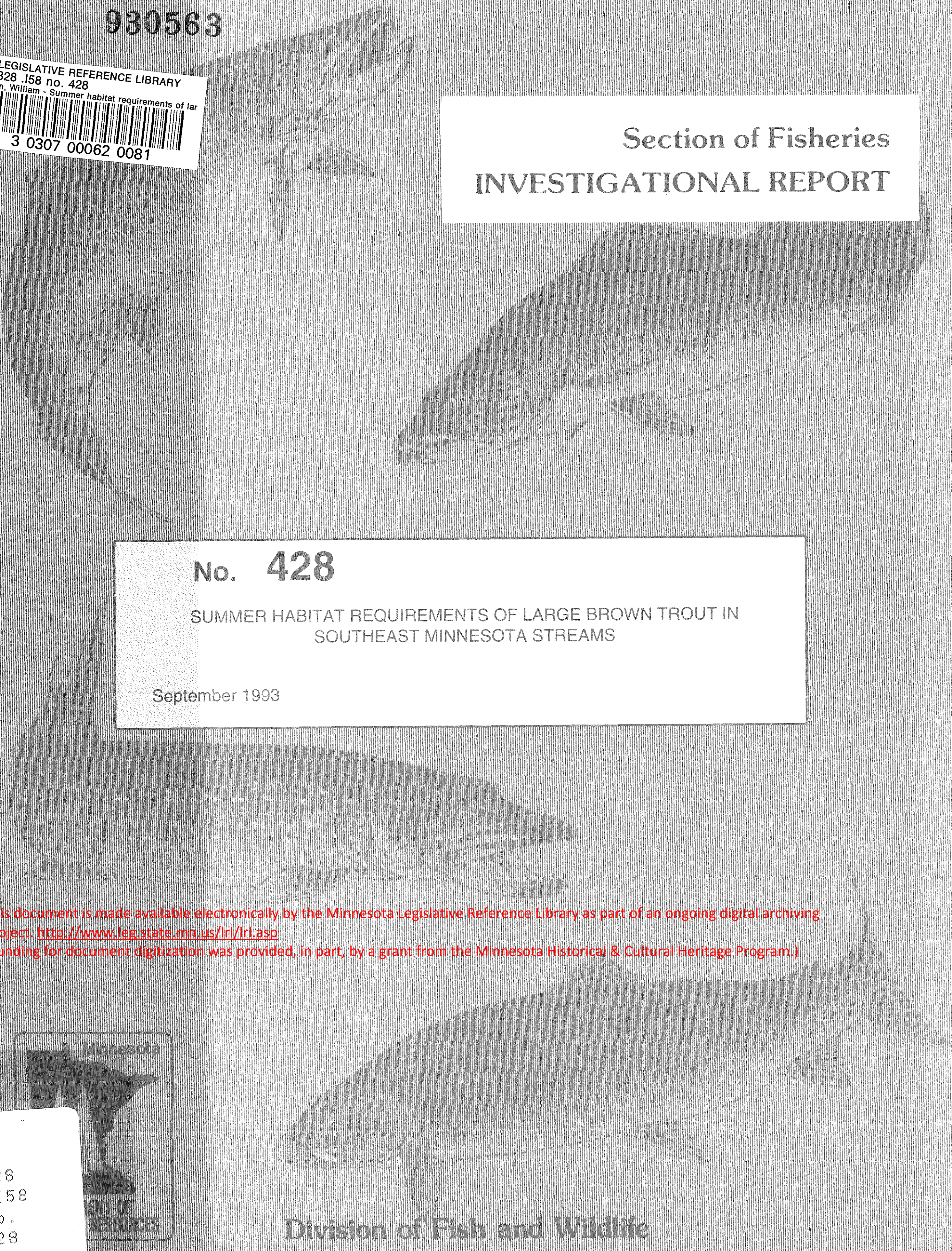

Section of Fisheries

INVESTIGATIONAL REPORT

No. 428

SUMMER HABITAT REQUIREMENTS OF LARGE BROWN TROUT IN SOUTHEAST MINNESOTA STREAMS

September 1993

Minnesota
DEPARTMENT OF NATURAL RESOURCES

Division of Fish and Wildlife

Minnesota Department of Natural Resources
Investigational Report 428, 1993

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

William C. Thorn and Charles S. Anderson

Minnesota Department of Natural Resources
Section of Fisheries
500 Lafayette Road
St. Paul, MN 55155

Abstract.--We quantified the relationship between summer habitat variables and the presence or absence of large brown trout *Salmo trutta* (>380 mm) with stepwise logistic regression. Large brown trout were associated with large pools, with four kinds of cover, and with water deeper than 60 cm. Habitat improvement and special regulations have not increased abundance of large brown trout in southeast Minnesota streams. We conclude that habitat requirements were not adequately addressed. To increase abundance of large brown trout when habitat is limiting, we recommend increasing the quantity and variety of cover, especially overhead bank cover, and area of water deeper than 60 cm. When summer habitat is not limiting abundance, angling and winter habitat should be investigated.

Introduction

Anglers attach importance to the size of trout they catch in southeast Minnesota streams, but abundance of large brown trout *Salmo trutta* is low. Angler satisfaction was related to the length of trout caught (Hirsch 1989), and anglers rated size more important than the number caught (Hirsch 1989; Thorn 1990a; Wiechman 1990). Wiechman (1990) concluded that when abundance was adequate, management should focus on increasing the size of trout available for anglers. However, the mode for abundance of brown trout >380 mm in 54 stream reaches was 0/km with a mean of 5/km (Thorn, Minnesota Department of Natural Resources, unpublished data). Increasing the abundance and catch of large trout should increase angling quality in southeast Minnesota streams.

Trout management in southeast Minnesota has not increased abundance of brown trout >380 mm. Habitat improvement increased

[1] This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program. Completion Report, Study 681, D-J Project F-26-R Minnesota.

biomass of adult trout, mostly <300 mm (Thorn 1988a, 1990b), and a no-kill regulation on a stream with improved habitat, increased abundance of 200-380 mm brown trout (Thorn 1990a). Very few stocked brown trout survived for one year (Thorn 1992a; Wiley et al. 1993).

