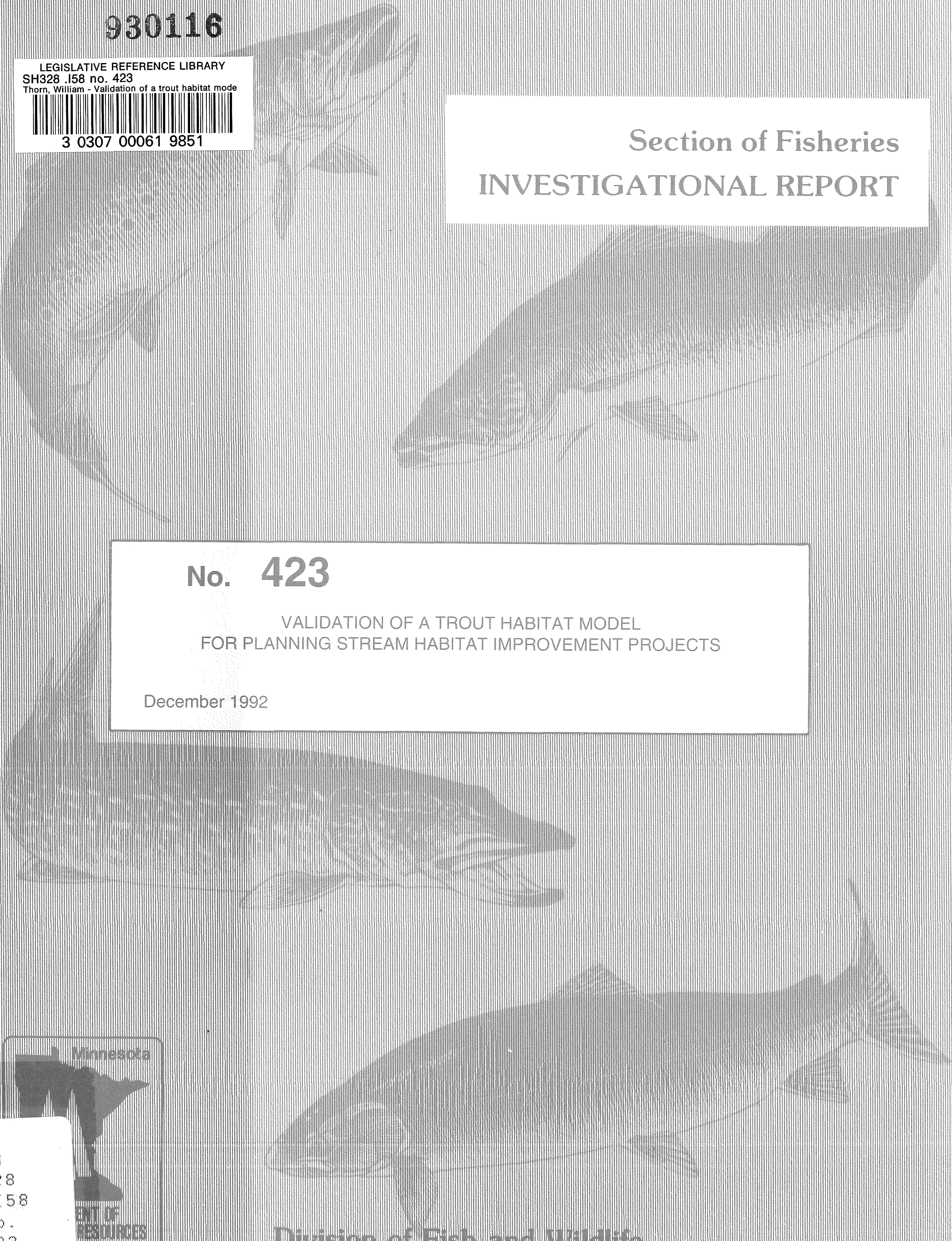

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VALIDATION OF A TROUT HABITAT MODEL FOR PLANNING STREAM HABITAT IMPROVEMENT PROJECTS

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VALIDATION OF A TROUT HABITAT MODEL FOR PLANNING STREAM HABITAT IMPROVEMENT PROJECTS[1]

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Abstract.--The utility of predictive habitat models to design habitat improvements for brown trout in southeast Minnesota streams was tested in two ways. First, overhead bank cover, a key limiting habitat variable identified by the models, was altered in a series of treatments in the design of a habitat improvement project. This form of cover for adult brown trout was the most important variable that could be manipulated. After improvement, biomass and density increased as predicted by the stream reach models. Second, predictions of the models were compared to observed populations in streams improved before 1984 by the more orthodox methods of intensive riprapping of eroded streambanks and irregular installation of artificial overhead bank cover. Predictive abilities of the models were poor for these streams because overhead bank cover treatments were relatively low and uniform (<12% of thalweg length), and because natural fluctuations in additional habitat variables (especially aquatic vegetation) caused trout abundance to fluctuate. Revised models calculated with the combined data (original and test sets) reinforced the importance of adult cover as the major limiting factor that can be manipulated to increase abundance of brown trout in degraded southeast Minnesota streams.

Introduction

Successful habitat management identifies and mitigates factors limiting trout abundance (Meehan 1991). For over 40 years, Minnesota fishery managers have improved habitat for brown trout *Salmo trutta* in degraded, southeast streams on the assumption that adult cover limited brown trout abundance. Enhancement of habitat in southeast Minnesota was necessary because habitat may not return to its natural state in a reasonable time after removal of deleterious practices (Brouha 1991). Success of habitat management has been variable (Minnesota Department of Natural Resources, stream files) because many projects did not establish specific objectives (Barber and Taylor 1990) to address adult cover requirements. Also, most evaluations did not clearly consider natural fluctuations in wild trout abundance. Habitat management in

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southeast Minnesota was typical of past approaches to fisheries management; it was nonexperimental because managers did not treat each project as a deliberate experiment to test their assumptions, identify optimal management, and learn from past actions (McAllister and Peterman 1992).

During the 1970s and 1980s, studies in other areas of the United States defined brown trout habitat requirements, developed models predicting trout abundance or biomass, and recommended using models to analyze habitat changes (Wesche 1976; Binns and Eiserman 1979; Oswood and Barber 1982; Raleigh et al. 1986). Thorn (1988a) developed quantitative models for habitat requirements of brown trout (< 300 mm) in southeast Minnesota streams, and concluded that overhead bank cover (OBC) was the most critical cover type limiting brown trout. Therefore, adding OBC should increase trout abundance and show that adult cover limits brown trout abundance in southeast Minnesota.

When choosing a model for management purposes, fishery managers must consider natural variation in abundance, generality of the model, sample size and degrees of freedom, coefficient of determination, and ease and expense of measuring habitat variables (Fausch et al. 1988). Hall and Knight (1981) reported that temporal and spatial variation in stream salmonid abundance can be several orders of magnitude, and Thorn (1990) showed that brown trout abundance in southeast Minnesota streams fluctuated several-fold among years. Because of population fluctuations and multiple variables considered, several models with < 20 degrees of freedom had $R^2 > 0.75$ but the fit was partly by chance and lacked generality (Fausch et al. 1988). Most models can be applied only in the same ecoregion where developed because of low predictive abilities elsewhere (Fausch et al. 1988). Binns and Eiserman (1979) used their Habitat Quality Index (HQI) to evaluate habitat management in Wyoming streams, but HQI did not predict biomass in Montana, Ontario, and Minnesota (White et al. 1983; Bowlby and Roff 1986; Thorn 1988a).

