WISCONSIN DEPARTMENT OF NATURAL RESOURCES
RESEARCH REPORT 157
April 1993

Salmonid Population Trends Following Stream-Bank Debrushing and Beaver Control on a Lake Superior Tributary

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Abstract

This 13-year study (1978-91) documented long-term trends in abundance of wild resident and juvenile anadromous salmonids in a Lake Superior tributary following simultaneous stream-bank debrushing, in-channel placement of brush bundles, beaver (*Castor canadensis*) trapping, and beaver dam removal. Physical habitat conditions for salmonids improved in the 1,067-m treatment zone following application of these techniques (54% increase in mean depth and 8% decrease in mean width), but salmonid population responses included both positive and negative results from a management perspective. Densities of age-0 brown trout (*Salmo trutta*) and steelhead (anadromous rainbow trout, *Oncorhynchus mykiss*) increased from too few to estimate before treatment (1978) to averages of 1,035/km and 466/km, respectively, during the 9-year posttreatment period. Age-1 brown trout abundance increased steadily throughout most of the posttreatment evaluation but declined sharply the last year. Numbers of age-1 steelhead also improved slightly. The steelhead and some of the brown trout were anadromous presmolts; hence the stream's smolt-producing capacity was enhanced during most of the posttreatment period. However, numbers of age-2 and older brown trout declined following the treatment, presumably because of increased angler harvest. A low population of native brook trout (*Salvelinus fontinalis*) did not benefit from the treatment, nor did a newly established population of coho salmon (*Oncorhynchus kisutch*), which fluctuated considerably for reasons independent of the treatment. Despite the mixed results of this study, these techniques showed enough promise for enhancing presmolt abundances to warrant further testing, either separately or combined, on other low-gradient, anadromous salmonid streams having dense alder canopies and poor natural reproduction.

Contents

Introduction

A 1978 fisheries survey of the Little Brule River, Douglas County, indicated that the carrying capacity of this anadromous salmonid stream was not being attained because of poor salmonid recruitment, due primarily to channel damage by beaver (*Castor canadensis*) dams and a dense canopy of speckled alder (*Alnus rugosa*). During 1979-81, we carried out a project of stream-bank debrushing and beaver control to rehabilitate and enhance salmonid habitat. Changes in stream morphometry and populations of anadromous presmolts were assessed through 1991. This report presents results of this 13-year study.

The potential beneficial effects on trout populations from stream-bank debrushing have been thoroughly described by Hunt (1979) and include (1) increased growth of aquatic macrophytes for trout shelter and aquatic invertebrate production; (2) narrowing and deepening of the stream channel, which leads to increased velocity, more undercut banks, and additional exposed gravel for spawning and invertebrate production; and (3) firmer banks less susceptible to erosion and slumping.

The long-term deleterious effects of beaver impoundments on salmonid habitat in Wisconsin have long been viewed as a severe threat to salmonid populations (Knudsen 1962, Avery 1983). Beaver ponds have often been found to benefit trout populations for the initial 2-4 years after creation, indicated by increased numbers of larger trout (Salyer 1934, Hale and Jarvenpa 1950, Patterson 1951, Knudsen 1962, Hale 1966). However, considerable evidence points to a number of negative outcomes attributable to beaver impoundments as they age, including warming of water; hindered salmonid movement and spawning; silting-in of gravel areas, which reduces their capacity to produce the aquatic insect larvae used for food by trout; and poor channel characteristics (Salyer 1934, Patterson 1951, Knudsen 1962, Hale 1966, Haugstad 1970). Although no hard data exist in the primary fisheries literature to document positive salmonid population responses to control of beaver, in recent years the state of Wisconsin has made a concerted effort to reduce the number of beaver and beaver dams on trout streams.

Habitat development techniques to enhance salmonid production have not been widely used or tested on Great Lakes tributaries, although a number of techniques have been used on west coast streams (Parkinson and Slaney 1975, Finnigan et al. 1980, and Hall and Baker 1982). Unfortunately, no evaluations documenting increased smolt yields attributable to habitat development exist in the primary literature, and only a few evaluations are available that document positive responses of anadromous parr to habitat enhancement, such as boulder groupings (Ward and Slaney 1979), or habitat rehabilitation, such as gabions (House and Boehne 1985) and large woody debris placement (House and Boehne 1986). Habitat concerns about west coast streams pertain mostly to damage to riparian areas from logging and livestock grazing and are thus substantially different from those facing fisheries managers in the Great Lakes basin.

We hypothesized that riparian debrushing and beaver control techniques could be used to ameliorate unfavorable habitat conditions that restrict anadromous salmonid spawning and rearing of juveniles in sand-bottomed, low-gradient, brush-choked streams, and thereby increase smolt production. These techniques had not previously been tested on anadromous salmonid streams; if they were shown to be effective on such streams, they would have wide applicability in the Great Lakes basin. This study was also the first to document the response of a population of rainbow trout (*Oncorhynchus mykiss*, also known as steelhead) to habitat development in Wisconsin.

Description of the Study Area and Habitat Development Project

The Little Brule River (46°30′N, 91°35′W) in eastern Douglas County is a major tributary to the Bois Brule River, a renowned trout stream and canoe trail which flows north into Lake Superior. The Little Brule River originates from an unnamed spring pond and flows north into the Bois Brule River. The Little Brule River drains a well-forested watershed of approximately 21.3 km^2. Stream length is 4.5 km, and surface area is 2.4 ha. The average gradient is 3.8 m/km, estimated normal flow is 0.36 m^3/sec., average width is 5.2 m, and approximate average depth is 24 cm. The average pH is 7.3, methyl purple alkalinity is 66 ppm, and specific conductance (at 25 C) is 91 μmhos (Sather and Johannes 1973). The stream is spring-fed, with a highly stable flow regime, clear water, and a predominantly sand bottom with some scattered patches of gravel. Dominant species of instream vegetation include watercress (*Nasturtium officinale*), forget-me-nots (*Myosotis scorpioides*), duckweed (*Lemna minor*), and elodea (*Elodea canadensis). Comprehensive physical descriptions of the Bois Brule River system and information about its fisheries are given by Niemuth (1967) and Scholl et al. (1984).

