pool width, supports their contention. Future analyses should consider use of hierarchical modeling approaches to build and test nested logistic models, to better contrast the relative influences of reach- and pool-scale effects. Such hierarchical modeling approaches include Generalized Linear Models with the Generalized Estimation Equation (GEE), Generalized Linear Mixed Models (GLMM), or Non-Linear Mixed Models (NLINMIX) (Kuss 2002).

Abiotic stream features are hierarchically linked, with features at larger spatial scales influencing features at smaller scales (Frissell et al. 1986; Allan 1995; Roth et al. 1996). Such linkages often confound identification of the most important abiotic variables influencing biotic responses. Widespread collinearity among many variables at various spatial scales has now been detected in several studies of southeast Minnesota streams (Blann 2000, 2004; Dieterman et al. in review; this study, Table 6). Streams with higher discharge would be expected to have larger and wider pools with more deep water as reflected in a greater P2-value. Additionally, larger pools may have a higher probability of having a cover type such as woody debris or overhead bank cover present. Thus, large trout may be responding directly to the cover types and greater pool volume, but it is the larger-scale features such as larger basin area and greater discharge that ultimately influence large trout abundance. For example, Thorn and Anderson (2001b) did not find an increase in large trout abundance in a study of habitat rehabilitation in Hay Creek, where cover types such as instream rock, riprap, and overhead bank cover were added. They suggested that the lack of increase in large trout abundance may have been due to factors hindering growth, such as water temperature or prey availability. Our results suggest that the lack of an increase may have been due to the smaller stream size of Hay Creek and that riprap was not important. Future studies of fish and fish habitat associations should focus more on manipulative studies that isolate the effects of habitat features of interest, so that broad associations identified in previous studies can be verified.

Assuming our study reach selection was representative, our method of classifying habitat as poor with mean P2-values < 0.15, fair with values from 0.15 to < 0.30, good with values from 0.30 to < 0.50, and excellent with values ≥ 0.50, met most criteria for a good reach-scale habitat index. This method accounted for past stream degradation by classifying most reaches as poor (8 reaches) or fair (10 reaches), yet still classified a few reaches as good (6 reaches) or excellent (2 reaches). Large trout abundance differed significantly between poor or fair and good classes, which permits application with the MNDNR (2000) decision-making key. Few excellent-quality reaches likely limited our ability to adequately compare large trout abundance among all four habitat classes. This could be retested if future assessments collect large trout abundance information and classify habitat with this method.

Our mean P2-value index to habitat quality may be sensitive to the length of stream sampled, and therefore should not be calculated for reach lengths exceeding those used in its development in this study. We never sampled a stream reach shorter than 0.32 km nor longer than 1.47 km with fewer than 8 pools nor more than 18 pools (Table 7). Larger streams generally had fewer pools per length of reach (personal observation). Therefore, when determining the length of stream to assess for calculation of a mean P2-value, reach lengths may be the best guide for larger streams (i.e., generally watershed basin areas > 5,000 ha and mean widths > 6.0 m), whereas number of pools may be a better criteria to use for smaller streams.

A general limitation of studies of association is that some important variables may not be included in the analysis. Although our results found physical habitat and discharge to be important, associated with presence and abundance of large trout, we did not examine potential influence of water quality, connectivity/energy sources, and biotic interactions. Also, some factors may interact and exhibit synergistic effects. For example, Dieterman et al. (2004) suggested that water temperature, a water quality factor, influenced the composition and availability of prey items (i.e., energy sources) that in turn promoted faster growth of brown trout. Previous modeling results showed that large brown trout abundance may be linked to faster growth rates. Dieterman et al. (in review) examined biotic interactions among age 0, 1, and 2 brook *Salvelinus fontinalis*, brown *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss* in southeast Minnesota streams. They found trout densities explained at most 15% of the variation in incremental growth, indicating that these biotic interactions were of only minor importance in influencing growth, and consequently abundance of large brown trout. Other parameters, such as water temperature, that could directly influence large trout P/A and abundance, should be incorporated in future studies, and more thermally marginal streams could also be included. Warmwater stream sampling and angler reports indicate that large brown trout are occasionally captured in streams considered to be too warm for trout for at least a portion of each year (MNDNR unpublished data). Finally, angling mortality, another biotic interaction, is a parameter that could have influenced our results and should be examined in future studies. Measurement of angler mortality may necessitate alternative methods of measurement, other than traditional creel surveys, because of the low abundance of large brown trout and infrequent creel interviews. For example, Weiss (1999) was unable to estimate exploitation of brown trout age groups older than age 2 in nine southeast Minnesota streams because of low sample sizes.

