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Long-term Assessment of Habitat and Trout Population Responses to Habitat Improvement in a Small, Southwest Michigan Stream

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Abstract.–Stream habitat improvement is a common technique used by fisheries managers desiring to increase production and angler catch rates of important sport fishes. However, high costs of assessment combined with a lack of rigorous scientific evaluation (e.g., long-term data, pre-treatment information, and control sites) and thorough statistical analyses have led to much criticism of this practice in recent years. To address this issue, we measured the physical habitat and trout population in Silver Creek, Michigan before and after the addition of instream structure and control of bank erosion. Channel width decreased in the treated zone and additional coarse substrate was exposed after habitat improvement. These beneficial changes to channel morphology have persisted for more than a decade after project completion and did not cause adverse changes such as increased bank erosion in untreated portions of the stream. Total brown trout *Salmo trutta* biomass in a treatment zone (TZ) where instream structures were added significantly increased over time in comparison to a reference zone (RZ) without habitat improvement. Increases were driven by an increase in the number of fish in the 8–12 in size group. When compared to RZs in two nearby streams, the average density of acceptable-size (greater than 8 in) brown trout was variable among periods (before habitat improvement, after habitat improvement, and after a regulation change) and zones. Abundance of acceptable-size trout increased over time in the TZ while holding steady or decreasing in the other RZs. Although volunteer reports from anglers indicated that fishing effort in Silver Creek was nearly four times higher in the TZ than the RZ, catch rates were similar and the brown trout population was able to persist. Total brown trout biomass in the TZ remained nearly 40% higher in 2005–07 compared to the 5-year period before habitat improvement was completed in 1995 likely due to improved spawning or nursery habitat and the presence of instream structures.

Introduction

Adding structure to trout streams to improve physical habitat originated in Michigan in the early 1900s to remediate loss of cover, pollution, and overfishing. These efforts were intensively studied at the time, and by the late 1930's the use of instream structure as a fisheries management tool became common practice. The results of early studies (e.g., Hubbs et al. 1932; Shetter et al. 1946; Tarzwell 1936) and even more recent work in Wisconsin (Hunt 1976, 1988) indicated substantial benefits to trout populations, particularly increases in abundance of larger fish. Over the past two decades improving instream habitat by adding structure to stabilize stream banks, provide overhead or instream cover, and diversify channel morphology has resurged (Thompson 2006) with many of the original techniques developed early in the 20th century still in use by fisheries managers today.

Although stream habitat improvement is a common practice, it sometimes is criticized because of its high cost and lack of scientifically rigorous evaluation. Modern evaluations are rare and share similar shortcomings to historical efforts, including lack of pretreatment data, controls, and rigorous statistical analyses. Habitat data are often unavailable to determine if the addition of structure achieves desirable effects on channel morphology. Population responses are poorly measured, and many evaluations fail to account for changes in fishing pressure, which can complicate interpretation of the influence of instream structures (Thompson 2006). These shortcomings present challenges for fisheries managers who must make decisions on the cost, benefits, effectiveness, and appropriate use of structure to improve physical stream habitat in hopes of increasing the abundance, survival, growth, and ultimately catch rates of game species such as trout.

If habitat improvement increases the biomass of trout, angler catch rates and satisfaction may also increase, thereby enhancing the recreational benefits and public value generated by trout streams. Thus, reducing the uncertainty about the effects of stream habitat improvement is necessary for effective fisheries management. The objectives of this study were twofold: 1) To determine if the addition of instream structure improved physical habitat in a treatment zone (TZ) of Silver Creek, Michigan by producing desirable changes in channel morphology such as stream narrowing, deepening, and increased exposure of coarse substrates; and 2) To determine if improved physical habitat resulted in an increase in the abundance (numbers and biomass), survival, growth, and angler catch rates of brown trout *Salmo trutta*. To do so, we used physical habitat measurements and volunteer information on angler effort and catch rates, along with trout population data collected over a period of thirteen years, to compare conditions within the TZ with those in nearby reference zones (RZs) before and after habitat improvement.

Methods

Study Site

Silver Creek is a small second-order tributary to the Kalamazoo River, Michigan. It has a drainage area of approximately 20 mi^2 and a mean annual discharge of 12 ft^3/s (Allen et. al. 1972). Located in the extreme corner of southeastern Allegan County and north-central Kalamazoo County, this high-quality designated trout stream has a top-quality reputation for its coldwater fishery. Stocking of trout by the state was discontinued in 1962 because substantial levels of natural reproduction by brown trout and some limited natural reproduction of brook trout provided excellent angling opportunities (Dexter 1993).

In 1993 several partners including state and federal government agencies, not-for-profit organizations, and local angling groups initiated planning for a stream habitat improvement project in Silver Creek to remediate damage caused by a cattle herd of approximately 24 animals. Before 1995, the herd had full access to all riparian areas within the TZ. Grazing and stream crossing by the herd contributed to severe localized bank erosion which caused an estimated 140 tons of sediment to erode into Silver Creek each year (United States Department of Agriculture, Natural Resource Conservation Service, unpublished data). Given the devastating long-term effects of sedimentation to coldwater stream communities (Alexander and Hansen 1983, Alexander and Hansen 1986), planning efforts for reducing sediment and improving cover were initiated immediately after the landowner agreed to install an electric fence to exclude all cattle from the riparian zone, with the exception of one managed crossing.

Habitat Improvement

Project partners stabilized the cattle crossing with gravel and installed approximately 500 ft^2 of instream habitat and bank stabilization structures at 10 rehabilitation sites within the TZ between August and October of 1995. An additional five sites upstream from the TZ were also treated, but these sites accounted for less than 5% of total instream structure. Habitat improvement included the addition of lunker structures, half-logs, brush bundles, and rip rap as described by Hunt (1993). The stream channel was modified to reduce braiding in two locations, and an extensive log jam that exacerbated bank erosion at high flows was removed. A total of 120 yd^3 of field stone, 50 yd^3 of topsoil, 50 yd^3 of 6A gravel, fifty 8-ft cedar posts, 19 half-logs, and 450 linear feet of sod were used for the project. Total project cost was $13,076 USD (1995), including 794 h of labor.

Field Measurements

Station boundaries and physical habitat.–Fisheries managers used boundaries from pre-existing trout population index stations within the TZ and an upstream RZ (Figure 1) in Silver Creek to delineate stations for measuring physical habitat, volunteer angler catch rates, and trout population size (Table 1). The RZ was located 1.2 miles upstream of the TZ. Habitat measurements including width, depth, substrate composition, and bank stability were collected at transects spaced every 50 ft in the TZ and RZ immediately before habitat improvement (August 1995) and after habitat work was completed (August 2000 and 2007 in the TZ and August 2007 in the RZ) using the methods described in Platts et al. (1983). Habitat measurements made at permanent transects established in 1995 were replicated in 2000 and 2007 by the same field personnel to minimize the possible effects of observer bias.