Cover and water depth are important habitat components for brown trout. In southeast Minnesota streams, Thorn (1988b) found that overhead bank cover (OBC) and area of water deeper than 60 cm (D60) were the most important variables for predicting brown trout biomass in pools. Thorn (1988b) also stated that brown trout >300 mm were rare in his fish samples used for model development. Heggenes (1988a, 1988b) reported that the larger trout in his studies preferred deeper areas with abundant cover. Kennedy and Strange (1982) also showed that brown trout moved from shallow to deeper water as they increased in size, and that trout densities and depths were significantly positively correlated. However, the exact role of depth as brown trout cover is unclear. Thorn (1988b) did not find the area of water deeper than 90 cm to be correlated with biomass or density, and Kennedy and Strange (1982) concluded that density and depth relationships were not linear.

The objectives of this study were to quantify summer habitat of large brown trout in southeast Minnesota streams, and recommend habitat management techniques to increase abundance of large brown trout. If summer habitat of large brown trout was different from that of smaller adults, habitat improvements could be designed to increase summer habitat and abundance of large trout. However, if summer habitats of large and small adult brown trout were similar, the lack of response of large trout to habitat improvements would show other variables, such as exploitation or winter habitat, limit their abundance.

Study Area

Southeast Minnesota trout streams begin from cold (9°C) springs and are productive (alkalinity, 220-250 mg/l; total phosphate, 0.02-0.16 mg/l; total nitrate, 0.49-2.34 mg/l). Agriculture is the main land use of the region and agricultural runoff has degraded trout habitat in most streams. Waters (1977) generally described trout streams of southeast Minnesota.

Brown trout are the most abundant trout species in this region and support popular fisheries. Biomass of brown trout ranged from <25 kg/hectare in extremely degraded habitat to >200 kg/hectare after habitat improvement (Thorn 1988a, 1992b). During the 1980s, angling pressure on five streams ranged from 535 to 3,081 h/km (Hayes 1990; Thorn 1990a). After habitat improvement in Hay Creek, pressure increased from 387-701 h/km to 1,054-1,283 h/km (Thorn 1988a).

The streams selected for study (Table 1) provided a range of brown trout abundance, non-trout species abundance, stream size, habitat quality, land use, and angling pressure in southeast Minnesota. The South Branch of the Root River was excluded from sampling because extreme width and depth prevented sampling.

Methods

From July through mid-September in 1991 and 1992, we electrofished 511 pools in 21 streams with one pass, usually moving upstream, using a stream electrofisher similar to that described by Novotny and Priegel (1971). To eliminate influence of seasonal and local movements, we sampled during the day in summer. In summer, large trout stay in or near cover during the day, and those that move do so at night (Clapp et al. 1990; Regal 1992). Workers only attempted to capture large trout (>380 mm), so we assume capture probabilities approached 1.0. Previous analyses of mark-recapture experiments had shown capture probability increased with size, and that capture probability was often above 0.7 for large trout when workers were attempting to capture all adult trout (Anderson, In review). Large brown trout (>380 mm) were measured and weighed, and scales and fin rays were collected to determine age and backcalculate growth (Frie 1982). On six streams, we collected scales from trout of all lengths. Von Bertalanffy growth functions were calculated for these populations with the computer program FISHPARM (Prager et al. 1989) to evaluate growth potential for large trout. The number of pools electrofished per stream ranged

Table 1. General description of streams sampled for large brown trout.

County	Stream	Width[a] (m)	Late summer discharge[a] (m_3/sec)	Habitat[b] quality	Riparian corridor
Fillmore	Diamond Cr.[c]	2.4,3.7	0.04,0.07	good, excellent	wooded
Fillmore	Kedron Cr.	5.3	0.05	fair	grass
Goodhue	Hay Cr.	5.6	0.25	excellent	pasture
Goodhue	Spring Cr.	6.5	0.13	poor	wooded
Houston	Crooked Cr.	8.6	0.51	poor	wooded
Houston	Thompson Cr.	5.4	0.57	fair	wooded
Houston	Winnebago Cr.	7.5	0.54	poor	pasture, wooded
Olmsted	Mill Cr.	6.7	0.20	poor	pasture, grass
Olmsted	Trout Run	7.0	0.39	good	wooded
Wabasha	East Indian Cr.[c]	4.0,6.5	0.04,0.07	poor, fair	wooded, grass
Wabasha	West Indian Cr.[c]	4.2,6.5,6.5	0.21,0.21,0.27	excellent, fair, poor	wooded, grass
Winona	Beaver Cr.	6.7	0.22	good	wooded
Winona	Cedar Valley Cr.	3.9	0.11	fair	wooded
Winona	Garvin Br.[c]	4.9, 8.4	0.08,0.66	good, poor	wooded, grass
Winona	Gilmore Cr.	3.4	0.08	fair	wooded
Winona	Little Pickwick Cr.	2.1	0.05	fair	wooded, grass
Winona	Pickwick Cr.	4.5	0.13	fair	pasture
Winona	Whitewater R., Mid. Br.[c]	5.8,12.2	0.23,0.77	good, fair	pasture, wooded
Winona	Whitewater R., No. Br.	11.6	0.61	fair	wooded
Winona	Whitewater R., So. Br.[c]	10.7	0.53	poor, fair, good	wooded, pasture

[a] From stream survey reports (MNDNR, unpublished data)
[b] From Minnesota DNR (1993)
[c] More than one stream reach

from 4-89. When a pool was too deep to effectively wade, it was electrofished downstream by one or two people floating in belly boats. One small stream was sampled with a commercial backpack electrofisher.

We anticipated that capturing rare large trout would require electrofishing many kilometers of streams and that it would not be possible to measure habitat variables in every pool; therefore, in each stream reach, habitat variables were measured in all pools with large brown trout and usually in an equal number of pools without large brown trout. In 1991, pools without large trout in each reach were randomly selected for measurement from among those electrofished. In 1992, a pool adjacent to each pool with a large trout was sampled. The habitat variables included three measures of pool size (pool length T, width W, and area AREA), five measures of cover expressed as a percent of pool area (overhead cover OC, overhead bank cover OBC, debris DEB, overhead cover by riprap RR, and instream rocks IR), two measures of the length of overhead bank cover (length of OBC L_{obc}, length of OBC per thalweg length L_{obc}/T), and four measures of deep water expressed as a percent of pool area (water deeper than 60 cm D60, 90 cm D90, 120 cm D120, and 150 cm D150). Habitat variables were measured according to Thorn (1988b) and Platts et al. (1983).