The Bois Brule River and several of its larger tributaries, including the Little Brule River, sustain wild populations of resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) as well as anadromous, or lake-run, populations of brown trout and steelhead (anadromous rainbow trout). In recent years coho salmon (*O. kisutch*) and chinook salmon (*O. tshawytscha*) have successfully reproduced in the Bois Brule River system; however, juvenile coho salmon have only sporadically been found in the Little Brule River since 1973, and juvenile chinook salmon have never been found there.

The Little Brule River serves as the water source for a state-owned trout rearing station located at the stream's approximate midpoint. The study area is located downstream from the trout rearing station (Fig. 1) and is approximately 40 river km from Lake Superior via the Bois Brule River.

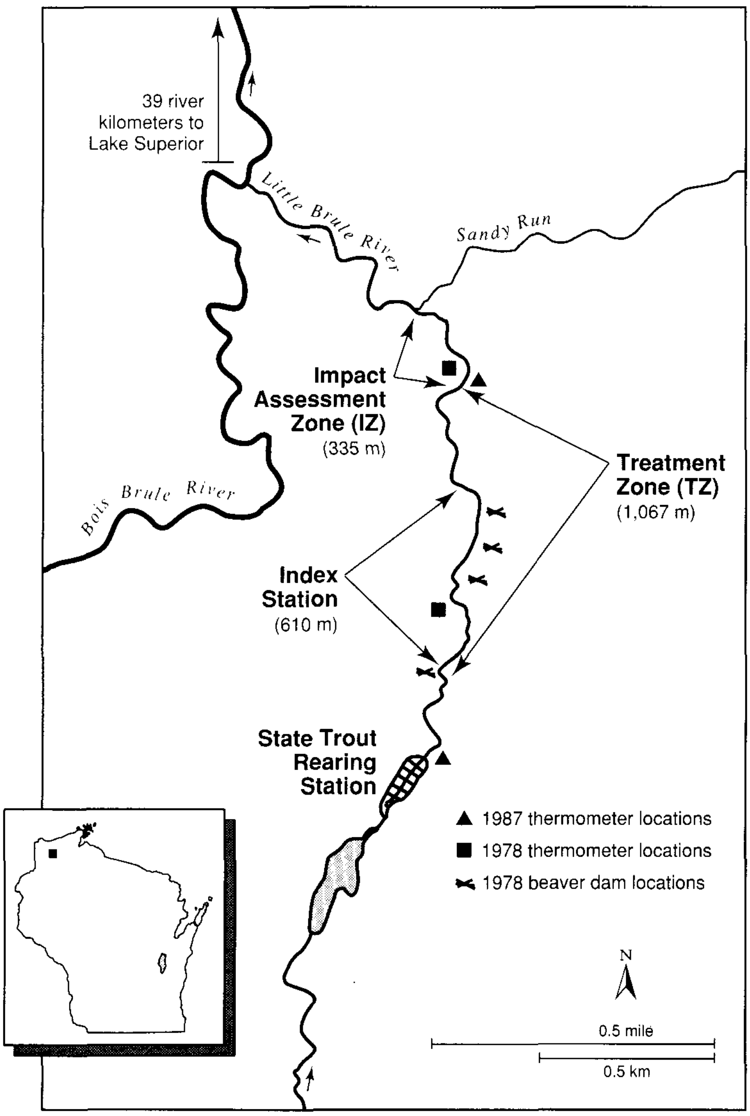

Figure 1. *Little Brule River study area.*

The study area before treatment included 4 beaver dams (1 active dam and 3 inactive ones, Fig. 1). The stream channel showed evidence of degradation from beaver activity, and the channel's excessive width, shallowness, and slumping banks were typical of a stream hampered by dense riparian alder growth. (See Hunt 1979 for a discussion of the long-term effects of dense alder growth along trout streams.) The stream appeared to be lightly fished, although no sport fishery data were collected at any time before the study. Trout are difficult for anglers to exploit in such streams because the dense alder growth hampers access. There was little evidence of successful salmonid spawning, and few young-of-the-year were present. Age-1 salmonids were present but may have migrated into this section of the Little Brule River from other areas.

In 1979 the Wisconsin Department of Natural Resources (DNR) and volunteers from the Brule River Sportsmen's Club Inc. cooperated to remove dams and woody stream-bank vegetation within 9-m wide strips along both stream banks. Brush bundles were also installed on the lower inside edges of stream bends. The cutting schedule included 610 m of brushing in 1979, 305 m in 1980, and 152 m in 1981. A DNR crew worked the following 3 summers (1980-82) recutting alder sprouts. The total habitat development cost to the DNR was about $1,200, with an additional 1,200 hours of volunteer labor. All beaver in the river reach from the trout rearing station to the river's mouth were removed in 1979 by a local trapper.

The pretreatment phase of our study began in August 1978, when the study zone boundaries were established, physical measurements of the stream channel were made, and the salmonid populations were surveyed. The posttreatment phase of the study was conducted during 1983-91. Study zone boundaries defined 3 areas (Fig. 1):

- Treatment Zone (TZ)—the 1,067-m stretch of river that received habitat development in 1979-81. The treatment zone was sampled in its entirety before treatment (1978) and after treatment (1983 and 1987).