Fishery managers are most concerned with variables that are limiting and can be manipulated; however, variables not physically manipulated or not included in models also can influence brown trout abundance and cause deviations from expectations or from model predictions. For this reason, to be useable, models must include most of the variables that significantly limit fish abundance, and should be tested for each region of use. Models may be considered valid if experimental manipulation produces population responses in accord with predictions, or if data from other streams and years confirm predictions (Fausch et al. 1988). Such tests may reveal additional limiting variables. Stream flow may be the most influential variable influencing trout abundance (White 1975; Bowlby and Roff 1986; Wesche et al. 1987a), but cannot be manipulated in natural channels. Late winter and early spring flooding influenced brown trout reproduction in southeast Minnesota streams (Anderson 1983). The resulting population fluctuations may have a great influence on catch and may obscure results of management activities (Thorn 1990). Angler harvest may have caused variation in biomass in Wyoming streams unaccounted for by habitat features, and limited model predictions (Wesche et al. 1987a).

In this study, I tested the utility of predictive models in the design and evaluation of habitat improvements in a southeast Minnesota trout stream, tested models on other streams, revised the models to improve their precision and generality, and made recommendations for habitat enhancement. I designed habitat improvements in Section A of West Indian Creek with a variable of the stream reach model for biomass (Thorn 1988a), and evaluated the improvements by comparing abundance before and after improvement, as well as by comparing predicted abundance with the measured abundance. To test the generality of Thorn's (1988a) models, I compared predicted and observed values from other improved streams, including Hay Creek, which has a no-kill regulation. Then I combined model development data and validation data to calculate new models, and compared them to the original models.

Study Area

Instream habitat for trout in streams in the Driftless Area of southeast Minnesota was degraded by agricultural development of the region. Settlers were attracted to the valleys in the mid-to-late 1800's because of rich soil and abundant timber and water, and removed native vegetation for agriculture, fuel, and lumber (Waters 1977). Settlement of the valleys often eliminated the riparian source of large woody debris, necessary for creating and maintaining fish habitat (Hicks et al. 1991). Settlers plowed the uplands, and logged and grazed the hillsides. This increased flooding (Waters 1977), erosion, and sedimentation (Trimble and Lund 1982). Trout habitat decreased because of instream and flood plain sedimentation (Waters 1977; Trimble and Lund 1982), which covered the stream bottom and corridor vegetation. In most streams, the native brook trout *Salvelinus fontinalis* was replaced by the non-native brown trout, which tolerated warmer and more turbid water (Becker 1983).

Since the 1930's, land use of the Driftless Area has generally improved, erosion and sedimentation has decreased, and infiltration has increased (Trimble and Lund 1982). However, Minnesota Department of Natural Resources (MNDNR) stream surveys through the 1980s documented degraded physical habitat for trout and recommended habitat improvements to restore trout populations. Frequent flooding prevented natural improvement of habitat because native stream corridor vegetation had been replaced with agriculture or, when restored, had not grown long enough to improve instream habitat. Riparian zones may need 25-100 years to begin contributing woody debris to the stream channel (Lyons and Courtney 1990; Armentrout 1991) to begin restoration of pools, riffles, and trout cover. Also, the time for self-healing restoration of a stream after a major perturbation may be more than a century (Hicks et al. 1991; Hunter 1991, Gasper 1992).

Southeast Minnesota trout streams begin from coldwater springs and are productive. MNDNR improved habitat for brown trout on all study streams (Table 1) between 1970 and 1984 by riprapping eroded stream banks and irregularly installing instream cover structures. All study streams are in the Driftless Area, sustained wild brown trout populations, and have not been stocked since at least 1984.

Table 1. General description[a] of streams sampled to test validity of the models.

Stream	Identifier	Width (m)	Gradient (m/km)	Velocity (cm/sec)	Late summer discharge (m^3/sec)
Trout Run	TR1	11.6	1.9	27.1	0.87
Trout Run	TR2	9.3	2.6	27.5	0.52
Trout Run	TR3	9.5	1.5	18.1	0.52
Trout Run	TRSR1	7.2	3.3	15.9	0.46
Trout Run	TRSR2	7.1	0.3	17.2	0.39
Gribben	GRB1	5.3	9.2	16.0	0.09
Gribben	GRB2	5.7	4.2	14.6	0.03
Diamond	DIA1	3.7	6.3	16.3	0.07
Diamond	DIA2	3.1	5.2	19.2	0.07
Diamond	DIA3	2.4	8.7	10.8	0.04
Diamond	DIA4	2.6	15.4	15.7	0.03
Torkelson	TORK1	3.5	5.8	7.5	0.05
Torkelson	TORK2	3.1	4.5	16.6	0.05
Hemmingway	HEM1	3.6	7.7	17.3	0.07
Hemmingway	HEM2	3.6	8.8	21.3	0.07
Hay	HAY1	7.0	2.3	20.1	0.25
Hay	HAY2	6.5	2.9	14.0	0.25
West Indian	WI	4.2	3.6	22.1	0.21

[a] From stream survey reports (MNDNR, unpublished data)

Methods

I designed habitat improvements in Section A of West Indian Creek (0.57 km) with OBC to provide adult cover. OBC was the variable most frequently included in predictive models (Thorn 1988a), and was easily manipulated with installation of "lunker structures" (Vitrano 1988). I randomly assigned an OBC treatment to each of the 11 pools in the study reach. The treatments were installation of OBC between 0% and 60% of the thalweg length (L_{obc}/T) in multiples of 5%. Planned lengths of OBC were slightly modified during construction in 1987 (Table 2). To slope and riprap streambanks for erosion control, much of the riparian woody vegetation was removed.

After improvement (fall 1987), I stocked wild brown trout from an adjacent watershed to reduce the time for the population to respond to enhanced habitat (Hunt 1976; Thorn 1988b). Each pool was stocked at one-half the biomass predicted from Wesche's modified Cover Rating (Thorn 1988a). The stream reach was electrofished near the end of the angling season before improvement (1980 to 1987) and for four years after improvement (1988 to 1991). All captured

Table 2. Lengths of overhead bank cover (OBC) added to pools of Section A West Indian Creek in 1987 to provide L_{OBC}/T (length of OBC per thalweg length).

Pool number	OBC(m)	L_{OBC}/T
1	9.8	0.57
2	0.0	0.00
3	21.9	0.55
4	4.9	0.11
5	14.6	0.20
6	24.4	0.39
7	17.1	0.36
8	9.8	0.28
9	4.9	0.29
10	9.8	0.40
11	9.8	0.21

trout were measured, and a sample was weighed to develop a length-weight relationship. I estimated abundance for individual pools and riffles by depletion (Platts et al. 1983), and summed individual pool and riffle estimates to calculate stream reach abundance. For the first two years a backpack electrofisher prevented trout movement from pools during sampling. However, as reported by Heggenes et al. (1990), few or no fish were shocked with the backpack electrofisher, and I discontinued its use for the rest of the study.