The habitat selection model.--We assume large brown trout in streams throughout southeast Minnesota have similar habitat requirements and select pools in similar ways. Specifically, in any stream, the probability of a pool with habitat variables X_i having a large trout present is described by the same habitat selection function $r(X_i)$. One may choose the habitat selection function from among any of those constrained to take values between 0 and 1. We chose the family of conventional logistic models,

$$r(X_i) = \frac{\exp(\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots)}{1+\exp(\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots)}, \qquad (1)$$

because it is biologically interpretable and is commonly used to describe habitat suitability for stream fish (Bovee 1986; Aadland et al. 1991). The primary objective of this study was to obtain an estimate of this habitat selection model, but this function could not be fit directly from the data.

If every pool had been measured, analysis could proceed directly by common logistic regression methods (Hosmer and Lemeshow 1989). In each stream, however, only a fraction Q_S of pools without large trout were measured, therefore an assumption of the logistic model is not met and estimates calculated with this model will be erroneous. To obtain sound estimates of the coefficients of the logistic habitat selection model, one must fit a model conditioned upon the pool being in the measured set. The derivation of the conditional model is in some ways similar to conditional models developed by Millar and colleagues (Millar and Walsh 1992; Walsh et al. 1992) to compare retention probabilities of two trawl meshes. The conditional model described below incorporates the fractional sampling of pools without large trout in its design. It allows hypotheses about the effects of habitat variables and their interactions to be tested with likelihood ratio tests, and produces measures of the reliability of the estimated selection curve parameters.

The conditional model.--The probability of a pool having a large trout and being measured is $r(X_i) \times 1 = r(X_i)$, since all electrofished pools with large trout were measured. The probability of an electrofished pool being without large trout and also being measured is $(1 - r(X_i))Q_S$, where Q_S is the proportion of pools without large trout that were measured in each stream. Finally, the probability that an electrofished pool in a stream is measured is the sum of these probabilities, $r(X_i) + (1 - r(X_i))Q_S$. The conditional probability of a pool having had a large trout, given that the pool was measured, is therefore

$$\phi(X_i) = \frac{P[\mathit{large\ trout\ in\ pool}]}{P[\mathit{pool\ was\ measured}]}$$

$$\phi(X_i) = \frac{r(X_i)}{r(X_i) + Q_S(1 - r(X_i))}. \qquad (2)$$

The probability of a pool not having had a large trout, given that the pool was measured, is $1-\phi(X_i)$.

Let the number of measured pools with habitat characteristics X_i be $N_{X,\pm}$. Let the observed number of these with large trout be $N_{X,+}$, and let the observed number without be $N_{X,-}$. According to the model, $N_{X,+}$ is distributed as a binomial $(N_{X,\pm},\phi(X_i))$ random variable. The log-likelihood function for the observed data is

$$\sum_{X_i} [N_{X,+} \log_e \phi(X_i) + N_{X,-} \log_e (1 - \phi(X_i)], \qquad (3)$$

where the summation is over all unique combinations of habitat characteristics in the set of variables being examined.

Substituting equation (1) for $r(X_i)$ into equation (2) yields

$$\phi(X_i) = \frac{\exp(\beta + \beta_1 X_1 + \beta_2 X_2 + ...)}{Q_S + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}. \qquad (4)$$

This equation can be fit with data on the set of measured pools if the outcome variable is coded as 1 or 0, representing the presence or absence of large trout, respectively. We fit this model by nonlinear regression and maximum likelihood methods implemented in SYSTAT (Wilkinson 1990). Standard errors for the β coefficients were calculated by SYSTAT. We followed both stepwise forward and purposeful approaches (sensu Hosmer and Lemeshow 1989) to determine the subset of habitat variables and interaction terms to include in the final habitat selection model. The stepwise forward approach to searching for main effects was taken because several of the habitat variables measuring area and length of cover were closely related to each other, and the series of depth measures were nested (the area of D90 was included in the area of D60), thus a backward approach would have started with many uninterpretable models. To avoid excluding important variables from the model, the P values chosen to enter and remove variables were 0.15 and 0.20, respectively.

In initial analysis, D90, D120, and D150 were included as main effects. All depth variables except D90 were purposefully deleted from subsequent analyses because the D120 and D150 coefficients were unstable, and because it confused interpretability to consider nested depth variables and their interaction terms. The same main effects (minus D120 and D150) were again selected when the stepwise forward process was then repeated. Following selection of the main effects terms, as recommended by Hosmer and Lemeshow (1989), appropriate transformations of the habitat variables were made so variables would have linear relationships to the logit ($r(X_i)$). The included variables D60, L_{obc}/T, and DEB were transformed to dichotomous variables (reflecting presence or absence of each habitat feature). We considered 10 possible two-way interaction terms involving the D60, L_{obc}/T, DEB, IR, and RR variables to be interpretable and potentially biologically meaningful; no three-way interactions were considered meaningful. Individually, three of the two-way interactions significantly improved the model fit, and jointly all three significantly improved the fit, thus the final habitat selection model included the three interaction terms.

The estimates of the β parameters were substituted into the logistic model (1) to obtain the habitat selection function of biological interest, $\hat{r}(X_i)$. Odds ratios OR were calculated to show approximately how much more likely the presence of a large trout would be among pools with habitat variables at one level than among those pools with habitat variables at another level (Hosmer and Lemeshow 1989). A change between two levels of an independent variable was considered to have a significant effect on the probability of habitat use by a large trout if the 95% confidence interval of the OR for that variable did not include 1.0.

Results

We collected 157 large brown trout (Appendix Table 1) in 107 pools from 21 stream reaches (Table 1). Habitat variables were measured for these pools and for 108 pools lacking large trout (Table 2). In five of six streams where all trout were examined, the asymptotic length (L_∞) was >380 mm (Table 3). Only three trout were older than age-5. The growth of large trout was relatively rapid (Table 4).

Many of the measured habitat features were rare; therefore, many variables had a limited range of values and a modal value of 0 in the

Table 2. Mean and range of variables in pools with (N=107) and without (N=108) brown trout (BNT) > 380 mm in southeast Minnesota streams, 1991 and 1992.

