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BROWN TROUT HABITAT USE IN SOUTHEASTERN MINNESOTA AND ITS RELATIONSHIP TO HABITAT IMPROVEMENT

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BROWN TROUT HABITAT USE IN SOUTHEASTERN MINNESOTA AND ITS RELATIONSHIP TO HABITAT IMPROVEMENT[1]

by

William C. Thorn
Fisheries Biologist

Minnesota Department of Natural Resources
Section of Fisheries

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ABSTRACT

The relationships of brown trout (*Salmo trutta*) biomass (kg/ha), density (fish/m^2), and mean length (mm) to habitat variables in streams of southeastern Minnesota were documented and described by regression models. The models were used to identify the limiting factors that should be changed in habitat improvement projects. Biomass and density of brown trout could best be enhanced by increasing length of overhead bank cover, area deeper than 60 cm, and amount of bank shade. Biomass and density could also be increased by reducing pool length to increase percent riffle area. The mean length of brown trout in pools may be increased by increasing area of deep water and total cover.

INTRODUCTION

Efforts to provide additional trout fishing opportunities by enhancing stream habitats have produced mixed results in southeastern Minnesota because the habitat factors limiting populations have not been identified. Trout angling in southeastern Minnesota is possible along about 560 km of streams that have water quality and physical habitats suitable for trout. Much of the physical habitat in these streams has been degraded by agriculture. Habitat improvements have been made sporadically for almost 40 years in these streams, and habitat improvement projects have been funded annually since 1970. Most funding has been directed at repairing badly eroded banks and providing some amount of trout cover. Moderate success of habitat improvement on two agriculturally damaged streams was documented recently (Thorn 1988). The large fish component (>300 mm TL) did not increase as expected, however, indicating that some basic requirements were not provided.

Factors limiting brown trout, *Salmo trutta*, populations have been described for some geographical areas, but not for southeastern Minnesota. Since factors limiting populations can vary, a study of populations in southeastern Minnesota was warranted. Binns and Eiserman (1979) developed a Habitat Quality Index (HQI) which related cover, bank stability, substrate, and other variables to trout biomass in Wyoming. Wesche (1976) developed a trout cover rating (CR) based on water depth, substrate size, and trout preference for cover that could also predict trout biomass in Wyoming. Oswood and Barber (1982) developed a model to predict trout abundance in Alaskan streams based on cover (forest debris and overhanging streambank vegetation) and the area of deep and fast water. The Habitat Suitability Index (HSI) for brown trout (Raleigh et al. 1986) attempted to provide a more general outline of optimum cover, substrate, and pool-riffle ratio characteristics for various life stages.

This study developed predictive equations, based on habitat use by brown trout, for estimating trout population characteristics (biomass, density, and mean length) in southeastern Minnesota streams. Models developed by Binns and Eiserman (1979) and Wesche (1976) were tested for their suitability for use in southeastern Minnesota, and the usefulness of habitat models in designing habitat improvement projects was evaluated.

STUDY AREA

I studied 22 stream reaches in 10 streams in the unglaciated driftless region in southeastern Minnesota (Fig. 1, Table 1). Topography is characterized by gently rolling uplands broken by steep-walled valleys. Land use is predominantly agricultural, but the valley sides are wooded. Streams are subject to flash flooding, although base flows are maintained by springs and groundwater seepage (Waters 1977). Water quality characteristics indicated the streams were productive (total phosphorus, 0.02-0.16 mg/l; total nitrate, 0.49-2.34 mg/l; alkalinity as $CaCO_3$, 220-250 mg/l). The brown trout populations examined varied from stocked populations without natural reproduction to wild populations. Brown trout reproductive success was strongly influenced by late winter and spring flooding (Anderson 1983). Biomass can range from 0 to over 300 kg/ha, and fishing pressure can exceed 1,200 hrs/km (Thorn, unpublished data).