Volunteer angler census.–We estimated effort, catch rates, and harvest in the TZ and RZ of Silver Creek by asking anglers to report information about each fishing trip completed in 1997 and 1998. Conspicuous signs describing the habitat improvement project and a request for angler catch and effort data were placed at the upstream and downstream ends of both sections. A box containing volunteer angler forms (with instructions) and pencils was attached to the sign post, along with another box for depositing completed forms. Anglers were asked to record the number of anglers in their party, total time fished, fishing method, and the number, size (inch group), and species of all trout captured. The boxes were checked regularly for completed forms throughout the open season (last Saturday in April to September 30). Before the opening day, fisheries managers ran advertisements in the local newspaper to increase public awareness of the project and to encourage angler reporting.

Trout population estimates.–Between 1991 and 2003, mark-recapture trout population estimates were intermittently collected from the TZ and RZ in Silver Creek to evaluate the addition of instream structures. Reference population data were also collected during the same period in nearby Spring Brook and Brandywine Creek (Figure 1, Table 2), which are also wild trout streams. Field personnel collected trout for mark-recapture population estimates at each site with a two-probe, 240 V DC electrofishing barge. Population estimates were usually conducted in mid-August, but were made as early as the end of July or as late as the middle of September. Stations began and ended at shallow riffle areas and no blocking nets were used. All brown trout and brook trout *Salvelinus fontinalis* captured on the first pass were measured and marked with a small caudal clip. Each fish captured was released after a sample of scales was removed for age analysis. Trout captured the next day on the second pass were measured, examined for marks, and released.

Statistical Analyses

We assembled all physical habitat measurements, volunteer angler reports, and mark-recapture electrofishing data collected from the TZ and RZ in Silver Creek along with the mark-recapture electrofishing data from the RZs in Spring Brook and Brandywine Creek. Mean width and depth of the stream channel, along with the median percent substrate composition, gravel embeddedness score, and bank stability score were calculated and compared for each year data were collected in the Silver Creek TZ and RZ. We also tallied and compared the total number of angler trips, hours spent fishing, catch, catch-per-effort (fish caught per hour), and harvest of trout between the TZ and RZ during 1997 and 1998. All angler-caught trout were placed into the size groups described below for trout population estimates.

Although our original intent was to monitor changes in both brown trout and brook trout *Salvelinus fontinalis* populations, insufficient numbers of brook trout were captured during field surveys to compute reliable population estimates. We also discovered that scale samples were not separated by individual sampling sites, which in combination with gaps in the years data were collected (Table 2), precluded comparisons of survival and growth between the TZ and RZs. Therefore, we compared population estimates of brown trout between the TZ and RZ in Silver Creek and between the TZ in Silver Creek and RZs in Spring Brook and Brandywine Creek.

We first grouped the years that brown trout population data were collected into three periods: before habitat improvement, after habitat improvement, and after a regulation change (Table 2). We next calculated total biomass (lbs/acre) and density (number/acre) estimates for each year that data were available. The period after the regulation change encompasses the years following habitat improvement when the brown trout minimum size limit (MSL) was increased from 8 in to 12 in in the TZ and RZs. Since one of the goals of habitat improvement was to increase the density of larger brown trout available for angler catch or harvest, we first calculated population estimates for the number of fish greater than 8 in total length (TL), representing fish of "acceptable" size based on the typical MSL for most Michigan trout streams. We also calculated the number of fish between 8 in and 12 in TL, representing fish that were protected after the regulation change, and the number of fish greater than 12 in TL. To determine if the addition of instream structure increased reproduction, we calculated population estimates for all brown trout less than 4 in (presumably young-of-year), since information from other Michigan streams suggests that nearly all brown trout smaller than 4 in are age 0 (A. Nuhfer, Michigan Department of Natural Resources, personal communication). All population estimates were calculated using the Chapman modification of the Petersen mark-recapture estimator (Ricker 1975).

We used analysis of variance (ANOVA) to determine if stream width, depth, and substrate were significantly different between zones and periods in Silver Creek. We also used ANOVA to determine if the total biomass, total density, and density of brown trout greater than 8 in, 8–12 in, and greater than 12 in were significantly different between zones and periods within Silver Creek and compared with density in the RZs of other nearby streams. When appropriate, the data were transformed to meet the necessary distributional assumptions for ANOVA. We used Bonferroni-adjusted *P*-values for multiple comparisons between the TZ and RZs within periods, and set the rejection criterion α at 0.05 for all analyses. All data were analyzed with SPSS version 15.0 (SPSS, Inc. 2006).

Results

We observed some changes in channel morphology within Silver Creek after habitat improvement work was completed. The average width became narrower in the TZ after habitat improvement (F=4.74, df=1,52, P=0.034) and remained stable in the RZ. Although not statistically different, the point estimates of average depth in both zones were surprisingly 1.8 in shallower in 2007 than in 1995. Bank stability scores improved from good to excellent in the TZ after habitat improvement work was completed in 1995 and remained excellent through 2007 (Table 3). Cobble substrate significantly increased in the TZ ($F=9.31$, $df=1,52$, $P=0.004$) following habitat improvement. However, gravel decreased at the same time in the TZ ($F=7.12$, $df=1,52$, $P=0.010$). No discernable change in fine substrates (sand, clay, and silt) occurred in the TZ or RZ after the addition of instream structure. The embeddedness score of coarse substrates was stable through time in the TZ where substrate was 25–50% embedded. However, embeddedness scores increased over time in the RZ such that coarse substrates were more than 75% embedded in 2007 (Table 4).

Angler reports collected in 1997 and1998 (the middle of the period following habitat improvement) and pooled between years indicated that fishing effort and brown trout harvest by volunteer anglers were much higher in the TZ compared to the RZ (81 vs. 20 trips, 391 vs. 99 total angler hours/acre, 23 vs. 4 fish harvested). However, overall brown trout catch rates (fish/h) were very similar between zones (Figure 2). More detailed records from one angler, which covered all three periods used in previous analyses, also showed similar catch rates between the TZ and RZ.

