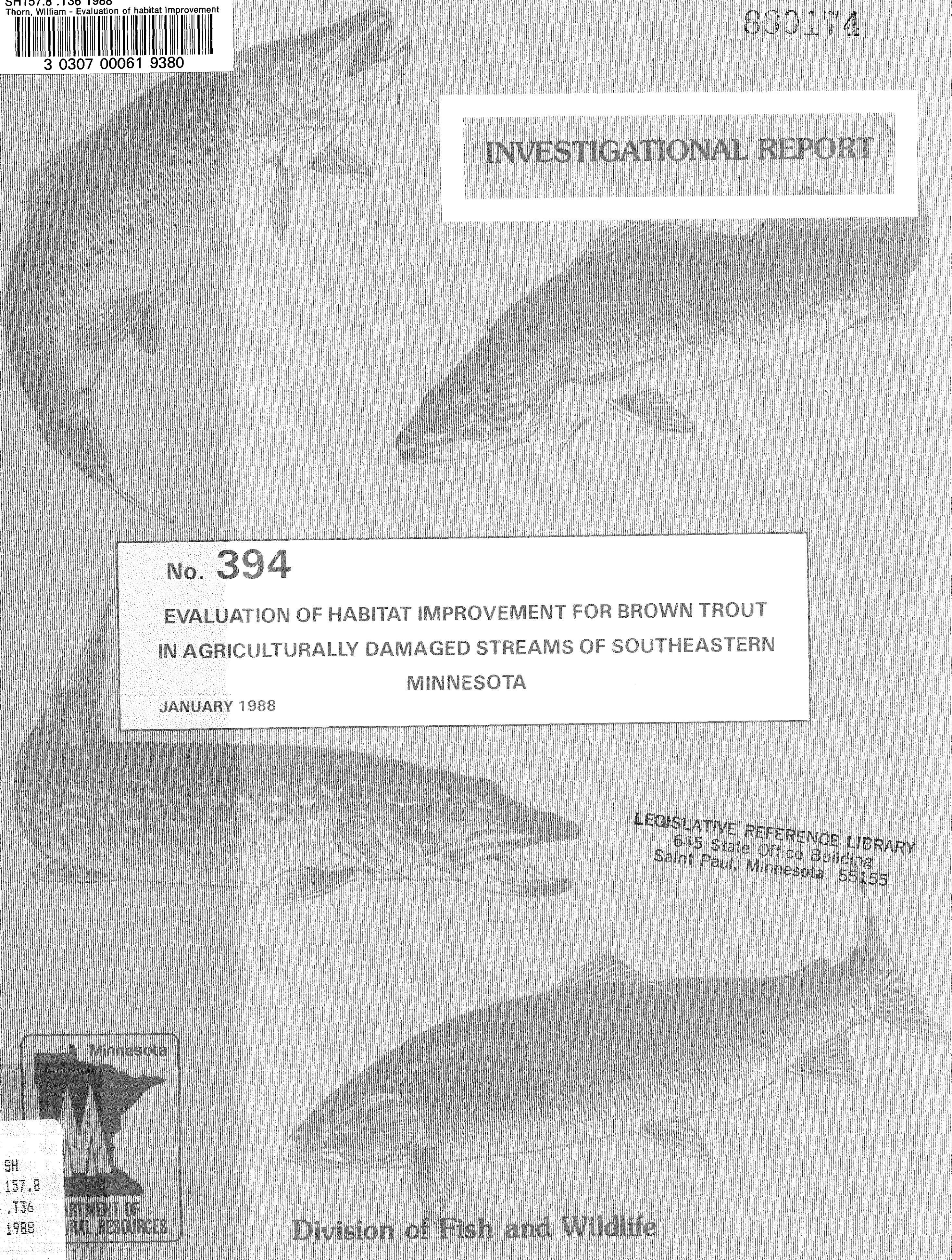

INVESTIGATIONAL REPORT

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EVALUATION OF HABITAT IMPROVEMENT FOR BROWN TROUT IN AGRICULTURALLY DAMAGED STREAMS OF SOUTHEASTERN MINNESOTA

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DEPARTMENT OF NATURAL RESOURCES

Division of Fish and Wildlife

EVALUATION OF HABITAT IMPROVEMENT FOR BROWN TROUT IN AGRICULTURALLY DAMAGED STREAMS OF SOUTHEASTERN MINNESOTA[1]

by

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ABSTRACT

Following habitat improvement to benefit wild brown trout (*Salmo trutta*) in two agriculturally degraded streams in southeastern Minnesota, trout cover increased and streambank erosion decreased, but channel morphology was virtually unchanged. Spring biomass of trout had increased from a mean of 26.7 kg/ha before habitat improvement to a maximum of 196.4 kg/ha six years after habitat improvement in Hay Creek. Spring biomass also increased for five years after improvement in West Indian Creek. The biomass increases resulted from immigration and an increase in overwinter survival. The rate of response by the trout populations to the enhanced habitat was influenced by angling pressure and harvest. The increases in pressure, harvest, and yield following habitat improvement were similar to those reported for other streams in Minnesota and Wisconsin. Benefits exceeded costs, even though not all values have been quantified. To further increase brown trout biomass and improve benefit/cost comparisons, managers in southeastern Minnesota should increase the amount of overhead bank cover, directly narrow the channel to increase sediment transport, restrict harvest temporarily after completion of the project, and evaluate the population response over several years.

INTRODUCTION

Habitat improvements have been made in brown trout (*Salmo trutta*) streams of southeastern Minnesota since 1946, but their effects on trout have not been fully documented or evaluated. Agricultural land use in southeastern Minnesota intensified flooding and erosion, thus diminishing the quality of the streams for trout and making habitat improvement difficult. An early habitat improvement (HI) project on three streams was considered unsuccessful, but no fish data were included in the report (Jarvenpa 1951). The only other Minnesota evaluation of HI was on a northern, wooded brook trout (*Salvelinus fontinalis*) stream (Hale 1969).

Habitat improvements have been made annually since 1970 with objectives of adding cover for adult trout, reducing streambank erosion, and reducing streambed sedimentation. Cover devices were added to simulate overhead bank cover (OBC), and rock riprap was added to repair eroded banks and provide cover. Overhead bank cover includes undercut banks and bank vegetation that provides trout cover all of the year. Intensive projects cost $6,000 to $19,000/km.

The HI program has increased as additional funding has become available. During 1978-81, project completion reports showed an average annual expenditure of $46,000. Since 1981 additional funding for HI has been provided by the Minnesota Trout Stamp program and the fishing license surcharge. The average annual expenditure for HI during 1982-86 was about $82,000. Costs have also increased and are projected to be $31,000/km by 1990.

Further increases in the HI program will be necessary to meet angling demands as interest in trout fishing increases. The Minnesota

Department of Natural Resources (MDNR) concluded that light fishing pressure (<63 hr/km) on streams in southeastern Minnesota was the result of lack of habitat for trout and proposed to improve an additional 48 km per year for six years (Minnesota DNR 1987). Thorn and Hawkinson (1978) concluded that increased harvest and pressure would not be desirable until HI increased the standing crop of trout. Success of stocking to increase standing crops has been limited by poor survival of stocked trout (Johnson 1983; Thorn, F-26-R project files). If HI is to be a major tool to increase angling opportunities, techniques should be evaluated.

This study evaluates trout population and habitat changes produced by HI projects on two agriculturally degraded streams in southeastern Minnesota, determines benefits and costs of HI, and recommends ways to meet the demands of increased angling pressure.

