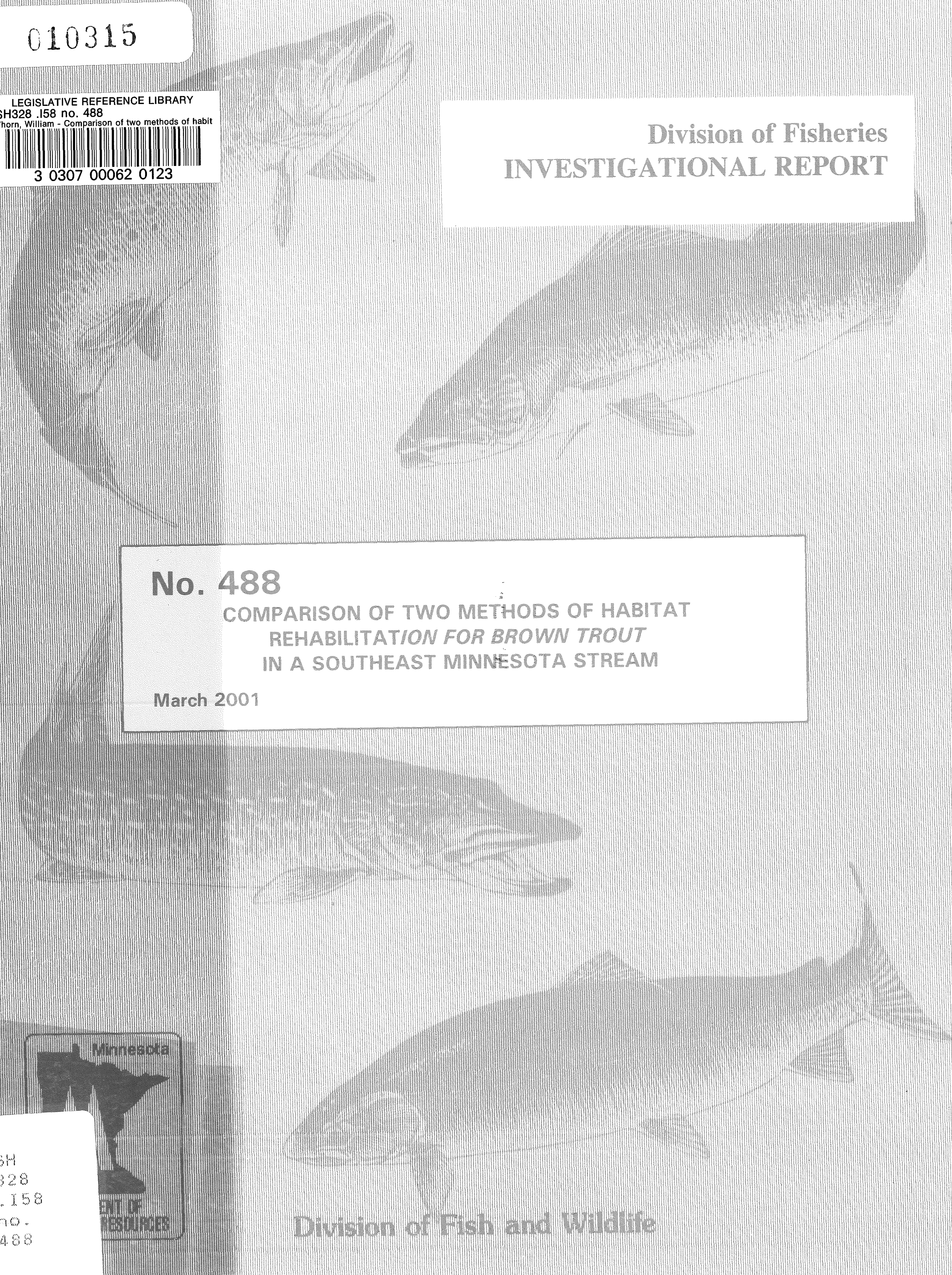

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COMPARISON OF TWO METHODS OF HABITAT REHABILITATION FOR BROWN TROUT IN A SOUTHEAST MINNESOTA STREAM[1]

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Abstract–We evaluated habitat rehabilitation with overhead bank cover and woody debris for brown trout *Salmo trutta* under a no-kill regulation in two reaches of Hay Creek. In both treatment reaches and a downstream reference reach under normal fishing regulations, cover for trout increased, as did abundance and biomass of adult trout (age-1 and older). These habitat and population changes showed that the reference reach was not an independent control. Thus we used a regional database as our control. Comparisons with the regional database showed that the increases in abundance for the treatment reaches and the reference reach were due to improved habitat, and not natural fluctuations in abundance.

Habitat rehabilitation was not as successful for larger trout. Abundance of trout longer than 300 TL mm did not significantly increase in either treatment reach. An increase was suggested in the reach improved with overhead bank cover; however, a fish kill prevented a complete evaluation. A habitat model for large trout suggested the probability of finding a trout longer than 380 mm TL should have increased in both treatment reaches after habitat rehabilitation, but abundance of trout longer than 380 mm TL did not increase. The failure to increase large trout abundance and the 25% decrease in mean asymptotic length suggest that forage and foraging sites limit abundance of large trout in Hay Creek. The potential of a stream to support rapid growth of trout may be critical to the production of more large trout in southeast Minnesota streams.

The use of woody debris for habitat rehabilitation in southeast Minnesota moderately increased brown trout abundance, enhanced stream morphology in a flood-prone stream, and cost about one-third the cost of the intensive addition of cover structures. However, benefits from using woody debris were less because it produced fewer trout, will require more frequent maintenance, and has a shorter life expectancy. Benefits may be increased if more large wood is available to further increase debris cover.