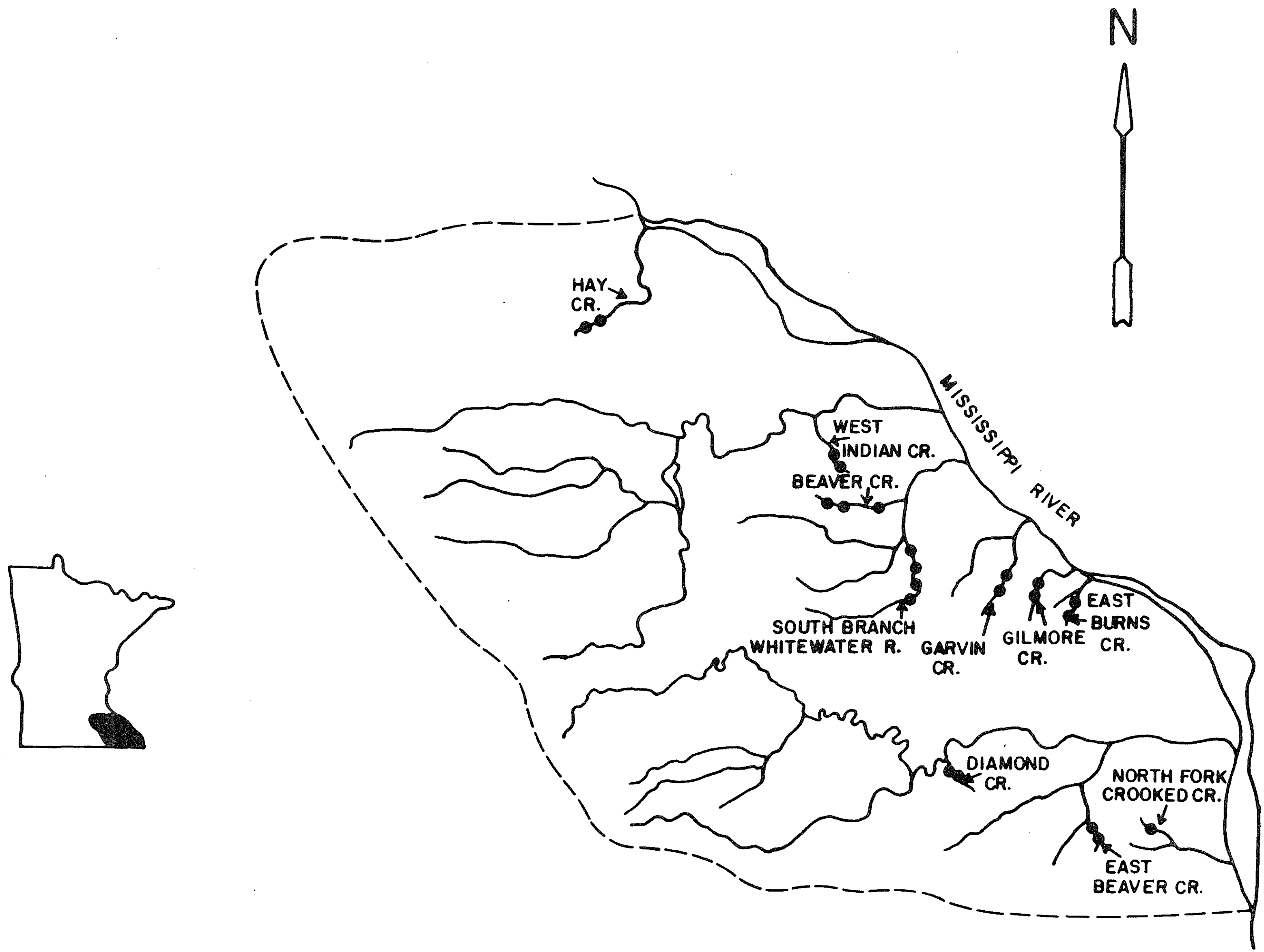

Figure 1. Study stream locations in southeast Minnesota.

Table 1. General description[a] of study streams.

Stream	Location	Width m	Gradient m/km	Velocity cm/s	Late summer discharge m^3/s
Hay Creek	T112N,R15W,S26,SW1/4	5.4	5.6	30.2	0.25
Hay Creek	T112N,R15W,S27,SE1/4	5.9	5.6	30.2	0.25
West Indian Creek	T109N,R11W,S16,SW1/4	5.1	2.8	17.4	0.21
West Indian Creek	T109N,R11W,S16,SW1/4	5.5	4.0	35.3	0.21
Beaver Creek	T108N,R10W,S16,SE1/4	6.7	1.5	40.5	0.22
Beaver Creek	T108N,R10W,S20,NW1/4	4.6	8.0	39.6	0.12
Beaver Creek	T108N,R10W,S19,NE1/4	4.5	2.7	19.3	0.12
S. Br. Whitewater R.	T107N,R10W,S14,SE1/4	12.6	2.5	37.2	0.53
S. Br. Whitewater R.	T107N,R10W,S14,SE1/4	8.0	4.9	46.1	0.53
S. Br. Whitewater R.	T107N,R10W,S24,NW1/4	10.7	3.8	45.9	0.53
S. Br. Whitewater R.	T107N,R10W,S24,SE1/4	11.6	5.6	30.2	0.53
Garvin Brook	T106N,R8W,S8,NE1/4	4.9	13.0	39.3	0.08
Garvin Brook	T106N,R8W,S5,SE1/4	4.4	7.5	33.5	0.08
East Burns Creek	T106N,R7W,S10,NE1/4	3.0	10.0	53.6	0.10
East Burns Creek	T106N,R7W,S10,SE1/4	2.6	5.8	25.3	0.08
Gilmore Creek	T107N,R7W,S31,NE1/4	3.3	14.6	40.5	0.09
Gilmore Creek	T107N,R7W,S31,SE1/4	3.4	7.2	24.3	0.08
East Beaver Creek	T102N,R6W,S5,SW1/4	4.8	8.0	51.5	0.36
East Beaver Creek	T102N,R6W,S8,NE1/4	5.4	6.8	61.3	0.36
N. Fk. Crooked Creek	T102N,R5W,S21,NE1/4	4.5	4.0	39.9	0.08
Diamond Creek	T103N,R9W,S14,NW1/4	3.5	6.0	22.9	0.05
Diamond Creek	T103N,R9W,S14,NE1/4	3.6	8.3	29.6	0.05

[a] From Stream Survey Reports. Various dates (1975-1986).

METHODS

Habitat variables were measured and the trout populations estimated for 67 pools and 64 riffles in 22 stream reaches. Study sites were selected to include a range of habitat variables and trout abundance. Variables were chosen for their possible influence upon brown trout populations and for the feasibility of their modification in habitat management projects. Variables were definable and measurable (Platts et al. 1983). Overhead cover (OC) was calculated from the mapped area of shade, broken water surface, and cover hanging above the water. Overhead bank cover was calculated from the area and length mapped as being beneath structure in the water. Overhead bank cover (OBC) was measured both as a percent of the stream area and as a proportion of the length of the thalweg (L_{OBC}/T). Six habitat rating variables were also estimated following methods described by the original authors (as noted in Table 2).