- Index Station—a 610-m stretch within the treatment zone, from which salmonid population data were collected annually from 1983 through 1991.
- Impact Assessment Zone (IZ)—an untreated 335-m stretch of river downstream from the treatment zone, from which comparative data on salmonid populations and physical characteristics of the stream were collected. This zone was sampled in 1978, 1983, and 1987.

Methods

Determinations of midchannel length, mean width, mean depth, surface area, and channel volume were made for the TZ and the IZ during August in 1978, 1983, and 1987. Widths were recorded at 15-m intervals along the entire midchannel course. Water depth was recorded at 30-cm intervals across the channel at each width transect. Substrate composition was estimated concurrently, according to methods used by Hunt (1985). Exposed substrate types were classified as clay, silt, sand, gravel, or vegetated. Water temperatures (C) were recorded with Taylor maximum-minimum thermometers near the boundaries of the TZ (Fig. 1) irregularly during August-November 1978 and weekly during July-September 1987.

Salmonid population data were collected from the entire study zone (TZ and IZ) in 1978, 1983, and 1987. In addition, the Index Station was sampled annually in 1983-91[1]. Sampling was conducted with DC electrofishing gear, following field procedures routinely employed by the DNR Cold Water Research Group (Avery and Hunt 1981). However, in 1978 AC electrofishing gear was used; consequently, sampling efficiency was poorer in 1978 than in later years. Salmonids collected on the first run were measured[2] to the nearest 2.54 mm and given a temporary identifying fin clip (tip of a caudal lobe) before being returned to the stream at the approximate center of the stretch from which they were collected. During the second run (usually the next day) salmonids were measured and tallied by 12.7-mm group as recaptures or new captures. Representative samples were weighed to the nearest gram and scale-sampled. In 1978, hatchery rainbow trout (representing approximately 12% of the rainbow trout > 152 mm) were easily identified by fin clips done prior to stocking and were not included in the population estimates.

Salmonid population estimates were made by 12.7-mm group using the Bailey modification of the Petersen formula (Ricker 1975). Density totals (no./km) for age groups and species were derived by summing appropriate 12.7-mm group estimates. Sampling variances were calculated according to the formula $V(N) = N^2(C-R)/(C+1)(R+2)$, where V = the sampling variance, N = the estimated size of the population at the time of marking, C = the number of fish sampled during the second run, and R = the number of recaptures from the second run. Density comparisons focused on age-0, age-1, age-2+, and quality-sized ($\geq$ 254 mm) categories by species.

Age determinations were made by examination of length-frequency distributions with scale-aged subsamples (MacDonald 1987). Ages 0 and 1 were virtually discrete and easily discernible from the length frequencies.

Results

Physical Characteristics

Dramatic changes in physical characteristics of the TZ occurred by 1983. Mean depth increased by 46%, mean width decreased by 49%, and amount of gravel substrate increased by 400% (Table 1). Unexpectedly, mean width increased and percent gravel substrate decreased to near pretreatment levels by the 1987 survey. Yet mean depth continued to increase slightly from 1983 to 1987. These apparently contradictory results are explained by the posttreatment development of shallow, heavily vegetated shelves along substantial portions of both banks (Fig. 2). Sediment transport and deposition following removal of the beaver dams may have had a significant impact on channel morphometry. There was no indication of recolonization efforts by beaver in the study area at any time during the study.

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[1]During the study period, numbers of age-0 coho salmon fluctuated considerably in the Bois Brule River system because of much variation in numbers of adult spawners ascending the river. Fluctuating numbers of age-0 coho salmon in the Little Brule River study area are attributable to this annual variation in spawner numbers and are therefore unrelated to the habitat development project. Also, the inception of this project in 1978 coincided with the start of a 4-year stocking program of juvenile rainbow trout (average size 152-178 mm total length) each spring in the Little Brule River (30,000 yearly, 1978-81). These migratory fish were expected to smolt soon after stocking and migrate to Lake Superior, so they would not long compete with the wild populations.

[2]All length measurements were originally made to the nearest 0.1 inch and later converted to millimeters.

Table 1. *Physical characteristics of the treatment zone (TZ) and the impact assessment zone (IZ) (immediately downstream) on the Little Brule River before and after treatment.*

Study Phase	Date	Study Zone	Surface Area (m^2)	Mean Depth (cm)	Mean Width (m)	Channel Volume (m^3)	Composition of Exposed Substrate (%) Clay, Silt, Sand	Gravel	% Rooted Aquatic Vegetation
Pretreatment	Aug 1978	TZ	9,176	28	8.6	2,569	67	3	30
		IZ	2,010	33	6.0	663	67	3	30
Posttreatment	Aug 1983	TZ	4,684	41	4.4	1,920	48	15	37
		IZ	2,044	33	6.1	675	67	3	30
Posttreatment	Aug 1987	TZ	8,387	43	7.9	3,606	13	4	83
		IZ	2,727	43	8.1	1,173	26	1	73
% Change by 1983*		TZ	-49	+46	-49	-25	-28	+400	+23
		IZ	+2	0	+2	+2	0	0	0
% Change by 1987**		TZ	-9	+54	-8	+40	-81	+33	+177
		IZ	+36	+30	+35	+77	-61	-67	+143

*(1983 value - 1978 value) / 1978 value.
**(1987 value - 1978 value) / 1978 value.