Variable	Abbreviation	Pools with BNT > 380 mm Mean	Pools with BNT > 380 mm Range	Pools without BNT > 380 mm Mean	Pools without BNT > 380 mm Range
Length (m)	T	62.41	9.1-228.8	42.73	6.7-144.9
Area (m^2)	Area	457.40	21.8-2608.3	314.00	26.4-1428.0
Width (m)	W	6.55	2.3-18.9	6.47	1.8-14.0
Area overhead cover (%)	OC	7.79	0.0-40.0	8.15	0.0-71.9
Area overhead bank cover (%)	OBC	1.78	0.0-27.7	0.91	0.0-14.0
Area debris (%)	DEB	0.94	0.0-8.4	0.89	0.0-10.5
Area riprap (%)	RR	0.34	0.0-6.9	0.09	0.0-2.1
Area instream rocks (%)	IR	0.79	0.0-2.0	0.13	0.0-1.1
Length overhead bank cover (m)	L_{obc}	5.48	0.0-122.0	2.30	0.0-27.0
Length overhead bank cover/thalweg length (%)	L_{obc}/T	12.27	0.0-125.0	7.45	0.0-75.0
Area deeper than 60 cm (%)	D60	19.27	0.0-91.0	12.25	0.0-62.7
Area deeper than 90 cm (%)	D90	4.34	0.0-59.5	3.31	0.0-39.7
Area deeper than 120 cm (%)	D120	0.81	0.0-13.5	1.09	0.0-26.1
Area deeper than 150 cm (%)	D150	0.16	0.0-9.5	0.39	0.0-18.4

Table 3. Predicted and actual () lengths in mm and asymptotic length (von Bertalanffy L∞) for brown trout in six southeast Minnesota streams.

	Age								
Stream	1	2	3	4	5	6	7	8	L∞
Cedar Valley Creek	137 (153)	232 (240)	311 (313)	378 (372)	435 (441)	482	522	555	733
Diamond Creek	123 (127)	209 (221)	285 (293)	350 (346)	407	457	500	537	786
Hay Creek (A)	140 (146)	233 (228)	285 (283)	314 (322)	331	340	345	348	352
Hay Creek (B)	153 (160)	247 (251)	314 (316)	363 (359)	398	424	442	455	490
South Branch Whitewater River	141 (147)	233 (249)	306 (313)	364 (353)	409 (426)	446	475	498	586
West Indian Creek	137 (145)	236 (242)	303 (298)	348 (363)	378	399	413	422	442

data. For this reason, several of the main effects variables (D60, DEB, and L_{obc}/T) had to be transformed to dichotomous variables to obtain linearity in the logit before fitting interaction terms. The final model thus relates the probability of finding a large trout to the presence or absence of these habitat features, and not to the quantity of those features.

Large brown trout were found associated with large pools, a variety with cover types, and water >60 cm deep (Table 5). The odds of finding a large trout improved as the three continuous variables, T, RR, and IR, increased. For example, the odds of finding a large trout increased by a multiple of 3.2 with a 50 m increase in T, by a multiple of 4.8 with addition of RR cover over 2% of pool area, and by a multiple of 24.9 with addition of IR cover over 1% of pool area (Table 6). These multiples are known as odds ratios OR. The ranges of values for habitat variables presented in Table 6 approximate the ranges in the data (Table 2). Few pools had IR or RR cover greater than 1% of the pool area, therefore values of 0 and 1% were used for these variables in calculating odds ratios for specific changes in habitat characteristics (Table 7) and probabilities of finding a large trout when various kinds of cover are present (Table 8).

Table 4. Characteristics of large brown trout > 380 mm sampled in southeast Minnesota streams.

Mean length	421 mm
Maximum length	554 mm
Mean weight	2.25 kg
Maximum weight	2.25 kg
Length at age -1	165 mm
Length at age -2	257 mm
Length at age -3	318 mm
Length at age -4	369 mm
Length at age -5	440 mm

Table 5. Estimated coefficients (β) and standard errors (SE) for the multivariate logistic model for habitat selection by large brown trout in southeast Minnesota streams, 1991-92.

	Coefficient	
Variable	β	SE
Constant	-6.027	0.868
T	0.023	0.006
RR	0.788	0.425
D60	2.014	0.754
DEB	1.625	0.454
IR	3.216	0.990
L_{obc}/T	3.476	0.989
$D60xL_{obc}/T$	-1.252	1.042
DEBxIR	-1.603	1.033
$IRxL_{obc}/T$	-3.311	1.071

The odds of finding a large brown trout was changed most by the addition of L_{obc}/T, from among the dichotomous variables, and in decreasing order by the addition of IR (at 1% of area), D60, and DEB (Table 7). In general, the probability of finding a large trout increased as the number of kinds of cover present increased; however, some combinations of cover types yielded diminishing returns. The negative coefficients of the interaction terms were all of such a magnitude that if the better cover variable was present, the addition of the second cover variable (and the interaction) would scarcely change the odds of finding a large trout (Table 5). An example can clarify combinations of cover at which returns are diminished. The odds of finding a large brown trout increased by a multiple of 32.3 when adding L_{obc}/T to a pool without IR or D60. If IR (1%) is added to a pool with L_{obc}/T already present, the odds increased by a multiple of 0.9, showing no additional benefit. The other interaction terms show the addition of D60 to a pool with L_{obc}/T present (OR = 2.1) and the addition of DEB to a pool with IR=1% (OR = 1.0) yield little or no return. Confidence intervals for the OR's that include interaction terms were broad (Table 7).

Potential changes in the probability of finding a large trout as cover variables are added to a pool can be understood by inspecting Table 8, which gives capture probabilities and odds for several levels of T, and for all combinations of RR, IR, and dichotomous cover variables. A pool with T of 200 m, or a more common 50 m pool with only IR (1%) or L_{obc}/T, would have a probability approximately 0.2 of holding a large trout. A 50 m pool with a combination of DEB and L_{obc}/T or D60 and IR (1%) would have probabilities >0.5. Three combinations of three variables have probabilities approximately 0.75.

Table 6. Odds ratios (OR) and 95% confidence intervals (CI) for specific changes in pool length (T) and percent riprap cover (RR). A 50 m increase in T, for example, increases the odds of finding a large trout by a multiple of 3.2.

Variable	Change	Odds Ratio OR	Lower CI	Upper CI
T	1 m	1.0	1.0	1.0
	10 m	1.3	1.1	1.4
	50 m	3.2	1.8	5.7
	100 m	10.0	3.1	32.3
	200 m	99.5	9.5	1,045.2
RR	1 %	2.2	1.0	5.1
	2 %	4.8	0.9	25.6
	3 %	10.6	0.9	129.4
	4 %	23.4	0.8	654.6
	5 %	51.4	0.8	3,311.0
IR	1 %	24.9	3.6	173.5
	2 %	621.4	12.8	30,115.6

Table 7. Odds ratios (OR) and 95% confidence intervals (CI) for specific changes in pool habitat characteristics. The variables indicate the presence or absence of water deeper than 60 cm (D60), overhead bank cover (L_{obc}/T), and debris (DEB), and instream rock cover (IR) at 0 or 1% of pool area. The second line, for example, shows the addition of D60 to a pool with L_{obc}/T present increases the odds of finding a large trout by a multiple of 2.1.