STUDY AREAS

Hay Creek and West Indian Creek are located in the driftless or unglaciated area of southeastern Minnesota (Fig. 1). Streams in the agricultural uplands have gentle gradients, but where they drain to the Mississippi River they have eroded through limestone bedrock, forming rugged valleys with hardwood covered slopes. Agricultural use of the uplands and the gradient between the uplands and valley bottom promote flash flooding. Where the aquifers are exposed in the valley bottoms, cold springs (9C) occur. Streams are productive (225 mg/l total alkalinity).

About 19.5 km of Hay Creek is managed for brown trout. Other common fish species were blacknose dace (*Rhinichthys atratulus*), white sucker (*Catostomus commersoni*), and brook stickleback (*Culea inconstans*).

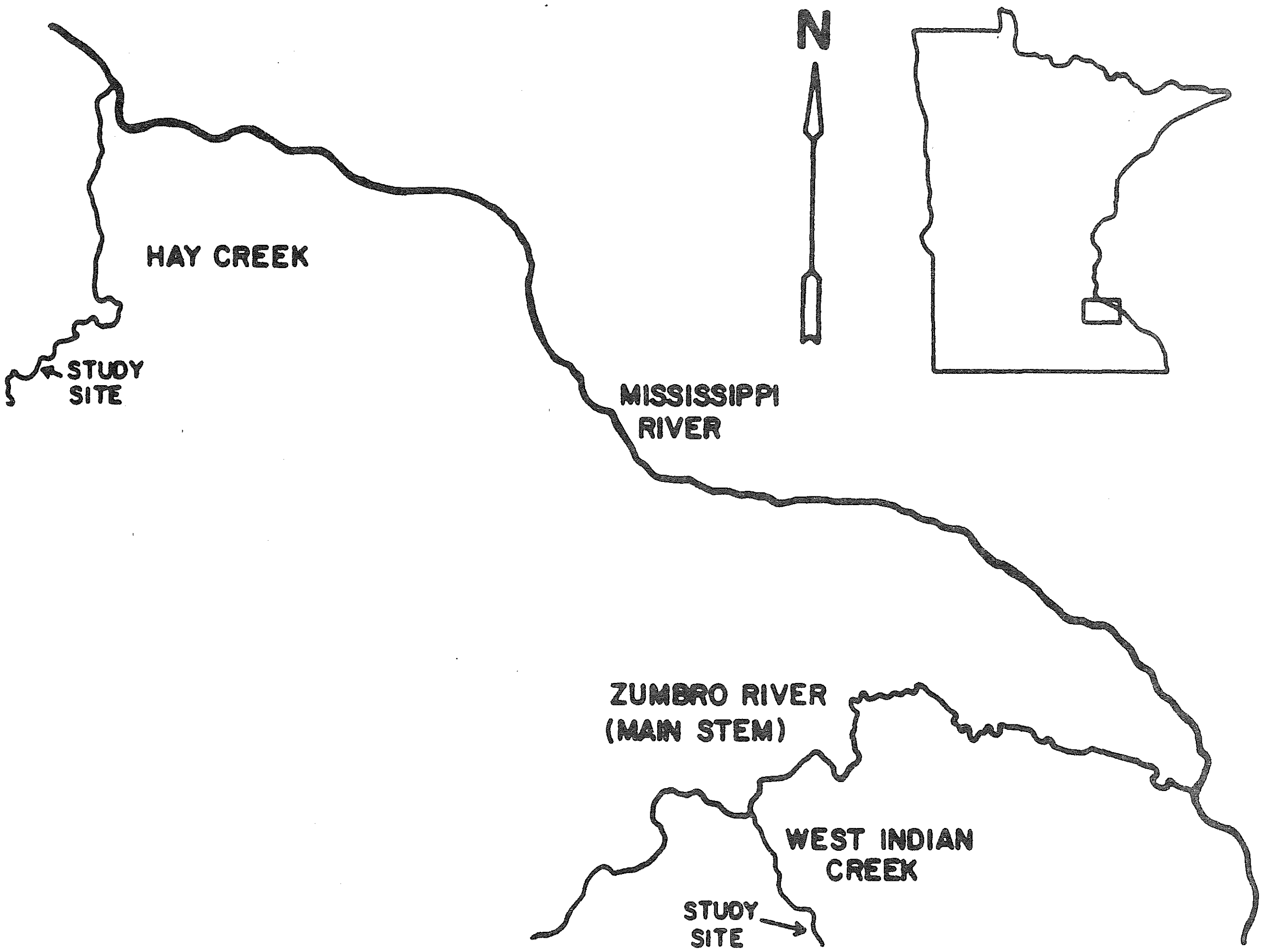

Figure 1. Location of study streams in southeast Minnesota.

Trout stocking in the study section was discontinued in 1982 because few stocked trout were caught while electrofishing. The fishery was characterized by heavy pressure (>313 hr/km) and high yields (Table 1).

On West Indian Creek, 8.9 km has been managed for wild brown trout since 1978. Brook trout were stocked during 1975-78 in the headwaters (above the study area) to re-establish the species, but only a remnant population remains. Other common species were blacknose dace, white sucker, and slimy sculpin (*Cottus cognatus*). Fishing pressure on West Indian Creek was classified as moderate (63-313 hr/km) for Division of Fish and Wildlife planning purposes, although there was no creel survey of the stream (S. Hirsch, Minn. Dept. Nat. Res., personal communication 1986).

METHODS

The habitat improvements in Hay Creek and West Indian Creek were planned and completed by Fisheries Management and are considered as representative projects on agriculturally degraded streams. Changes in the brown trout numbers and biomass, and in selected physical stream characteristics were measured to evaluate the improvements. For all analyses of changes in populations over time after HI, the P-values are from the test that regression slope coefficients were different than zero.

Trout populations were surveyed in a 0.31 km section of Hay Creek (Section A) in 1975-79 before HI and in 1980-85 after HI. Section A and an additional 0.81 km of stream were improved in 1978-79. The entire improved reach was designated Section AB to show it included Section A. Populations were described for each section in 1980-85 to illustrate before/after changes in Section A and overall responses in

Table 1. Contrasts of fishing pressure, harvest, and yield of brown trout between unimproved and improved areas on Hay Creek. Pressure, harvest, and yield increased more rapidly in Section AB after its 1979 improvement than in unimproved areas. Ninety-five percent confidence limits are in parentheses.

	Unimproved areas		Improved Section AB	
	1975[a]	1983[b]	1983[b]	1984[c]
Hrs/km	387 (346-429)	701 (624-779)	1283 (974-1590)	1054 (754-1354)
Harvest/hr	0.25 (0.15-0.35)	0.17 (0.0-0.39)	0.19 (0.05-0.33)	0.21 (0.10-0.41)
Harvest/km	93 (55-131)	134 (111-158)	253 (133-373)	242 (133-351)
Yield (kg/ha)	43.5	46.1	84.9	108.0

[a] Calculated from Thorn and Hawkinson (1978) based on 12.5 km.
[b] Calculated from Hirsch and Gates (1983) based on 18.4 km.
[c] Thorn, F-26-R, Study 221 files.

Section AB.