I also monitored brown trout abundance by electrofishing in Section B (0.77 km) of West Indian Creek for a control reach to document natural changes in abundance. Habitat was improved in 1981. Stream reach abundance was estimated by mark and recapture (Ricker 1975).

Predictive models (Model 1; Table 3) were tested on Sections A and B of West Indian Creek before and after habitat improvement, and on other streams improved before 1984 (sampled in 1989 and 1990). I sampled 17 reaches in 1989 on streams that had been improved before 1984, and resampled 10 of these reaches in 1990. Each stream reach had three pools and three riffles. I estimated trout abundance as described for Section A of West Indian Creek, and measured habitat as described by Thorn (1988a). Data for model development and evaluation were collected in late summer; therefore, model predictions do not represent carrying capacity. Data from Hay Creek, improved in 1978 (Thorn 1988b) and under a no-kill regulation since 1985 (Thorn 1990), tested model predictions on a population without angling mortality. I compared predictions for biomass and density in stream reaches, pools, and riffles, and for mean lengths of trout in pools and riffles to actual values by simple correlation (Binns and Eiserman 1979; McClendon and Rabeni 1987), and by prediction errors using cross validation techniques (Binns and Eiserman 1979; Weisburg 1985; Lanka et al. 1987).

Finally, I combined development and evaluation data sets to recalculate new predictive models (Binns and Eiserman 1979). The new models were compared to the original models with coefficients of determination (R^2) and prediction errors.

Results

Evaluation of Habitat Improvements

Habitat improvements in Section A of West Indian Creek were designed with L_{obc}/T, yet five stream reach model variables were changed by the project (Table 4). The increase in L_{obc}/T should tend to increase biomass and density, and increases in area deeper than 60 cm (D60) and percent pool length (PL) should tend to increase biomass. The decrease in percent pool bank shade (PBS) should decrease biomass and density, and the increase in velocity (VEL) should decrease density.

Biomass and density of brown trout in Section A of West Indian Creek increased after habitat improvement (Tables 5 and 6). Mean fall biomass increased 984% (t = 5.290, P <0.01), and mean fall density increased 2,220% (t = 3.887, P <0.01). The major design variable, L_{obc}/T, explained 65% of the variation in biomass of brown trout (P <0.01) and 54% of the variation in density (correlation, P <0.05). The other manipulatable and important variable, D60, explained only 8% and 5% (P >0.05) of the variation in biomass and density, respectively.

Abundance increased because of habitat improvements, not because of population fluctuations (Table 5). During 1985 to 1987, mean

Table 3. Models and variables describing biomass (B=kg/hectare), density (D=fish/m^2), and mean length (mm) of brown trout in stream reaches, pools, and riffles in southeast Minnesota streams. Model 1 is from Thorn (1988a). Model 2 was developed from Model 1 and validation data.

		R^2
	Stream reach	
Biomass		
Model 1:	$B = 462.396 - 4.697(PL)^a + 2.302(D60)^b - 23.217(GRAD)^c + 1.189(PBS)^d + 6.423\,(L_{OBC}/T)^e$	0.82
Model 2:	$B = 215.572 + 5.748(L_{OBC}/T) + 2.938(TC)^f - 4.810(VEL)^g$	0.45
Density		
Model 1:	$D = 0.146 - 0.004(VEL) + 0.002(PBS) + 0.005(L_{OBC}/T)$	0.56
Model 2:	$D = 0.237 + 0.006(L_{OBC}/T) + 0.002(PBS) - 0.006(VEL)$	0.42
	Pools	
Biomass		
Model 1:	$B = 38.822 + 2.859(D60) + 4.390(L_{OBC}/T)$	0.42
Model 2:	$B = 53.892 + 1.244(AV)^h + 2.210(D60) + 3.817(L_{OBC}/T)$	0.28
Density		
Model 1:	$D = 0.034 + 0.004(L_{OBC}/T) + 0.003(D60) + 0.0003(PBS)$	0.37
Model 2:	$D = -0.017 + 0.001(AV) + 0.002(D60) + 0.004(L_{OBC}/T) + 0.002(PBS) + 0.002(TC)$	0.26
Mean Length		
Model 1:	$MM = 237.972 + 0.788(D60) - 0.807(PBS) + 0.613(TC)$	0.52
Model 2:	$MM = 211.617 + 1.324(D60) - 0.514(PBS)$	0.24
	Riffles	
Biomass		
Model 1:	$B = 20.071 + 76.472(IR)^i + 17.809(RR)^j + 1.550(OC)^k + 0.471(L_{OBC}/T)$	0.39
Model 2:	$B = 22.572 + 8.625(D60) + 0.464(L_{OBC}/T) + 1.745(OC)$	0.30
Density		
Model 1:	$D = 0.026 + 0.050(IR) + 0.001(L_{OBC}/T) + 0.015(RR) - 0.0001(AV)$	0.36
Model 2:	$D = 0.030 + 0.014(D60) - 0.003(DEB) + 0.0004(L_{OBC}/T)$	0.43
Mean Length		
Model 1:	$MM = 187.261 + 32.179(IR) + 1.245(AV) + 10.461(D60)$	0.45
Model 2:	$MM = 86.946 + 8.769(DEB) + 1.022(L_{OBC}/T) + 6.005(OC)$	0.18

[a] Pool length (%)
[b] Area deeper than 60 cm (%)
[c] Gradient (m/km)
[d] Pool bank shade (%)
[e] Length OBC/thalweg length
[f] Area total cover (%)
[g] Velocity (cm/sec)
[h] Area of aquatic vegetation (%)
[i] Area instream rock cover (%)
[j] Area riprap cover (%)
[k] Area overhead cover (%)

fall biomass and density were greater in improved Section B than in unimproved Section A ($t = 8.071$, $P < 0.05$ and $t = 9.245$, $P < 0.01$). After improvement of Section A (1988 to 1991), mean fall biomass and density in Section A had improved to levels similar to those in Section B ($t = 2.969$ and -2.900, $P > 0.05$). Mean biomass and density in Section B for these two periods did not change ($t = 0.422$ and 0.649, $P > 0.05$). Biomass during two drought years (1988 to 1989) in Section A of West Indian Creek with 23% L_{obc}/T was 52% and 32% greater than in Section B with only 2% L_{obc}/T.

Model Validation

West Indian Creek.--Before improvement of Sections of A and B, no OBC existed, and the stream reach models overestimated biomass and density (Table 6). In Section A after improvement with OBC, the stream reach models predicted biomass and density adequately. After

Table 4. Effects of habitat improvement on model variables (Thorn 1988a) in Section A, West Indian Creek. Variables were measured two years before and two years after habitat improvement.