A significant zone*period interaction within Silver Creek and among Silver Creek, Spring Brook, and Brandywine Creek indicated variability in the total biomass of brown trout through time in the TZ and RZs (Table 5). In both instances biomass was very similar in the TZ and RZs before and immediately after habitat improvement, but was significantly higher in the TZ compared to all RZs after the regulation change (Figure 3, Table 6). Brown trout reproduction, as measured by young-of-year density, was much higher in the TZ compared to the other RZs regardless of period (Figure 4, Table 5).

The density of brown trout greater than 8 in was different among the TZ and RZs in Silver Creek, Spring Brook, and Brandywine Creek during the three periods examined as indicated by significant zone*period interactions (Table 5). Before habitat improvement, the density of acceptable-size fish was significantly lower in the TZ compared to both the Silver Creek and Spring Brook RZ. The density of brown trout greater than 8 in increased in the TZ during the two periods following habitat improvement, while mostly decreasing through time in all reference zones (Figure 5). During the period after the regulation change, the density of acceptable-size brown trout was significantly higher in the TZ compared to both the Spring Brook and Brandywine Creek RZs (Table 6). Although not statistically different, the density of brown trout greater than 8 in was more than 40% higher in the TZ than in the Silver Creek RZ following the regulation change.

Increases in the density of brown trout greater than 8 in in the TZ were driven only by an increase in the density of fish in the 8–12 in size range, particularly during the period after the fishing regulation change (Figure 6). Estimated density of 8–12 in brown trout varied significantly through time in the TZ and RZs (Table 5), mirroring estimates of fish greater than 8 in. However, the magnitude of the difference between point estimates in the TZ and RZs was larger. Before habitat improvement, the density of 8–12 in brown trout in the TZ was lower than the three RZs. After habitat improvement was completed, the density of brown trout 8–12 in increased through time in the TZ to a level that was significantly higher than all RZs after the regulation change (Table 6). The densities of brown trout greater than 12 in throughout all zones were usually less than 20 fish/acre across all years of study. Brown trout greater than 12 in were significantly lower in Silver Creek during the two periods following habitat improvement, regardless of the presence of instream structure. Although not significantly different, point estimates of the density of brown trout greater than 12 in showed a similar decrease in the Spring Brook and Brandywine Creek RZs during the same periods.

Discussion

In our study, bank stabilization and installation of instream cover improved trout habitat by narrowing the stream, exposing additional coarse substrate, and increasing streambank stability. The most substantial change in stream morphology that we observed after habitat improvement was a significant narrowing of the stream channel in the TZ. Typically, reduced stream width promotes higher water velocity, greater stream power, and increased scouring of the channel, thereby moving fine sediments and exposing coarse substrates used by spawning trout and other aquatic organisms such as benthic macroinvertebrates. Lower water levels present during the time when post-treatment measurements were made in 2000 and 2007 may have contributed to stream channel (wetted width) narrowing, but there was no change in stream width in the RZ, which suggests that the habitat improvement project was the primary cause of narrowing.

Although average width in the TZ decreased after habitat improvement, it is interesting to note that average depth decreased by nearly 2 in. Lower water levels present during post-treatment measurements in 2000 and 2007, relative to the pre-treatment measurements collected in 1995, are again the most plausible explanation for this observation. Although flow records are not available for Silver Creek, annual discharge measurements during August in nearby Augusta Creek were more than 30% lower in 2000 and 2007 compared to 1995. Also, the mean monthly flow in August of 1995 was 37% higher than the mean August flow for the entire period of record (1965–2007, United States Geological Survey 2008). Thus the channel morphology measurements recorded in 2000 and 2007 probably reflect both the average conditions and effects of stream habitat improvement.

The increase in bank stability in the TZ, which has persisted for more than a decade after stream habitat improvement, indicates that the project successfully curbed sediment erosion into the stream in this reach. Moreover, the channel narrowing we observed in the TZ did not create new bank erosion problems either within or downstream of the project area. We believe that the much larger increase in coarse substrates observed in the Silver Creek TZ compared to the RZ reflects the success of erosion control measures and perhaps an increase in the stream's power to scour and transport fine sediments from the TZ. This hypothesis is supported by the finding that embeddedness of coarse substrates did not change in the TZ after stream improvement whereas coarse substrates became more embedded in the RZ over time. Since the same field personnel completed visual observations of substrate in 1995, 2000, and 2007 the potential for observer bias was reduced. Therefore, the decrease in gravel substrate in the TZ and the commensurate increase in cobble substrate is probably attributable to transport of smaller gravel particles out of the section during high flow events. Much smaller changes in substrate occurred in the RZ during the same period, suggesting that observer bias was not an issue and that the changes recorded in the TZ did not occur as a result of a broader, landscape-scale change in flow regime.

Both volunteer angler behavior and the trout population responded to the changes in physical habitat and increase in cover afforded by stream habitat improvement. Although pre-habitat improvement volunteer angler reports were not available for comparison, angling effort in the Silver Creek TZ was much higher than in the RZ within the time period after habitat improvement. This is not surprising given the notable body of literature which indicates that anglers often fish more intensively in improved sites due to real or perceived improvements in the quality of fishing after habitat improvement projects are completed (Thompson 2006). Changes in fishing regulations in 2000 and the perception of many anglers that an increase in the MSL would result in an increase in the number of larger fish may have lead to even greater increases in angling effort in the years after most volunteer angler reports were collected . The detailed records from one volunteer angler whose fishing trips covered all three periods used in the analyses of trout populations suggests that angler effort increased in the TZ and decreased in the RZ through time. If an increase in fishing effort and harvest did occur in the TZ, the brown trout population was still able to persist.

The beneficial effects of the habitat improvement project on stream morphology have persisted for more than a decade and are believed to be the primary reason that the density of 8–12 in brown trout increased over time in the TZ. Density of 8–12 in trout did not increase, and in most cases actually declined, over the same period in unimproved RZs. Although initial placement of instream structure within the TZ did not result in a statistically significant increase in 8–12 in brown trout, point estimates did increase and abundance was significantly higher compared to RZs after the regulation change (Figure 6, Table 6). The observed increases of brown trout 8–12 in in the TZ following the change in fishing regulations cannot be attributed to the regulation change itself because similar changes did not occur in any of the RZs, which had the same regulations as the TZ during the post-regulation change period. Although the regulation change affords fish in this size group protection from harvest, a more plausible explanation for the increase in density is a delayed effect of habitat improvement and immigration into the reach. Platts and Nelson (1988) showed that short-term changes in fish populations may be unrelated or only weakly related to habitat attributes such that more substantial changes in population dynamics may not be fully exhibited in less than a decade (Walters 1997). Hunt (1976) likewise observed that the brook trout population in an improved section of Lawrence Creek, Wisconsin, did not reach its new, higher carrying capacity until the fifth and sixth year after habitat development. A delayed effect of habitat improvement is supported in this study by the gradual increase of acceptable-size brown trout in the TZ through time.