Land use was pasture at the Hay Creek study area. Prior to improvement, stream banks were generally nonvegetated and severely eroded. Only 8 m of OBC was present. Low quality pools provided the remaining trout cover. During 1978-79, 1.12 km of Hay Creek was improved at a cost of $25,561/km. Three instream structures were built during HI, adding 60 m of permanent OBC (an increase of 650%), and 635 m of streambank was riprapped with large (0.3-1.0 m diameter) rock. A 657 m section in the middle of the improved stream reach was fenced annually with single strand electric wire to exclude cattle during the summer. Cattle exclusion was expected to allow growth of riparian vegetation, narrowing and deepening of the stream, and development of undercut banks. Changes in the physical characteristics of the stream were monitored separately for the fenced and unfenced portions of Section AB. Population data were not collected separately for fenced and unfenced portions of Section AB.

West Indian Creek (2.67 km) was divided into four sections for evaluation: A, B, C, and D, proceeding upstream. Sections A (0.66 km) and C (0.50 km) were unimproved control sections. Habitat in treatment Section B (0.77 km) was improved in 1981 at a cost of $18,028/km. Adjacent land use of these three sections was corn tillage on one bank and woodlot on the other. The streambank adjacent to the corn field was severely eroded while that on the wooded side was moderately eroded. Low quality pools and some woody debris characterized the trout cover. In Section B, two instream structures providing 60 m of overhead bank cover were built, 590 m of riprap was installed, and banks were sloped and seeded. Also, woody vegetation within 10 m of the stream was removed (brushing) to promote narrowing and deepening of the stream and the formation of undercut banks for trout cover (Hunt 1979). Section D (0.76 km) had been a pastured woodlot, but cattle were removed in 1981 after the land was purchased for a state forest. No other HI treatment was done, but pool quality was better than in Sections A or C.

Trout population estimates were made in spring prior to the fishing season and in fall near the end of the fishing season. Trout were sampled by electrofishing, and population estimates were made by the adjusted Chapman mark and recapture method (Ricker 1975). During spring sampling, all trout were considered "adults," although age-I fish could be recognized from length frequency distributions.

Separate estimates for age-0 trout were made during fall sampling. Prior to 1975, the angling season began 1 May and ended 15 October. From 1975 to 1981, the season started 1 March and ended 30 September or the last Sunday in September. Since 1982, the season has opened the second Saturday in April and closed 30 September. Possession limits prior to 1975 were 10 fish (not more than three >406 mm). This limit was reduced to five in 1975 (not more than three >406 mm).

The number and biomass of brown trout in Hay Creek Section AB were closely related to figures for Section A after improvement (two pools in Section AB could not be sampled and were excluded from all analyses). Therefore, the following regression formulas were used to estimate the pre-improvement population in Section AB (y) from the population in Section A (x):

Spring no./km	$y = 0.785x + 146.110$	($P < 0.05$);
Fall no./km	$y = 1.005x - 11.612$	($P < 0.01$);
Spring kg/ha	$y = 0.793x + 20.780$	($P < 0.01$);
Fall kg/ha	$y = 0.869x + 2.368$	($P < 0.01$).

The trout population of West Indian Creek was sampled in four years prior to improvement (1975, 1978, 1980, and 1981) and for five years after HI (1982-86). Prior to 1980, population estimates were made for the entire 2.67 km reach of West Indian Creek, but after 1980 estimates were made separately for the four study sections.

Both streams were mapped prior to habitat alteration, three years after HI, and at the end of the study to evaluate effects of HI on channel morphology. Physical characteristics measured were: pool, riffle, and total lengths; pool, riffle, and total area; pool, riffle and average width; and pool area with water depth >46 cm. Platts et al. (1983) reported that accuracy and precision for pool and riffle identification was poor, therefore only changes of greater than 10% were considered meaningful in this study. On Hay Creek, the physical characteristics during summer were also compared before and after cattle exclusion on both the exclosure and unfenced sections. Natural stream changes prohibited statistical evaluation (paired t-test) of changes in physical characteristics on West Indian Creek and limited the analysis to 12 of the 17 original pools and 13 of the 18 original riffles for Hay Creek.

RESULTS

Brown Trout Population - Hay Creek

Effects of HI upon the adult brown trout biomass were more pronounced for spring populations than for fall populations. Spring biomass fluctuated without directional trend in Section A prior to HI (1976-79), but increased significantly over time after HI (1980-85) ($r^2 = 0.73$, $P < 0.05$) (Table 2, Fig. 2). The spring biomass increased from a mean of 26.7 kg/ha prior to HI to a mean of 114.9 kg/ha after HI ($t = -3.77$, $P < 0.01$, Table 2). Spring biomass of Section AB also increased significantly over time after HI ($r^2 = 0.68$, $P < 0.05$). The mean spring biomass increased from an estimated 42.0 kg/ha prior to HI to 118.7 kg/ha after HI and reached a maximum of 226.4 kg/ha in 1985 (Table 3). Fall biomass fluctuated without a directional trend before and after HI in Section A and after HI in Section AB (Tables 2 and 3).

Habitat improvement did not change mean numbers of age-0 trout present in the fall, but it did reduce variability of recruitment to age-I. Fall numbers of age-0 trout fluctuated without a significant trend after HI (Table 3). However, spring numbers of age-I trout

Table 2. Biomass and numbers of brown trout in Hay Creek Section A (0.31 km; 0.21 ha) before and after the 1978-79 habitat improvement. Ninety-five percent confidence limits are in parentheses.

Year	Adult kg/ha	Adults/km	YOY/km
	Before improvement		
Fall 1975	6.1 (0-14.0)	13 (3-23)	1,013 (691-1544)
Spring 1976	39.0 (29.7-48.3)	403 (201-883)	
Fall 1976	75.4 (61.7-89.1)	319 (292-352)	101 (60-114)
Spring 1977	19.1 (12.1-26.1)	77 (40-164)	
Fall 1977	30.6 (20.7-40.5)	94 (50-195)	0 (0)
Spring 1978	19.3 (10.7-28.0)	101 (60-114)	
Fall 1978	---[a]	---[a]	Low[b]
Spring 1979	29.5 (19.5-39.4)	128 (107-158)	
Fall 1979	---[a]	---[a]	Good[b]
Spring mean	26.7 (13.6-39.8)	177 (0-386)	
Fall mean	37.4 (0-108.7)	142 (0-464)	
	After improvement		
Spring 1980	86.6 (69.7-103.5)	1,034 (775-1406)	
Fall 1980	132.0 (102.7-161.3)	396 (289-560)	3 (3-10)
Spring 1981	76.6[c]	377[c]	
Fall 1981	33.4 (24.6-42.1)	114 (104-128)	215 (161-315)
Spring 1982	101.3 (70.3-132.2)	272 (161-490)	
Fall 1982	32.4 (21.9-42.8)	94 (50-198)	232 (158-349)
Spring 1983	90.3 (71.2-109.3)	950 (745-1091)	
Fall 1983	91.4 (58.9-123.9)	218 (100-393)	117 (57-255)
Spring 1984	138.0 (98.3-177.7)	279 (174-463)	
Fall 1984	67.1 (47.4-86.8)	138 (121-154)	836 (762-909)
Spring 1985	196.4 (150.0-242.7)	1,034 (785-1396)	
Spring mean	114.9 (73.6-156.2)	658 (307-10,029)	
Fall mean	71.3 (28.1-114.5)	192 (65-319)	281 (0-614)

[a] No estimate.
[b] Indicated by subsequent electrofishing.
[c] Estimated by regression of 0.31 km data on 1.12 km data 1980-85 (excluding spring 1981). Number/km = 0.881x + 51.059 and kg/ha = 0.877x + 6.901. x = 1.12 km sector estimate.