Habitat rehabilitation with abundant overhead bank cover and woody debris can be designed and evaluated with predictive models. We recommend including both abundant overhead bank cover and woody debris in habitat rehabilitation projects whenever feasible.

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Introduction

Replacement of native vegetation in riparian corridors with agricultural vegetation has reduced habitat quality in southeast Minnesota streams. Before agricultural development, grasses were the dominant riparian vegetation in the oak savanna of north central United States (Lyons et al. 2000a), but trees may have been the dominant vegetation in some riparian corridors in southeast Minnesota (MNDNR 1988). Forested riparian corridors are now most common (46%), grasslands or pasture less so (31%), and 18% are cultivated (Blann 2000). Forested riparian corridors were often dominated by boxelder *Acer negundo* (Nerbonne 1999), a fast-growing and short-lived invasive species that almost completely shades the understory.

Stream ecosystem restoration in southeast Minnesota began with soil conservation practices between the 1930s and 1950s (Thorn et al. 1997). By the 1970s, erosion and flooding had decreased, adult trout cover limited abundance of naturalized brown trout *Salmo trutta* in most streams, and emphasis on habitat management changed from stream bank erosion control to adding cover structures. Biomass of brown trout was related to the length of overhead bank cover per thalweg length (L_{obc}/T) added to pools (Thorn 1992).

In forested streams, woody debris provides trout cover and forms pools and riffles, and is a principal component of habitat rehabilitation (Reeves et al. 1991, Dolloff 1994). In southeast Minnesota streams, cover from woody debris (DEB) was not abundant (average was 2.3% of pool area). Woody debris was not an important variable for describing trout abundance and biomass, but was associated with percent bank shade, a variable in several predictive models (Thorn 1988b). This woody debris provided cover for large trout in summer (Thorn and Anderson 1993) and winter (Marwitz et al. In preparation). Therefore, we recommended that DEB should provide cover to at least 5% of the pool area (Thorn et al. 1997). The use of woody debris to rehabilitate habitat in southeast Minnesota trout streams has not been evaluated.

Large brown trout are important to some southeast Minnesota trout anglers (MNDNR 1997). To increase abundance of brown trout longer than 380 mm, Thorn and Anderson (1993) recommended increasing cover to 50% L_{obc}/T, or 25% L_{obc}/T and abundant other cover variables, including DEB.

A management goal is often to achieve the maximum biomass of a stream reach, but we do not know this value for the productive southeast Minnesota streams. From the stream reach model (Thorn 1988b) and validation pool by pool (Thorn 1992), we speculate that increasing L_{obc}/T to 50% would produce a biomass of 400 kg/ha. The evaluation of adding abundant L_{obc}/T and DEB would also enable us to test the predictive models (Thorn 1988b) on stream reaches with more abundant cover than in the streams from which the models were developed.

Our objectives were to compare habitat rehabilitation using abundant overhead bank covers with rehabilitation using woody debris, to evaluate the potential maximum biomass for southeast Minnesota streams, and to further test predictive models.

Methods

Study Sites and Habitat Rehabilitation

Hay Creek is a 19.5 km spring-fed tributary to the Mississippi River. Biomass of wild brown trout ranges from less than 50 kg/ha in badly degraded reaches to more than 350 kg/ha in a previously rehabilitated reach under a no-kill regulation. Habitat was rehabilitated in 2.6 km between 1978 and 1986. Trout have not been stocked in Hay Creek since 1989.

The 4.4 km study length (12.4-16.8 km from mouth) was 0.5 km downstream from the previously rehabilitated reach, and was divided into three reaches (AB, C, and D). Habitat was rehabilitated in Reach AB (most upstream reach) and Reach C (downstream of Reach AB). Reach D (downstream of Reach C) served as an unimproved reference.

Reaches AB and C were placed under a no-kill regulation in 1991 (with barbless hooks and bait allowed since 1992) to ensure rapid and complete colonization of the enhanced habitat by brown trout. The fishing season began the Saturday nearest 15 April and ended 30 September. These two reaches were also under a special winter (1 January - 31 March) no-kill regulation, also with barbless hooks and bait allowed, starting in 1996. Reference Reach D was under standard regulations of a daily bag limit of five trout with one longer than 406 mm. In 1998, the period of September 15-30 was placed under a region-wide no-kill regulation, and in 1999, the period of 1 April through the day before the normal fishing opening day was also placed under a no-kill regulation. Barbless hooks were required and bait fishing was allowed during these two catch-and-release periods.

In Reach AB (1.58 km), the riparian corridor was used for grazing and row crops. We estimated that streambanks for more than 75% of the reach length were eroded, bank height often exceeded 2 m, streambed sedimentation was severe, and cover for trout was not abundant. Cover was present from water deeper than 60 cm (D_{60}) in 9 of 19 pools, and from DEB and D_{60} in 5 pools. No cover was present from L_{obc}/T, instream rocks (IR), and riprap (RR). Gradient was 2.4 m/km.

Habitat was rehabilitated in Reach AB during 1991-93 with structures for L_{obc}/T, and riprap for erosion control and cover. Most cover structures were "lunkers" (Vetrano 1988), but "crib" or "pole" structures were placed in several deep pools. Lunker structures, built mostly of planks, were assembled on land, and the other two kinds of structures were built in stream from logs, boards, wire, and rock. Riprap was placed on top of cover structures and on other eroded streambanks. Our design called for varying amounts of L_{obc}/T to be added to individual pools. Streambanks for 93% of the reach length, and often both sides of the stream, were sloped and seeded with grasses. Seven deflectors were added to enhance flow patterns.