Our study design did not allow us to determine if survival or growth rates changed through time in the Silver Creek TZ compared with the RZ. Either increases in survival or increases in immigration could explain why stream improvements in the TZ were associated with higher abundance after the regulation change. Densities of YOY in Silver Creek during this period were 42% higher in the TZ and 56% higher in the RZ compared to the “after improvement” period (Figure 4) but significant increases in the density of 8–12 in fish occurred only in the TZ. Riley and Fausch (1995) and Gowan and Fausch (1996) also found that abundance of adult trout and biomass significantly increased after habitat modifications, but because they had batch marked trout in treatment and control zones they were able to identify immigration into the TZ as the primary cause of increased abundance. They concluded that their habitat manipulation, installation of log weirs, increased trout abundance because immigration from other stream reaches was not impeded by migration barriers. Our success in achieving higher densities of acceptable-sized trout in the TZ of Silver Creek also suggests that even if survival *within* the reach did not change after treatment, overall survival over a longer reach of stream was presumably enhanced when migrating trout that encountered the TZ took up residence. Total brown trout biomass in the TZ remained nearly 40% higher in 2005–07 compared to the 5-year period before habitat improvement was completed in 1995 (T. Wills, Michigan Department of Natural Resources, unpublished data).

Management Implications

The cost:benefit ratio must be evaluated for projects like this in order for fisheries managers to strategically capitalize on limited resources. For this project the total cost amounted to $12.45 per linear foot in the TZ, or $32,690 per acre of water. Using a value of $24 per angler day (United States Fish and Wildlife Service 2006) and the minimum reported angler trips from our voluntary angler survey, it would take 11.2 years to recover the costs of the project. When this report was written twelve years after the habitat work was completed the TZ continued to provide angler benefits, although maintenance efforts requiring some financial expenditure and volunteer labor must be completed on a semi-annual basis.

Although we were able to use physical habitat measurements and long-term population data to illustrate the positive effects of adding instream structure to a degraded section of a wild trout stream, our study has several shortcomings. A rigorous, statistically-designed creel survey in the TZ and RZ would have increased our confidence in assessing the true effects of changes in angling effort. Without these data, we were forced to rely on volunteer angler reports which are subject to potential bias and unknown error. Further, our inability to compare growth and survival within Silver Creek due to a simple oversight hindered our capacity to determine the mechanistic processes behind the increases that we observed in the trout population. Even though our case study shows the potential of instream habitat improvement to sustainably enhance the recreational benefits and public value generated by trout streams, future work in which growth, survival, and movement are more carefully monitored will provide even greater assistance to fisheries managers responsible for making sound decisions on the effectiveness of habitat improvement in Michigan trout streams.

Acknowledgments

We would like to thank Paul and Thelma Dalrymple for granting admission to their property, not only for completion of this project but also for angler access to Silver Creek. The Kalamazoo Valley Chapter of Trout Unlimited (KVCTU), the St. Joseph Valley Fly Fishers, the Fly Fishing Federation Fort Wayne Chapter, Augusta Creek Watershed Association, Southwest Michigan Land Conservancy, Indiana Department of Natural Resources, the former Land and Water Management Division of the Michigan Department of Natural Resources (DNR), and the United States Soil Conservation Service (currently the United States Department of Agriculture Natural Resource Conservation Service) all provided volunteer help or financial assistance to the project. Major funding for the habitat improvement work was provided by the Great Lakes Commission. Chuck Maltby of KVCTU provided site designs. Fisheries staff from the DNR Plainwell office including Dan Anson, Sally Markham, Denny Gordon, and Donald Waite suffered with a smile through the implementation and evaluation of the project. Dr. Daniel Hayes of Michigan State University provided statistical consultation. This research was supported with funds from a Federal Aid in Sport Fish Restoration Act (Study 558, Project F-80-R, Michigan) grant to the DNR Fisheries Division.