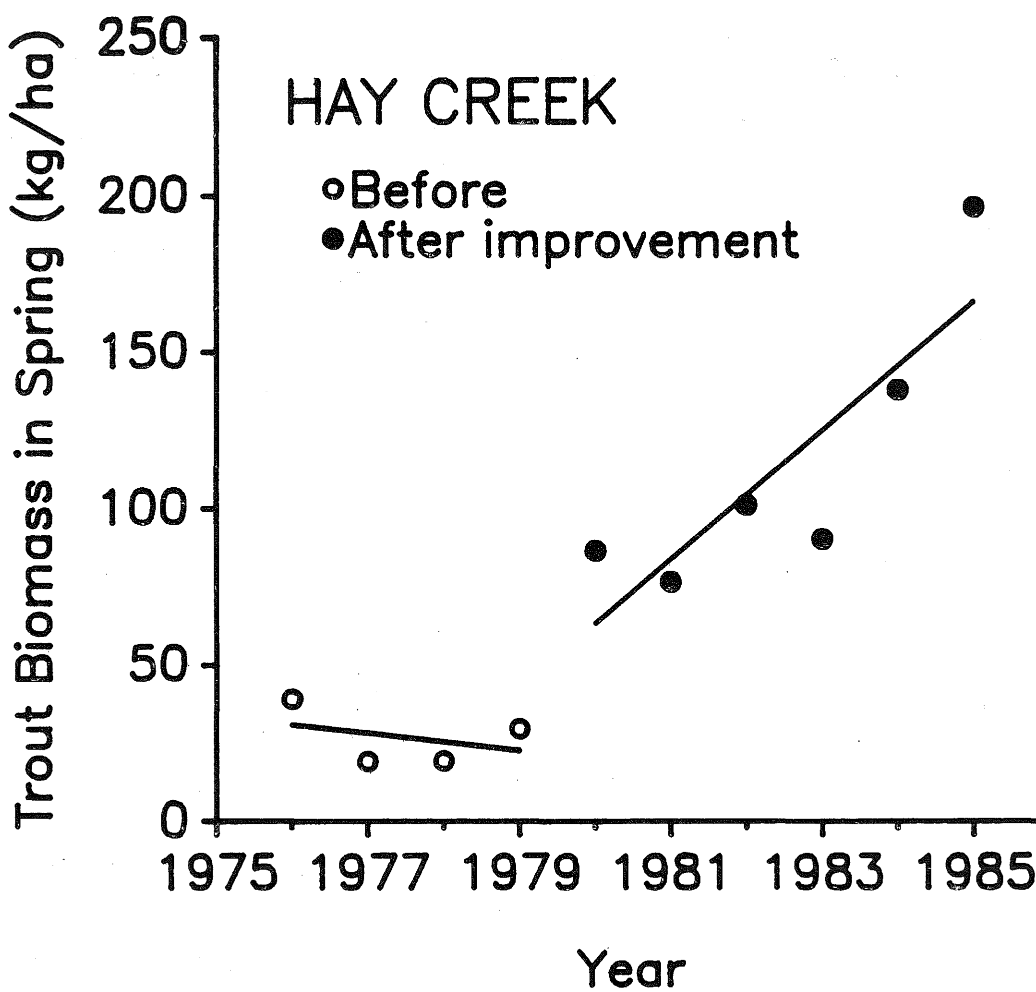

Figure 2. Spring biomass of brown trout before and after habitat improvement in Hay Creek Section A.

Table 3. Biomass and numbers of brown trout in Hay Creek Section AB (1.12 km; 0.62 ha) before and after the 1978-79 habitat improvement. Ninety-five percent confidence limits are in parentheses.

Year	Adult kg/ha	Adults/km	YOY/km
	Before improvement		
Spring 1978	35.3	126	
Spring mean[a]	42.0 (24.2-59.8)	285 (0-764)	
Fall mean[a]	34.9 (17.5-52.4)	131 (84-178)	
	After improvement		
Spring 1980	80.6 (61.3-99.8)	940 (795-1114)	
Fall 1980	144.2 (121.9-166.6)	423 (364-493)	30 (16-64)
Spring 1981	79.5 (69.1-90.0)	370 (305-482)	
Fall 1981	44.1 (36.6-51.5)	147 (111-200)	232 (181-299)
Spring 1982	104.1 (87.7-120.5)	262 (194-359)	
Fall 1982	38.7 (29.7-47.8)	93 (67-128)	363 (300-438)
Spring 1983	88.2 (75.3-101.2)	672 (582-779)	
Fall 1983	103.9 (87.0-120.9)	231 (174-315)	130 (70-267)
Spring 1984	133.1 (112.1-154.0)	300 (217-405)	
Fall 1984	62.5 (49.4-75.7)	128 (120-136)	1,035 (1009-1062)
Spring 1985	226.4 (203.0-249.7)	1,367 (1,157-1,615)	
Spring mean	118.7 (67.2-170-2)	652 (254-1050)	
Fall mean	78.7 (32.8-124.6)	204 (68-340)	358 (0-767)

[a] Estimated by regression formulas; see Methods.

in Section A increased from 40 fish/km before HI to 178 fish/km after HI ($t = -2.11$, $P < 0.10$) and the coefficient of variation declined from 106% to 61%. The strong 1975 year-class contributed to variation in numbers and biomass prior to HI (Table 2). Growth rates, as reflected by the mean length of age-I trout in spring, varied from year to year but did not change measurably in response to HI (Fig. 3).