Trout were sampled by electrofishing, and the Zippin (1958) removal method was used to estimate the population size of brown trout older than age 0. Population estimates were made for each study reach, pool, and riffle. Trout populations were estimated and habitat variables were measured in August and early September, when flows had stabilized after early summer rains. Since 75% of the annual angling pressure occurred by 1 July (Thorn, unpublished data), the effects of harvest during the sampling period should be small. Total lengths of 1,291 trout were measured. A length-weight relationship ($\log_e W = 3.00 \log_e L - 11.50$) was used to estimate weights (Thorn, unpublished data).

The influence of habitat variables upon brown trout biomass and density in stream reaches, pools, and riffles was first examined by

Table 2. Mean and range of habitat variables used to develop predictive equations for density (fish/m^2) and biomass (kg/ha) of brown trout in southeastern Minnesota streams. Twenty-seven variables were used to develop the equation for stream reach, 17 for pools, and 14 for variables.

Variable	Abbreviation	Reach		Pool		Riffle	
		Mean	Range	Mean	Range	Mean	Reach
Length (m)		175.2	57.5-314.9	42.3	9.1-125.6	15.9	1.5-71.0
Width (m)		5.7	2.6-12.6	5.8	1.6-16.5	5.5	1.7-18.6
Area (m^2)		1168.2	187.4-3980.2	302.6	19.4-1613.1	85.0	4.1-309.8
Area overhead bank cover (%)[a]	OBC	1.1	0.0-3.8	2.1	0.0-28.1	0.4	0.0-9.2
Area debris cover (%)	DEB	2.3	0.0-17.7	3.2	0.0-75.3	1.1	0.0-31.2
Area instream rock cover (%)	IR	0.1	0.0-0.5	0.1	0.0-1.5	0.1	0.0-1.6
Area riprap cover (%)	RR	0.4	0.0-2.1	0.6	0.0-9.6	0.2	0.0-5.8
Area overhead cover (%)[b]	OC	2.6	0.0-15.2	3.9	0.0-46.7	1.0	0.0-44.9
Area total cover (%)[c]	TC	6.5	0.0-20.6	13.0	0.0-87.2	2.7	0.0-44.9
Area of aquatic vegetation (%)[d]	AV	9.1	0.0-31.0	11.0	0.0-90.0	19.3	0.0-90.0
Area deeper than 45 cm (%)	D45	21.7	0.0-59.3	31.0	0.0-76.6	1.3	0.0-22.4
Area deeper than 60 cm (%)	D60	11.3	0.0-35.5	14.6	0.0-53.6	0.2	0.0-7.3
Area deeper than 90 cm (%)	D90	2.6	0.0-11.3	3.4	0.0-34.5	0.0	0.0-0.0
Pool area (%)	PA	71.6	42.4-100.0				
Pool length (%)	PL	70.4	37.6-100.0				
Pool total cover (%)[c]	PC	8.0	0.6-21.0				
Riffle total cover (%)[c]	RC	3.0	0.0-19.3			2.7	0.0-44.9
Length OBC/thalweg length[j]	L_{OBC}/T	10.1	0.0-40.66	17.2	0.0-99.3		
Gradient (m/km)	GRAD	6.3	1.5-14.6				
Velocity (cm/sec)	VEL	36.1	17.4-61.3				
Pool bank shade (%)	PBS	25.8	0.0-89.3	39.2	0.0-100.0	6.4	0.0-119.1

Table 2. Continued.

Variable	Abbreviation	Reach		Pool		Riffle	
		Mean	Range	Mean	Range	Mean	Reach
Stream bank soil alteration rating[e]	SBSAR	4.1	1.0-5.0				
Stream bank vegetative rating[f]	SBVR	3.9	3.0-5.0				
Stream bank cover rating[g]	SBCR	2.3	2.0-3.0				
HSI Pool quality rating[h]	HSI	2.1	1.0-3.0	2.1	1.0-3.0		
PLATTS Pool quality rating[i]	PLATTS	3.7	2.0-4.7	3.7	1.0-5.0		
Riffle quality rating[k]	RQ	2.7	0.0-4.7			2.8	1.0-5.0

[a] Length of OBC with water depth of 15 cm and width of 9 cm.
[b] Cover provided by shade, water turbulence, or bottom relief.
[c] OBC + DEB + IR + RR + OC of pools and riffles.
[d] Visually estimated and converted to area.
[e] Table 4 from Armor and Platts (1983).
[f] Table 5 from Armor and Platts (1983).
[g] Table 6 from Armor and Platts (1983).
[h] Pool quality rating of Habitat Suitability Index for brown trout (Raleigh et al. 1986)
[i] Pool quality rating from Platts et al. (1983).
[j] Length OBC divided by thalweg length (Wesche 1980).
[k] Table 3 from Armor and Platts (1983).

simple correlation analysis. There were 27 variables examined in the stream reach analyses, 17 in the pool analyses, and 16 in the riffle analyses. Sets of habitat variables which were not closely correlated with each other were then examined in stepwise regression analyses to model biomass and density in reaches, pools, and riffles. The entry and exit criteria chosen were P-In = P-Out = 0.15. The influence of habitat variables upon mean length of brown trout in pools and riffles was examined similarly (Table 2). Since I could not verify the overall models by comparing their predictions with data from other streams (after Binns and Eiserman 1979) or a subsequent year (after McClendon and Rabein 1987), I did a preliminary verification by randomly dividing the data for pools and riffles (n >60) in half. Models were computed from each half to see whether the regression coefficients were similar and whether the models could predict values observed in the other half.