Variables	Change (%)	Benefit (+/-)
PL[a]	-16.2%	+
D60[b]	+16.3%	+
GRAD[c]	Unknown	Unknown
PBS[d]	-48%	-
L_{OBC}/T[e]	+22.3%	+
IR[f]	+1.9%	+
RR[g]	+5.3%	+
OC[h]	Decrease	-
VEL[i]	49%	-
AV[j]	Unknown	+
TC[k]	Increase	+

[a] Pool length (%)
[b] Area deeper than 60 cm (%)
[c] Gradient (m/km); not measured before, change not probable
[d] Pool bank shade (%)
[e] Length OBC/thalweg length
[f] Area instream rock cover (%); not present before habitat improvement
[g] Area riprap cover (%); not present before habitat improvement
[h] Area overhead cover (%); not measured before improvement, but decrease probable because of PBS and surface area reduction
[i] Velocity (cm/sec)
[j] Area of aquatic vegetation (%); abundance varies naturally, potential positive benefit because riffle area increased 60%
[k] Area total cover (%); not measured before, but only cover present was D60 and some large woody debris

Table 5. Estimated fall biomass (kg/hectare) and density (fish/m^2) of adult brown trout and abundance of age-0 (YOY) brown trout in Sections A and B of West Indian Creek, 1980-91.

Year	kg/hectare	fish/m_2	YOY/km
Section A			
1980	9.7	.004	0
1981	2.3	<.001	14
1982	28.5	.004	92
1983	28.0	.009	83
1984	17.5	.008	129
1985	14.5	.007	79
1986	7.9	.002	136
1987[a]	13.3	.001	511
1988	285.9	.227	709
1989	145.6	.135	10
1990	98.1	.038	553
1991	129.6	.062	347
Section B			
1980	13.5	.005	0
1981[a]	29.1	.005	47
1982	18.5	.004	118
1983	40.5	.010	151
1984	53.2	.018	318
1985	109.0	.035	32
1986	111.8	.038	1,039
1987	80.6	.042	2,627
1988	138.8	.112	106
1989	98.9	.065	30
1990	60.0	.017	159
1991	65.2	.026	471

[a] Habitat was improved

improvement, confidence limits overlapped broadly for predicted and observed biomass and density values (Table 6). Pool model predictions for biomass and mean length of trout were positively correlated with observed values, however the relationships were not consistently significant in successive years (Table 7). In pools, predicted biomass was correlated with actual biomass in 1990, and predicted mean length of trout was correlated with actual length in 1990 and 1991. Predicted and actual density were not correlated in 1990 or 1991. In riffles, no predictions were correlated with actual values in either year. Average prediction errors tended to be lower for pool model predictions than for riffle model predictions.

Streams improved before 1984. None of the seven variables in the original models (or AV) explained more than 11% of the variation in biomass or 13% of the variation in density (correlation) in stream reaches improved before 1984. Together, these eight variables explained 54% and 21% of the variation in biomass and density, respectively (multiple regression, see new model development). Mean L_{obc}/T was only 5.3%, and L_{obc}/T explained only 9% of variance in biomass and 10% of that in density.

The range of L_{obc}/T in streams improved before 1984 (sampled in 1989) was much less than the range in model development streams (sampled in 1985; Table 8) or Section A of West Indian Creek. Stream morphology variables

Table 6. Actual and predicted biomass (kg/hectare) and density (fish/m^2) (with 95% confidence limits in parentheses) of Sections A and B of West Indian Creek, before and after habitat improvement (HI).

	Section A	Section B
	Biomass (kg/hectare)	
Before HI		
Actual[a]	15.2(0.0-37.1)	21.3(15.8-26.8)
Predicted	39.7(0.0-83.2)	47.6(4.5-90.7)
After HI		
Actual[b]	164.8(31.8-297.8)	94.9(26.2-163.6)
Predicted	223.0(182.6-263.4)	110.8(69.2-152.4)
	Density (fish/m^2)	
Before HI		
Actual	0.005(0.000-0.015)	0.005(0.005-0.005[c])
Predicted	0.177(0.082-0.272)	0.177(0.082-0.272)
After HI		
Actual	0.116(0.000-0.386)	0.049(0.00-0.127)
Predicted	0.180(0.101-0.259)	0.138(0.070-0.206)

[a] Means from 1980-87 for Section A and 1980-81 for Section B.
[b] Means from 1988-91 for Section A and 1982-91 for Section B.
[c] Rounded to three decimal places.

Table 7. Correlation coefficients (r) and average prediction error (APE) for tests of Model 1 relating trout biomass, density, and mean length of trout to habitat variables. Asterisks indicate significant correlations at P < 0.05* or P < 0.01**.

Statistic	Section A, West Indian Creek				Other Improved Stream						Hay Creek			
	Pool model		Riffle model		Reach model		Pool model		Riffle model		Pool model		Riffle model	
	1990	1991	1990	1991	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
							Biomass							
r	0.79**	0.47	0.12	0.00	0.15	0.19	0.33*	0.03	0.11	0.97**	0.83**	0.12	0.01	0.00
APE (%)	28	1	90	100	241	131	52	36	142	271	208	41	427	7
							Density							
r	0.52	0.42	0.11	0.00	0.34	0.11	0.16	0.21	0.11	0.97**	0.04	0.06	0.71*	0.00
APE (%)	38	53	75	50	60	20	29	29	175	425	252	52	375	50
							Mean Length							
r	0.85**	0.73*	0.16	0.00	NA	0.26	0.33	0.21	0.20	0.03	0.45	0.01	0.00	
APE (%)	24	21	41	27		2	49	34	66	45	78	2	19	

Table 8. Mean and range of habitat variables used in predictive equations (Table 1), 1985 and 1989. Asterisks indicate that 1989 mean is significantly different from 1985 mean (*,P < 0.05, **,P < 0.01).

		Reach		Pool		Riffle	
Variable	Year	Mean	Range	Mean	Range	Mean	Range
IR[a]	1985					0.1	0.0-1.6
	1989					0.4	0.0-7.8
RR[b]	1985					0.2	0.0-5.8
	1989					0.5	0.0-18.3
OC[c]	1985					1.0	0.0-44.9
	1989					1.5	0.0-30.1
TC[d]	1985			6.0	0.0-87.2		
	1989			8.3	0.0-80.7		
AV[e]	1985	9.1	0.0-31.0	11.0	0.0-90.0	19.1	0.0-90.0
	1989	>90.0[f]		>90.0[f]		12.1	0.0-90.0
D60[g]	1985	11.3	0.0-35.5	14.6	0.0-53.6	0.2	0.0-7.3
	1989	14.3	0.0-39.9	14.5	0.0-57.9	0.6	0.0-28.7
PL[h]	1985	70.4	37.6-100.0				
	1989	76.7	54.4-93.0				
L_{OBC}/T[i]	1985	10.1	0.0-40.7	17.2	0.0-99.3	6.4	0.0-119.1
	1989	5.3	0.0-12.4	9.6	0.0-123.5	0.8	0.0-37.1
GRAD[j]	1985	6.3	1.5-14.6				
	1989	5.3	0.3-15.4				
VEL[k]	1985	24.5	17.4-61.3				
	1989	17.4	7.5-27.5				
PBS[l]	1985	22.8	0.0-89.3	25.7	0.0-100.0		
	1989	33.6	5.0-56.2	44.6**	0.0-100.0		

[a] Area instream rock cover (%)
[b] Area riprap cover (%)
[c] Area overhead cover (%)
[d] Area total cover (%)
[e] Area of aquatic vegetation (%)
[f] Observation
[g] Area total cover (%)
[h] Pool length (%)
[i] Length OBC/thalweg length
[j] Gradient (m/km)
[k] Velocity (cm/sec)
[l] Pool bank shade (%)

were not different, however mean length, width, and area of pools, riffles, and reaches for the two years were similar (*t*-tests, $P > 0.05$).