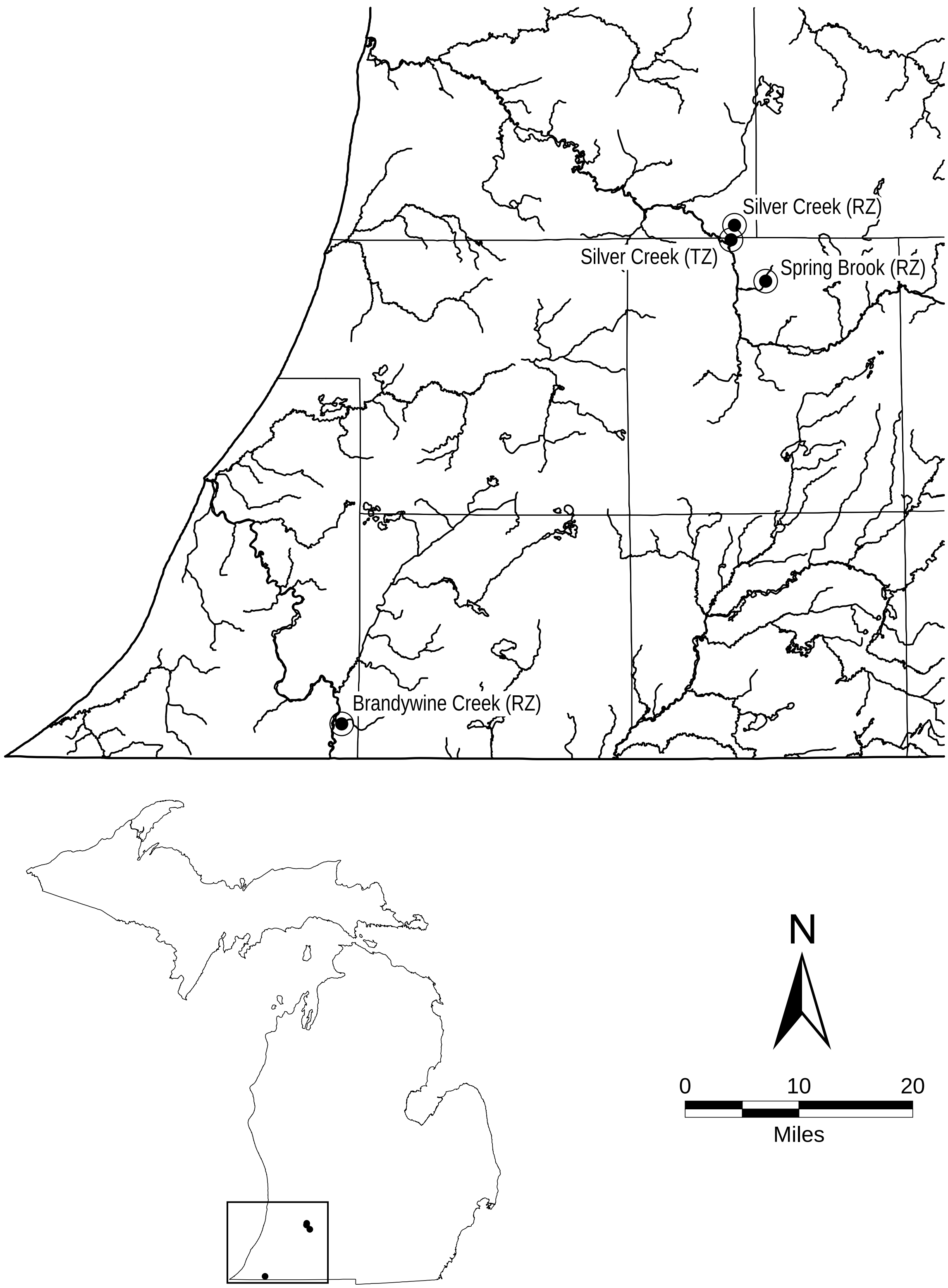

Figure 1.–Location of the habitat improvement treatment zone (TZ) and reference zones (RZ) in Silver Creek, Spring Brook, and Brandywine Creek, Michigan.

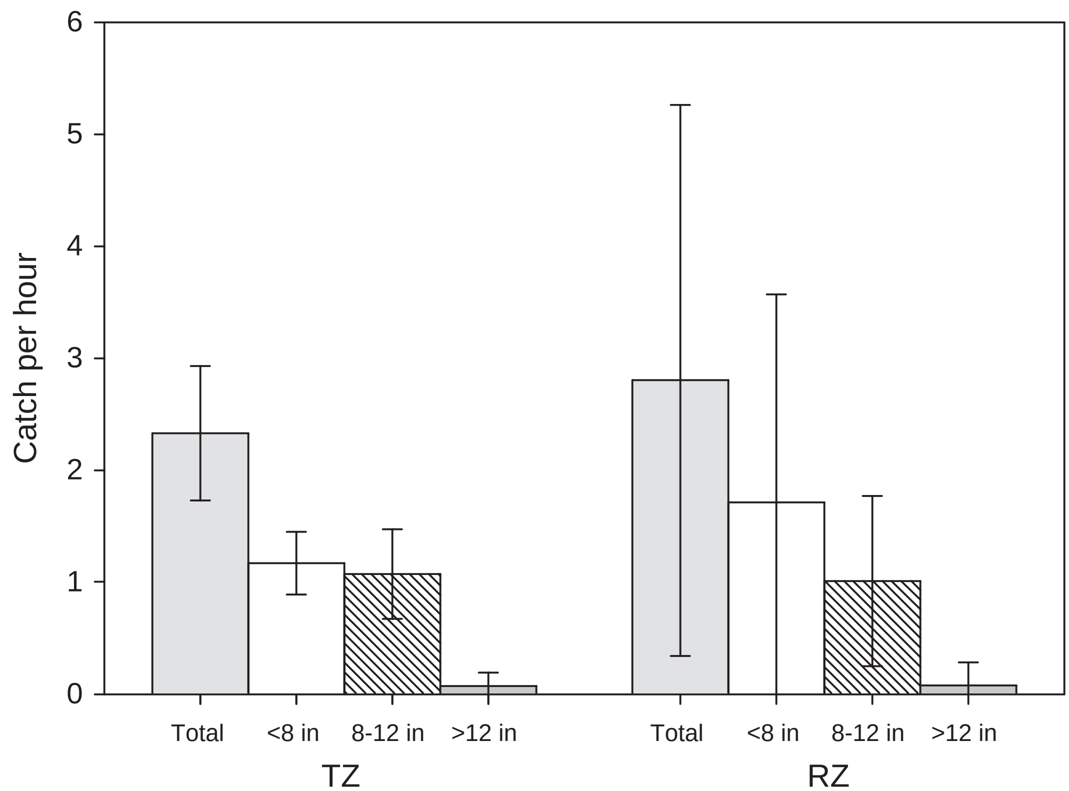

Figure 2.–Volunteer angler catch rates of brown trout (±2 SD) by size group in Silver Creek, Michigan during 1997–98. TZ = treatment zone, RZ = reference zone.