Habitat improvement did not significantly increase total numbers of

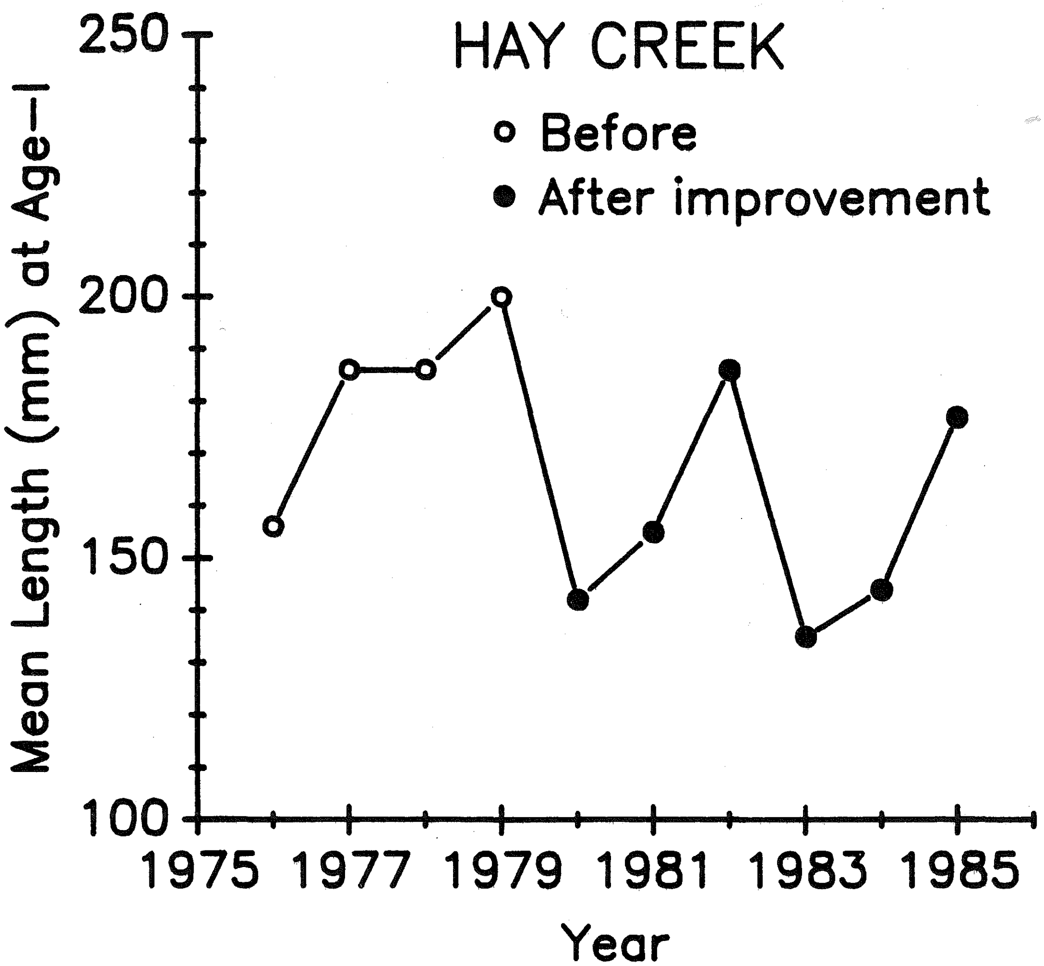

Figure 3. Mean length of yearling brown trout in spring in Hay Creek Section A.

adult brown trout. Spring and fall numbers fluctuated before and after HI without a significant trend in Section A or Section AB.

Brown trout preferred pools with overhead bank cover. The three pools with artificial OBC comprised 23% of the sampled area, but produced 30% of the adult trout taken during the spring and 47% of those taken in the fall (Table 4). A one-tailed, paired observations t-test rejected the hypothesis that there were equal numbers of trout in pools with and without OBC (spring, $P < 0.05$; fall, $P < 0.01$).

Brown Trout Population - West Indian Creek

Spring biomass increased over time after treatment in Sections B and D but fluctuated without a significant trend in control Sections A and C (Table 5, Fig. 4). Spring biomass in Section B was 13.8 kg/ha prior to HI and increased to 137.9 kg/ha after HI ($r^2 = 0.97$, $P < 0.01$). In Section D, a woodlot, trout biomass was 56.4 kg/ha before cattle were removed and increased to 153.2 kg/ha afterward ($r^2 = 0.80$, $P < 0.05$). The slight increases in spring biomass in the control sections were not statistically significant. The changes could have occurred because the controls were adjacent to the improved areas or could reflect natural habitat changes or fluctuating recruitment.

Fall biomass in Section B was 21.3 kg/ha before HI but increased after HI to 111.8 kg/ha in 1986 ($r^2 = 0.93$, $P < 0.01$). In Section D, fall biomass was 35.9 kg/ha when cattle were present, but increased to 130.6 kg/ha after cattle removal ($r^2 = 0.91$, $P < 0.05$). Fall biomass in control Section A increased from 6.0 kg/ha to 28.5 kg/ha in the first year after HI, but then decreased significantly ($r^2 = 0.94$, $P < 0.01$) during post-HI years. These changes in Section A may have resulted from fish movement away from HI activity, chance fluctuations in

Table 4. The number of brown trout in pools with artificial overhead bank cover in Hay Creek and their percent of the total number of adults. Trout were tabulated by pool during the first electrofishing run.

	Pool 9				Pool 13				Pool 16				Total			
	Spring		Fall		Spring		Fall		Spring		Fall		Spring		Fall	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1981	---[a]		7	7.4	---		18	19.1	---		12	12.8	---		37	39.4
1982	5	4.9	4	7.3	7	4.2	10	18.2	14	13.7	14	25.5	26	25.5	28	50.9
1983	74	17.1	21	17.4	34	7.8	22	18.2	33	7.6	19	15.7	141	32.5	62	51.2
1984	30	23.3	16	17.2	20	15.5	18	19.4	19	14.7	11	11.8	69	53.5	45	48.4
1985	58	11.2	---		73	14.1	---		47	9.1	---		178	34.4	---	
Mean	42	14.1	12	12.3	33	10.4	17	18.7	28	11.3	14	16.5	103	36.5	43	47.5

[a] No samples were taken.

Table 5. Biomass (kg/ha) of adult brown trout in West Indian Creek study sections, 1980-86. Habitat was improved during 1981 in Section B by bank stabilization and construction of cover devices, and in Section D by fencing out cattle. Sections A and C were unimproved. Ninety-five percent confidence limits are in parentheses.

	Section			
	A	B	C	D
Year	Control	Improved	Control	Fenced
		Before habitat improvement		
Fall 1980	9.7(3.0-16.3)	13.5(6.1-20.9)	23.7(12.1-35.3)	36.8(29.2-45.4)
Spring 1981	2.3(0-19.6)	13.8(6.2-21.4	29.3(15.3-43.3)	56.4(38.9-73.9)
Fall 1981	2.3(0-5.4)	29.1(12.3-45.9)	19.0(6.5-31.5)	34.9(0-104.4)
Fall mean	6.0	21.3	21.4	35.9
		After habitat improvement		
Spring 1982	20.2(5.5-34.8)	24.5(10.3-38.6)	11.4(1.3-21.5)	43.6(0.9-86.4)
Fall 1982	28.5(7.7-49.4)	18.5(6.2-30.7)	24.5(10.1-38.9)	28.0(0-144.7)
Spring 1983	26.7(15.1-38.4)	55.3(36.3-74.2)	19.8(10.6-29.0)	63.0(53.7-72.3)
Fall 1983	28.0(13.0-43.0)	40.5(24.9-56.1)	19.7(7.8-31.7)	64.7(41.1-88.3)
Spring 1984	35.3(20.5-50.1)	100.3(73.9-126.7)	25.6(14.7-36.6)	145.1(130.7-159.6)
Fall 1984	17.5(6.9-28.1)	53.2(39.1-67.4)	51.2(33.2-69.3)	56.7(48.2-65.1)
Spring 1985	25.8(16.9-34.7)	123.2(97.8-148.6)	109.9(68.7-151.1)	123.6(118.8-128.5)
Fall 1985	14.5(7.1-21.8)	109.0(89.2-128.8)	44.7(27.1-62.3)	105.5(28.4-182.6)
Spring 1986	35.8(21.6-49.9)	137.9(112.1-163.8)	45.5(26.4-64.5)	153.2(139.4-168.3)
Fall 1986	7.9(0-21.4)	111.8(82.2-141.3)	36.5(15.5-57.4)	130.6(50.1-211.2)
Spring mean	28.8(18.3-39.3)	48.2(0-107.9)	42.4(0-86.5)	105.7(50.7-160.7)
Fall mean	19.3(9.4-29.2)	57.0(0-112.9)	35.3(20.6-50.0)	77.1(31.8-122.4)