Two models developed by Binns and Eiserman (1979) and Wesche (1976) to predict brown trout biomass were tested for their applicability to southeastern Minnesota streams. Variables in Binns and Eiserman's Model II were rated from 0 (worst) to 4 (best) from stream surveys (Minn. Dept. Nat. Res. files), from measurements, or from best guesses (Table 3). Wesche's (1976) Cover Rating (CR) system was modified to use preference factors calculated for the study streams (Table 4). Correlation coefficients between the observed and predicted values were then calculated.

RESULTS

The vast majority of trout older than age 0 were found in pools, rather than riffles, and trout larger than 300 mm TL were relatively rare (Fig. 2). For these reasons, the regression models for stream

Table 3. Habitat variables and formula for Model II of Binns and Eiserman (1979).

Habitat variable	Symbol
Late-summer stream flow	X_1
Annual stream flow variation	X_2
Maximum summer stream temperature	X_3
Nitrate-nitrogen	X_4
Percent cover	X_7
Percent eroding banks	X_8
Substrate (submerged aquatic vegetation)	X_9
Water velocity	X_{10}
Stream width	X_{11}
Food index[a]	F
Shelter index[b]	S

[a] $F = (X_3)(X_4)(X_9)(X_{10})$

[b] $S = (X_7)(X_8)(X_{11})$

$$\text{Trout biomass (kg/ha)} = \text{antilog}_{10}[-0.903 + 0.807 \log_{10}(X_1 + 1) + 0.877 \log_{10}(X_2 + 1) + 1.233 \log_{10}(X_3 + 1) + 0.631 \log_{10}(F + 1) + 0.182 \log_{10}(S + 1)][1.12085].$$

reaches were similar to those for pools, and the models of biomass and density reflect the distribution of the numerically dominant smaller trout. The preliminary multiple regression models for population characteristics in pools appeared stable, since the coefficients were similar for each half of the data, and the predictions of each model were significantly correlated with the observed values in the other

Table 4. Variables and formulas for the cover rating system of Wesche (1976) and the modified cover rating system for southeastern Minnesota.

Wesche	Southeastern Minnesota
$CR = (L_{OBC}/T)(PF_{OBC}) + (A/SA)(PF_a)$	$CR = (L_{OBC}/T)(PF_{POOL}) + (\%\ riffle\ TC/100)(PF_{RIFFLE})$
CR = Cover rating	
L_{OBC} = Length of overhead bank cover (OBC) in study section with water water depth of 15 cm and a width of 9.1 cm	
T = Thalweg length of stream section	
A = Surface area of study section with water depth at least 15 cm and a substrate size at least 7.6 cm	
SA = Total surface area of study section	
PF_{OBC} = Preference factor of trout for OBC (0.75)	PF_{POOL} = Preference factor for pools (0.90)
PF_a = Preference factor of trout for rubble-boulder areas (0.25)	PF_{RIFFLE} = Preference factor for riffles (0.10)
$Log\ Y = 0.0204 + 5.338CR$	$Y = 48.508 + 404.744CR$
Y = Standing crop (kg/ha)	