In streams improved before 1984 that were sampled to test model generality (including Hay Creek with no legal harvest), three habitat variables differed markedly from the levels in the model development streams (Table 8). Mean coverage by aquatic vegetation (AV) was 9.1% in model development data, and increased to >90% in 1989 and fell to about 50% in 1990; PBS was significantly greater in 1989 than in 1985 (t = -3.394, $P < 0.01$).

Variables not included in the models caused trout abundance to fluctuate in these streams. Therefore, models did not consistently predict biomass, density, or mean length of trout for stream reaches, pools, and riffles in streams improved before 1984 (Table 7). Predicted and actual biomass and density were not correlated because mean biomass and density in 1989 were greater than for model development streams in 1985 (t = -2.894 and -3.011, $P < 0.01$). Also, mean biomass and density in these other improved streams were significantly less in 1990 than in 1989 (t = 4.903, and t = 3.679, $P < 0.01$). In Hay Creek, predicted stream reach biomass was 48.2 kg/hectare (95% confidence limits of 15.1 - 81.3 kg/hectare) and actual biomass was 270.7 kg/hectare in 1989 and 73.8 kg/hectare in 1990, and predicted density was $0.06/m^2$ (0.00 - $0.12/m^2$) and actual density was $0.22/m^2$ and $0.04/m^2$. Average prediction errors were generally higher for streams improved before 1984 than for Section A of West Indian Creek.

New Model Development

Combining model development data (1985, Model 1) and validation data from 1989 from streams improved before 1984 sets into new regression equations (Model 2) increased sample size from 22 to 39, added one variable (AV) to the models, and decreased coefficients of determination (Table 3).

In Section A of West Indian Creek, Model 2 predicted biomass and density in pools better than Model 1. Predicted biomass from Model 2 was correlated with actual biomass in 1990 and 1991 (r = 0.84, P <0.01 and r = 0.61, P <0.05); predicted biomass from Model 1 (Table 7), was significantly correlated only in 1990. Predicted and actual density were correlated with Model 2 in both years (r = 0.69 and 0.62, P <0.05), and were not correlated with Model 1 (Table 7) in either year. Model 1 predicted mean length of trout in pools in both years (Table 7), and Model 2 successfully predicted trout length in only one year (r = 0.69, P <0.05 and r = 0.52, P >0.05). Model 2 was not tested for riffles in West Indian Creek because only one trout was captured in riffles in the two years of sampling.

Discussion

Habitat improvements cannot be fully evaluated until trout numbers have had time to respond to the enhanced habitat. Hunt (1976) recommended delaying collection of post-treatment data for 5-6 years because abundance of age-0 brook trout had not significantly increased three years after improvement (the mean was 1,454/km and the range was 777-2,040/km) in Lawrence Creek, Wisconsin (Hunt 1971). Thorn (1988b) reported a five year response period for brown trout in Hay Creek and Section B of West Indian Creek. Abundance of age-0 trout in these two streams also did not change for five years after improvement, averaged 358/km and 332/km, and ranged from 30-1,035/km and 32-1,039/km, respectively. In Section A of West Indian Creek, biomass in the improved habitat peaked one year after completion of improvements (1988) because of the large 1987 year class, and the wild fish stocked in fall of 1987. Poor results of testing models on other improved streams cannot be attributed to insufficient response time because they all were improved at least five years before this study.

This study showed that habitat improvements for brown trout in southeast Minnesota streams could be successfully designed with the predictive pool habitat model for biomass. Habitat improvements that greatly increased OBC increased trout biomass and density, and reduced effects of drought on trout biomass. These increases supported the common management assumption that cover limited adult trout abundance in most southeast Minnesota streams, and that improving this habitat would increase trout abundance. Post-season biomass and density in the stream reach, and mean length of trout in pools after habitat improvement were successfully predicted. The stream reach model for biomass should also be used to set realistic expectations on the results of improvement projects (or alternative designs). This study is an example of experimental management (McAllister and Peterman 1992), whereby treatments greater and less than traditional levels are introduced and monitored. Such experimental management is a more powerful way to examine effectiveness of management methods than correlative study or routine monitoring.

Habitat improvements in southeast Minnesota streams should emphasize intensive installation of OBC because it is the most important, manipulatable variable limiting summer abundance of brown trout in these streams, and it provides winter cover (Cunjak and Power 1987). Wesche et al. (1987b) also reported that OBC was the most important variable influencing abundance of brown trout in Wyoming streams.

Models did not predict abundance in other southeast Minnesota streams improved before 1984 because managers had installed little OBC, and habitat and trout abundance fluctuated more than in Section A of West Indian Creek. Improvements to streams improved before 1984 added just 0-12.4% L_{obc}/T (mean of 5.3%), compared to 0-57% L_{obc}/T (mean of 22.3%) added to Section A of West Indian Creek. Although projects before 1984 apparently increased trout abundance, the size of the increase could not be predicted from any set of measured variables. The limited range of OBC that was used provided only a weak signal of population response within the noise of annual population fluctuations and fluctuations of other variables.

Managers suggested that the poor fit of the models on streams improved before 1984 was because habitat improvement was a developed "art" and a reflection of "feel" they developed by working with a stream and not against it. This assumption, however, would be expected to make each project more efficient, and should produce a stronger relationship between trout abundance and measured variables. It is relevant to note that Section A of West Indian Creek was improved by a much less experienced crew, and that the successful design produced predictable results. I conclude that some limiting variable(s) have not been included in the models or in the older habitat improvement designs, and that experimental management (McAllister and Peterman 1992) may help identify these variables and move habitat improvement farther from an art toward a science. Forage availability and water quality are two variables which may influence spatial requirements of trout and may influence success of habitat improvement design, although no data supports speculation that these factors differed in streams improved before 1984 and West Indian Creek.

Stream flow probably explained much of the remaining variation in biomass and density because flow fluctuations influenced habitat variability. When drought eliminated flushing flows and allowed growth of AV, another type of adult cover, AV became an important but unmanipulatable model variable (Model 2). Brown trout recruited from pre-drought years into this additional cover, and biomass increased. Then biomass decreased though water levels increased, because AV decreased and few wild trout recruited from the drought years. Failure to evaluate habitat variability was a design defect of many models that failed to relate fish populations to habitat (Orth 1987).