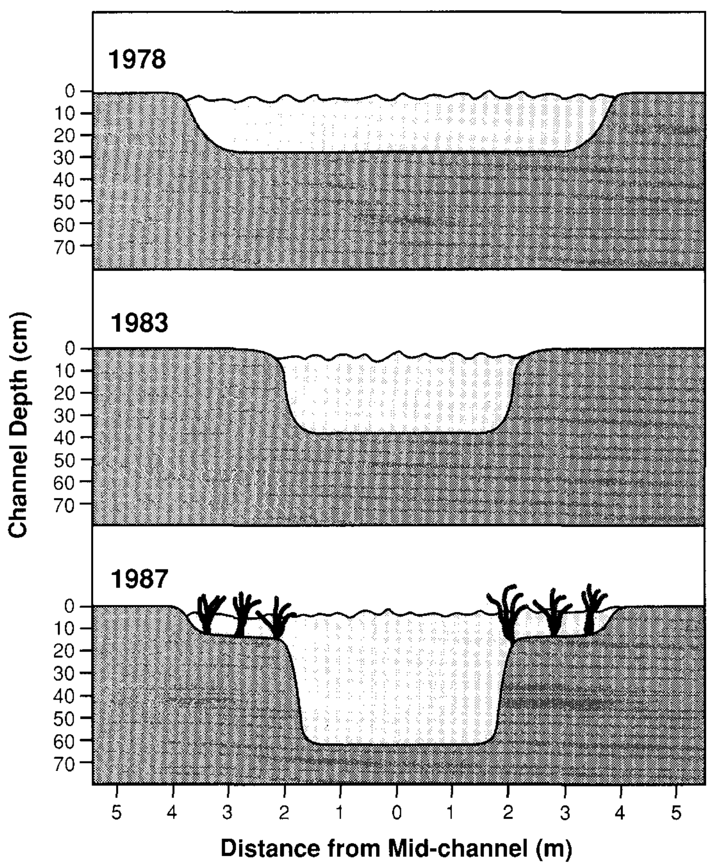


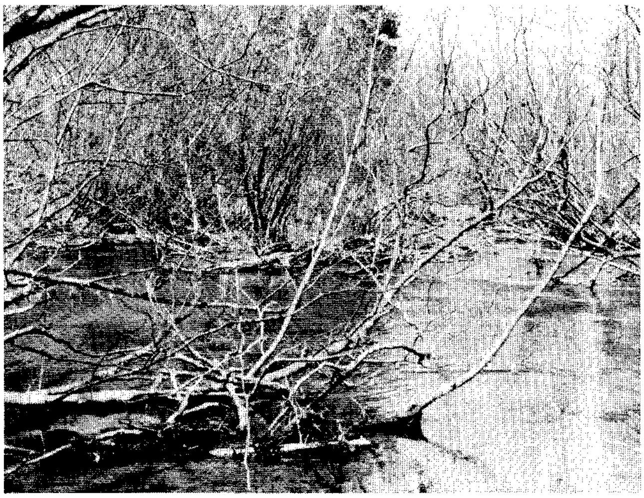
Figure 2. *Composite conceptualization of channel morphometry changes occurring in the Little Brule River treatment zone before (1978) and after (1983 and 1987) stream-bank debrushing, installation of brush bundles, and beaver control.*

Rooted aquatic macrophytes increased 23% by 1983. Beds of elodea made up most of this initial increase. Aquatic macrophytes subsequently continued to increase (177% increase from 1978 to 1987); this increase was largely a response to the development of the shallow shelves along both banks, which were heavily colonized by watercress and forget-me-nots.

Summer water temperatures were not noticeably affected by the treatment. During both 1978 and 1987, maximum summer water temperatures near the downstream end of the study zone were consistently cooler than temperatures near the upper end. Average temperature differences were 1.9 C in 1978 (N = 14) and 1.5 C in 1987 (N = 26).

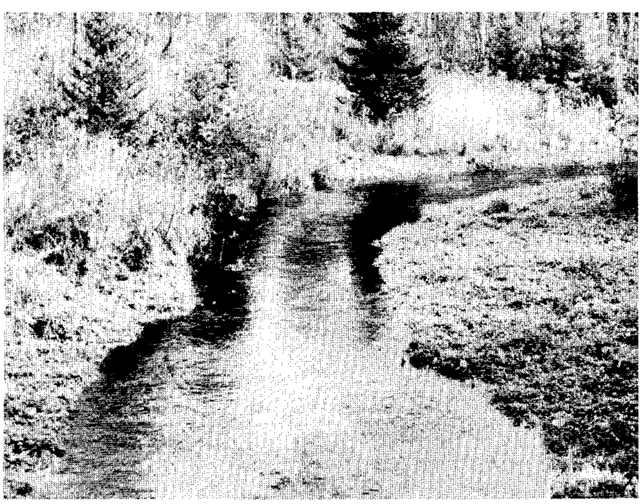
Brush bundles installed at the lower inside edges of bends functioned as expected by quickly silting in and accelerating the channel-constriction process. Undercut banks (located mostly at outside bends) appeared to become more numerous following treatment, but this increase was not quantified.

Physical characteristics in the IZ remained essentially unchanged from 1978 to 1983 (Table 1). However, substantial change occurred by 1987. Rooted aquatic vegetation increased by 143%, and exposed clay, silt, sand, and gravel decreased correspondingly. Channel volume, width, depth, and surface area increased. Thus, by 1987 many of the physical changes noted for the TZ also occurred in the IZ.



This wide, shallow, alder-choked stretch of the Little Brule River was typical of its pretreatment condition in 1978.

Several years after debrushing and beaver dam removal (1983), the river had deepened and narrowed considerably.



By 1987 shallow, shelf-like areas had developed along portions of both banks, although the main channel retained its depth. The shallow shelves were heavily colonized by watercress and forget-me-nots.