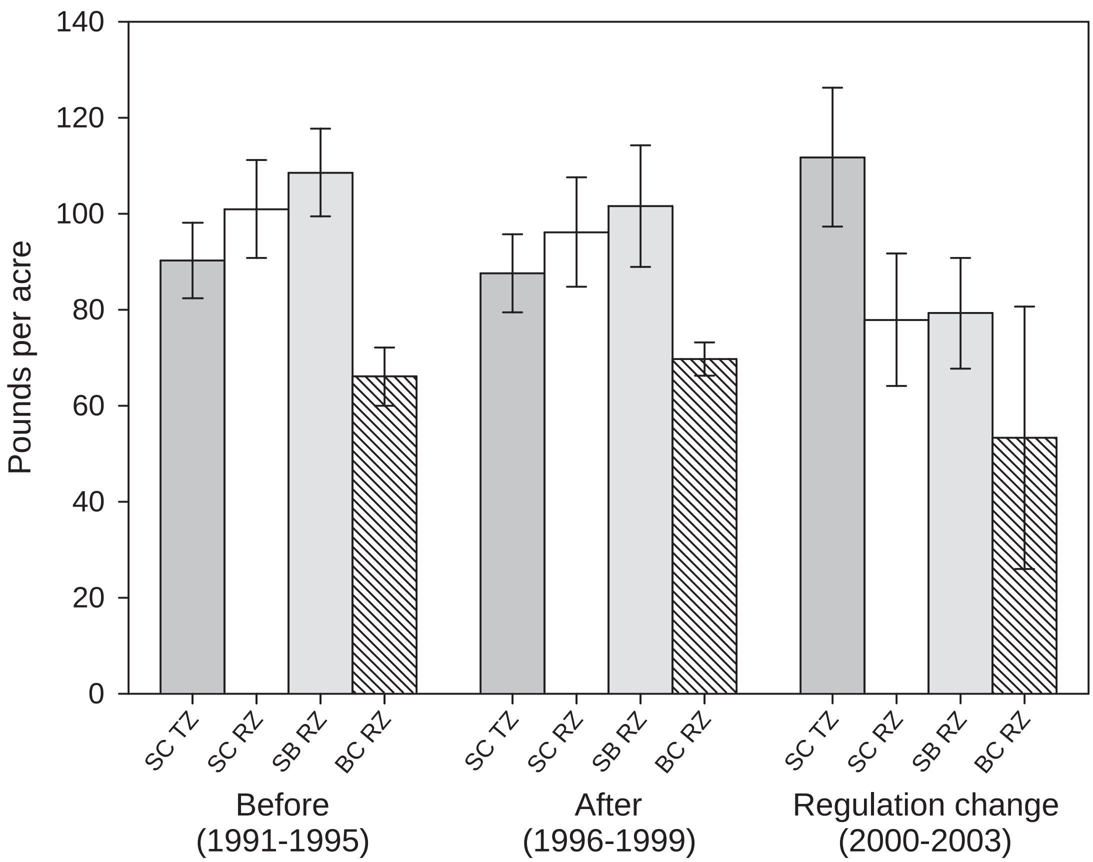

Figure 3.–Mean total biomass of brown trout (±2 SE) by zone across all periods of study. Time periods are before habitat improvement, after habitat improvement, and after a regulation change. SC = Silver Creek, SB = Spring Brook, BC = Brandywine Creek. TZ = treatment zone, RZ = reference zone.

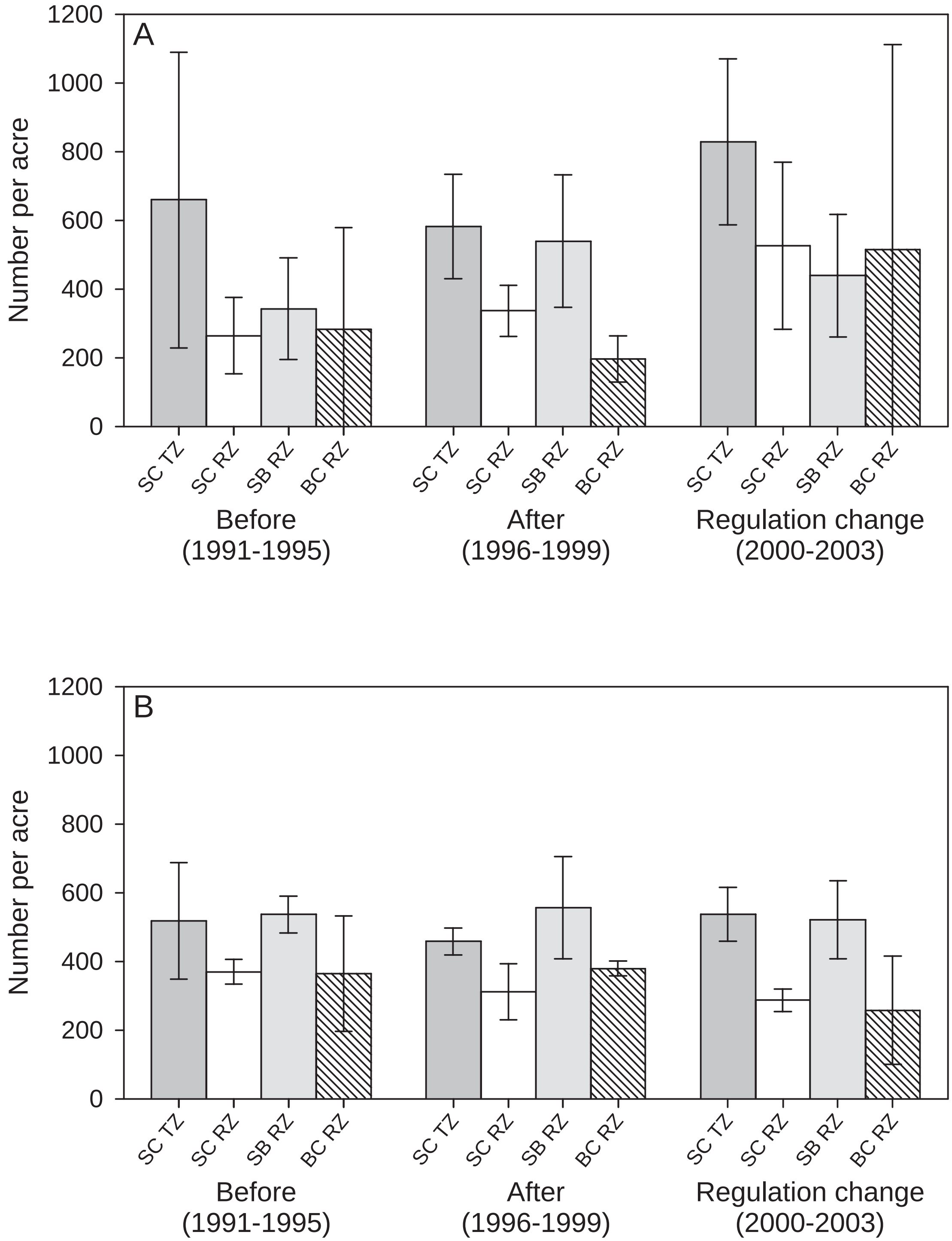

Figure 4.–Mean density of young-of-year (A) and yearling-and-older (B) brown trout (±2 SE) by zone across all periods of study. Time periods are before habitat improvement, after habitat improvement, and after a regulation change. SC = Silver Creek, SB = Spring Brook, BC = Brandywine Creek. TZ = treatment zone, RZ = reference zone.