The riparian corridor of Reach C (2.33 km) was forested. Boxelder, 15-25 cm diameter breast height and about 35 years old (K. Jacobson, MNDNR, personal communication), was the dominant tree. Some older and larger cottonwood *Populus deltoides* and black willow *Salix nigra* were present, mostly in the lower end of the reach. We estimated that stream banks for more than 50% of the reach were eroded, bank height seldom exceeded 2 m, and streambed sedimentation was severe. Cover for trout was present from D_{60} in 11 of 26 pools, from DEB in 1 pool, and from DEB and D_{60} in 11 pools. No cover was present from L_{obc}/T, IR, and RR. Gradient was 2.4 km/m.

In 1994, 1.66 km of woody debris were intiutively placed in Reach C to provide bank erosion control and to provide overhead cover from woody debris. Also, 1.74 km of stream bank were sloped and seeded, about 73% of the thalweg length. Seldom were both sides sloped. Trees with branches removed were placed parallel to the bank on outside bends with the largest diameter end upstream. Smaller wood was placed between the tree and the bank to provide L_{obc}/T. Trees with branches were similarly placed to provide L_{obc}/T and DEB. Branches were placed on some streambanks and within some pools to provide DEB. We used downed trees and cut standing trees in the riparian corridor, preferentially taking trees greater than 25 cm diameter. A large debris concentration spanning the creek with potential to damage private land during high water was removed. The traditional methods of riprap (46 m) and cover structures (33 m) were restricted to three pools adjacent to agricultural fields.

The riparian corridor and trout habitat in reference Reach D (0.43 km) were similar to those in Reach C, except that DEB was about twice that in Reach C because of more older and larger trees in the corridor. A spanning debris concentration that had accumulated for many years on an abandoned railroad trestle was removed to restore the channel and reduce the potential for downstream damage to private lands and bridges.

Data Collection and Analysis

To evaluate habitat rehabilitation, we measured physical habitat variables, cover, and trout abundance, biomass, and growth in the treatment and reference reaches before and after rehabilitation. We measured physical habitat variables with transects, and individually measured each cover. Because of poor accuracy and precision for identification of pools and riffles (Platts et at. 1983) and measurement error, we considered only changes greater than 10% for physical habitat and cover variables to be meaningful (Thorn 1988a). We also measured habitat suitability for large brown trout (longer than 380 mm) before and after habitat rehabilitation for each reach from the presence of the cover types for large trout (Thorn and Anderson 1993). We identified the probability of a large trout in each pool from Table 8 of Thorn and Anderson (1993), calculated an average probability for each reach before and after rehabilitation, and compared the average probability before and after rehabilitation with a *t* test.

In each study reach, trout abundance and biomass were estimated from electrofishing and the adjusted Chapman mark and recapture method (Ricker 1975) in spring prior to the fishing season in pretreatment and posttreatment years, and in fall near the end of the fishing season during the posttreatment years. Our pretreatment trout population data was collected for Reach AB during 1991-1993, and for Reach C during 1991-1994. Post-treatment data was collected for Reach AB during 1994-1997 and 1999, and for Reach C during 1995-1999. Because of a fish kill in Reach AB in July 1997, we did not use fall 1997 and spring 1998 data. We also estimated abundance of age-0 trout in fall, identified from a length-frequency distribution. In 1992, we collected scales to determine rates of growth and mean asymptotic length (Ricker 1975) on all study reaches. At the end of the study, we collected scales in Reaches C and D to determine changes in growth. We could not evaluate growth changes in Reach AB because of the fish kill. The regional data base of trout abundance and biomass (MNDNR, unpublished data) was a second reference. We followed the methods of Solazzi et al. (2000) to evaluate changes in trout abundance and biomass. For each population parameter, we calculated the ratio of the treatment to reference for each year, logarithmically transformed the ratios to equalize variances, estimated mean ratios for pretreatment and posttreatment periods, and compared means with a *t* test. For both treatment reaches, the null hypothesis was that the mean ratio after treatment was not greater than the mean ratio before treatment. For Reach AB, where we expected the habitat rehabilitation to increase brown trout abundance, we used a one-tailed test, and for Reach C, where effects of using woody debris were unknown, we used a two-tailed test.

We tested the applicability of the stream reach models (Thorn 1988b) for predicting abundance and biomass in the treatment reaches with L_{obc}/T and DEB more abundant than in the streams from which the models were developed. If the measured mean fell inside of the 95% confidence limits of the predicted value, the measured and mean values were not different (Thorn 1992). We used the mean of the last two years of evaluation as the measured value because of increasing abundance and the fish kill. We tested the applicability of the pool models (Thorn 1988b) for predicting abundance and biomass by examining the correlation of predicted and measured trout abundance values for each pool. Trout abundance was estimated by depletion (Platts et al. 1983) in each pool of Reaches AB and C in the last year of evaluation.

Results

Habitat Changes

Habitat rehabilitation improved three cover variables and three habitat variables in Reach AB, and three cover variables in Reach C (Table 1). In Reach AB, D_{60} increased 154%, L_{obc}/T increased from 0% to 48.8%, the mean estimate of probability of finding a large brown trout increased 500%, depth increased 44%, surface area decreased 16%, and width decreased 21%. In Reach C, DEB increased to 3.6%, L_{obc}/T increased from 0% to 18.1%, and the mean probability of finding a large brown trout increased 333%. We attribute the decrease in surface area in Reach C to measurement error for the stream length. We estimated that bank erosion decreased in Reach AB from more than 75% of the stream length to less than 5%, and in Reach C from more than 50% to less than 25%. Cover from riprap and instream rocks increased

Table 1. Changes in stream morphology and cover in study reaches of Hay Creek. Habitat was improved in Reach AB by intensive addition of cover structures and in Reach C by addition of woody debris. Reach D was the reference reach. Data from 1992 was collected before improvements, and data in 1995 and 1998 after improvements. An * denotes change >10% since 1992, and ** denotes P <0.01.