Our reach-scale abundance model with the new P2-value as a predictor should be further tested. We only collected relevant data to validate our reach-scale abundance model from six reaches in 2004. In the other 15 reaches, we only noted P/A of the 5 cover types (i.e., riprap, woody debris, instream rock, overhead bank cover, and water deeper than 60 cm) identified as important in the original Table 8 of Thorn and Anderson (1993). Thus, we did not have data on P/A of water deeper than 90 cm to validate our reach-model based on the newer mean P2-values (Table 5-this report). However, results from our pool-scale analyses somewhat corroborated our reach-scale model, because the primary cover components in our reach-scale predictor, P2-value, were derived from pool-scale analyses. This also illustrates the benefits of using a multi-scale approach such as ours. Nevertheless, additional data on P/A of overhead bank cover, woody debris, instream rock, and water deeper than 90 cm should be collected in conjunction with trout abundance information to further test our reach-scale model.

If catchability of large brown trout was not consistent among our study streams, it could have influenced our results. Conventional thinking would suggest that larger streams with greater discharge, depth, and width might reduce large trout catchability. However, our strong positive correlations between large trout abundance and discharge and mean depth (Table 6) indicate that we captured more large trout in larger streams, and casts doubt on the idea of lower catchability in larger streams. If catchability was indeed lower, thean the implication is that our statistical relationships should only be stronger than what we found and the variables we identified should be even more important.

In summary, we found large brown trout presence or abundance to be associated with selected physical habitat and hydrology features in pools and reaches of southeast Minnesota streams. Large brown trout are most abundant in the largest streams, as indicated by an association with late summer, low-flow discharges. The largest streams may have the best combinations of pool-scale instream cover types used by large trout in late summer, and include wide pools, deep water, instream rocks, overhead bank cover, and woody debris. The pool-scale cover types are reflected in our new reach-scale mean P2-value index. Our results should be used to help prioritize streams for large trout management and contribute to an instream habitat management program for large brown trout.

Management Implications

We recommend managers begin prioritizing streams for large trout management based on discharge during late summer.

Streams with the greatest discharge should have the highest priority. Streams with discharge ≥ 0.43 m^3/s (the 75th percentile in our dataset) should then be evaluated for habitat quality as measured by the mean P2-value for a representative study reach. Streams with good-excellent habitat quality should be electrofished to assess large brown trout abundance. Measured large trout abundance should then be compared to expected abundance calculated from our reach-scale regression model. If abundance is greater than 25% of the expected value, then the stream should simply be monitored (MNDNR 2000). We suggest that measured abundance values between 25% and 75% of the expected values be considered normal variation. If abundance is lower than the 25th percentile, then other factors such as angler harvest or water chemistry parameters should be investigated. Similarly, values greater than 75% of expected values may suggest influences of factors other than physical habitat. For example, Etna Creek had a measured abundance of large brown trout of 22.6/km that exceeded 75% of the expected value (i.e., 11.4/km) for a stream reach with a mean P2-value of 0.233. Perhaps such high abundance was due to immigration of trout from an adjacent large warmwater stream during our summer sampling period.