Effect of adding	To pools with	OR	Lower CI	Upper CI
D60	L_{obc}/T = 0[a]	7.5	1.8	32.8
D60	L_{obc}/T = 1[b]	2.1	0.5	9.1
DEB	IR = 0	5.1	2.1	12.4
DEB	IR = 1	1.0	0.2	5.7
IR	DEB, L_{obc}/T = 0	24.9	3.6	173.5
IR	DEB = 1, L_{obc}/T = 0	5.0	0.9	27.7
IR	L_{obc}/T = 1, DEB = 0	0.9	0.1	5.8
L_{obc}/T	D60, IR = 0	32.3	4.7	224.6
L_{obc}/T	D60 = 1, IR = 0	9.2	3.5	24.6
L_{obc}/T	IR = 1, D60 = 0	1.2	0.1	13.1
D60 + L_{obc}/T	IR = 0	46.9	12.9	371.5
DEB + IR	L_{obc}/T = 0	25.5	4.2	154.9
IR + L_{obc}/T		29.4	2.2	393.8

[a] absent
[b] present

Table 8. Probability (P) and odds of finding a large brown trout in pools with various combinations of habitat variables.

	Variable					P	Odds
T(m)	RR(%)	DEB(±)	D60(±)	IR(%)	L_{obc}/T(±)		
			No cover				
10	0	0	0	0	0	0.003	0.003
50	0	0	0	0	0	0.008	0.008
100	0	0	0	0	0	0.023	0.024
200	0	0	0	0	0	0.194	0.240
			1 cover type				
50	1	0	0	0	0	0.016	0.017
50	0	1	0	0	0	0.037	0.039
50	0	0	1	0	0	0.054	0.057
50	0	0	0	1	0	0.160	0.190
50	0	0	0	0	1	0.198	0.246
			2 cover types				
50	1	1	0	0	0	0.078	0.085
50	1	0	1	0	0	0.112	0.126
50	0	1	0	1	0	0.163	0.194
50	0	0	0	1	1	0.183	0.224
50	0	1	1	0	0	0.225	0.290
50	1	0	0	1	0	0.295	0.418
50	0	0	1	0	1	0.345	0.528
50	1	0	0	0	1	0.331	0.542
50	0	1	0	0	1	0.556	1.251
50	0	0	1	1	0	0.587	1.423
			3 cover types				
50	0	1	0	1	1	0.186	0.229
50	1	1	0	1	0	0.299	0.427
50	0	0	1	1	1	0.324	0.480
50	1	0	0	1	1	0.330	0.493
50	1	1	1	0	0	0.389	0.638
50	1	0	1	0	1	0.537	1.161
50	0	1	1	1	0	0.593	1.455
50	0	1	1	0	1	0.728	2.680
50	1	1	0	0	1	0.733	2.751
50	1	0	1	1	0	0.758	3.130
			4 cover types				
50	0	1	1	1	1	0.329	0.491
50	1	1	0	1	1	0.335	0.504
50	1	0	1	1	1	0.513	1.055
50	1	1	1	1	0	0.762	3.200
50	1	1	1	0	1	0.855	5.894
			5 cover types				
50	1	1	1	1	1	0.519	1.079

Adding a fourth variable did little to the probability and adding a fifth variable decreased the probability.

Discussion

Past habitat improvement projects and special regulations did not increase abundance of large brown trout in southeast Minnesota streams because these streams did not have the quantity or diversity of cover required by large trout. Past habitat improvement projects commonly increased L_{obc}/T and D60, sometimes increased RR and IR, and may have generally reduced DEB. The amount of cover (% of area) in southeast Minnesota streams (Table 9), including improved streams, is generally less than the 35% recommended for brown trout by Raleigh et al. (1986). Furthermore, large trout seem to need more cover than smaller trout (Kennedy and Strange 1982), and brown trout also need more cover in winter than in summer (Cunjak and Power 1986; Meyers et al. 1992). The present study supports the conclusion of Thorn (1990a) that lack of habitat prevented special regulations from meeting the goal of increasing abundance of large brown trout. In that study (Thorn 1990a), biologists overestimated the habitat available for large trout.

Because most variables in this analysis had a limited range of values, they were coded to reflect presence or absence of cover; therefore, they cannot identify the degree to which more of one variable is better. Experimental management (McAllister and Peterman 1992) should seek to identify optimal levels of cover, and optimal combinations. Recent habitat management on West Indian Creek, southeast Minnesota, has greatly increased the cover variable, L_{obc}/T, above the traditional level (Thorn1992b). Traditional habitat improvements in Hay Creek increased abundance of L_{obc}/T to 6%, and mean spring biomass of brown trout (most < 300 mm) increased from 26.7 to 114.9 kg/hectare (Thorn 1988b). Then, three years of a no-kill regulation further increased mean spring biomass to 345.4 kg/hectare. Abundance of 200-380 mm brown trout increased from 129 to 750/km, however abundance of brown trout > 380 mm did not increase (Thorn 1990b). The intensive habitat improvements in West Indian Creek increased L_{obc}/T to 22%, and increased mean fall biomass of brown trout from 15.2 to 164.5 kg/hectare (Thorn 1992b). Abundance of large trout also increased from 0/km (or too few to estimate) prior to improvement to a mean of 7/km for seven estimates after improvement (Thorn, Minnesota Department of Natural Resources, unpublished data). The Wisconsin Department of Natural Resources emphasized "intensive installation of bank covers" to improve trout habitat (Hunt 1988a). Such improvements in Lawrence Creek increased L_{obc}/T from 4.4% to 24.3% (Hunt 1971). In several other similar projects, abundance of large brown trout (> 356 mm or 381 mm) increased from a mean of 7/km (range < 1-13) before to 18/km (range 7-60) after improvement (Hunt 1988b). Managers could use behavioral carrying capacity (Morhardt and Mesick 1988) to quickly determine carrying capacity of varying levels of cover in individual pools of enhanced habitat.