ABOVE PHOTOS: BOB DUBOIS

PHOTO: STEVE SCHRAM

Brush bundles installed along the inside bends of the Little Brule River quickly silted in, aiding the channel-constriction process.

Brown Trout

Abundance of age-0 brown trout in the index station of the TZ improved from too few to estimate in 1978 to an average of 1,035/km during the 9-year posttreatment sampling period (Table 2, Fig. 3). Numbers of age-1 brown trout in the index station declined following treatment, then increased steadily from 1983 through 1988, leveled off during 1989-90, and declined sharply in 1991 (Fig. 4). Age-2+ brown trout also declined following treatment but subsequently recovered somewhat from 1983-84 lows (Table 2). Large brown trout ($\geq$ 254 mm) declined the most severely following treatment (Table 2) and did not recover to their pretreatment level of abundance (54% reduction from the 1978 estimate to the 9-year posttreatment average).

Age-0 brown trout were much less abundant in the IZ than in the TZ in both 1983 and 1987 (Table 3). Age-1 brown trout in the IZ declined 65% from prior to treatment (1978) to 1983, then rebounded to slightly exceed the pretreatment estimate by 1987. Age-2 and older brown trout in the IZ declined 49% from pretreatment (1978) to 1983, and remained low in 1987.

Steelhead

Age-0 steelhead in the index station improved from too few to estimate in 1978 to an average of 466/km during the 9-year posttreatment sampling period (Table 2, Fig. 3). However, in 1991 age-0 steelhead were again too few to estimate, suggesting the 1978 low may have been attributable to normal annual variation in this stream. An increase in abundance of age-1 steelhead in the index station in 1983 was followed by a gradual decline to a 1991 estimate near the 1978 value (Fig. 4). Age-2+ steelhead in the index station declined following treatment in a fashion similar to age-2+ brown trout (Table 2), but this finding is reported tentatively because of small sample sizes in this category.

As with age-0 brown trout, numbers of age-0 steelhead were much lower in the IZ than in the TZ in both 1983 and 1987, and showed the same pattern of increase from 1983 to 1987 (Table 3). Age-1 steelhead abundance in the IZ more than doubled from pretreatment (1978) to 1983 and remained high in 1987.

Brook Trout

Trend evidence from the index station indicates that age-0 brook trout increased slightly following the treatment, from a 1978 pretreatment abundance that was too low to estimate, to a rather low posttreatment average of 70/km (Table 2, Fig. 3). Age-1 brook trout showed only minor fluctuations in numbers around an average slightly less than the 1978 value (Fig. 4). Low numbers of age-2+ brook trout similarly showed slight annual variations (Table 2) that did not appear to be related to the treatment. Overall, the brook trout population did not show a response to the treatment.

Numbers of brook trout of all age groups in the IZ were too low to estimate in both 1978 and 1983 (Table 3). Numbers of age-0 and age-1 brook trout in 1987 were substantially lower in the IZ than in the TZ.

Comparability of Index Station and Treatment Zone Estimates

The index station was slightly over one half the length of the TZ (610-m index station within 1,067-m TZ). Because annual index station estimates were used to represent the TZ, we compared estimates from the 2 areas for the years in which both areas were sampled. Index station estimates were within the 95% confidence limit range of the TZ estimate for the same year in 11 of the 21 possible age-group comparisons. In pooling age groups and years, index station estimates differed from TZ estimates by an average of 15%. There was no apparent directional bias to the differences; in 10 cases the index station estimates were greater than the TZ estimates, in 10 cases they were less, and they were the same in one case.

Discussion

This project appeared to benefit the younger age groups (ages 0 and 1) of brown trout and steelhead. Natural reproduction of all salmonid species was poor during the pretreatment year and was at least somewhat improved during most of the posttreatment period. On a cautionary note, however, the presence of more age-1 than age-0 salmonids in 1978 could indicate that 1978, like 1991, was simply a particularly poor year for age-0 salmonids. One year of data alone were not adequate to describe the pretreatment condition. Additionally, the use of AC electrofishing gear in 1978 made sampling age-0 fish more difficult that year than in following years, when DC gear was used. Nonetheless, the probability that the treatment provided at least some benefit to the age-0 year classes cannot be discounted. Age-1 brown trout showed substantial gains during most of the

Table 2. *Salmonid density estimates (95% confidence limits in parentheses) before (1978) and after (1983-91) habitat alteration in the 610-m Little Brule River treatment zone index station.*