For streams with discharge ≥ 0.43 m^3/s and poor-fair habitat quality, we recommend instream habitat management. Prevalence of water deeper than 90 cm, woody debris, instream rocks, and overhead bank cover within pools should be assessed and added as needed. Instream rocks, as boulder clusters, are also an important cover type for large brown trout in winter as shown by Marwitz et al. (unpublished).

For smaller streams with discharge < 0.43 m^3/s, large trout management is more complex. These streams are unlikely to have wider and larger pool areas or water deeper than 90 cm. Thus, habitat quality will likely be poor-fair in most instances and managers may simply need to recognize the limited biological potential in these systems for supporting abundant large trout. Managers may consider increased cooperation with land management agencies, such as the Natural Resources Conservation Service, to target watersheds and implement watershed management approaches to bolster streamflows. Regulatory agencies should also continue to protect late summer baseflows from water withdrawals for municipal, industrial, agricultural, or private uses. We recommend that all large trout habitat management, whether in large or small streams of various habitat quality, be considered experimental management and evaluated.

Managers should consider collecting information on late summer discharge, large brown trout abundance, and area of overhead bank cover, instream rock, woody debris, rip rap, and water depths exceeding 60, 90, 120, and 150 cm to aid application, evaluation, and refinement of these models. Some variables, such as area of water deeper than 120 or 150 cm, were not adequately evaluated due to extreme rarity. Also, continuous variable measurements can always be collapsed to P/A, but P/A data cannot be expanded.

The emphasis of these data was on physical habitat, but managers should remain aware of other factors potentially influencing large brown trout, such as water quality and biotic interactions. Biotic interactions with anglers or mammalian and avian predators can result in high mortality for large brown trout (Meyers et al. 1992; Marwitz et al., unpublished). Also, large brown trout are able to make extensive long distance movements (Meyers et al. 1992; Young 1994; Bettinger and Bettoli 2004), and connectivity to winter refugium or spawning areas may be extremely important. Such movements could have implications in the success of a comprehensive habitat management program. For example, how close do pools with overwintering habitat, in the form of deep water, woody debris, and instream rocks, have to be to pools providing important summer habitat? Can small streams support higher abundances of large brown trout than predicted by our P2-values if connected to larger streams? Similar movement studies should be investigated in southeast Minnesota to further our understanding of the importance of habitat quality and juxtaposition to promote greater large trout abundance.

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Appendix Table A1. Values for biological variables measured to develop a model of large brown trout (LT) abundance (LT/km, LT/ha) in stream reaches in southeast Minnesota.

Stream reach	LT/km	LT/ha	Trout density (#/ha)	Trout biomass (kg/ha)
		2003		
Badger	1.55	5.40	726	99
Beaver, Lower	30.77	43.52	1512	224
Beaver, Upper	18.80	22.53	2115	215
Beaver, West	9.72	14.90	1452	118
Bee	7.07	9.53	1677	160
Big Springs	0.00	0.00	2162	120
Crooked, North Fork	1.15	2.17	809	88
Daley, improved	2.10	7.19	1924	199
Daley, unimproved	0.00	0.00	680	36
Etna	22.64	38.35	2048	72
Ferguson	3.14	10.80	6465	219
Miller	1.00	2.20	181	14
Money	6.23	12.02	20	9
Money, West	4.40	9.87	246	39
Pine (New Hartford)	12.30	15.23	1085	128
Root River, South Branch	1.38	1.19	1977	161
Root River, South Fork	1.96	2.70	1914	110
Rush, improved	28.22	39.91	3565	278
Spring Valley	13.74	17.72	1621	108
Wisel	2.72	3.18	289	56
		2004		
Lynch	5.81	11.30	1396	64
Pine, improved	8.24	11.58	243	64
Pine, unimproved	3.78	4.59	146	36
Rush, unimproved	24.16	29.23	520	55
Thompson, upper	0.94	2.69	366	60
Watson, upper	0.00	0.00	77	13

Appendix Table A2. Mean values for instream habitat/cover variables measured to develop a model of large brown trout abundance in stream reaches in southeast Minnesota.