Even though fishing pressure increased after habitat improvement in southeast Minnesota trout streams (Thorn 1988b), angling harvest did not influence model evaluation. The intensive addition of OBC in Section A of West Indian Creek increased biomass and density as predicted even though angling pressure probably increased. On streams improved before 1984 with little OBC, including Hay Creek with a no-kill regulation, habitat variation and trout abundance fluctuations influenced model predictions more than angling. Also, study design minimized the potentially confounding influence of angling.

Although other variables prevented these models from consistently predicting abundance, the models met most of the requirements of Fausch et al. (1988), so they are recommended for management use in project design in southeast Minnesota streams. Sample size was >20, variables were easily measured, and some limiting variables were manageable. An important variable was manipulated and the responses matched predictions. Also, Fausch et al. (1988) showed that few habitat models with an adequate sample size had an $R^2 > 0.50$. The models of the present study showed that adult cover limited trout abundance, and this limiting factor can be managed.

Because managers will be held accountable in the future for their actions (Rabeni 1990), they must establish achievable goals and objectives (Barber and Taylor 1990), manage experimentally (McAllister and Peterman 1992), and improve institutional memory (Hilborn 1992). In habitat management, managers must emphasize management for objectives rather than activity-oriented management (White 1991). Active adaptive management provides a framework for management to choose and evaluate management actions as they are carried out (Walters and Hilborn 1978). The evaluation ensures institutional memory. Habitat management before 1984 was nonexperimental and did not appreciably advance the "state of the art."

Model variables other than OBC should not be ignored in habitat improvement projects. Other kinds of adult cover would provide diversity for habitat (Hicks et al. 1991) and angling. Riprapping eroded stream banks eliminated stream bank erosion, increased deep water (D60), and increased brown trout overwinter survival (Thorn 1988a). Deep water provides year-round cover for large brown trout, and winter cover for adult brown trout of all sizes

(Raleigh et al. 1986; Cunjak and Power 1987; Heggenes 1988). Trees planted for PBS (pool bank shade) when woody vegetation has been removed from the riparian corridor, will provide woody debris to the stream and may maintain cover and create habitat complexity after OBC structures deteriorate (20-25 years). Whenever possible, riparian woody vegetation should not be removed. Restoring meandering in degraded streams would increase stream length, reduce gradient (GRAD), and increase stream reach biomass. However, adult cover should not be increased in riffles because riffle depth in most southeast Minnesota streams is inadequate for adult trout.

To increase trout abundance in southeast Minnesota streams, short-term and long-term management of limiting factors is necessary. Instream habitat devices manipulate stream characteristics, and accelerate recovery of perturbed streams (Swales 1989) and provide an interim solution for stream restoration until long-term objectives are met (Everest et al. 1991). Therefore, short-term management (20-25 years) installs OBC to provide immediate cover for trout, and riprap to reduce bank erosion and to provide deep water for larger trout. Long-term management (>25 years) should consider variables to maintain cover and habitat complexity after in-stream work deteriorates. Riparian zones should be managed for long-term recruitment of large woody debris into stream channels (Hicks et al. 1991), and trees planted in the riparian corridor may not contribute woody debris to the stream until after many years of growth (Andrus et al. 1988). Long-term land use changes may restore meandering to increase stream length and reduce gradient, pool length, and velocity, and improve riffle quantity and quality.

Management Implications

Adult cover limited brown trout abundance in a degraded southeast Minnesota stream. Habitat can be enhanced to overcome this limiting factor by installing overhead bank covers.

Habitat improvements can be designed with OBC using the stream reach model, and realistic expectations can be established. Post-season biomass and density were predicted. Model 2 is generally recommended because it was developed from a larger sample.

This study is an example of experimental management that will increase the "state of the art" of habitat management. Designing and evaluating habitat improvements with model variables improves accountability, and allows managers to learn from past actions and improve future management. Therefore, models of this study are recommended for use in Driftless Area trout streams.

Trout abundance fluctuated less in streams with abundant OBC than in other streams. On streams improved before 1984, specific limiting factors were not identified, clear objectives were not established, habitat and trout abundance fluctuated more, and unmanageable variables not included in the models determined abundance.

Abundance in improved stream reaches can be increased quickly by stocking wild trout or by natural recruitment from strong year classes. A temporary harvest restriction or a combination of stocking and harvest restriction are other ways to obtain a rapid response and thereby maximize benefits and speed evaluation.

Habitat enhancement planning should include short term approaches of instream and streambank work, and long term approaches of riparian zone and watershed management.

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Appendix Table 1. Predicted and actual biomass (kg/hectare) and density (fish/m^2) of brown trout in reaches of streams improved before 1984. Stream abbreviations in Table 1.

Stream	Biomass			Density		
	Predicted	Actual		Predicted	Actual	
		1989	1990		1989	1990
TR1	226.8	332.6		0.14	0.32	
TR2	114.0	284.6	56.5	0.17	0.24	0.05
TR3	170.3	141.0	65.1	0.20	0.23	0.08
TRSR1	160.5	213.3		0.13	0.27	
TRSR2	93.2	304.9	111.3	0.13	0.25	0.08
GRB1	20.9	130.8		0.18	0.22	
GRB2	76.4	247.4	108.9	0.19	0.27	0.07
DIA1	71.2	126.1		0.19	0.15	
DIA2	35.3	275.7	203.9	0.12	0.24	0.14
DIAL3	-15.7	379.3		0.26	0.38	
DIAR4	-95.4	118.6	81.5	0.14	0.11	0.03
TORK1	185.4	398.4	178.2	0.21	0.68	0.13
TORK2	41.3	213.2	84.5	0.16	0.30	0.04
HEM1	-0.8	41.9	20.7	0.17	0.05	0.03
HEM2	94.8	113.0	51.5	0.17	0.11	0.07
HAY1	146.6	65.1		0.19	0.04	
HAY2	184.2	41.4		0.18	0.04	

Appendix Table 2. Predicted and actual biomass (kg/hectare), density (fish/m^2), and mean length (mm) of brown trout in Section A, West Indian Creek, fall 1990 and 1991.