	Estimated Density (no./km)										
Age Group	**1978**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**Post-treatment Avg.**
Steelhead											
Age 0	*	690(312)	202(128)	738(455)	73(47)	1,330(237)	648(187)	244(174)	271(71)	*	466(179)
Age 1	231(61)	415(52)	354(51)	417(45)	420(41)	331(29)	332(38)	178(16)	164(15)	205(13)	313(33)
Age 2+	*	17(9)	7(0)	47(7)	12(5)	33(7)	*	11(0)	*	22(6)	17(4)
Coho salmon											
Age 0	*	*	*	69(28)	*	124(36)	*	36(20)	72(13)	7(0)	34(11)
Brown trout											
Age 0	*	1,105(432)	517(313)	1,691(440)	830(100)	1,306(178)	1,134(152)	2,064(351)	381(79)	284(63)	1,035(234)
Age 1	276(64)	95(29)	285(43)	267(39)	411(38)	604(42)	765(46)	96(41)	61(34)	114(10)	433(36)
Age 2+	161(36)	53(12)	65(9)	147(20)	109(22)	227(13)	125(13)	167(14)	108(13)	80(0)	120(13)
>254 mm	130(34)	37(10)	55(6)	79(12)	53(14)	75(5)	101(12)	53(8)	49(8)	44(0)	61(8)
Brook trout											
Age 0	*	*	*	257(105)	47(16)	109(50)	49(14)	61(17)	60(14)	44(17)	70(26)
Age 1	131(102)	21(9)	48(23)	110(33)	122(21)	96(22)	108(12)	202(19)	105(15)	40(6)	95(18)
Age 2+	*	*	*	13(0)	16(6)	13(0)	*	8(0)	8(0)	8(0)	7(1)
Age-group totals											
Age 0	*	1,795(744)	719(441)	2,755(1,028)	950(163)	2,869(501)	1,831(353)	2,405(562)	784(177)	335(80)	1,605(450)
Age 1	638(227)	531(90)	687(117)	794(117)	953(100)	1,031(93)	1,205(96)	1,076(76)	930(64)	359(29)	841(87)
Age 2+	161(36)	70(21)	72(9)	207(27)	137(33)	273(20)	125(13)	186(14)	116(13)	110(6)	144(19)
Combined total	799(263)	2,396(855)	1,478(567)	3,756(1,172)	2,040(296)	4,173(614)	3,161(462)	3,667(652)	1,830(254)	804(115)	2,590(554)

* Denotes too few recaptures for an estimate calculation.

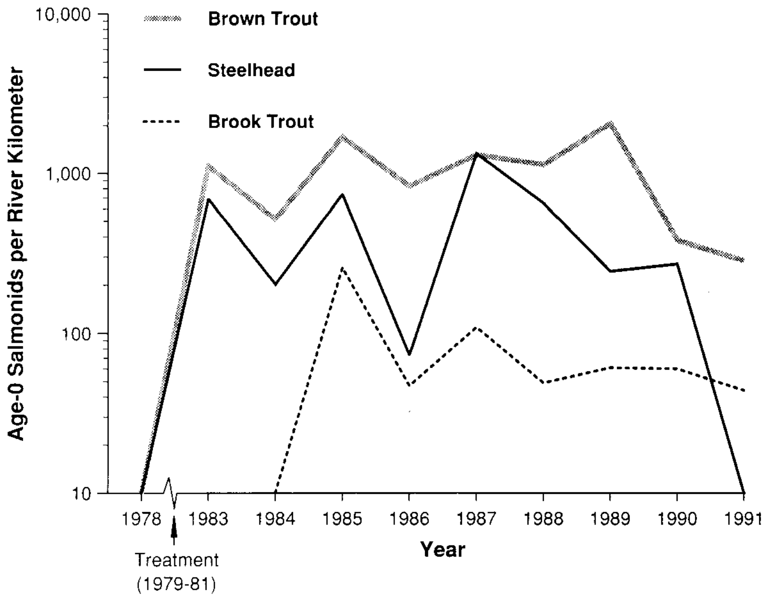


Figure 3. *Number of age-0 salmonids per river kilometer in the Little Brule River index station before (1978) and after (1983-91) stream-bank debrushing, installation of brush bundles, and beaver control. All age-0 salmonids in 1978, all brook trout in 1983 and 1984, and all steelhead in 1991 were too scarce to estimate.*

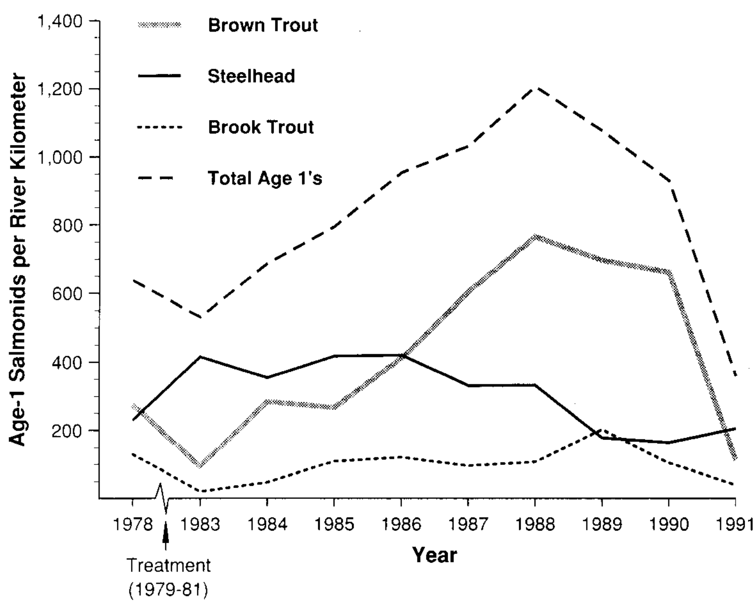


Figure 4. *Number of age-1 salmonids per river kilometer in the Little Brule River index station before (1978) and after (1983-91) stream-bank debrushing, installation of brush bundles, and beaver control.*

posttreatment period but declined sharply the last year, for unknown reasons. Interpretation of results for age-1 steelhead is also unclear. However, we have an indication that at least some degree of benefit to age-1 steelhead also occurred, since the posttreatment density average for this group was about 35% greater than the 1978 estimate and this increase occurred largely during a time period (1983-88) in which a trend of declining harvest of steelhead (D. Pratt, Wis. Dep. Nat. Resour., pers. comm.) suggests that the number of adult steelhead spawners in the Brule River system were at a pronounced low compared to the late 1970s.