Reach	Year	Length	Surface area[a]	Mean surface width[b]	Mean depth[b]	Pool area	D60[c]	DEB[d]	L_{OBC}/T[e]	IR[f]	RR[g]	P[i]
AB	1992	1.58 km	0.94 ha	5.6 m	0.27 m	92.4%	13.8%	0.4%	0.0%	0.0%	0.0%	0.071
AB	1995	1.64 km	0.78 ha*	4.6 m*	0.40 m*	92.4%	33.6%*	trace[h]	47.8%*	trace[h]	trace[h]	
AB	1999	1.65 km	0.79 ha*	4.4 m*	0.39 m	90.0%	35.0%*	trace[h]	48.8%*	trace[h]	0.3%	0.426**
C	1992	2.33 km	1.76 ha	6.1 m	0.34 m	88.4%	15.4%	0.4%	0.0%	0.0%	0.0%	0.119
C	1998	2.51 km	1.56 ha*	6.2 m	0.37 m	81.1%	15.1%	3.6%*	18.1%*	trace[h]	trace[h]	0.515**
D	1992	0.43 km	0.29 ha	6.7 m	0.32 m	83.5%	16.5%	0.8%	0.0%	0.0%	0.0%	0.286
D	1995	0.45 km	0.30 ha	6.8 m	0.30 m	84.6%	19.5%	1.6%	0.0%	0.0%	0.0%	
D	1998	0.46 km	0.35 ha*	7.8 m*	0.35 m	83.5%	23.8%*	7.3%*	0.0%	trace[h]	0.0%	0.246

[a]Sum of individual pools and riffles
[b]Calculated according to MNDNR 1978
[c]Percent of pool area deeper than 60 cm
[d]Percent of pool area with cover from debris
[e]Percent of thalweg length with overhead bank cover
[f]Percent of pool area with cover from instream rocks
[g]Percent of pool area with cover from riprap
[h]Trace, < 0.1%
[i]Mean probability of finding a large trout in a pool

from not present to trace amounts in both treatment reaches.

Changes in number of pools and pool length were greater in Reach C than in Reach AB. The number of pools increased from 19 to 22 in Reach AB, and from 27 to 43 in Reach C. After habitat rehabilitation, the mean pool length was much closer to the length expected when riffles occur every 5-7 stream widths (Leopold 1994) in Reach C than in Reach AB. Before habitat rehabilitation, average pool lengths were 79 m in Reach AB and 77 m in Reach C, and after rehabilitation, average pool lengths were 67 m and 46 m, respectively. The expected average pool lengths were 25-35 m for Reach AB and 30-42 m for Reach C.

In reference Reach D, abundance of two cover and two habitat variables improved (Table 1), and the number of pools increased from six to nine. Cover from DEB and D_{60} increased 813% and 44%, respectively, and surface area and width increased 21% and 16%, respectively. Most of these changes occurred after LWD spanned the stream and collected additional debris, thereby increasing cover and depth. It is important to note that about 25% of the woody debris in Reach D had been added to Reach C, but had moved downstream during high water events. The mean probability of finding a large brown trout before and after rehabilitation did not change (P >0.05).

Trout Population Changes

Abundance and biomass in Reach AB increased until a fish kill in July 1997 (Table 2). The fish kill reduced fall 1997 biomass to less than 10 kg/ha, but the kill did not extend downstream beyond Reach AB. After sampling in spring 1998, we transferred 390 wild brown trout from a no-kill reach 2 km upstream into Reach AB to hasten recovery. Biomass in fall 1998-1999 equaled or exceeded pre-fish kill fall biomass, but abundance of larger trout did not return to pre-fish kill abundance by the end of the study.

After habitat rehabilitation, spring biomass (Table 2) of brown trout significantly increased in the treatment reaches and reference reach relative to biomass in the regional database (t -tests, P <0.01). Mean biomass increased in Reach AB by 757% in the posttreatment period compared with the pretreatment period, whereas biomass increased by 40% in the regional database (excluding the year influenced by a fish kill in AB, as noted in Methods). Mean biomass increased in Reach C by 289% compared to 32% in the regional database. Mean biomass did not increase in the treatment reaches relative to reference Reach D (P >0.05). The time frames of the comparisons differ for the treatments, as noted in Methods. In reference Reach D, mean biomass increased by 601% during the evaluation of Reach AB, and 282% during the evaluation of Reach C.

Trout abundance in each reach of Hay Creek (Table 2) also significantly increased relative to abundance in the regional database after habitat rehabilitation (P <0.01). Mean abundance increased in Reach AB by 641% in the posttreatment period compared with the pretreatment period, and in the regional database by 77%. Mean abundance increased in Reach C by 622% compared to 28% in the regional database. Mean abundance did not increase in the treatment reaches relative to reference Reach D (P >0.05). In reference Reach D, mean abundance increased 1,031.% during the evaluation of Reach AB, and 476% during the evaluation of Reach C.

Mean abundance of brown trout longer than 300 mm (Table 2) did not increase in the treatment reaches after habitat rehabilitation relative to abundance in the regional database (P >0.05). However, an increase in Reach AB is suggested because abundance was increasing after rehabilitation until the fish kill, and mean abundance after rehabilitation (101/km) was much greater than in other reaches of Hay Creek and in the regional database. In reference Reach D, mean abundance of brown trout longer than 300 mm increased 640% compared to 88% in the regional database (over the same years used to evaluate reach AB; P <0.05).