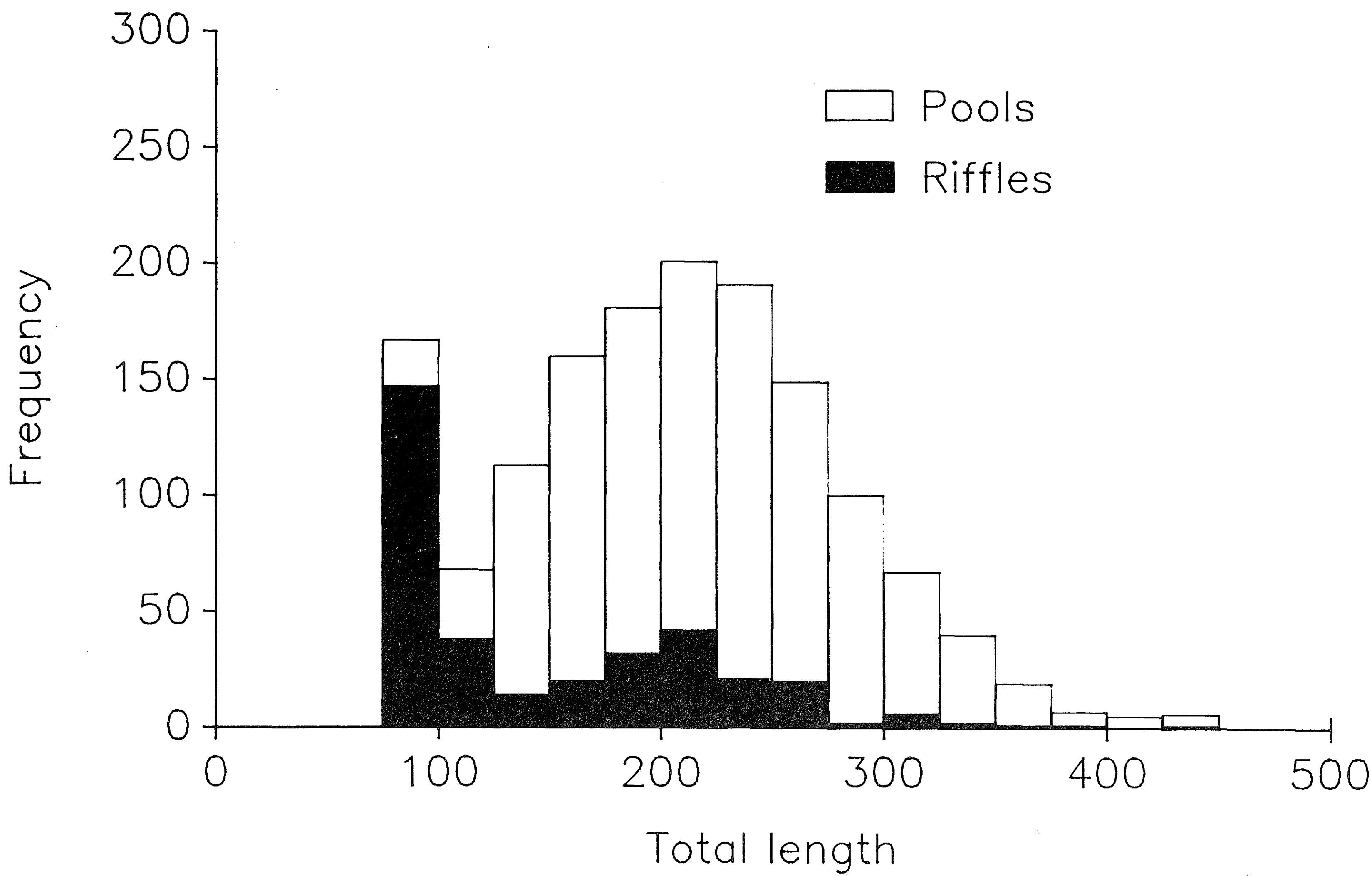

Figure 2. Length frequency distribution of brown trout in pools (n=1,474) and riffles (n=347).

half of the data. The preliminary models for population characteristics in riffles had differing coefficients and poor predictive abilities, thus even the results of the overall riffle models summarized below should be applied with caution.

Biomass

Brown trout biomass in stream reaches decreased with greater pool size and increased with overhead bank cover (OBC), the Streambank Soil Alteration rating, and both HSI and PLATTS pool quality rating variables ($P < 0.05$, Table 5). Five variables selected by stepwise regression explained 82% of the variation in biomass (Tables 6, 7). Area deeper than 60 cm, pool bank shade, and (relative) length of overhead bank cover positively influenced biomass, while pool length and gradient negatively influenced biomass.

In pools, biomass decreased significantly with greater pool area, length, and width. Biomass increased with cover provided by overhead bank cover and pool area deeper than 60 cm ($P < 0.05$, Table 5). Both pool quality rating systems were again correlated with observed biomass values ($P < 0.01$). Two variables, area deeper than 60 cm and length of overhead bank cover, were selected by stepwise regression (Table 6) and explained 43% of the variation of biomass in pools (Table 7).

Biomass in riffles was significantly correlated with three cover variables: cover from instream rocks, riprap, and total cover (Table 5). The selected model included four variables (cover from instream rocks, riprap, overhead cover, and length of overhead bank cover and explained 39% of the variation in biomass in riffles (Table 7).

Table 5. Significant correlation coefficients between habitat variables and biomass (kg/ha) and density (fish/m^2). Asterisks indicate significance at P <0.05* or P <0.01**. Abbreviations are defined in Table 2.

	Reach		Pool			Riffle		
Variable	Biomass	Density	Biomass	Density	Length	Biomass	Density	Length
Length		-0.471*	-0.294*	-0.318**	0.417**		0.256*	0.341**
Width		-0.446*	-0.313*	-0.339**	0.456**		-0.287*	
Area		-0.459*	-0.309*	-0.318**	0.446**			0.262*
OBC	0.718**	0.437*	0.536**	0.395**			0.352**	
DEB								0.308*
IR						0.454**	0.361**	
RR						0.289*	0.310*	
OC					0.305*			0.287*
TC					0.304*	0.260*		0.489**
AV					0.266*		0.291*	
D45			0.248*		0.617**			0.256*
D60			0.271*		0.605**			
D90					0.379**			
PA	-0.481*							
PL	-0.431*							
GRAD								
VEL								
PBS		0.436*		0.350**	-0.521**			
% PC								

Table 5. Continued.

	Reach		Pool			Riffle		
Variable	Biomass	Density	Biomass	Density	Length	Biomass	Density	Length
% RC								
L_{OBC}/T	0.721**	0.493*	0.600**	0.499**				
SBSAR	0.434*							
SBVR								
SBCR								
HSI	0.621**		0.511**	0.355**	0.335**			
PLATTS	0.559**		0.414**	0.328**				
RQ								

Table 6. Habitat variables examined in a stepwise regression to determine models predicting brown trout population characteristics for study reaches, for pools, and for riffles. Abbreviations are defined in Table 2.