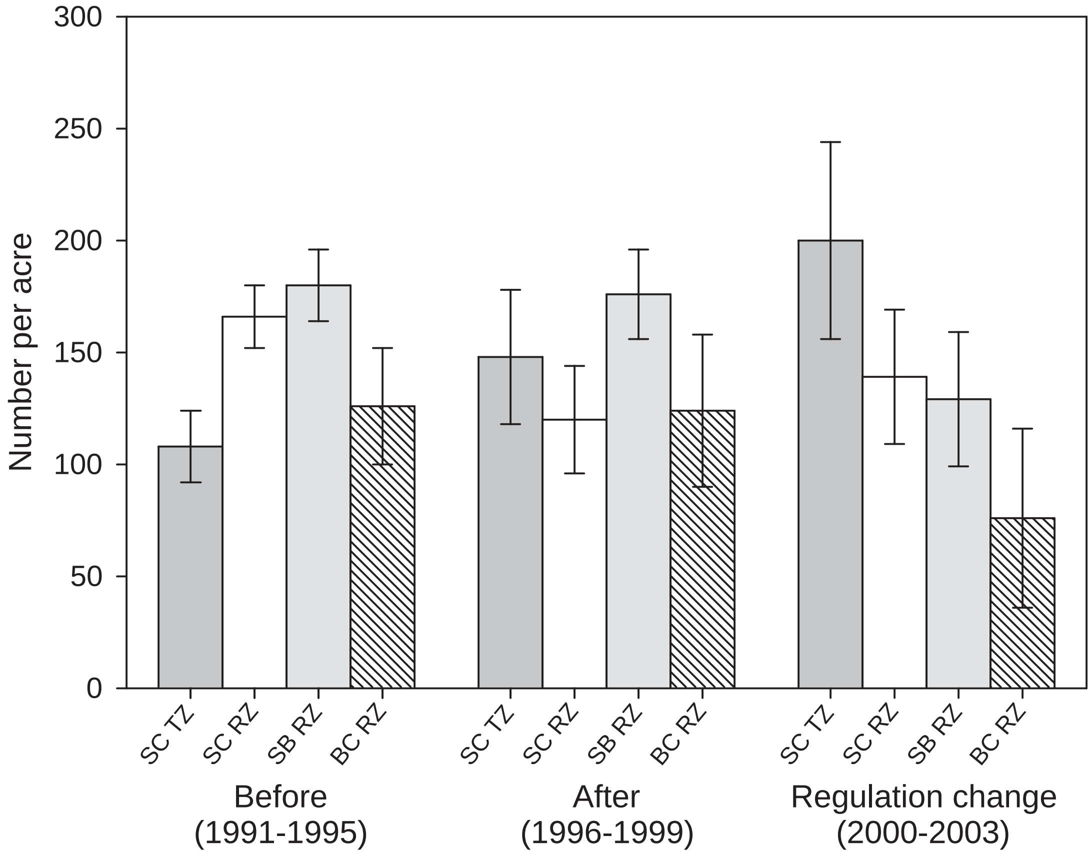

Figure 5.–Mean density of brown trout greater than 8 in (±2 SE) by zone across all periods of study. Time periods are before habitat improvement, after habitat improvement, and after a regulation change. SC = Silver Creek, SB = Spring Brook, BC = Brandywine Creek. TZ = treatment zone, RZ = reference zone.

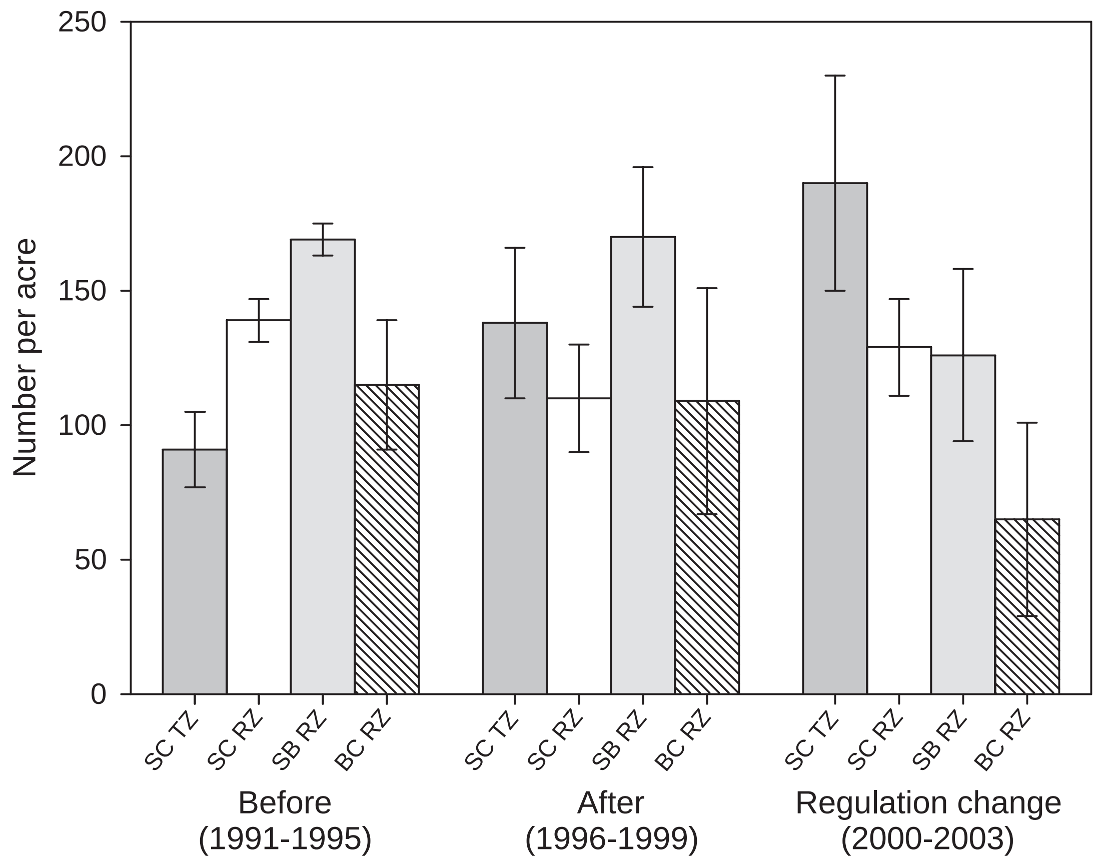

Figure 6.–Mean density of brown trout 8-12 in (±2 SE) by zone across all periods of study. Time periods are before habitat improvement, after habitat improvement, and after a regulation change. SC = Silver Creek, SB = Spring Brook, BC = Brandywine Creek. TZ = treatment zone, RZ = reference zone.

Table 1.–Selected characteristics of sampling stations used to evaluate habitat improvement in Silver Creek, Michigan. TZ=treatment zone, RZ=reference zone.

Stream	County	Zone	Survey station	Minimum size limit for brown trout	Area (acres)	Length (ft)	Average width (ft)
Silver Creek	Kalamazoo	TZ	Dalrymple Farm	8 in (before 1999) 12 in (2000 to present)	0.40	1,050	16.7
	Allegan	RZ	Brenner property	8 in (before 1999) 12 in (2000 to present)	0.25	800	13.4
Spring Brook	Kalamazoo	RZ	DE Avenue	8 in (before 1999) 12 in (2000 to present)	0.39	1,090	15.6
Brandywine Creek	Berrien	RZ	Third Street	8 in (before 1999) 12 in (2000 to present)	0.42	940	19.5

Table 2.–Years in which trout population estimates were available to evaluate the effects of habitat improvement in Silver Creek, Michigan. An "X" denotes available data. Time periods are before habitat improvement (before), after habitat improvement (after), and after a change in the minimum size limit (regulation change). TZ = treatment zone, RZ = reference zone.