Stream	L_{obc}/T %	OBC %	IR %	RR %	DEB %	D60 %	D90 %	D120 %	D150 %	Aquatic veg. %	Initial P-value	New P2-value	Habitat quality[a]	Pool type[b]
							2003							
Badger	162.3	30.02	0.00	0.00	0.00	1.20	0.01	0.00	0.00	0	0.250	0.117	2	3.0
Beaver, low	48.0	2.50	0.00	0.02	0.16	26.90	5.20	0.00	0.00	22	0.465	0.513	2	2.5
Beaver, upper	3.1	0.11	0.09	0.38	0.44	19.39	5.32	0.00	0.00	18	0.397	0.364	3	2.5
Beaver, West	4.5	1.90	0.10	0.05	0.21	14.10	0.20	0.00	0.00	90	0.358	0.223	4	2.9
Bee	2.2	0.12	0.13	0.05	0.03	13.50	9.50	0.20	0.00	73	0.467	0.358	3	2.6
Big Springs	17.6	3.00	0.40	0.60	0.00	22.90	0.50	0.00	0.00	35	0.336	0.146	2	2.7
Crooked, N. Fork	0.9	0.13	0.04	0.00	0.04	0.07	0.02	0.00	0.00	37	0.125	0.104	2	1.2
Daley, improved	33.8	10.20	0.40	0.30	0.10	3.45	0.29	0.00	0.00	21	0.334	0.189	3	2.7
Daley, unimproved	1.0	0.11	0.09	0.00	0.30	0.05	0.00	0.00	0.00	2	0.100	0.047	2	1.0
Etna	23.8	1.29	0.30	0.17	0.19	6.60	0.58	0.34	0.00	20	0.335	0.233	4	1.4
Ferguson	27.6	10.90	0.60	0.40	0.10	3.90	0.00	0.00	0.00	19	0.264	0.092	4	2.8
Miller	0.3	0.03	0.00	0.00	1.10	0.14	0.00	0.00	0.00	0	0.100	0.039	1	1.0
Money	2.7	0.17	0.00	0.00	1.55	9.30	0.08	0.00	0.00	0	0.330	0.175	3	1.5
Money, West	33.7	2.40	0.03	0.00	0.05	3.70	0.04	0.00	0.00	9	0.471	0.196	2	1.5
Pine (NH)	13.6	0.73	0.10	0.04	0.15	9.55	2.52	0.00	0.00	29	0.307	0.243	3	1.6
Root River, S. Branch	2.0	0.07	0.16	0.00	0.07	5.70	0.30	0.08	0.00	1	0.270	0.208	4	1.4
Root River, S. Fork	10.7	1.20	0.16	0.03	1.70	18.60	4.60	1.60	0.00	67	0.408	0.308	4	2.9
Rush, improved	10.3	1.20	0.20	0.20	0.02	23.90	5.20	0.40	0.00	15	0.539	0.432	4	3.2
Spring Valley	6.4	0.32	0.10	0.04	0.58	7.53	2.18	0.52	0.00	1	0.300	0.302	3	2.2
Wisel	0.6	0.01	0.05	0.00	0.43	3.43	0.47	0.08	0.01	8	0.238	0.146	3	1.7
							2004							
Lynch	0.1	0.84	0.02	0.00	0.16	12.40	7.00	0.00	0.00	0	0.164	0.164	2	1.8
Pine, improved	21.3	2.76	0.21	0.16	0.07	66.10	25.90	3.30	0.00	0	0.486	0.514	3	3.2
Pine, unimproved	1.4	0.09	0.02	0.00	0.63	9.40	1.90	0.20	0.00	0	0.227	0.176	2	1.6
Rush, unimproved	2.0	0.16	0.06	0.01	3.39	19.60	3.40	1.00	0.00	0	0.268	0.337	2	2.0
Thompson, upper	6.3	0.53	0.06	0.00	0.39	23.00	8.50	0.50	0.00	0	0.285	0.195	2	1.5
Watson, upper	1.1	0.11	0.00	0.00	0.20	0.15	0.01	0.00	0.00	0	0.096	0.063	1	1.0