Virtually all the steelhead and a sizeable proportion of the brown trout produced in the Little Brule River are anadromous presmolts (see Krueger and May 1987; identification of anadromous versus resident brown trout was based on their location in the river). Hence, the smolt-producing capability of the Little Brule River during most of the posttreatment period was enhanced. A low population of brook trout did not exhibit a positive response to the treatment, nor did a newly established population of coho salmon, which fluctuated considerably because of variation in numbers of adult spawners ascending the Bois Brule River each year.

The sharp decline observed in larger brown trout ($\geq$ 254 mm) following treatment (Table 2) probably reflected a period of increased angler harvest shortly after treatment. Increases in angling pressure, harvest, and angler preferences for improved fishing conditions are known to accompany trout habitat improvement projects in Wisconsin (Hunt 1988). In similar studies, angler use and harvest both increased after treatment nearly 300% in the TZ of Lawrence Creek (Hunt 1971), and angler trips increased 300% after treatment in the TZ on the Little Plover River (Hunt 1979). Anglers exhibited a decided preference for those sections of Rowan Creek (Larson 1982) and South

Table 3. *Salmonid density estimates (95% confidence limits in parentheses) in the Little Brule River treatment zone (TZ) and impact assessment zone (IZ) before (1978) and after (1983 and 1987) streambank debrushing, installation of brush bundles, and beaver control.*

	Estimated Density (no./km)					
	1978		1983		1987	
Age Group	**TZ**	**IZ**	**TZ**	**IZ**	**TZ**	**IZ**
Steelhead						
Age 0	*	*	622(261)	30(34)	1,132(176)	752(266)
Age 1	224(60)	225(156)	424(43)	488(146)	287(22)	418(60)
Age 2+	*	*	25(7)	61(46)	26(5)	*
Brown trout						
Age 0	*	*	800(276)	34(34)	1,051(112)	371(147)
Age 1	271(53)	331(145)	104(25)	115(78)	552(29)	369(39)
Age 2+	204(36)	279(132)	59(9)	141(47)	212(12)	118(32)
Brook trout						
Age 0	*	*	*	*	142(52)	10(11)
Age 1	136(110)	*	29(10)	*	108(18)	58(21)
Age 2+	*	*	*	*	13(0)	*
Coho salmon						
Age 0	*	*	*	*	154(29)	1,257(272)
Age-group totals						
Age 0	*	*	1,422(537)	64(68)	2,479(369)	2,390(696)
Age 1	631(223)	556(301)	557(78)	603(224)	947(69)	845(120)
Age 2+	204(36)	279(132)	84(16)	202(93)	251(17)	118(32)
Combined total	835(259)	835(433)	2,063(631)	869(385)	3,677(455)	3,353(848)

* Denotes too few recaptures for an estimate calculation.

Fork Main Creek (Pratt 1983) where habitat development projects had been undertaken. In our study, an increase in angler use was observed on the Little Brule River following treatment, but the change was not quantified. The Little Brule River is typical of many small, brush-choked streams in northern Wisconsin that are difficult for most anglers to fish effectively. In essence, the stream-bank debrushing transformed a section of stream that had functioned partially as a fish refuge (because of difficult fishing conditions) into a more easily exploitable fishery.

A balanced interpretation of the mixed results of this and other evaluations of riparian debrushing is needed. Studies by Hunt (1979, 1985, 1986) have demonstrated that in some cases trout habitat, standing stocks, and the trout fishery can be improved by removing woody stream-bank vegetation along sections of small, low-gradient, heavily shaded streams in central and western Wisconsin. Trout habitat quality in all 6 treatment zones in Hunt's studies showed some improvement, while growth, density, and biomass of brook trout or brown trout improved in 4 of the 6 cases. However, the promise generated by Hunt's results is blunted somewhat by findings from a number of management studies on stream-bank debrushing done in Wisconsin (summarized in Hunt 1988) which, in general, have been rather disappointing. While debrushing projects are obviously not a panacea for trout stream management, they have shown enough merit for improving salmonid abundances or growth to warrant further testing. Despite their widespread use, these techniques have simply not been evaluated thoroughly enough for biologists to understand why they work in some cases but not in others. Rigorous evaluations of the impacts of debrushing projects on trout populations, including pre- and post-treatment monitoring of the sport fishery, are especially needed; assessment of a project's contribution to an increased, sustained level of harvest would be an important part of the evaluation process.

We could not separate the effects of beaver control from those of debrushing. Although scientific documentation of positive salmonid population responses to control of beaver are virtually nonexistent, a widely accepted scenario of gradual habitat degradation caused by beaver impoundments presents a strong case for beaver control on low-gradient trout streams. Haugstad (1970) documented improved reproduction of brook trout in 3 of 14 streams in Minnesota following beaver control. Furthermore, several habitat improvement techniques, including stream-bank debrushing, have been suggested for use following beaver dam removal to hasten the rehabilitation of stream channels damaged by these impoundments (Salyer 1934, Haugstad 1970).

In this study, benefits of beaver dam removal may have included exposure of additional gravel for spawning and improved access for spawners and juveniles to the entire river. Because beaver dams are known to hinder the movement of salmonids to spawning areas and the post-hatch dispersal of fry (Salyer 1934, Hale 1966), removal of the dams may have provided the main benefit in reproductive success. Historically, improved access to spawning areas through barrier removal has been a common form of habitat enhancement for anadromous salmonids on the west coast, but it is also one of the least documented (Hall and Baker 1982).

Some of the salmonid population changes that occurred in the TZ were mirrored (though often less dramatically) in the downstream IZ. This observation lends support to the theory that benefits of these types of habitat development may also accrue to adjacent downstream reaches.