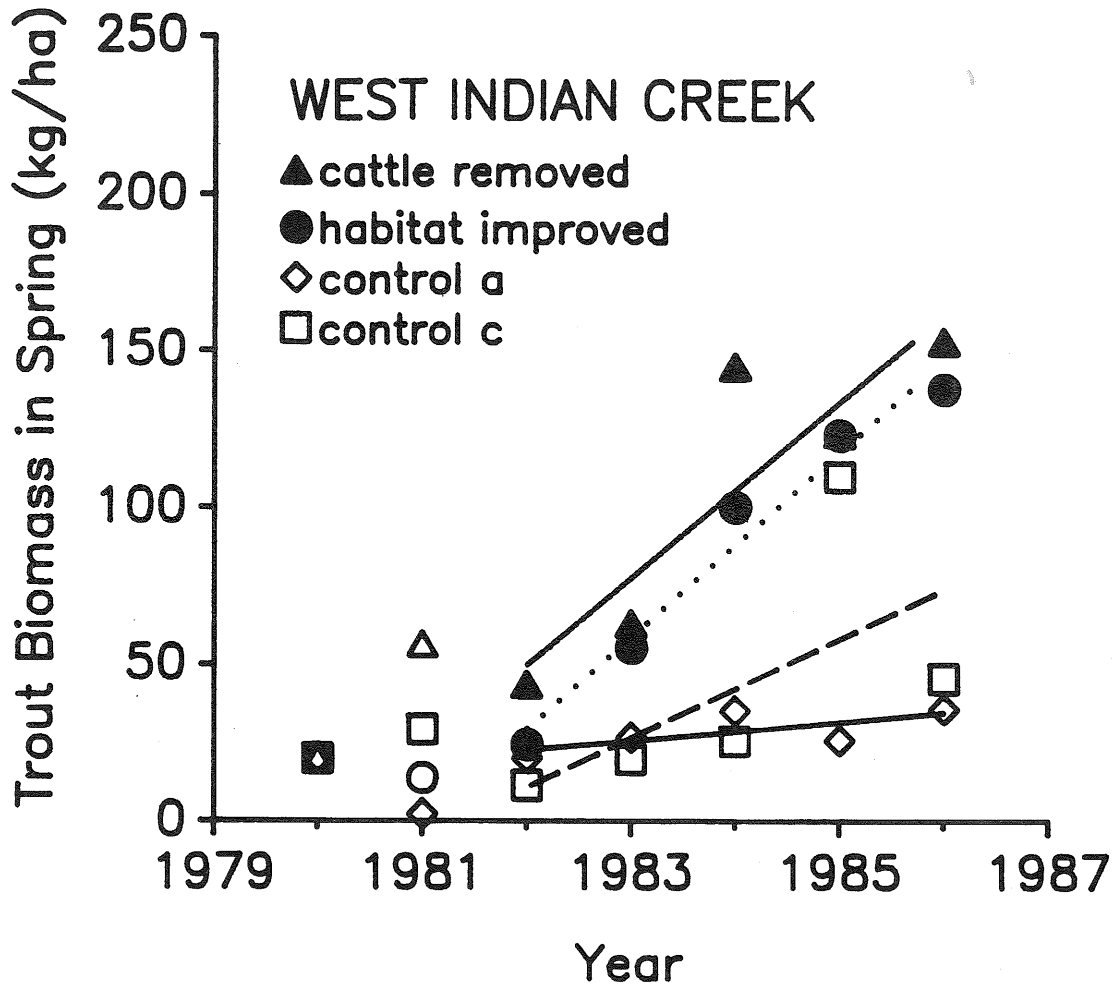

Figure 4. Spring biomass of brown trout in improved and control sections of West Indian Creek. Habitat improvements were made in 1981. Open symbols show biomass before habitat improvement.

year-classes, changes in angler activity, or temporary impoundment by beaver. In control Section C, the fall biomass increased from 21.4 kg/ha before HI to 35.3 kg/ha, but the change was not significant.

The mean number (number/km) of trout increased slightly in each of the four sections after HI. This pattern held for adults in spring and fall (Table 6) and for age-0 fish (Table 7). The consistency of these changes strongly suggests trout numbers increased in the improved sections and the adjoining controls, yet not one of the changes was significant. When spring numbers of trout older than age-I were examined separately, however, there were significant increases after improvement in Section B ($r^2 = 0.89$, $P < 0.05$) and after cattle removal in Section D ($r^2 = 0.81$, $P < 0.05$).

The distribution of adult brown trout in Section B (the only section with artificial OBC) did not indicate a preference for pools with artificial OBC in spring or fall (paired t-test, $P > 0.05$, Table 8). Two pools, comprising 23% of the pool area, produced 30% of the trout captured during the sample in spring and 26% in fall.

<u>Physical Characteristics - Hay Creek</u>

The most important physical change in the stream was the 28.7% increase in area deeper than 46 cm (Table 9). Pool width changed significantly (paired comparisons, $t = 2.640$, $P < 0.05$). Most of the changes in physical characteristics occurred within the first three years after HI. Physical changes in fenced and unfenced portions of the improved area were similar, with slight increases in riffle width and riffle area (Table 10), so summer fencing was not sufficient to further improve stream morphology.

Table 6. Numbers (number/km) of adult brown trout in West Indian Creek study sections, 1980-86. Habitat was improved during 1981 in Section B by bank stabilization and construction of cover devices, and in Section D by cattle removal. Sections A and C were unimproved. Ninety-five percent confidence limits are in parentheses.

	Section			
Year	A Control	B Improved	C Control	D Fenced
		Before habitat improvement		
Fall 1980	23 (12-48)	25 (14-47)	46 (28-84)	122 (87-178)
Spring 1981	5 (2-12)	18 (10-34)	50 (26-102)	122 (88-165)
Fall 1981	3 (0-3)	26 (10-65)	20 (8-48)	44 (27-74)
Fall mean	13	26	33	83
		After habitat improvement		
Spring 1982	39 (17-97)	55 (31-103)	32 (18-66)	100 (58-181)
Fall 1982	23 (11-53)	21 (12-43)	34 (20-64)	38 (21-74)
Spring 1983	97 (62-158)	134 (82-231)	64 (30-148)	291 (171-525)
Fall 1983	35 (20-68)	51 (32-83)	32 (14-62)	149 (91-257)
Spring 1984	127 (80-212)	227 (166-319)	68 (42-116)	421 (352-504)
Fall 1984	33 (18-67)	95 (68-136)	90 (58-150)	191 (148-245)
Spring 1985	95 (65-161)	379 (330-418)	314 (210-482)	612 (487-766)
Fall 1985	30 (15-62)	183 (142-234)	68 (38-134)	252 (194-318)
Spring 1986	79 (46-148)	195 (136-292)	76 (30-188)	327 (230-484)
Fall 1986	8 (6-18)	99 (79-153)	40 (30-90)	148 (88-268)
Spring mean	87 (51-123)	198 (64-332)	111 (0-238)	350 (142-558)
Fall mean	26 (14-38)	90 (22-158)	47 (10-84)	156 (69-243)

Physical Characteristics - West Indian Creek

The magnitude of changes in control Sections A and C were similar to those in Sections B and D, so no effects of HI on channel characteristics were recognizable against the background changes produced by flooding (Table 11). Substantial changes in physical characteristics occurred in control Sections A and C as a result of periodic flooding alone. Riffle area, pool area with depth greater than 46 cm, and riffle width changed more than 10% in all four sectors.

Table 7. Numbers (number/km) of age-0 brown trout in West Indian Creek, 1980-86. Nine-five percent confidence limits are in parentheses.

Year	Section A Control	Section B Improved	Section C Control	Section D Fenced
	Before habitat improvement			
1980	0 (0)	0 (0)	0 (0)	0 (0)
1981	14 (6-148)	47 (25-96)	58 (22-146)	152 (82-312)
Mean	7	24	29	76
	After habitat improvement			
1982	92 (62-148)	118 (83-173)	180 (124-266)	508 (382-717)
1983	83 (47-162)	151 (147-317)	90 (42-204)	893 (684-1,164)
1984	129 (83-220)	318 (243-430)	404 (304-552)	514 (438-604)
1985	79 (47-139)	32 (9-58)	36 (10-66)	123 (82-194)
1986	136 (61-339)	1,039 (692-1,632)	434 (226-916)	513 (323-855)
Mean 1982-86	84 (47-121)	332 (0-786)	229 (28-430)	510 (208-812)

Table 8. The number and percent of adult brown trout in pools with artificial overhead bank cover in Section B of West Indian Creek. Trout were tabulated by pool during the first electrofishing run.