		Silver Creek		Spring Brook	Brandywine Creek
Year	Period	TZ	RZ	RZ	RZ
1991	Before	X	X	X	
1992					X
1993					
1994		X	X	X	X
1995		X	X	X	
1996	After	X	X	X	X
1997		X	X	X	
1998		X	X	X	X
1999		X	X	X	
2000	Regulation change	X	X	X	X
2001		X		X	X
2002				X	
2003		X	X	X	X

Table 3.–Channel characteristics and bank stability in Silver Creek, Michigan before and after habitat improvement. Data collected after the addition of instream structures are in bold. Standard deviations are in parentheses. Bank stability scores are: 4 (excellent, greater than 80% of stream bank covered), 3 (good, 50–79% of stream bank covered), 2 (fair, 25–49% of stream bank covered), 1 (poor, less than 25% of stream bank covered; Platts et al. 1983). TZ = treatment zone, RZ = reference zone.

Zone	Year	Mean (SD) width (ft)	Mean (SD) Depth (in)	Bank stability score
TZ	1995	19.6 (6.2)	7.3 (4.1)	3
	2000	**16.7 (3.4)**	**6.8 (2.5)**	**4**
	2007	**16.7 (4.1)**	**5.5 (2.6)**	**4**
RZ	1995	13.3 (2.1)	8.9 (3.0)	4
	2007	**13.4 (2.3)**	**7.1 (2.3)**	**4**

Table 4.–Substrate composition and gravel embeddedness in Silver Creek, Michigan before and after habitat improvement. Data collected after the addition of instream structures are in bold. Embeddedness scores are: 5 (less than 5% embedded), 4 (5–25% embedded), 3 (25–50% embedded), 2 (50–75% embedded), 1 (greater than 75% embedded; Platts et al. 1983). TZ = treatment zone, RZ = reference zone.

		Median						
		Percent composition						Embeddedness
Zone	Year	Boulder	Cobble	Gravel	Sand	Clay	Silt	score
TZ	1995	0	0	70	4	0	0	3
	2000	**0**	**35**	**48**	**6**	**0**	**0**	**3**
	2007	**0**	**30**	**49**	**3**	**0**	**0**	**3**
RZ	1995	0	8	30	23	32	0	3
	2007	**0**	**18**	**32**	**17**	**23**	**0**	**1**

Table 5.–*P*-values from analysis of variance modeling the effects of zone (treatment or reference) and period (before habitat improvement, after habitat improvement, and after a regulation change) on brown trout biomass and density. *N* refers to the total number of population estimates used in the analysis. TZ = treatment zone, RZ = reference zone.

Comparison	*N*	Metric	Source of variation	F	df	*P*
Within stream (Silver Creek TZ vs. RZ)	19	Total biomass	Zone	7.31	1, 13	0.018
			Time period	–	–	NS
			Zone*period	4.10	2, 13	0.042
		Density <4 in	Zone	15.33	1, 13	0.002
			Time period	–	–	NS
			Zone*period	–	–	NS
		Density >8 in	Zone	–	–	NS
			Time period	–	–	NS
			Zone*period	8.45	2, 13	0.004
		Density 8–12 in	Zone	–	–	NS
			Time period	5.87	2, 13	0.015
			Zone*period	9.04	2, 13	0.003
		Density >12 in	Zone	–	–	NS
			Time period	4.31	2, 13	0.037
			Zone*period	–	–	NS
Among streams (Silver Creek TZ vs. Spring Brook and Brandywine Creek RZs)	28	Total biomass	Zone	16.66	1, 19	<0.001
			Time period	–	–	NS
			Zone*period	4.05	2, 19	0.015
		Density <4 in	Zone	5.87	1, 19	0.01
			Time period	–	–	NS
			Zone*period	–	–	NS
		Density >8 in	Zone	6.70	1, 19	<0.001
			Time period	–	–	NS
			Zone*period	7.75	2, 19	0.001
		Density 8–12 in	Zone	10.72	1, 19	0.001
			Time period	–	–	NS
			Zone*period	7.98	2, 19	0.001
		Density >12 in	Zone	–	–	NS
			Time period	–	–	NS
			Zone*period	–	–	NS

Table 6.–Bonferroni-adjusted *P*-values from multiple comparison tests evaluating mean differences in biomass and density between the treatment zone and reference zones within periods before and after habitat improvement. Period 1 = before habitat improvement, Period 2 = after habitat improvement, Period 3 = after regulation change.

Metric	Period	Comparison	t	df	*P*
Total biomass	1	TZ vs. Silver Creek RZ	–	–	NS
	2	TZ vs. Silver Creek RZ	–	–	NS
	3	TZ vs. Silver Creek RZ	3.14	13	0.023
	1	TZ vs. Spring Brook RZ	–	–	NS
	2	TZ vs. Spring Brook RZ	–	–	NS
	3	TZ vs. Spring Brook RZ	3.61	19	0.011
	1	TZ vs. Brandywine Creek RZ	–	–	NS
	2	TZ vs. Brandywine Creek RZ	–	–	NS
	3	TZ vs. Brandywine Creek RZ	5.83	19	<0.001
Density >8 in	1	TZ vs. Silver Creek RZ	-2.83	13	0.043
	2	TZ vs. Silver Creek RZ	–	–	NS
	3	TZ vs. Silver Creek RZ	–	–	NS
	1	TZ vs. Spring Brook RZ	-3.33	19	0.021
	2	TZ vs. Spring Brook RZ	–	–	NS
	3	TZ vs. Spring Brook RZ	3.52	19	0.014
	1	TZ vs. Brandywine Creek RZ	–	–	NS
	2	TZ vs. Brandywine Creek RZ	–	–	NS
	3	TZ vs. Brandywine Creek RZ	5.72	19	<0.001
Density 8–12 in	1	TZ vs. Silver Creek RZ	–	–	NS
	2	TZ vs. Silver Creek RZ	–	–	NS
	3	TZ vs. Silver Creek RZ	3.00	13	0.031
	1	TZ vs. Spring Brook RZ	-3.64	19	0.010
	2	TZ vs. Spring Brook RZ	–	–	NS
	3	TZ vs. Spring Brook RZ	3.18	19	0.030
	1	TZ vs. Brandywine Creek RZ	–	–	NS
	2	TZ vs. Brandywine Creek RZ	–	–	NS
	3	TZ vs. Brandywine Creek RZ	5.86	19	<0.001

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