[a]1 – poor, 2 – fair, 3 – good, 4 – excellent

[b]From Thorn and Anderson (2001)

Appendix Table A3. Values for selected stream reach variables measured to develop a model of large brown trout abundance in southeast Minnesota stream reaches.

Stream	Length (km)	Mean width (m)	Mean depth (m)	Area (ha)	Stream class[a]	Pool bank shade	Bank erosion[b]
			2003				
Badger	0.65	2.94	0.26	0.19	4	0	1.0
Beaver, low	0.65	7.84	0.43	0.46	9	20	1.3
Beaver, upper	0.75	8.26	0.44	0.62	9	28	1.1
Beaver, West	0.82	7.60	0.80	0.54	9	43	1.0
Bee	0.75	6.77	0.38	0.73	9	19	1.0
Big Springs	0.49	2.56	0.27	0.13	1	13	1.0
Crooked, N. Fork	0.87	4.81	0.21	0.46	10	16	1.0
Daley, improved	0.47	2.92	0.15	0.14	9	3	1.1
Daley, unimproved	0.55	3.29	0.16	0.17	8	66	2.6
Etna	0.53	5.12	0.34	0.34	9	36	1.1
Ferguson	0.32	2.79	0.22	0.09	8	41	1.0
Miller	0.99	4.80	0.16	0.45	10	81	1.1
Money	0.48	4.55	0.29	0.25	10	47	1.3
Money, West	0.45	4.30	0.30	0.30	6	24	1.1
Pine (NH)	1.24	6.18	0.26	0.79	9	5	1.0
Root River, S. Branch	0.72	10.90	0.22	0.84	9	26	1.2
Root River, S. Fork	1.02	6.85	0.44	0.74	9	33	1.0
Rush, improved	0.89	6.70	0.53	0.63	9	14	1.6
Spring Valley	0.87	7.24	0.35	0.68	9	47	1.4
Wisel	1.47	8.84	0.23	1.26	9	9	1.2
			2004				
Lynch	0.93	4.77	0.39	0.44	8	18	1.6
Pine, improved	1.00	6.29	0.54	0.69	9	6	1.0
Pine, unimproved	1.05	8.19	0.36	0.86	9	37	2.1
Rush, unimproved	0.53	8.01	0.37	0.44	9	40	2.4
Thompson, upper	0.82	3.93	0.37	0.37	10	50	2.2
Watson, upper	0.85	4.63	0.28	0.39	10	63	3.0

[a]Thorn and Anderson (1999)

[b]Thorn and Anderson (2001), 1 – light, 2 – moderate, 3 – severe

Appendix Table A4. Stream reach morphology variables measured to develop a model of large brown trout abundance in southeast Minnesota stream reaches.