	Pool 1				Pool 2				Total			
	Spring		Fall		Spring		Fall		Spring		Fall	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1982	1	4.3	1	9.1	4	17.4	5	45.5	5	21.7	6	54.5
1983	5	10.2	1	4.0	3	6.1	6	24.0	8	16.3	7	28.0
1984	11	19.6	1	2.0	16	28.6	7	14.0	27	48.2	8	16.0
1985	14	9.5	10	9.9	17	11.6	6	5.9	31	21.1	16	15.8
1986	14	16.3	3	7.9	25	29.1	2	5.3	39	45.3	5	13.2
Mean	9	12.0	3	6.6	13	18.5	5	18.9	22	30.5	42	25.5

Table 9. Physical changes in Hay Creek Section AB from pre-habitat improvement (1978) to post-habitat improvement (1981, 1984).

Physical characteristics	1978	1981	1984	% Change 1978-84
Number of pools	17	14	16	- 5.9
Number of riffles	18	15	17	- 5.5
Total pool length (m)	915	907	899	- 1.7
Total riffle length (m)	189	231	234	+23.8
Total length (m)	1104	1138	1133	+ 2.6
Pool area (ha)	.579	.515	.504	-13.0
Riffle area (ha)	.110	.091	.122	+10.9
Total area (ha)	.689	.607	.625	- 9.3
Pool area >46 cm (ha)	.181	.218	.233	+28.7
Pool width (m)	6.4	5.5	5.5	-14.1
Riffle width (m)	5.8	4.3	5.2	-10.3
Average stream width (m)	6.2	5.4	5.5	-11.3

Table 10. Physical changes in the fenced and unfenced portions of Hay Creek Section AB between 1981 and 1984.

Physical	Fenced			Unfenced		
characteristics	1981	1984	% change	1981	1984	% change
Pool length (m)	519	515	- 0.8	388	383	- 1.3
Riffle length (m)	138	136	- 1.5	93	98	+ 5.4
Total length (m)	657	651	- 0.9	481	482	+ 0.2
Pool area (ha)	.305	.282	- 7.5	.211	.222	+ 5.2
Riffle area (ha)	.056	.071	+26.8	.036	.049	+36.1
Total area (ha)	.361	.353	- 2.2	.247	.271	+ 9.7
Pool area >46 cm (ha)	.114	.118	+ 3.5	.103	.101	- 1.9
Pool width (m)	5.9	5.5	- 6.8	5.4	5.8	+ 7.4
Riffle width (m)	4.0	5.2	+30.0	3.8	5.6	+31.6
Stream width (m)	5.5	5.4	- 1.8	5.1	5.7	+11.8

Table 11. Changes in physical characteristics of West Indian Creek, 1980-85. In 1981, trout habitat was improved in Section B and cattle were removed from Section D.

	1980	1983	1985	% Change 1980-85	1980	1983	1985	% Change 1980-85
	A (Unimproved)				B (Improved)			
Number of pools	12	11	10	- 17.7	12	11	11	- 8.3
Number of riffles	11	10	9	- 18.2	11	10	10	- 9.1
Pool length (m)	599	523	598	- 0.2	673	642	614	- 8.8
Riffle length (m)	65	144	65	0	81	151	162	+100.0
Total length (m)	664	667	663	- 0.2	754	793	776	+ 2.9
Pool area (ha)	.372	.287	.378	+ 1.2	.372	.307	.326	- 17.5
Riffle area (ha)	.031	.080	.039	+ 25.8	.031	.067	.076	+145.2
Total area (ha)	.403	.367	.417	+ 3.5	.403	.374	.402	+ 0.3
Pool area >46 cm (ha)	.051	.061	.107	+111.8	.093	.307	.139	+ 49.5
Pool width (m)	6.2	5.5	6.5	+ 4.8	5.5	4.8	5.3	- 3.6
Riffle width (m)	4.7	5.6	6.0	+ 81.7	3.9	4.5	4.7	+ 15.4
Total width (m)	6.1	5.5	6.3	+ 3.3	5.3	4.7	5.2	- 1.2
	C (Unimproved)				D (Cattle removed)			
Number of pools	11	10	10	- 9.1	13	12	13	0.0
Number of riffles	10	9	9	- 10.0	12	12	13	+ 8.3
Pool length (m)	419	363	362	- 13.6	624	598	531	- 14.9
Riffle length (m)	77	122	98	+ 27.3	136	165	264	+ 94.1
Total length (m)	496	485	460	- 7.3	760	763	795	+ 4.6
Pool area (ha)	.229	.177	.202	- 11.8	.423	.379	.379	- 10.4
Riffle area (ha)	.028	.055	.050	+ 78.6	.054	.071	.153	+183.3
Total area (ha)	.257	.232	.252	- 1.9	.477	.450	.532	+ 12.7
Pool area >46 cm (ha)	.047	.019	.036	- 24.3	.105	.089	.168	+ 52.4
Pool width (m)	5.5	4.9	5.6	+ 1.8	6.8	6.3	7.1	+ 4.4
Riffle width (m)	3.6	4.5	5.1	+ 41.7	4.0	4.3	5.8	+ 45.0
Total width (m)	5.2	4.8	5.5	+ 5.8	6.3	5.9	6.7	+ 6.3

DISCUSSION

Brown trout populations continued to increase five years after HI on agriculturally degraded streams in southeastern Minnesota, although the physical habitat appeared to have stabilized sooner. Five years after HI, spring biomass of adult brown trout had increased about 100 kg/ha in improved and cattle removal sections in West Indian Creek (899% and 171%, respectively) and about 170 kg/ha in Hay Creek (368%). Hunt (1976) noted that a brook trout population needed five to six years to fully respond to HI. When special regulations allowed no harvest on Hay Creek in 1985-86, spring biomass continued to increase (Thorn, F-26-R Study No. 221), indicating carrying capacity had not been reached six years after HI.

The increases in trout biomass following HI were attributable to increased overwinter survival or movement into the improved areas and not to changes in growth. In the improved area of Hay Creek, spring numbers of age-I fish increased, although fall numbers of age-0 fish did not change. The same pattern was evident when older fish were considered separately. The apparent overwinter survivorship of age-0 fish in Hay creek increased from 35% before HI to 164% after HI. A value greater than 100% indicates movement of fish into enhanced habitat. The apparent overwinter survivorship of age-0 fish had a lower coefficient of variation in improved Sections B and D of West Indian Creek than in the control sections (A = 38%, B = 15%, C = 36%, D = 19%), suggesting reduced variability in survival in improved sections. Older fish had a slightly higher mean overwinter survivorship in improved Sections B and D (A = 52%, B = 105%, C = 42%, D = 64%) and a lower coefficient of variation (A = 79%, B = 25%, C = 62%, D = 30%). Increased overwinter survival or movement into the improved areas was thus indicated for all age-classes. Large fluctuations in year-classes were probably caused by floods and other abiotic conditions (Anderson 1983).