Variable	Study reach	Pools	Riffles
AV	X	X	X
D60	X	X	X
PBS	X	X	
PC	X	X	
L_{OBC}/T	X	X	
PA	X		
PL	X		
GRAD	X		
VEL	X		
OBC			X
IR			X
RR			X
DEB			X
OC			X

Table 7. Models and variables selected to describe biomass (B=kg/ha) of brown trout in stream reaches, pools, and riffles. Abbreviations are defined in Table 2.

	Stream reaches	Pools	Riffles
	B = 462.396	B = 38.822	B = 20.071
	− 4.697(PL)	+ 2.859(D60)	+ 76.472(IR)
	+ 2.302(D60)	+ 4.390(L_{OBC}/T)	+ 17.809(RR)
	− 23.217(GRAD)		+ 1.550(OC)
	+ 1.189(PBS)		+ 0.471(L_{OBC}/T)
	+ 6.423(L_{OBC}/T)		
R^2	0.82	0.42	0.39

Density

Density of brown trout in stream reaches increased with both overhead bank cover variables, and with bank shade, but decreased with greater pool length, width, and area (Table 5). The regression model selected three of the nine variables considered (Table 6) and explained 56% of the variation in density (Table 8). Pool bank shade and length of overhead bank cover positively influenced density while velocity had a negative influence.

Density in pools was significantly correlated with HSI and PLATTS pool quality ratings in addition to the five variables important in stream reaches (Table 5). The final model selected to describe density in pools contained three variables (length of overhead bank cover, area deeper than 60 cm, and pool bank shade), but explained only 37% of the variation in density (Table 8).

Density of trout in riffles was most influenced by size of the riffle and by four measures of cover (Table 5). Density was positively correlated with riffle length but negatively correlated with riffle width ($P < 0.05$). Significant correlations of density with overhead bank cover, instream rocks, riprap, and aquatic vegetation were found. The stepwise model describing density in riffles selected four of the seven variables considered (Table 6), but only described 36% of the variation (Table 8). Instream rocks, length of overhead bank cover, and riprap positively influenced density of trout in riffles, while aquatic vegetation negatively influenced density.

Total Length of Fish

Mean length of brown trout in pools was significantly correlated with measures of pool size (3), cover (3), deep water (3), pool

Table 8. Models and variables selected to describe density (D=fish/m^2) of brown trout in stream reaches, pools, and riffles. Abbreviations are defined in Table 2.

Stream reaches	Pools	Riffles
D = 0.146	D = -0.034	D = 0.026
-0.004(VEL)	+0.004(L_{OBC}/T)	+0.050(IR)
+0.002(PBS)	+0.003(D60)	+0.001(L_{OBC}/T)
+0.005(L_{OBC}/T)	+0.003(PBS)	+0.015(RR)
		-0.0001(AV)
R^2 0.56	0.37	0.36

quality (1), and pool bank shade (Table 5). Stepwise regression selected three variables and explained 52% of the variation in mean length (Tables 6, 9). Mean length increased with area deeper than 60 cm and with total cover, but was negatively related to pool bank shade.

The mean length of brown trout in riffles was significantly correlated with measures of riffle size (2), instream cover (3), and water depth (3) (Table 5). A regression model with three variables, cover from instream rocks, aquatic vegetation, and area deeper than 60 cm, explained 45% of the variation in mean length of brown trout in riffles (Tables 6, 9).

Evaluation of Existing Models

Model II of Binns and Eiserman (1979) did not adequately predict biomass of trout in streams of southeastern Minnesota (Fig. 3). The predicted values explained only 10.9% of the observed variation in biomass and none of the 11 variables used in their model was significantly correlated with biomass.

Table 9. Models and variables selected to describe mean length (mm) of brown trout in pools and riffles.

	Pools	Riffles
	Length = 237.972	Length = 187.261
	+0.788(D60)	+32.179(IR)
	-0.807(PBS)	+1.245(AV)
	+0.613(TC)	+10.461(D60)
R^2	0.52	0.45

The modified version of Wesche's (1976) Cover Rating (CR) predicted biomass values that were highly correlated with values observed in southeastern Minnesota streams. Predicted values explained 54.0% of the observed variation in biomass (Fig. 3, $P < 0.01$).