When habitat is limiting for large brown trout, we recommend that managers increase the area > 60 cm deep and overhead bank cover, especially if D60 and L_{obc}/T are absent, because increasing them during habitat improvement increased biomass of smaller trout, and this analysis showed a strong association with the presence of large trout. The other four variables (T, RR, DEB, and IR) were not as important habitat variables for smaller brown trout as D60 and L_{obc}/T (continuous variables in Thorn 1988b), and have more limited applicability to habitat improvement in southeastern Minnesota streams. However, in some stream reaches, these four variables can provide large trout

Table 9. Abundance of trout cover (%) in pools in southeast Minnesota streams. RR, D60, DEB, IR, and OBC are areal measurements; L_{obc}/T, a linear measurement.

	RR	D60	DEB	IR	OBC	L_{obc}/T
This study						
large BNT present	0.3	19.3	0.9	0.8	1.8	12.3
large BNT absent	0.1	12.3	0.9	0.1	0.9	7.5
1985[a]	0.6	14.6	3.2	0.1	2.1	17.2
1989[b]		14.3				9.6

[a] from Thorn (1988a)
[b] from Thorn (1992b)

habitat and habitat diversity. Habitat management has not changed stream morphology (Thorn 1988a), and is unlikely to increase T by the factor necessary to benefit large trout abundance (Tables 6 and 8). Because L_{obc}/T is a dichotomous variable in our model, it does not decrease when T is increased. Increasing T through restoration of natural meandering, or reducing it by exposing riffles under the middle of pools (riffle dropping), will have only small direct effects on large brown trout. These methods that change T may be warranted for other reasons, however. Because woody riparian vegetation has been removed from many stream reaches by agriculture or during the improvement project, a source of DEB may not be available. However, in many of these reaches, riprap, added to reduce stream bank erosion and stream bed sedimentation, can produce small increases in RR cover. Such reaches should also have banks planted with trees for future DEB. Trees are recommended over grasses because Larscheid and Hubert (1992) showed that the proportion of quality-size brown trout (>250 mm) was negatively correlated with overhanging grasses in Wyoming streams, and stream morphology is determined by large woody DEB (Swanston 1991). Instream rocks (IR) should not be routinely added to streams <7 m wide because field observations showed velocities in these streams were inadequate to maintain cover under many instream rocks. Instream rocks can cause lateral scour which may negate efforts to narrow and deepen streams in habitat improvement projects.

The relative rarity of large trout in study streams cannot be attributed to factors limiting reproduction or growth rates. Reproduction and stocking enabled recruitment to adult sizes. Quality and quantity of prey did not appear to be limiting because large trout were sampled where the composition of the fish prey base ranged from only juvenile trout to very abundant nontrout species. Growth did not limit recruitment to 381 mm as growth was relatively rapid compared to that in other areas (Table 10).

A comprehensive habitat management plan for brown trout should also include winter habitat, which may differ from summer habitat.

Table 10. Mean length (mm) at annulus for brown trout in streams from southeast Minnesota, Michigan, and western United States.

	Length at annulus		
Age	Minnesota	Michigan[a]	Western[b]
I	165	132	156
II	257	208	241
III	318	259	331
IV	369	343	407
V	440	406	439

[a] Average of northern lower peninsula (Nuhfer 1988).
[b] Average of fast-growing populations (Nuhfer 1988).

Large brown trout may migrate seasonally to the preferred habitats (Clapp et al. 1990; Meyers et al. 1992). However, most streams in southeast Minnesota are smaller and have less cover than those larger streams with abundant cover, where large brown trout migrate to winter habitat (Clapp et al. 1990; Meyers et al. 1992).

High mortality rates may be a second factor limiting the abundance of large trout in southeast Minnesota streams. Few trout were sampled older than age-5 or >500 mm. Angling mortality could not be evaluated by this study design because no measures of harvest were available on most streams. Thorn (1990a) noted that the failure of special regulations to increase numbers of large trout in Minnesota streams could result from movement of large trout in and out of short protected reaches. In the Peshtigo River, Wisconsin, high mortality was associated with seasonal migrations (Meyers et al. 1992). Angling can influence abundance, and restrictive regulations can maintain or increase abundance. Anderson and Nehring (1984) found that angling pressure >988 h/hectare eliminated trout >350 mm, and Hunt (1991) listed several authors that reported increases in large trout abundance after implementation of restrictive harvest regulations.

We conclude that trout streams in southeast Minnesota have the potential to produce large trout because habitat (adult cover) generally limits their abundance, and cover can be increased by judicious habitat management. However, habitat managers need to increase the amount of cover added to streams to increase abundance of large trout.

Management Implications

Streams in southeast Minnesota have potential for more large trout with habitat management, because habitat is commonly limiting abundance. However, most streams will not produce many trout >500 mm.

Managers should increase cover levels and kinds above the traditional amounts to increase large trout abundance, and use experimental management to determine the best combination of variables and quantities. We recommend a minimum of 50% L_{obc}/T or 25% L_{obc}/T and abundant DEB, IR, or RR.

This study improves management abilities to evaluate special regulations to increase large trout abundance. When managers have determined that exploitation rather than habitat limits abundance, a harvest restriction should maintain or increase abundance. Detailed evaluation of large trout habitat may explain why past special regulations failed to increase large trout abundance.

Winter habitat of large brown trout in southeast Minnesota should be investigated to complete a comprehensive habitat management program.

References

Aadland, L. P., C. M. Cook, M. T. Negus, H. G. Drewes, and C. S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments. Minnesota Department of Natural Resources, Fisheries Investigational Report 406, St. Paul.

Anderson, C. S. In review. Measuring and correcting for size-selection in electrofishing mark-recapture experiments.

Anderson, R. M., and R. B. Nehring. 1984. Effects of a catch-and-release regulation on a wild trout population in Colorado and acceptance by anglers. North American Journal of Fisheries Management 4:257-265.

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper 21. Biological Report 86(7). U.S. Fish and Wildlife Service. Washington D.C.

Clapp, D. F., R. D. Clark, and J. S. Diana. 1990. Range, activity, and habitat of large, free-ranging brown trout in a Michigan Stream. Transactions of the American Fisheries Society 119:1022-1034.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout *(Salvelinus fontinalis)* and brown trout *(Salmo trutta)*. Canadian Journal of Fisheries Aquatic Science 43:1970-1981.

Frie, R. V. 1982. Measurement of fish scales and backcalculation of body lengths using a digitizing pad and microcomputer. Fisheries (Bethesda) 7(6):5-8.

Hayes, M. 1990. Evaluation of special regulations for a winter trout season on the Middle and South Branches of the Whitewater River. Minnesota Department of Natural Resources, Fisheries F-29-R Completion Report 402, St. Paul.