Enhanced overwinter survival was attributed to the increased cover provided by OBC, riprap, and aquatic vegetation since other changes in channel characteristics were relatively small. Prior to HI, winter cover was provided only by deep water in two or three pools in each stream and by a few meters of OBC. After HI, trout in Hay Creek were found in disproportionate numbers in pools with artificial OBC. After cattle removal from the woodlot section of West Indian Creek, overwinter survival of age-I and older fish improved and there was lower variability of recruitment to age-I. Prior to their removal, cattle physically destroyed much of the aquatic vegetation during summer, leaving little cover for small trout during winter. After permanent cattle removal, vegetation provided extensive cover for age-0 trout into the winter. Juvenile brown trout used cover especially during winter (Hartman 1963).

The increases in angling pressure, harvest, and yield after HI on Hay Creek were similar to those reported for other streams in Minnesota and Wisconsin. On the improved section of a northeastern Minnesota stream, Hale (1969) found harvest of brook trout to increase 362% as pressure increased 203%, while in the control section harvest increased 51% as pressure increased 65%. Hunt (1968, 1971) reported that pressure increased 188% during the three years after HI and that yield and harvest of brook trout increased 196% and 191%, respectively. I found increases of pressure (234%), harvest (250%), and yield (177%) on

Hay Creek after HI. Harvest increased although stocking was eliminated during this study. Over the same period, pressure increased only slightly on two unimproved trout streams in southeastern Minnesota (F-26-R files), thus the large increases in pressure on Hay Creek were a response to HI.

Angling pressure may have reduced the rate at which brown trout responded to HI in the two study streams. The spring biomass increased by 20-30 kg/ha each year after HI. Fall biomass increased in West Indian Creek where fishing pressure was moderate (roughly 63-313 hr/km) but did not increase under heavy pressure (1,169 hr/km) in Hay Creek. Exploitation rates in Hay Creek for 1983 and 1984 were 54% and 102% of the preseason population. In these years, yields were 124% and 103%, respectively, of the preseason biomass. Hunt (1985a) recommended that long-term exploitation rates should not exceed 40% of the brown trout greater than 150 mm in Wisconsin streams.

The benefits from HI in Hay Creek greatly exceeded the costs of HI. Over a 25 year projected life of the project (Hale 1969; Hunt 1971), the annual cost of the Hay Creek improvement was $1,282, of which $260 was maintenance cost (including fence maintenance, L. Gates, Minn. Dept. Nat. Res., personal communication 1986). Angler expenditures for increased angling trips (called benefits in much of the literature on HI) were $13,390, about ten times the annual costs for HI. The estimated number of trips increased by 515 between 1975 and 1983-84, and the average daily expenditure of a Minnesota angler in 1980 was $26 (U.S. Dept. Interior, Fish and Wildlife Service and U.S. Dept. Commerce, Bureau of Census 1982). Greater benefits may be realized on similar streams by temporarily restricting harvest after HI. This may allow a more rapid increase of trout biomass and a greater increase in angling trips.

The annual HI cost is commonly compared to the cost of stocking catchable trout to provide an equivalent fishery (Hale 1969; Hunt 1971). After HI, an average of 586 trout were caught; 278 were harvested and 308 were released (Hirsch and Gates 1983; Thorn, F-26-R files). Return of stocked fish to the angler on Hay Creek in 1983 was 24% (Hirsch and Gates 1983), so 2,441 trout would have to be stocked to provide a similar harvest. Survival of stocked, catchable trout after stocking is low (11.3% after 60-120 days; Johnson 1983) so they could seldom be caught more than once. The cost to produce and distribute 2,441 catchable trout would be $5,288.83 (M. Ebbers, Minn. Dept. Nat. Res., personal communication 1986), thus the annual stocking cost would be about four times the annual costs for HI. Intensive HI should not be done for a put and take fishery because survival rates are low for stocked trout and the population would not increase to a greater carrying capacity.

The wild trout fishery has additional value. In Idaho, a wild trout fishing trip was worth $20 more to anglers than a general coldwater fishing trip (mostly for stocked fish) because there were more and bigger wild fish (Sorg et al. 1984). Wild trout also survive longer and may be caught more than once. Much of the value of a wild trout fishery is intrinsic and undefined (Abrams 1984) and values can be attributed to non-users (Rockland 1985).

On streams which lack wild trout, special stocking procedures and harvest regulations may be essential for HI projects to be beneficial. If conditions appear suitable for reproduction, wild trout from an appropriate source should be introduced and temporarily protected from harvest.

HI methods used on Hay Creek and West Indian Creek did not narrow and deepen the stream to create undercut banks for brown trout cover, so addition of cover should be intensified. After HI, overhead bank cover and riprap provided cover to 10.6% of the stream area in Hay Creek and 15.4% of the area in West Indian Creek. Raleigh et al. (1986) concluded that a cover area >35% of the total stream area would provide adequate cover for adult brown trout. Cover should be placed close to the stream bottom (DeVore and White 1978). The structures in West Indian Creek which were over 40 cm above the streambed did not attract fish as well as the lower structures in Hay Creek.

Cattle removal from the stream corridor may be a very cost-effective way to improve trout populations in streams that retain adequate cover for adult trout. Cattle were removed from West Indian Creek when land was purchased for a state forest, but easements with permanent grazing restrictions or fencing could be used on similar streams. Even though summer fencing did not produce changes in the channel of Hay Creek, anglers preferred the fenced section for aesthetic values and lower turbidity.

Until more success of removal of streambank woody vegetation (brushing) is demonstrated for large and flood-prone streams, this labor intensive technique should only be used experimentally. Hunt (1979, 1985b, 1986) reported variable results from brushing and showed that floods retard beneficial changes in channel morphology. Hunt (1985b) concluded that brushing can enhance trout carrying capacity of small, heavily shaded trout streams in northern Wisconsin.

The lack of success of brushing on West Indian Creek was related to that stream's greater width and more frequent flooding. Since brushing increases water temperatures, effects of brushing on trout populations in marginal downstream waters should also be considered in planning HI.

The amount of riffle area may be limiting trout production. Raleigh et al. (1986) concluded that 30-50% of a stream should be riffle-run for optimal brown trout habitat. HI only increased riffles from 10-15% of the stream area to 20% and there was little decrease in sedimentation of pools. In many southeastern Minnesota trout streams, stream width must be reduced by one-third so the discharge at base flows will transport sediment, change channel morphology, and provide cover in deeper pools.

MANAGEMENT IMPLICATIONS

HI for brown trout in agriculturally degraded streams of southeastern Minnesota has been moderately successful. The removal of cattle through purchase of the stream corridor or easements with fencing may be a cost-effective way to improve trout populations in streams that are disturbed by cattle but retain cover for adult trout. In more severely degraded streams where intensive HI projects are needed greater success appears possible if the amount of overhead bank cover is increased and revised methods deepen pools and increase riffles. HI projects should be designed to increase transport of streambed sediment at normal flow so that pools deepen, undercut banks form, and riffle area increases. Stream bank brush removal should not be used in large or flood prone streams in attempts to change channel morphology or increase cover.

Trout populations increase for six years or more after HI. The rate of response may be influenced by angler pressure and harvest. Special regulations that temporarily restrict harvest immediately after HI may allow an immediate response of the trout population and maximize benefits.

The benefits from HI and management for wild trout will be greater than benefits of managing for stocked catchable trout. Intensive HI should not be done for a put and take fishery.

On wild trout streams, benefits from intensive HI exceeded the costs, even though several intrinsic values could not be quantified.

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