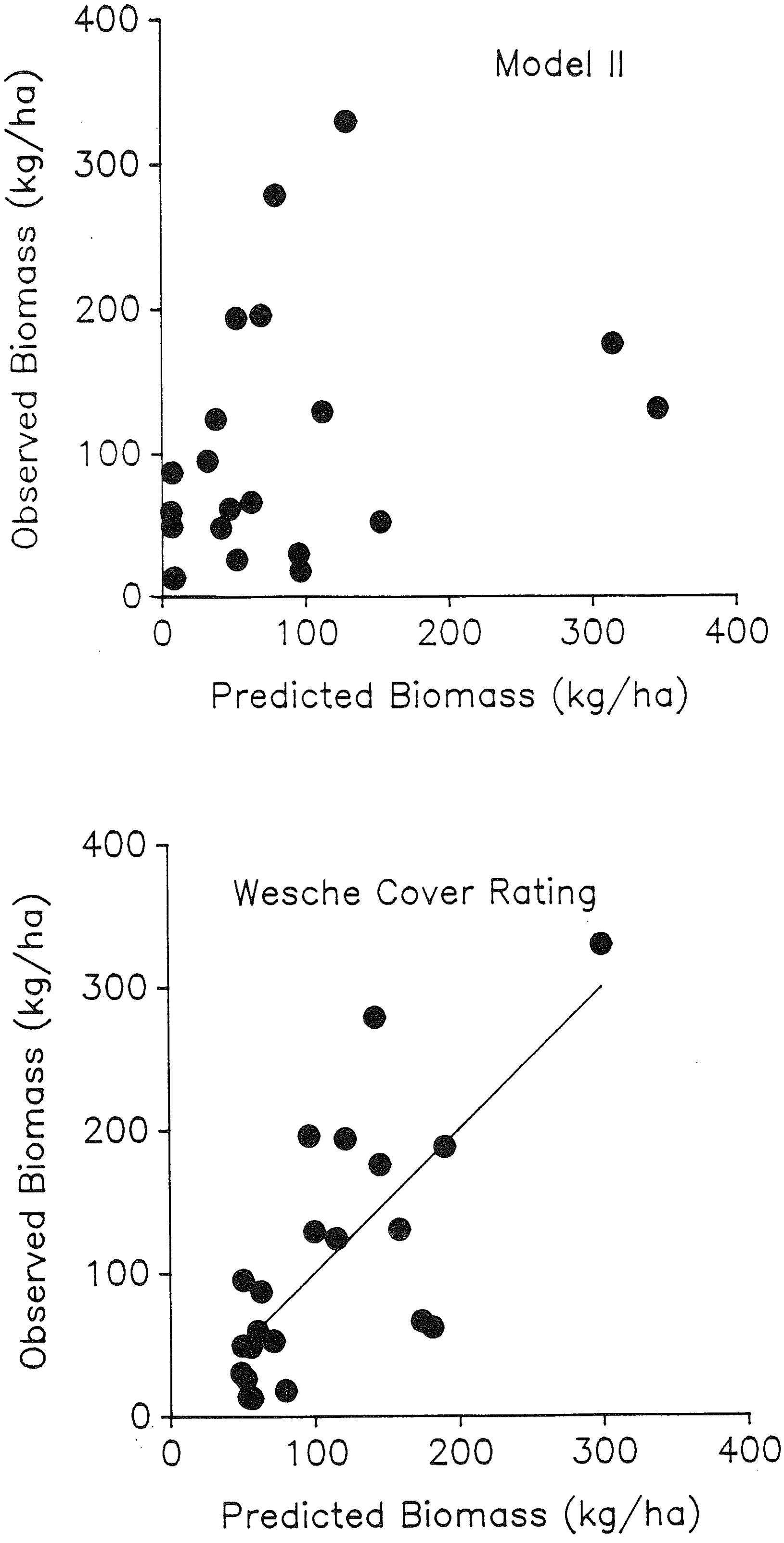

Figure 3. Plots of observed trout biomass in southeastern Minnesota streams versus predicted biomass based on Binns and Eiserman's (1979) Model II and on Wesche's (1976) Cover Rating.

DISCUSSION

Cover appears to be as critical a factor in determining biomass and density of brown trout in the small streams of southeastern Minnesota as it is in other areas. Devore and White (1978) found that 81-83% of the 25-30 cm brown trout in experimental channels were under cover. Brown trout were quite specific in choosing cover, as they preferred cover 10 cm rather than 15 or 20 cm above the streambed. Lewis (1969) reported that cover was the most important variable influencing the brown trout population in a Montana stream. Wesche's (1976) cover rating system could be used to estimate biomass of brown trout in Wyoming. In southeastern Minnesota streams, cover variables had the greatest influence on biomass and density of brown trout and were the most frequent variables in significant correlations and the final models. A Wesche Cover Rating modified to use local habitat preference factors was correlated with biomass in these Minnesota streams.

Overhead bank cover was the most important type of cover limiting brown trout in southeastern Minnesota streams, although it ranked third, behind overhead cover and debris, in area of cover provided. The length of overhead bank cover explained 52% of the variation in biomass in reaches and 44% in pools, and 24% of the variation in density in reaches and 25% in pools. Instream rocks and riprap provided relatively little area for cover for trout. Although overhead cover (above the water) was abundant, its correlation with biomass in pools was negative and not significant ($r = -0.138$, $P < 0.05$). Enk (1977) similarly concluded that overhead bank cover was the major factor limiting trout abundance in two Michigan streams.

The greater importance of overhead bank cover than water depth as cover for brown trout has been noted in other studies. In Wyoming, Wesche et al. (1987a) found water deeper than 45 cm influenced the Cover Rating in large streams (average discharge >2.8 m/sec), but not in small streams, yet length of overhead bank cover was important in streams of both sizes.

Although overhead bank cover most influenced biomass and density of brown trout, low riffle area may limit populations in some streams. Riffles are usually the primary food-producing area for salmonids (Hawkins et al. 1983) and streams with 30-50% riffle area are considered optimal for production of brown trout (Raleigh et al. 1986). In degraded streams of southeastern Minnesota, riffle areas may be only 10% of the stream area (Thorn 1988). In the present study, riffles averaged 28% of the stream area. The observation that trout biomass in stream reaches was negatively related to percent pool area (and therefore positively correlated with riffle area) suggests that the size of riffles influences the biomass in pools downstream.