Heggenes, J. 1988a. Physical habitat selection by brown trout *(Salmo trutta)* in riverine systems. Nordic Journal Freshwater Research 64:74-90.

Heggenes, J. 1988b. Effects of short-term flow fluctuations on displacement of, and habitat use by, brown trout in a small stream. Transactions of American Fisheries Society 117:336-344.

Hirsch, S. 1989. Fishing quality indices for three southeast Minnesota trout streams. Minnesota Department of Natural Resources, Fisheries Management Report 30, St. Paul.

Hosmer, D. W., Jr., and S. Lemeshow. 1989. Applied Logistic Regression. Wiley, New York.

Hunt, R. L. 1971. Response of a brook trout population to habitat development in Lawrence Creek. Wisconsin Department of Natural Resources, Technical Bulletin 48, Madison.

Hunt, R. L. 1988a. Habitat development techniques used to improve brown trout fisheries in Wisconsin. Pages 6-11 *in* J. C. Borawa, editor. Brown Trout Workshop: Biology and Management. Trout Committee, Southern Division of American Fisher-

ies Society.
Hunt, R. L. 1988b. A compendium of 45 trout stream habitat development evaluations in Wisconsin during 1953-1985. Wisconsin Department of Natural Resources, Technical Bulletin 162, Madison.
Hunt, R. L. 1991. Evaluation of a catch and release fishery for brown trout regulated by an unprotected slot length. Wisconsin Department of Natural Resources, Technical Bulletin 173, Madison.
Kennedy, G. J. A., and C. D. Strange. 1982. The distribution of salmonids in upland streams in relation to depth and gradient. Journal of Fishery Biology 20:579-591.
Larscheid, J. G., and W. A. Hubert. 1992. Factors influencing the size structure of brook trout and brown trout in southeastern Wyoming mountain streams. North American Journal of Fisheries Management 12:109-117.
McAllister, M. K., and R. M. Peterman. 1992. Experimental design in the management of fisheries: a review. North American Journal of Fisheries Management 12:1-18.
Meyers, L. S., T. F. Thuemler, and G. W. Kornely. 1992. Seasonal movements of brown trout in northeast Wisconsin. North American Journal of Fisheries Management 12:433-441.
Millar, R. B., and S. J. Walsh. 1992. Analysis of trawl selectivity studies with an application to trouser trawls. Fisheries Research 13:205-220.
Minnesota Department of Natural Resources. 1993. Fisheries management planning guide for streams and rivers. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, St. Paul.
Morhardt, J. E., and C. F. Mesick. 1988. Behavioral carrying capacity as a possible short term response variable. Hydro Review 7:32-40.
Novotny, D. W., and G. R. Priegel. 1971. A guideline for portable direct current electrofishing systems. Wisconsin Department of Natural Resources, Technical Bulletin 51, Madison.
Nuhfer, A. J. 1988. A comparison of growth of brown trout from selected western rivers with growth of brown trout from Michigan rivers. Michigan Department of Natural Resources, Fisheries Technical Report 88-6, Lansing.
Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experimentation Station, General Technical Report INT-138, Ogden, Utah.
Prager, M. H., S. B. Saila, and C. W. Recksiek. 1989. FISHPARM: a microcomputer program for parameter estimation of nonlinear models in fishery science, second edition. Old Dominion University Oceanography Technical Report 87-10.
Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout. United States Department of the Interior, Fish and Wildlife Service Biological Report 82 (10.124).
Regal, G. E. 1992. Range of movement and daily activity of wild brown trout in the South Branch Au Sable River, Michigan. Michigan Department of Natural Resources, Fisheries Research Report 1988, Lansing.
Swanston, D. N. 1991. Natural processes. Pages 139-180 *in* W. R. Meehan, editor. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.
Thorn, W. C. 1988a. Evaluation of habitat improvement for brown trout in agriculturally damaged streams of southeastern Minnesota. Minnesota Department of Natural Resources, Fisheries Investigational Report 394, St. Paul.
Thorn, W. C. 1988b. Brown trout use in southeastern Minnesota and its relationship to habitat improvement. Minnesota Department of Natural Resources, Fisheries Investigational Report 395, St. Paul.
Thorn, W. C. 1990a. Evaluation of special regulations for trout in southeast Minnesota streams. Minnesota Department of Natural

Resources, Fisheries Investigational Report 401, St. Paul.

Thorn, W. C. 1990b. Effects of habitat improvement and a special regulation on a brown trout population. Pages 45-53 *in* J. C. Borawa, editor. Brown Trout Workshop: Biology and Management. Trout Committee, Southern Division of American Fisheries Society.

Thorn, W. C. 1992a. Evaluation of trout stocking in southeast Minnesota streams. Pages 130-148 *in* M. Marcinko and D. Graff, editors. Proceedings of the East Coast Trout Culture and Management Workshop. East Coast trout Culture and Management Workshop, American Fisheries Society. Bethesda, Maryland.

Thorn, W. C. 1992b. Validation of a trout habitat model for planning stream habitat improvement projects. Minnesota Department of Natural Resources, Fisheries Investigational Report 423, St. Paul.

Walsh, S. J., R. B. Millar, C. G. Cooper, and W. M. Hickey. 1992. Codend selection in American plaice: diamond versus square mesh. Fisheries Research 13:235-254.

Waters, T. F. 1977. The Streams and Rivers of Minnesota. University of Minnesota Press, Minneapolis.

Wiechman, J. D. 1990. Evaluation of fishing quality indices and sizes of brown trout preferred by anglers in southeast Minnesota. Minnesota Department of Natural Resources, Fisheries Investigational Report 402, St. Paul.

Wiley, R. W., R. A. Whaley, J. B. Satake, and M. Fowden. 1993. Assessment of stocking hatchery trout: a Wyoming perspective. North American Journal of Fisheries Management 13:160-170.

Wilkinson, L. 1990. SYSTAT: The System for Statistics. SYSTAT, Inc., Evanston, Illinois.

Appendix Table 1. Length (mm), weight (kg), age, year class, and year collected for brown trout > 380 mm in southeast Minnesota streams.