Mean abundance of brown trout longer than 380 mm (Table 2) did not increase in the treatment reaches after habitat rehabilitation relative to abundance in the regional database (P >0.05). Mean abundance decreased 83% in reference Reach D and increased 80% in the

Table 2. Abundance and biomass of brown trout in Hay Creek and the regional data base, 1991-1999.

	Adult biomass (kg/ha)		Abundance (#/km) Total adults		> 300mm		Age-0	≥ 380mm	
	Spring	Fall	Spring	Fall	Spring	Fall	Fall	Spring	Fall
				Reach AB[a]					
1991	10.6		25		11			1[d]	
1992	15.7		84		18			6	
1993	59.0		377		66			6[d]	
1994[b]	106.9		322		78			8[d]	
1995[b]	168.4	229.5	1245	572	53	80	367	4[d]	13
1996[b]	161.4	155.5	782	391	105	116	2857	12	7
1997[b]	498.3	7.2[c]	2241	42[c]	198	9[c]	299[c]	8	0[c]
1998[b]	91.6	224.3	618	751	17[d]	126	956	1[c,d]	3[d]
1999[b]	281.7	291.0[e]	1411	978[e]	72	75[e]		9	5[e]
				Reach C[a]					
1991	23.0		67		24			1[d]	
1992	29.6		167		19			3[d]	
1993	36.9		279		18			3[d]	
1994	52.2		302		43			3	
1995[b]	80.5	108.0	900	469	59	73	906	5	4
1996[b]	117.0	90.7	998	409	57	29	1353	6[d]	2[d]
1997[b]	108.5	88.7	1552	498	42	41	2355	4	4
1998[b]	155.5	110.9	1650	750	23	24	512	1[d]	4[d]
1999[b]	225.4		2268		16			1[d]	
				Reach D					
1991	13.8		93		9[d]			0	
1992	24.0		98		5[d]			5[d]	
1993	30.4		181		1[d]			2[d]	
1994	116.4		807		16[d]			0	
1995	139.0	57.0	1072	311	21[d]	20[d]	1144	0	2[d]
1996	134.4	79.7	1171	309	38	5[d]	582	2[d]	0
1997	175.7	106.7	1413	493	76	44	2656	0	2[d]
1998	203.7	179.5	2283	1180	33	26[d]	1578	0	0
1999	230.4		2552		40			0	
				Regional Averages					
1991	55		243		29		2193	2	
1992	86		758		24		1168	4	
1993	124		1016		19		509	3	
1994	112		726		34		784	5	
1995	130		872		48		853	4	
1996	97		569		42		703	4	
1997	113		709		45		792	4	
1998	117		864		47		1121	6	
1999	165		1385		53		1110	10	

[a] Under no-kill regulation since 1991
[b] After habitat improvements
[c] Due to summer fish kill
[d] Estimate is sum of unmarked trout in marking and recapture samples because of <3-4 recaptures
[e] Pool data only

regional database (P <0.05) during the evaluation of Reach AB, and did not change (P >0.05) during the evaluation of Reach C.

Growth of trout in Reach C decreased after habitat rehabilitation (Table 3). Growth increments for ages 1-4 in 1998 were less than in 1992 (P <0.05). In reference Reach D, growth increments decreased significantly only for age 4 (P <0.05). The estimated asymptotic length decreased about 25% in Reaches C and D. We could not evaluate growth of trout in Reach AB because of the fish kill.

Costs

The initial cost and life expectancy of habitat rehabilitation were greater in Reach AB than in Reach C, and the annual cost was less in Reach AB. Habitat rehabilitation cost $92,215/km in Reach AB and $23,015/km in Reach C. Thorn (1988a) projected a life expectancy for cover structures and riprap in another reach of Hay Creek to be 25 years. Because maintenance over 22 years was only $260 and the work showed very little deterioration, we increased the life expectancy for Reach AB to 40 years. The life expectancy of Reach C was estimated at 10 years (J. Wagner, MNDNR, personal communication). Therefore, annual costs were $2,305/km for 40 years in Reach AB, and $2,371/km for 10 years in Reach C. Unknown maintenance costs expected every five years (J. Wagner MNDNR, personal communication) will further increase the annual cost in Reach C.

Habitat rehabilitation in Hay Creek cost more when more rock was used (Table 4), and rock costs were more for this project than for most other projects. To control bank erosion, bank sloping and seeding was the least expensive method, and riprapping was the most expensive. To increase cover for trout, structures cost about twice as much as woody debris. Costs for structures included those for wood, rock to cover structures, bank sloping and seeding, and road building. Costs for woody debris were mostly labor to cut, place, and anchor woody debris.

Model Applicability

The reach models successfully predicted biomass and density after habitat rehabilitation with abundant L_{obc}/T in Reach AB, and biomass after habitat rehabilitation with abundant DEB in Reach C (Table 5). Measured and predicted biomass in pools were correlated in Reaches AB and C after habitat rehabilitation, and measured and predicted density were correlated in Reach AB and not in Reach C (Figure 1). The negative values predicted for density in three pools of Reach AB were due to low abundance of the three model variables. Overhead bank cover was absent in all three pools, D_{60} was present (4.9%) in one pool, and per cent pool bank shade was estimated to be only 10% for this reach.

Table 3. Growth increments and maximum length in treatment Reach C and reference Reach D. Increments in 1998 noted with * or ** are significantly different (P < 0.05 or P < 0.01) from those in 1992.