Stream	% Pool	% Riffle	Gradient (m/km)	Sinuosity	Discharge (m^3/s)	% Fines	WD[a]
			2003				
Badger	100.0	0.0	0.93	1.7	0.197	100.0	11.4
Beaver, low	90.4	9.6	2.00	1.9	0.827	71.3	18.4
Beaver, upper	81.9	18.1	3.53	1.2	0.711	61.7	18.9
Beaver, West	89.7	10.3	3.54	1.6	0.231	33.4	9.5
Bee	85.4	14.6	4.19	1.4	0.216	19.6	7.7
Big Springs	84.2	15.8	5.27	1.6	0.051	70.3	9.6
Crooked, N. Fork	52.3	47.7	5.40	1.2	0.211	46.0	23.4
Daley, improved	77.3	22.8	5.84	1.4	0.073	56.4	19.0
Daley, unimproved	70.1	29.9	3.55	1.4	0.138	72.7	20.2
Etna	89.1	11.9	3.41	1.6	0.069	65.5	15.1
Ferguson	60.4	39.6	11.84	1.5	0.112	35.0	12.6
Miller	87.0	13.0	3.98	1.5	0.203	92.0	30.8
Money	87.8	12.2	4.68	1.6	0.067	67.2	15.9
Money, West	89.5	10.1	3.90	2.7	0.088	79.9	14.6
Pine (NH)	83.1	16.9	3.62	1.7	0.201	46.5	23.4
Root River, S. Branch	77.2	22.8	4.13	2.0	0.222	1.0	49.5
Root River, S. Fork	84.1	15.9	5.14	1.5	0.197	49.0	15.4
Rush, improved	79.2	20.8	3.48	2.2	0.427	55.0	12.6
Spring Valley	81.7	18.3	1.84	2.3	0.293	24.0	21.0
Wisel	81.0	9.0	3.62	1.9	0.195	54.3	38.9
			2004				
Lynch	85.0	15.0	1.70	2.2	0.117	83.6	10.7
Pine, improved	79.3	20.7	1.59	1.8	0.503	47.0	11.5
Pine, unimproved	82.2	18.8	1.98	1.8	0.503	76.0	22.2
Rush, unimproved	85.4	14.6	3.22	1.7	0.849	74.0	21.2
Thompson, upper	90.6	9.4	2.10	1.4	0.142	78.0	10.4
Watson, upper	80.8	19.2	2.78	2.0	0.161	60.9	16.4

[a]Width:Depth ratio

Appendix Table A5. Selected watershed variables measured to develop a model of large brown trout abundance in southeast Minnesota stream reaches.

Stream	Basin area (ha)	Basin slope (%)	Land Use (%) Urban	Cropland	Hay/grass	Forest	K-factor	Min. perm. (in/hr)[a]
			2003					
Badger	2,964	16.85	2	42	17	39	0.44	0.88
Beaver, low	12,792	10.07	2	57	13	27	0.62	0.69
Beaver, upper	11,686	10.53	2	60	13	25	0.69	0.62
Beaver, West	6,220	12.72	3	61	15	21	0.33	0.50
Bee	860	17.00	2	71	11	16	0.20	0.41
Big Springs	1,515	21.64	2	58	15	25	0.32	0.60
Crooked, N. Fork	4,233	14.79	4	53	17	25	0.40	0.60
Daley, improved	1,569	28.08	1	38	13	45	0.40	0.60
Daley, unimprov.	1,842	23.49	1	41	15	45	0.40	0.60
Etna	1,784	6.92	2	85	9	3	0.30	0.60
Ferguson	1,373	19.73	2	73	11	14	0.26	6.44
Miller	4,076	17.83	2	60	14	24	0.36	0.71
Money	1,733	35.45	2	51	16	31	0.35	0.60
Money, West	2,412	20.50	2	49	20	29	0.34	0.60
Pine (NH)	5,264	19.71	2	47	15	35	0.35	0.60
Root River, S. Branch	17,824	3.06	2	81	8	8	0.29	0.60
Root River, S. Fork	7,545	9.19	2	64	18	15	0.36	1.87
Rush, improved	14,555	10.44	3	69	14	14	0.28	4.38
Spring Valley	7,808	5.77	5	76	8	11	0.30	0.60
Wisel	10,404	9.84	3	66	18	13	0.29	2.86
			2004					
Lynch								
Pine, improved	11,690	11.06	2	68	14	16	0.28	1.97
Pine, unimproved	11,934	10.11	2	67	14	17	0.29	2.05
Rush, unimproved								
Thompson, upper	2,727	19.82	1	43	15	41	0.38	0.60
Watson, upper	2,622	11.11	4	82	8	5	0.35	0.92

[a]Minimum soil permeability (inches/hr)