	Biomass			Density			Mean Length		
	Predicted	Actual		Predicted	Actual		Predicted	Actual	
		1990	1991		1990	1991		1990	1991
Pool Number									
1	294.8	207.9	356.4	0.20	0.07	0.12	251	305	319
2	38.8	0.0	0.0	0.04	0.00	0.00	218	0	0
3	363.5	363.5	322.1	0.27	0.09	0.15	266	299	263
4	188.4	46.9	93.4	0.13	0.03	0.04	263	260	281
5	164.6	71.4	91.5	0.10	0.04	0.05	246	260	260
6	312.0	103.8	201.1	0.23	0.06	0.13	270	262	237
7	314.1	210.0	130.4	0.23	0.08	0.10	274	273	238
8	226.5	138.4	365.0	0.06	0.06	0.14	260	275	283
9	247.0	260.8	580.8	0.17	0.08	0.19	265	315	265
10	365.9	201.2	210.0	0.29	0.03	0.07	283	366	277
11	188.9	102.0	79.7	0.14	0.05	0.06	251	273	199
Riffle Number									
1	20.4	0.0	0.0	0.02	0.00	0.00	212	0	0
2	20.2	0.0	0.0	0.02	0.00	0.00	250	0	0
3	20.3	0.0	0.0	0.02	0.00	0.00	250	0	0
4	22.4	0.0	0.0	0.03	0.00	0.00	194	0	0
5	20.4	0.0	0.0	0.02	0.00	0.00	287	0	0
6	20.9	91.2	0.0	0.02	0.00	0.00	287	293	0
7	20.4	0.0	0.0	0.02	0.00	0.00	299	0	0
8	20.4	0.0	0.0	0.02	0.00	0.00	312	0	0
9	21.1	0.0	0.0	0.02	0.00	0.00	299	0	0
10	20.1	0.0	0.0	0.02	0.00	0.00	299	0	0

Appendix Table 3. Predicted and actual biomass (kg/hectare), density (fish/m^2), and mean length (mm) of brown trout in pools, 1989 and 1990. Habitat was improved before 1984. Stream abbreviations in Table 1.

Stream	Pool	Biomass			Density			Mean Length		
		Predicted	Actual		Predicted	Actual		Predicted	Actual	
			1989	1990		1989	1990		1989	1990
TR1	1	114.5	562.9		0.08	0.55		299	219	
TR1	2	198.0	370.9		0.28	0.37		285	217	
TR1	3	595.4	572.1		0.48	0.48		253	231	
TR2	1	114.5	161.3	10.4	0.09	0.15	0.01	228	212	219
TR2	2	181.2	147.6	57.5	0.25	0.16	0.05	207	201	233
TR2	3	133.2	517.6	107.7	0.15	0.41	0.09	242	227	226
TR3	1	133.2	151.1	94.8	0.11	0.23	0.09	245	190	217
TR3	2	39.2	81.4	5.6	0.24	0.19	0.02	166	162	169
TR3	3	149.2	218.9	60.5	0.28	0.30	0.13	187	197	218
TRSR1	1	169.1	523.4		0.19	0.57		263	218	
TRSR1	2	224.0	342.1		0.26	0.41		232	211	
TRSR1	3	135.7	220.8		0.14	0.32		247	198	
TRSR2	1	120.8	354.3	136.5	0.14	0.28	0.11	229	225	233
TRSR2	2	176.7	347.7	100.8	0.14	0.30	0.07	273	219	245
TRSR2	3	133.3	546.5	236.4	0.18	0.43	0.14	237	225	257
GRB1	1	124.3	119.1		0.34	0.26		161	168	
GRB1	2	38.8	9.4		0.23	0.03		167	143	
GRB1	3	151.7	342.6		0.31	0.54		209	187	
GRB1	4	41.9	78.9		0.12	0.14		202	182	
GRB2	1	38.8	233.2	74.7	0.07	0.28	0.08	213	204	196
GRB2	2	95.6	761.3	365.9	0.12	0.70	0.20	233	223	249
GRB2	3	149.4	413.6	202.6	0.25	0.48	0.13	202	206	238
DIA1	1	124.7	114.9		0.15	0.13		212	207	
DIA1	2	38.8	350.9		0.23	0.43		173	201	
DIA1	3	85.1	104.6		0.01	0.14		240	196	
DIA2	1	41.6	336.5	430.5	0.00	0.20	0.23	232	255	254
DIA2	2	38.8	97.7	437.1	0.04	0.15	0.44	221	181	247
DIA2	3	48.8	587.7	0.0	0.19	0.53	0.00	187	220	0
DIAL3	1	38.8	239.8		0.12	0.31		200	192	
DIAL3	2	141.5	509.4		0.26	0.45		198	221	
DIAL3	3	38.8	389.6		0.21	0.53		174	190	
DIAR4	1	214.4	298.5	136.7	0.19	0.25	0.05	227	224	287
DIAR4	2	38.8	18.0	0.0	-0.03	0.02	0.00	239	206	0
DIAR4	3	38.8	157.4	430.2	-0.03	0.21	0.16	240	188	288
TORK1	1	373.8	380.5	273.3	0.29	0.66	0.20	273	184	238
TORK1	2	159.8	481.9	87.2	0.36	0.83	0.07	201	184	232
TORK1	3	57.8	658.1	489.4	0.05	1.12	0.36	229	186	234
TORK2	1	69.8	172.1	0.0	0.15	0.29	0.00	207	179	0
TORK2	2	38.8	86.2	178.2	0.04	0.23	0.17	218	151	197
TORK2	3	110.4	270.6	127.8	0.17	0.34	0.06	220	199	275
HEM1	1	38.8	0.0	0.0	0.04	0.00	0.00	219		0
HEM1	2	193.0	171.9	50.5	0.34	0.17	0.06	194	222	187
HEM1	3	38.8	31.2	10.0	0.08	0.06	0.04	208	171	137
HEM2	1	38.8	6.5	3.9	0.19	0.03	0.03	179	134	114
HEM2	2	159.1	569.7	233.0	0.30	0.45	0.18	185	237	210
HEM2	3	38.8	68.9	43.5	0.19	0.12	0.12	179	183	148
HAY1	1	166.1	57.3		0.16	0.04		257	244	
HAY1	2	125.2	54.0		0.36	0.03		182	253	
HAY1	3	127.0	109.1		0.13	0.06		250	256	
HAY2	1	204.5	105.0		0.21	0.10		264	220	
HAY2	2	38.8	36.7		0.27	0.03		167	223	
HAY2	3	182.2	14.1		0.34	0.02		217	202	

Appendix Table 4. Predicted (Thorn 1988a) and actual biomass (kg/hectare), density (fish/m^2)and mean length (mm) of brown trout in pools in Hay Creek under special regulation. Habitat was improved in 1978, and a no-kill regulation was imposed in 1985.

Pool number	Biomass			Density			Mean Length		
	Predicted	Actual		Predicted	Actual		Predicted	Actual	
		1989	1990		1989	1990		1989	1990
HCSRP1	60.0	229.5	153.8	-0.01	0.17	.05	245	225	309
HCSRP2	50.3	75.8	212.4	-0.02	0.35	.05	253	236	263
HCSRP3	40.9	185.9	59.0	-0.03	0.12	.02	241	240	297
HCSRP4	38.8	64.0	35.1	-0.03	3.03	.03	250	225	231
HCSRP5	38.8	31.1	148.0	-0.03	0.08	.23	254	244	313
HCSRP6	66.8	346.3	99.2	-0.01	0.20	.04	248	239	280
HCSRP7	38.8	62.5	0.0	-0.03	0.06	.00	238	245	0
HCSRP8	149.0	409.0	176.4	0.08	0.31	.07	271	235	288
HCSRP8A	38.8	10.4	0.0	-0.03	0.05	.00	238	221	0
HCSRP9	212.0	1030.6	65.9	0.15	0.30	.04	287	235	261
HCSRP10	195.7	590.5	89.3	0.13	0.20	.04	273	230	274
HCSRP10A	151.8	1098.5		0.09	0.49		269	237	
HCSRP11	116.1	562.8		0.05	0.25		260	222	
HCSRP12	121.4	315.4		0.05	0.23		261	212	
HCSRP12A	217.9	893.1		0.15	0.35		288	223	
HCSRP13	118.9	801.7		0.04	0.48		253	232	
HCSRP14	60.5	792.7		-0.01	0.15		244	242	
HCSRP15	38.8	197.7		-0.03	0.22		242	225	
HCSRP16	291.1	1072.5		0.21	1.03		274	232	
HCSRP16A	38.8	68.4		-0.03	0.16		238	214	

Appendix Table 5. Predicted and actual biomass (kg/hectare), density (fish/m²), and mean length (mm) of brown trout in riffles, 1989 and 1990. Habitat was improved before 1984. Stream abbreviations in Table 1.