Reach	Year	Growth increment (mm) 1	2	3	4	Maximum length (mm)[b]
CD[a]	1992	151.5	87.4	57.4	46.5	476
C	1998	144.3**	81.7*	46.50**	34.8*	352
D	1998	150.8	87.0	50.8	26.5*	363

[a]Data from C and D had to be combined because of low abundance in each reach.
[b]Calculated from Walford transformation.

Table 4. Comparison of costs per foot of five methods of habitat rehabilitation for southeast Minnesota streams (blank where no summary figures are available).

Method	Cost per foot[a] Hay Creek	Average	Range
Bank sloping and seeding	$2.50		
Woody debris	$10.46		
Riprap (1m), sloping, seeding	$27.50	$16.09[b]	$7.39-38.99
Riprap (1.5-2m)	$37.61		
Structures, rock, sloping, seeding	$22.11	$29.01[c]	$14.30-54.87

[a]Jim Wagner (MNDNR, personal communication)
[b]Twelve other streams, adjusted for 2001 prices
[c]Seven other streams, adjusted for 2001 prices

Table 5. Measured and predicted biomass (kg/ha) and density (#/m^2) after habitat rehabilitation in Reaches AB and C of Hay Creek. The 95% confidence limits are in parentheses. The first mean under biomass and density is from the last two posttreatment years; the second mean includes all posttreatment years.

Reach	Biomass Mean	Mean	Predicted	Density Mean	Mean	Predicted
AB	390.0[a]	243.3[b] (49.3-436.8)	383.2 (295.5-470.9)	0.381[a]	0.251[b] (0.084-0.418)	0.270 (0.081-0.421)
C	190.5[c]	137.4[d] (67.7-207.1)	245.6 (159.7-333.3)	0.315[c]	0.237[d] (0.138-0.336)	0.209 (0.067-0.407)

[a]1997, 1999
[b]1994-97, 1999
[c]1998-99
[d]1995-99

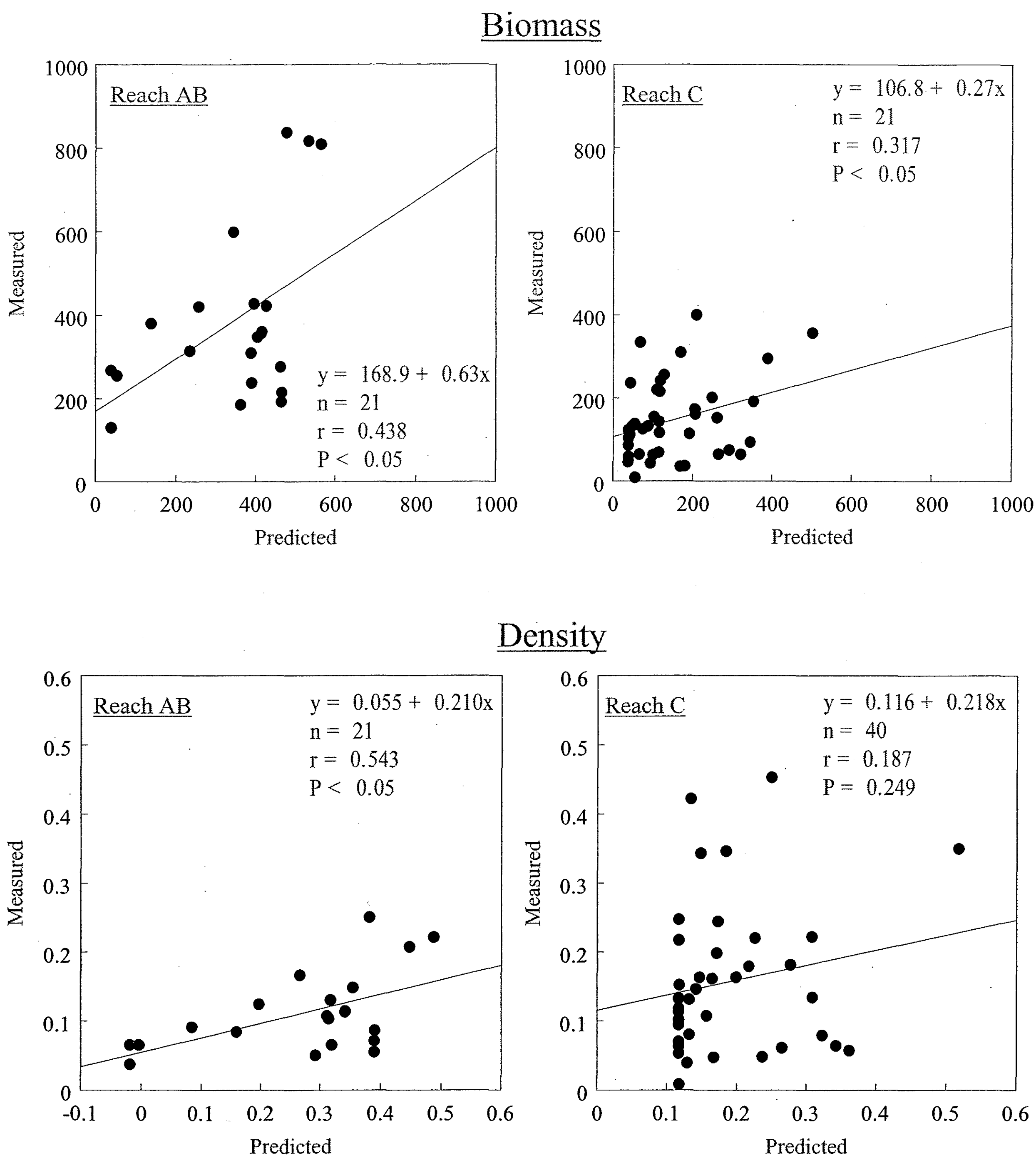

Figure 1. Relations between measured and predicted biomass (kg/ha) and between measured and predicted density of brown trout in pools within Reaches AB (1999) and C (1998) of Hay Creek.