Length	Weight	Age	Year class	Year collected
554	2250	ND[a]	ND	1991
427	932	3	1988	1991
393	702	3	1988	1991
391	666	3	1988	1991
464	1450	5	1986	1991
422	825	4	1987	1991
429	936	3	1988	1991
421	820	4	1987	1991
386	610	4	1987	1991
388	516	3	1988	1991
382	524	4	1987	1991
395	740	3	1988	1991
395	644	3	1988	1991
381	620	3	1988	1991
391	578	4	1987	1991
395	667	4	1987	1991
384	620	4	1987	1991
403	655	4	1987	1991
390	658	4	1987	1991
391	650	4	1987	1991
380	618	3	1988	1991
413	700	4	1987	1991
415	884	4	1987	1991
398	614	5	1986	1991
452	1036	4	1987	1991
380	640	4	1987	1991
395	650	4	1987	1991
531	1950	5	1986	1991
455	996	5	1986	1991
386	592	4	1987	1991
512	1800	5	1986	1991
402	638	4	1987	1991
384	550	3	1988	1991
391	656	4	1987	1991
430	662	4	1987	1991
403	740	4	1987	1991
410	725	3	1988	1991
465	862	4	1987	1991
423	925	5	1986	1991
388	565	4	1987	1991
403	771	3	1988	1991
393	600	4	1987	1991
381	544	4	1987	1991
384	578	3	1986	1991
484	1010	4	1987	1991
424	806	4	1987	1991
445	1400	6	1985	1991
532	1775	5	1987	1992
384	510	3	1989	1992
400	608	3	1989	1992
388	642	3	1989	1992
405	698	4	1988	1992
416	840	ND	ND	1992
385	720	3	1989	1992
381	647	3	1989	1992
520	1150	5	1987	1992
460	974	5	1987	1992
460	1000	4	1988	1992
428	728	4	1988	1992
391	566	3	1989	1992
411	574	4	1988	1992
402	668	4	1988	1992
399	552	4	1988	1992
406	608	3	1989	1992
429	634	4	1988	1992

Appendix Table 1. Continued.

Length	Weight	Age	Year class	Year collected
423	740	4	1988	1992
440	768	4	1988	1992
381	440	3	1989	1992
408	610	4	1988	1992
434	664	4	1988	1992
439	800	4	1988	1992
430	750	4	1988	1992
510	1600	7	1985	1992
456	946	3	1989	1992
460	994	5	1987	1992
455	944	4	1988	1992
412	740	3	1989	1992
382	520	3	1989	1992
460	800	4	1988	1992
388	560	4	1988	1992
471	1300	4	1988	1992
449	830	4	1988	1992
424	742	4	1988	1992
421	860	4	1988	1992
420	708	4	1988	1992
417	776	4	1988	1992
405	632	4	1988	1992
404	672	4	1988	1992
402	660	4	1988	1992
396	624	4	1988	1992
394	630	3	1989	1992
391	700	4	1988	1992
386	588	4	1988	1992
386	564	4	1988	1992
385	616	4	1988	1992
384	590	4	1988	1992
382	530	4	1988	1992
381	534	3	1989	1992
380	560	4	1988	1992
509	1650	4	1988	1992
502	1600	5	1987	1992
459	1500	4	1988	1992
440	796	ND	ND	1992
389	640	3	1989	1992
388	604	3	1989	1992
412	710	4	1988	1992
385	566	5	1987	1992
398	664	4	1988	1992
434	916	4	1988	1992
390	620	ND	ND	1992
412	728	4	1988	1992
436	890	4	1988	1992
395	688	5	1987	1992
445	844	4	1988	1992
412	755	4	1988	1992
394	690	4	1988	1992
420	770	4	1988	1992
523	ND	5	1987	1992
445	908	5[b]	NA[c]	1992
431	1024	5[b]	NA[c]	1992
390	664	3	1989	1992
410	636	4	1988	1992
390	700	3	1989	1992
435	824	4	1988	1992
524	1950	4	1988	1992
472	1040	5[b]	NA[c]	1992
395	850	4	1988	1992
397	800	3	1989	1992
410	1000	4	1988	1992
386	636	3	1989	1992
397	640	4	1988	1992
444	1300	4	1988	1992

Appendix Table 1. Continued.

Length	Weight	Age	Year class	Year collected
496	1600	4	1988	1992
510	1700	5	1987	1992
513	1650	4	1988	1992
522	1650	5	1987	1992
383	556	4	1988	1992
390	666	3	1989	1992
419	768	4	1988	1992
420	716	4	1988	1992
425	790	5	1987	1992
433	1010	4	1988	1992
384	588	6	1986	1992
390	496	ND	ND	1992
402	608	4	1988	1992

[a] Not determined.
[b] Stocked trout with one year added to age to account for 1.5 years in hatchery.
[c] Not applicable.

ACKNOWLEDGMENTS

A. Bindman provided statistical advice. M. Hayes and J. Wagner suggested study streams. D. Dieterman and D. Hatleli mapped and measured variables, electrofished all streams, and prepared and aged fin rays and scales. C. Milewski assisted with electrofishing and age analysis. D. Bushong assisted with electrofishing.

Edited by:
P.J. Wingate, Fisheries Research Manager

INVESTIGATIONAL REPORTS*

No. 418 Performance Evaluation of Four Muskellunge *Esox Masquinongy* Strains in Two Minnesota Lakes, by J. Younk and R. Strand. September 1992.

No. 419 Survival, Growth, Sexual Maturation, and Angler Harvest of Three Lake Trout Strains in Four Northeastern Minnesota Lakes, by G. Siesennop. September 1992.

No. 420 Applications of an Angler Diary for Muskellunge *Esox Masquinongy*, by J. Younk and M. Cook. September 1992.

No. 421 Effect of Size at Stocking on Harvest of Rainbow Trout in Bad Medicine Lake, by P. Cunningham and C. Anderson. October 1992.

No. 422 Opinions of Angler Groups and Fisheries Professionals in Minnesota, by P. Cunningham, and C. Anderson. November 1992.

No. 423 Validation of a Trout Habitat Model for Planning Stream Habitat Improvement Projects, by W. Thorn. December 1992.

No. 424 Analysis of Factors Affecting Growth of Northern Pike in Minnesota, by P.C. Jacobson. January 1993.

No. 425 Weight-length Relationships, Proximate Body Composition and Survival of Stocked Walleye Fingerlings, by F. Bandow and C. Anderson. February 1993.

No. 426 Potential Interactions Between Lake Trout and Smallmouth Bass in Lakes of Northeastern Minnesota, by P. Eiler and T. Sak. April 1993.

No. 427 Dispersal, Density-Dependent Growth, and Survival of Stocked Steelhead Fry in Lake Superior Tributaries, by T. Close and C. Anderson. June 1993.

*Complete list of all publications in the series available from Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Box 12, 500 Lafayette Road, St. Paul, Minnesota 55155-4012.