Additional hydrological variables may limit biomass and density in southeastern Minnesota streams. In southeastern Minnesota, ground water from seepage and springs is the major water source for most trout streams (Stream surveys, Minn. Dept. Nat. Res.). Anderson (1983) implied that increased groundwater levels provided warmer incubation temperature and improved reproductive success of brown trout in southeastern Minnesota. The agricultural land use, hard water, and limestone bedrock of the Ontario streams studied by Bowlby and Roff (1986) are similar to characteristics of streams in southeastern Minnesota. Bowlby and Roff concluded that quality of reproductive and under-yearling habitat as affected by groundwater may be the major limiting factor in southern Ontario streams. Bowlby and Roff suggested that groundwater influenced microcommunity biomass, summer water temperatures, reproductive habitat for trout, and possibly food. White (1975) concluded that annual changes in stream flow could govern abundance of brook trout, *Salvelinus fontinalis*, in a central Wisconsin stream.

The similarity of the density and biomass models suggests both reflect the habitats used by the numerically dominant small trout (∿200 mm TL) without providing much information on habitat use by the rare large trout. In contrast, the models of mean length indicate the larger trout are more associated with area deeper than 60 cm and with total cover than the common size groups, and are less associated with length of overhead bank cover and pool bank shade. Large, unshaded, shallow pools did not support either size group at high densities, so they are obvious candidates for trout habitat improvement work. Many long, shallow pools have sections of rock substrate buried under a few inches of silt, so careful improvement may restore a more natural alternation of smaller, deeper pools and rocky riffles.

The model predicting mean trout length in pools and riffles from habitat variables should be used with caution for trout larger than 300 mm since few were sampled. The models were based on mean lengths ranging from 123-300 mm in pools and 135-336 mm in riffles, and predicted mean lengths ranging from 168-303 mm in pools and 187-302 mm in riffles. Only 12% of the trout were sampled in riffles and only 48% of the riffles had trout older than age 0, so the models predicting population characteristics in riffles will be less reliable than those for pools or stream reaches.

Habitat improvement projects should add overhead bank cover to pools, increase area deeper than 60 cm in pools, increase the amount of bank shade, and decrease pool length. The addition of cover to riffles does not appear practical because riffle areas are small and hold relatively few trout larger than 150 mm. Methods that increase riffle area would provide more food production, more spawning area, and more cover for very small trout (<150 mm TL). These variables may then increase trout biomass and density in pools and produce the positive correlation of biomass with percent riffle area.

The inclusion of cover other than overhead bank cover into habitat improvement projects in southeastern Minnesota streams should be considered on an individual stream basis. Debris has been found to be a major component elsewhere (Binns and Eiserman 1979; Oswald and Barber 1982; Raleigh et al. 1986). In southeastern Minnesota streams, woody debris occurs only in wooded valley bottoms. The input of woody debris for cover may be associated with the percent bank shade variable in several of the final models describing biomass and density. In these streams, woody debris could be incorporated into habitat improvement design. Since riprapping had little relationship to trout population characteristics and is very expensive, it should be used only to control erosion and not as a primary source of cover. The primary value of rocks may be to provide energy-saving feeding sites rather than cover from predators (Backman 1984).

White (1973) stated that overhead cover from streamside vegetation provided little trout cover unless it was very close to the stream surface. In southeastern Minnesota, pool bank shade was more important than overhead cover in governing trout biomass and density.

Pool bank shade was important to the smaller trout, as shade was negatively related to trout mean length. Thus pool bank shade should be incorporated into habitat improvements designed to increase biomass of smaller trout (~200 mm TL), especially since bank shade can often be protected or produced inexpensively. Thorn (1988) showed that habitat improvement projects in southeastern Minnesota worked principally by increasing overwinter survival, so permanent cover devices, although more expensive, are likely to be of greater benefit than seasonal sources of bank shade.

Unexplained variation in biomass and density may be due to habitat variables that were not measured or to angling harvest. Wesche et al. (1987b) reported that a variable based on base flow and flow variation was the most significant single predictor of brown trout biomass in southeastern Wyoming streams of the 18 variables investigated. Lanka et al. (1987) found that geomorphic variables could predict trout biomass as accurately as habitat variables. Wesche et al. (1987b) also suggested that angler harvest may produce unexplained variation in biomass. Yields greater than 100 kg/ha and exploitation rates approaching 100% have been recorded in southeastern Minnesota (Thorn, F-26-R files).

MANAGEMENT IMPLICATIONS

These models of the habitat requirements for brown trout in southeastern Minnesota should be used to optimize benefits from habitat improvement projects, since improvements are costly. Intensive projects have cost between \$6,000 and \$19,000/km and costs are approaching \$30,000/km.

To increase biomass and density of brown trout, habitat improvement should increase trout cover, bank shade, and riffle area. Specifically, the length of overhead bank cover and area deeper than 60 cm should be increased. New or modified habitat improvement methods will be needed to deepen pools and increase riffle area.

If the goal of habitat improvement is to produce larger trout, habitat improvement methods will have to be modified. Larger trout were more associated with area deeper than 60 cm and total cover than were the numerically dominant small trout. Larger trout were less associated with pool bank shade and length of overhead bank cover.

Present habitat improvement methods emphasize the construction of overhead bank covers and riprapping of eroded stream banks. While these methods do enhance brown trout populations, the modified methods mentioned above should be thoroughly examined to provide a better benefit:cost ratio and to produce more quality-size trout.

Future research should be done to identify habitat requirements of brown trout larger than 300 mm and to determine if habitat improvement can restructure a population to favor larger trout.

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Edited by:

P. J. Wingate, Fisheries Research Manager

C. S. Anderson, Coldwater Fisheries Research Supervisor

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