Discussion

Our results suggest that the increased abundance of adult trout in Reaches AB, C, and D were due to habitat improvements, and that other factors (the no-kill regulation on Reaches AB and C, the fish kill in Reach AB, and any stream-wide changes in recruitment) were of minor importance. The great importance of habitat changes is supported by 1) increases in abundance in each reach relative to the regional control, 2) by greater increases in Reach AB than in C or D, and greater increases in C than in D, associated with the amount of increased cover, and 3) by correlations of observed biomass with predicted biomass in pools based on cover. A stream-wide increase in recruitment could contribute to an increase in abundance relative to the regional control, but would not explain the second and third points, nor is there any other evident reason for an increased recruitment coincident with years of habitat rehabilitation.

Although we could not measure harvest before habitat rehabilitation, it is unlikely that exploitation exceeded 50%, a value necessary for a no-kill regulation to be successful (Thorn 1990), because of the tradition of catch and release fishing on Hay Creek, and the generally high voluntary release rate of trout in the region. On Hay Creek, a no-kill regulation was imposed on 1.6 km in 1985 and on another 5.1 km in 1991. These 6.7 km opened for a no-kill winter season in 1996. Anglers voluntarily released an average of 81% (range of 57-99%) of the trout caught in 10 stream reaches in the region during 1998-1999 (Weiss 1999; 2000). Also, the increase in cover and trout abundance in Reach D under normal regulations suggests low exploitation in Hay Creek.

Our sampling showed rapid recolonization after the July 1997 fish kill. Most of the increase came from immigrants as the 390 adults we stocked in May 1998 accounted for only 32% of the estimated adults present in fall 1998. Under normal fishing regulations, colonization of enhanced habitat by brown trout ranged from one to five years (Thorn 1988a, 1992). Colonization was most rapid when there was a large year class, a stocking of wild trout, and a moderately abundant resident population (100 kg/ha) just upstream, and was slow when biomass was less than 50 kg/ha throughout the stream. Upstream from our study reach in Hay Creek, biomass exceeded 200 kg/ha. We suggest that wild brown trout can rapidly colonize habitat when biomass upstream exceeds 200 kg/ha, and the release rate of trout caught exceeds 50%.

In addition to the fish kill, a region-wide drought just before the study, followed by naturally increasing abundance, complicated our evaluation. Abundance of trout was increasing throughout the study (1991-1999) after the 1987-1989 drought reduced abundance of age-0 trout in 1989-1990, and age-1 trout in 1990-1991 (MNDNR, unpublished data). The low means and large variances of posttreatment means because of naturally increasing abundance made the comparison of measured means and predicted values after rehabilitation difficult, so we used the mean of the last two years to represent measured biomass. We concluded that measured and predicted values were similar, and that habitat rehabilitation with abundant L_{obc}/T and woody debris can be designed and evaluated with predictive models.

This study demonstrated the importance and difficulty of selecting an independent reference. We selected the downstream reference Reach D because trout biomass was similar to Reaches AB and C, and instream habitat quality was similar to Reach C. We failed to recognize that Reach D had more large trees for woody debris recruitment (K. Jacobson, MNDNR, personal communication) that would increase trout cover. Also, a more distant reference reach would have reduced the potential for trout from enhanced habitat to move into the reference reach.

For eroded stream reaches such as Reach AB, sloping and seeding stream banks with grass is appealing because of the low cost. Lyons et al. (2000a) recommended riparian corridor management for grasses to control erosion and provide trout cover from overhanging grass and undercut banks, but Lyons et al. (2000b) did not find trout abundance to be related to adjacent riparian land use in 23 southwest Wisconsin streams. In southeast Minnesota streams, we would not expect a measurable increase in brown trout abundance from just sloping and seeding stream banks. Blann (2000) found trout to be more associated with forested riparian corridors than with non-forested corridors in southeast Minnesota. Additionally, most southeast Minnesota streams were too flood-prone and too large for streambank brushing to replace trees with grass, and to produce beneficial changes in channel morphology (Thorn 1988a). In southeast Minnesota, the greatest biomass and density of brown trout were associated with bank shade, most of which was provided by woody vegetation in the riparian corridor (Thorn 1988b). Furthermore, the proportion of large brown trout (>250 mm) in Wyoming streams was negatively correlated with overhanging grasses (Larscheid and Hubert 1992), and in southeast Minnesota just 3 of the 157 large trout (MNDNR file data) sampled to study summer habitat of large trout (Thorn and Anderson 1993) were captured under overhanging grass. These three trout were captured under overhanging grass that was longer than 0.7m, and such stream reaches are extremely rare.

The high initial cost of habitat rehabilitation of degraded, agricultural stream reaches such as Reach AB, should not discourage habitat rehabilitation. The benefits that we measured (trout abundance and biomass, large trout abundance, and erosion) were greater in Reach AB with higher initial cost, greater longevity, and less maintenance than in Reach C. Cederholm et al. (1997) also found greater benefits from the method with the greatest initial cost because of greater longevity and less maintenance.

Our results suggest that energetically profitable feeding positions and insufficient forage limit large trout abundance in Hay Creek. Cover should not have limited abundance after habitat rehabilitation because our measure of physical habitat suitability for large trout increased. This suitability estimator does not include a measure of forage availability, however, and would be expected to fail if forage is limiting. Abundance of large trout did not change. A shortage of foraging sites would have caused larger trout to move to find habitat for themselves and their preferred prey (Behnke 1987). The native sculpins *Cottus spp.* are absent from Hay Creek, and the alternative prey, white sucker *Catostomus commersoni* and brown trout, may be only seasonally available.