We had intended to gain additional insight into the lengths of adjustment periods needed for salmonid populations to stabilize following major alterations of stream channels. Stream-bank debrushing and beaver dam removal initiated a series of gradual adjustments in stream channel morphometry; we expected salmonid populations to require several years to adjust to the changing habitat conditions. Longer-term evaluations of habitat improvement projects by Hale (1969) on the Split Rock River, Minnesota, and by Hunt (1976) on Lawrence Creek, Wisconsin, had indicated that unstable transition periods of 3-6 years were probable. Results from the Little Brule River index station appeared to support these conclusions, at least initially. Several of the categories examined showed declines in 1983 followed by rebounding later (age-1 brook trout and age-1+ brown trout). The data series from the index station indicates that in most cases rebounding of standing stocks appears to have leveled off during the first 8 years of the posttreatment phase (1983-90 inclusive) (Fig. 4). Although a poor year for all salmonid species in the Little Brule River in 1991 has brought this conclusion into some question, this decline is likely unrelated to the habitat development. (Numbers of juvenile steelhead and brown trout were low throughout most of the Bois Brule River system in 1991.)

Based on the promising changes to the stream channel recorded by this study, the hypothesis that combined applications of stream-bank debrushing and beaver control will produce physical benefits to salmonid habitat in certain types of streams deserves further testing. Although we have no satisfying explanation for the development of shallow, heavily vegetated shelves along substantial portions of both banks of the Little Brule River following treatment, the main channel continued to deepen during the posttreatment period, undercut banks remained at some outside bends, and hiding/resting cover for salmonids of different sizes seemed adequate. An increase in channel cross-sectional area between 1983 and 1987 implies a concurrent reduction in stream velocity (not measured), which may explain the reduction in amount of gravel substrate between the same years. Some alder regrowth occurred during the posttreatment phase but did not cause physical damage to the stream channel.

Because of increased solar radiation reaching the stream, debrushing projects might be expected to cause some warming of mid-summer water temperatures. However, we did not observe such an effect during this study. The cooling effects of spring inputs entering the Little Brule River at various points in the study zone apparently more than compensated for any warming caused by canopy removal. Removal of beaver dams may have also helped reduce summer water temperatures, through the effects of increased stream velocity and reduced surface area exposed to solar radiation as impoundments were eliminated.

Several confounding factors obscured some of the biological insight that could have been gained from this study. In retrospect, pretreatment and posttreatment creel survey data would have been especially helpful. Lack of such quantitative information precluded positive identification of the factor (increased harvest) suspected as the primary cause for the decline of brown trout $\geq$ 254 mm following treatment. A viable reference section not affected by the treatment may have clarified the evaluation. Data quantifying underbank resting/security cover before and after treatment would also have been useful. Future experiments evaluating stream-bank debrushing and beaver control should be set up to separately discern the effects of each of these study components.

Conclusions and Management Implications

1. **Further testing of these techniques, both separately and combined, is warranted.**

   Although this and other evaluations of stream-bank debrushing have had mixed results, we believe enough merit has been shown to warrant further testing. Studies should include at least 3 years of pretreatment data collection, a control section not influenced by the treatment, an extended posttreatment evaluation period, and replication. However, replication can also be taken as the summed results of other studies (an adaptive management interpretation), provided these studies are based on adequate experimental designs. We suggest delaying evaluations by a minimum of 4 years (preferably 6 or 7 years) after these types of development. The most useful evaluations of habitat development will also include pretreatment and posttreatment monitoring of the sport fishery.

2. **Emphasis on improvement of reproduction and/or juvenile recruitment in anadromous streams should be continued. Special regulations to protect presmolts, enforced in conjunction with the treatment, should be continued.**

   Our results suggest benefits are most likely to occur in younger age groups in low-gradient anadromous streams that have dense alder canopies, beaver dams, and poor natural reproduction. Management goals on anadromous streams usually focus on maximizing smolt production. More restrictive size limits were enacted in 1989 to protect presmolts on all Wisconsin tributaries to Lake Superior. These regulation changes should work well in conjunction with the habitat development techniques described in this report.

3. **Physical prerequisites should be considered.**

   Hunt (1979, 1985) provides useful recommendations regarding the physical prerequisites of suitable summer water temperatures and sufficient gradient to allow desirable physical changes to occur.

4. **Likely biological trade-offs should be considered.**

   As a result of habitat development techniques, a stream that may have functioned as a partial fish refuge because of difficult fishing conditions can be transformed into one with a more easily exploited fishery. Increased harvest may more than offset improved trout carrying capacities in some situations. The likelihood that increased angler use and harvest will accompany any such project is not necessarily negative but must be considered as part of the management strategy for that stream.

5. **Maintenance requirements should be incorporated into the management plan.**

   Maintenance requirements include periodic recutting of alder regrowth and continual beaver control. Considerable time and funds are invested in these types of habitat projects—protection of this investment should be a management priority.

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Acknowledgments

We thank D. Pratt, W. Blust, A. Saari, S. Plaster, M. Rackouski, W. Gobin, P. Newton, W. Armstrong, F. Stoll, and D. Fitzsimmons for assistance with various aspects of the field work. D. Pratt made much of the original data from the treatment zone index station available to us. P. Rasmussen assisted with data analysis. Critical reviews by L. Christenson, R. Hunt, and several anonymous reviewers improved the manuscript. C. Olson assisted with the figures. Last, but not least, we gratefully acknowledge members of the Brule River Sportsman's Club Inc., whose many hours of voluntary labor made this project possible. This study was supported in part with funds authorized under the Anadromous Fish Conservation Act (Project WI-AFS-16) and the Sport Fish Restoration Program (Project F-83-R).

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Printed on recycled paper.

Wisconsin Department of Natural Resources

PUBL-RS-157 93