Stream	Riffle	Biomass Predicted	Biomass Actual 1989	Biomass Actual 1990	Density Predicted	Density Actual 1989	Density Actual 1990	Mean Length Predicted	Mean Length Actual 1989	Mean Length Actual 1990
TR1	1	108.3	6.1		0.08	0.01		230	178	
TR1	2	88.4	70.6		0.03	0.07		289	219	
TR1	3	111.1	25.6		0.09	0.05		226	168	
TR2	1	20.1	23.9	0.0	0.03	0.04	0.00	200	162	0
TR2	2	20.1	32.7	24.5	0.01	0.04	0.04	424	184	177
TR2	3	20.1	9.1	0.0	0.03	0.02	0.00	187	144	0
TR3	1	20.1	278.8	0.0	0.02	0.44	0.00	580	188	0
TR3	2	20.1	26.5	21.2	0.02	0.06	0.04	299	160	175
TR3	3	20.1	81.7	95.5	0.02	0.21	0.14	299	156	188
TRSR1	1	48.8	78.3		0.04	0.09		194	215	
TRSR1	2	28.6	46.3		0.03	0.07		193	195	
TRSR1	3	43.4	27.6		0.04	0.05		187	186	
TRSR2	1	20.1	12.9	9.4	0.03	0.02	0.01	193	173	235
TRSR2	2	58.4	29.2	13.4	0.03	0.04	0.01	189	191	244
TRSR2	3	354.4	0.0	0.0	0.30	0.00	0.00	189	0	0
GRB1	1	96.7	50.3		0.03	0.17		213	147	
GRB1	2	20.1	0.0		0.03	0.00		187	0	
GRB1	3	20.2	10.7		0.03	0.03		187	150	
GRB1	4	20.7	4.0		0.03	0.01		187	152	
GRB2	1	25.1	49.9	0.0	0.03	0.11	0.00	187	165	0
GRB2	2	20.1	5.2	0.0	0.03	0.02	0.00	187	130	0
GRB3	3	37.4	3.0	0.0	0.04	0.01	0.00	187	157	0
DIA1	1	20.1	0.0		0.03	0.00		187	0	
DIA1	2	38.5	14.8		0.04	0.03		187	174	
DIA1	3	43.0	0.0		0.05	0.00		187	0	
DIA2	1	20.1	0.0	0.0	0.03	0.00	0.00	187	0	0
DIA2	2	20.1	49.6	0.0	0.03	0.08	0.00	200	175	0
DIA2	3	20.1	33.7	0.0	0.03	0.07	0.00	193	167	0
DIAL3	1	20.1	0.0		0.03	0.00		189	0	
DIAL3	2	20.1	53.8		0.02	0.09		237	171	
DIAL3	3	278.2	0.0		0.19	0.00		296	0	
DIAR4	1	21.7	0.0	0.0	0.03	0.00	0.00	193	0	0
DIAR4	2	20.1	0.0	0.0	0.03	0.00	0.00	187	0	0
DIAR4	3	30.1	0.0	0.0	0.03	0.00	0.00	187	0	0
TORK1	1	20.1	0.0	0.0	0.02	0.00	0.00	212	0	0
TORK1	2	20.1	0.0	0.0	0.03	0.00	0.00	187	0	0
TORK1	3	20.1	46.5	0.0	0.03	0.05	0.00	200	215	0
TORK2	1	20.1	0.0	0.0	0.02	0.00	0.00	225	0	0
TORK2	2	20.1	0.0	0.0	0.03	0.00	0.00	200	0	0
TORK2	3	122.0	28.1	0.0	0.09	0.07	0.00	255	150	0
HEM1	1	621.5	0.0	618.0	0.42	0.00	1.12	447	0	158
HEM1	2	52.3	0.0	19.6	0.05	0.00	0.02	202	0	143
HEM1	3	38.2	0.0	0.0	0.04	0.00	0.00	193	0	0
HEM2	1	20.1	0.0	0.0	0.03	0.00	0.00	189	0	0
HEM2	2	22.2	5.0	7.2	0.03	0.01	0.01	189	151	133
HEM2	3	74.1	22.7	0.0	0.06	0.08	0.00	211	147	0
HAY1	1	44.4	86.9		0.06	0.04		250	282	
HAY1	2	20.1	0.0		0.03	0.00		200	0	
HAY1	3	20.1	0.0		0.03	0.00		187	0	
HAY2	1	25.8	22.6		0.02	0.04		206	177	
HAY2	2	106.7	0.0		0.08	0.00		239	0	
HAY2	3	20.1	0.0		0.03	0.00		187	0	

Appendix Table 6. Predicted (Thorn 1988a) and actual biomass (kg/hectare), density (fish/m^2), and mean length (mm) of brown trout in riffles in Hay Creek under special regulations.

Riffle number	Biomass Predicted	Biomass Actual 1989	Biomass Actual 1990	Density Predicted	Density Actual 1989	Density Actual 1990	Mean Length Predicted	Mean Length Actual 1989	Mean Length Actual 1990
HCSRR1	20.1	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR2	22.4	1203.8	0.0	0.03	0.87	0.0	188	236	0
HCSRR3	20.1	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR4	20.2	254.5	0.0	0.03	0.22	0.0	188	223	0
HCSRR5	20.3	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR6	20.1	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR7	20.1	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR8	20.4	26.9	0.0	0.03	0.03	0.0	188	199	0
HCSRR9	20.1	0.0	0.0	0.03	0.00	0.0	188	0	0
HCSRR9A	20.1	0.0	0.0	0.03	0.00	0.0	187	0	0
HCSRR10	20.2	0.0	0.0	0.03	0.00	0.0	187	0	0
HCSRR11	20.1	261.0		0.03	0.22		188	222	
HCSRR12	21.4	0.0		0.03	0.00		188	0	
HCSRR13	20.1	77.7		0.03	0.07		187	221	
HCSRR14	20.1	125.1		0.03	0.13		188	207	
HCSRR15	20.1	100.4		0.03	0.11		188	201	
HCSRR16	20.1	22.4		0.03	0.05		188	169	
HCSRR17	20.1	421.0		0.03	0.39		188	216	
HCSRR17A	20.1	22.9		0.03	0.02		187	212	

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