Although habitat rehabilitation with woody debris should increase habitat for macroinvertebrates, energetically profitable feeding positions, and overall stream productivity (Roni and Quinn 2001; Sundbaum and Näslund 1998), Sundbaum and Näslund (1998) concluded that woody debris had a positive effect on density but not growth. It is possible that with increasing density, competition for food or forage sites prevents an increase in growth. In Hay Creek, growth of brown trout decreased in Reach C, and we suggest that a lack of energetically profitable feeding positions or forage species was the cause of the decrease in growth. In a reach of Hay Creek that was similar to Reach AB, rehabilitated with structures and riprap, and under a no-kill regulation, mean biomass increased from 101 kg/ha to 345 kg/ha without a change in growth (Thorn 1990). Because we added much of the woody debris to stream banks and only increased DEB in pools to 3.6%, much of the wood did not provide cover or energetically profitable feeding positions for trout. Addition of more woody debris in the channel throughout the pools may increase growth rates.

We would have preferred to add more large wood for L_{obc}/T. Much of the available wood was less than 25 cm diameter and too small for L_{obc}/T. Smaller wood provides DEB when clumped behind trees (Dolloff et al. 1994) that are longer than bankfull width and span the channel (Hilderbrand et al. 1997, 1998). Spanning jams and accumulated smaller wood increased cover in reference Reach D. However, the potential problems of bank erosion and downstream damage to private lands and bridges need to be resolved before spanning jams can be incorporated into habitat management in southeast Minnesota streams. Also, we placed the woody debris with human judgement (after Hilderbrand et al. 1998), but in future projects recommend a more engineered approach to imitate the distribution and abundance of wood in a reference stream (Cederholm et al. 1997).

Periodic maintenance is expected in Reach C to maintain 200 kg/ha of trout. Some woody debris will be lost to high water events and siltation, recruitment of wood will decrease because most large wood in the riparian corridor was used in this project, and the dominant boxelder will die and resprout before exceeding 25 cm in diameter. If the riparian corridor is to be managed for long-term recruitment of wood to the stream channel, we suggest trees that are longer-lived and grow larger than boxelder. The alternative to forested riparian management would be to add bank cover structures.

After adding woody debris to Reach C, we found a suggested increase in riffle area, a large increase in the number of pools and riffles, and a reduction in mean pool length to near the expected length. Such substantial changes for pools and riffles have not been found after habitat rehabilitation with rocks and structures. In degraded streams of southeast Minnesota, riffle area may be only 10% of the stream area (Thorn 1988a, this study), well below the 30-50% for optimal brown trout production (Raleigh 1986), and substantial changes in morphology have not been noted in streams rehabilitated with structures and rock (Thorn 1988a, 1992). Therefore, woody debris should also be included in habitat rehabilitation projects of similar streams to improve channel morphology.

We do not know if the woody debris changed stream morphology by altering flow and removing sediment to uncover gravel or from gravel recruitment. Coarse substrates can be recruited from eroded banks (Ralph et al. 1994), and in Reach C, we noted several banks that were not treated for erosion control with gravel at streambed height that could be recruited to downstream riffles during high water. The previous projects, with methods similar to those used in Reach AB, that failed to increase riffle area (Thorn 1988a, b), may have stopped erosion but eliminated the source of gravel for recruitment to riffles. Whatever the reason for changes in stream morphology, our results suggest that eliminating bank erosion may not be necessary. In Hay Creek, mean abundance of age-0 brown trout during 1995-1998 was similar in Reach AB (excluding 1997 because of the fish kill) with less than 5% bank erosion (1,383/km), Reach C with 25-50% bank erosion (1,281/km), and Reach D with more than 50% bank erosion (1,490/km).

Management Implications and Recommendations

This study further demonstrated the influence of cover for adult brown trout in the degraded streams of southeast Minnesota. It also showed the influence of riparian vegetation on instream habitat, and the importance in selecting an independent reference reach for evaluation. Hay Creek should not be managed for large trout at this time. We recommend experimental sculpin reintroductions and evaluation of potential foraging sites.

We recommend setting goals of 400 kg/ha for streams to be rehabilitated with abundant bank cover, and 200 kg/ha for streams to be rehabilitated with less intensive woody debris. In those streams rehabilitated with woody debris, wood should be placed experimentally throughout the pools to provide abundant feeding sites and changes in growth rates evaluated.

In streams where watershed conditions do not prevent brown trout reproduction, we recommend habitat rehabilitation for diversity of habitat, sizes of brown trout, and angling opportunities. For streams with forested riparian corridors, we recommend habitat rehabilitation with woody debris, and the judicious use of overhead bank cover structures, riprap and instream rocks when forage for large trout is abundant. For streams with open agricultural corridors and abundant forage for large trout, we recommend habitat rehabilitation with overhead bank cover structures and riprap, and judicious use of instream rocks and woody debris. The few streams with grassy riparian corridors could be managed for harvest of small to medium-sized brown trout, or with habitat rehabilitation similar to agricultural corridors.

In those streams, where watershed conditions limit brown trout reproduction, rehabilitation should emphasize erosion control until reproduction no longer limits trout abundance. Some of these streams that have abundant forage and cover for trout from D_{60} may be managed for large brown trout by simply increasing the presence of cover for large trout (Thorn and Anderson 1993).

In southeast Minnesota streams with brown trout reproduction, stream bank erosion control may no longer be a necessary management objective. This practice can be costly and may prevent beneficial morphological changes.

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