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EFFECTS OF WATERSHED BEST MANAGEMENT PRACTICES ON HABITAT AND FISH IN WISCONSIN STREAMS[1]

Lizhu Wang, John Lyons, and Paul Kanehl[2]

ABSTRACT: We evaluated the effectiveness of watershed-scale implementations of best-management practices (BMPs) for improving habitat and fish attributes in two coldwater stream systems in Wisconsin. We sampled physical habitat, water temperature, and fish communities in multiple paired treatment and reference streams before and after upland (barnyard runoff controls, manure storage, contour plowing, reduced tillage) and riparian (stream bank fencing, sloping, limited rip-rapping) BMP installation in the treatment subwatersheds. In Spring Creek, BMPs significantly improved overall stream habitat quality, bank stability, instream cover for fish, abundance of cool- and coldwater fishes, and abundance of all fishes. Improvements were most pronounced at sites with riparian BMPs. Water temperatures were consistently cold enough to support coldwater fishes such as trout (Salmonidae) and sculpins (Cottidae) even before BMP installation. We observed the first-time occurrence of naturally reproduced brown trout (*Salmo trutta*) in Spring Creek, indicating that the stream condition had been improved to be able to partially sustain a trout population. In Eagle Creek and its tributary Joos Creek, limited riparian BMPs led to localized gains in overall habitat quality, bank stability, and water depth. However, because few upland BMPs were installed in the subwatershed there were no improvements in water temperature or the quality of the fish community. Temperatures remained marginal for coldwater fish throughout the study. Our results demonstrate that riparian BMPs can improve habitat conditions in Wisconsin streams, but cannot restore coldwater fish communities if there is insufficient upland BMP implementation. Our approach of studying multiple paired treatment and reference streams before and after BMP implementation proved effective in detecting the response of stream ecosystems to watershed management activities.

(KEY TERMS: aquatic ecosystems; nonpoint source pollution; BMP evaluation; fish; physical habitat; stream; watershed management.)

INTRODUCTION

Although U.S. federal and state legislation has successfully reduced point-source pollution over the past 20 years, nonpoint source (NPS) pollution continues to degrade water-quality in the United States. In a 1992 assessment, NPS pollution from agricultural activities was ranked number one among the nation's five leading water pollution sources for streams and rivers (USEPA, 1994). Runoff from agricultural land located in upland areas can deliver animal wastes, inorganic nutrients, residues of pesticides and herbicides, and sediment to streams. Agriculture practices in riparian areas can result in loss of stream corridor vegetation and stream bank integrity, directly causing bank erosion and destabilization of the stream channel. Together, upland and riparian agriculture can harm stream water quality, habitat, and aquatic communities.

Since the late 1970s, many federal and state programs have been established to reduce agricultural NPS pollution through implementation of best management practices (BMPs) in riparian and upland areas. The major objectives of these programs are: to improve water quality, aquatic habitat, biological communities, and overall ecosystem integrity in the most cost-effective manner possible; to assist producers in reducing agricultural water pollutants; and to develop and test programs, policies, and procedures for controlling agricultural NPS pollution (Konrad *et al.*, 1985; Gale *et al.*, 1993). Because large amounts of funds and labor have been invested in controlling agricultural NPS pollution, efforts have been also made to evaluate whether BMPs have had a significant positive effect on the environment. The initial evaluations focused mainly on the efficiency of individual BMPs in removing one or more specific pollutants under particular conditions (e.g., Lant *et al.*, 1995; Moore *et al.*, 1995; Owens *et al.*, 1996; Robinson *et al.*, 1996; McGee *et al.*, 1997). However, extrapolation of these evaluation results to other pollutants or

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different environmental conditions has been challenging. More recently, evaluation efforts have begun to focus on responses of streams to a combination of different BMPs across whole watersheds. Such evaluations have been conducted at both the national level, such as the Section 319 National Monitoring Program involving more than 20 watersheds across the country (http://h2osparc.wq.ncsu.edu/319glossy/glossy.html), and the state level, such as Wisconsin's Priority Watershed Evaluation Study involving 33 streams and 81 sampling sites (Wolf, 1995; Wisconsin Department of Natural Resources, unpublished data).

In spite of the relatively large number of studies, the number of peer-reviewed publications describing responses of stream water quality to watershed-scale BMP implementation is small (Edwards *et al.,* 1996). In particular, few publications have examined responses of stream physical habitat and biological communities (see discussion section for details). There are two main reasons for this. First, stream responses to BMPs occur over long time periods, necessitating many years of data collection from reference and treatment streams before and after BMP implementation in order to complete a valid evaluation. Many studies have lacked sufficient spatial or temporal coverage for the detailed statistical analysis and strong inference required for scientific publication. Second, to date most watershed-BMP programs have been voluntary and have had limited and localized participation (Wolf, 1995). Consequently, changes in stream attributes have usually been small, transitory, and difficult to detect, even with a good experimental design, and there have been few results worthy of publication.

In this paper, we report on findings from our evaluation of two watersheds in Wisconsin. We were fortunate to have the funding and administrative support to conduct a ten-year study of responses of stream physical habitat and fish communities to watershed-scale BMP implementations across multiple sites in both treatment and reference watersheds. Our results illustrate the value of long-term monitoring coupled with a good experimental design for detecting change, but also reiterate the idea that stream changes will be minimal if BMP installation is limited.

METHODS

Study Design

A before-after-control-impact (BACI) experimental design was used to determine the effects of BMP implementation on stream habitat and biological communities in the study subwatersheds. This design has been considered the most appropriate and powerful for ecological field evaluations when sample sizes are limited and serial autocorrelation among samples is likely (e.g., Green, 1979; Stewart-Oaten *et al.,* 1992; Underwood, 1992, 1994; Stewart-Oaten and Bence, 2001), as was the case in this study. In the BACI design, data were collected simultaneously in an identical, standardized manner from both reference (control) and treatment (impact) streams several times before and several times after the occurrence of the treatment or the event being evaluated, in this case, the implementation of BMPs. Reference and treatment streams were paired and chosen to be as similar as possible, although the treatment stream was the only one to receive BMPs.

The BACI design we used was different from the conventional BACI design in several aspects. We chose to have two paired reference streams for each of the treatment streams to increase statistical power and in case some unanticipated change in land-use occurred in one of the reference streams during the study (Stewart-Oaten and Bence, 2001). We also had two regional least-impacted reference streams to provide an upper endpoint condition, representing the best possible condition that the treatment stream could achieve (Hughes *et al.,* 1986). We chose a fixed summer fish sampling time (advocated by Stewart-Oaten and Bence, 2001) instead of a random annual sampling time (advocated by Underwood, 1992, 1994) because both stream NPS pollution stress and observed changes following implementation of BMPs were likely to be greatest during this period. The fixed summer sampling time was also chosen to minimize seasonal variation in fish community characteristics and to maximize the efficiency of fish sampling.

Study Area

The study was conducted in two watershed areas, located in south-central and west-central Wisconsin (Figure 1). Each study area consisted of one treatment, two paired reference, and two regional least-impacted reference streams (Table 1), which were deliberately chosen to have similar characteristics in elevation, climate, surficial geology, soil, flow and temperature regimes, stream size, and stream segment gradient. Without human influence, the streams in each study area were expected to have similar water quality, physical habitat, and biological communities.

Spring Creek Study Area. The study streams are in south-central Wisconsin, second- to third-order,

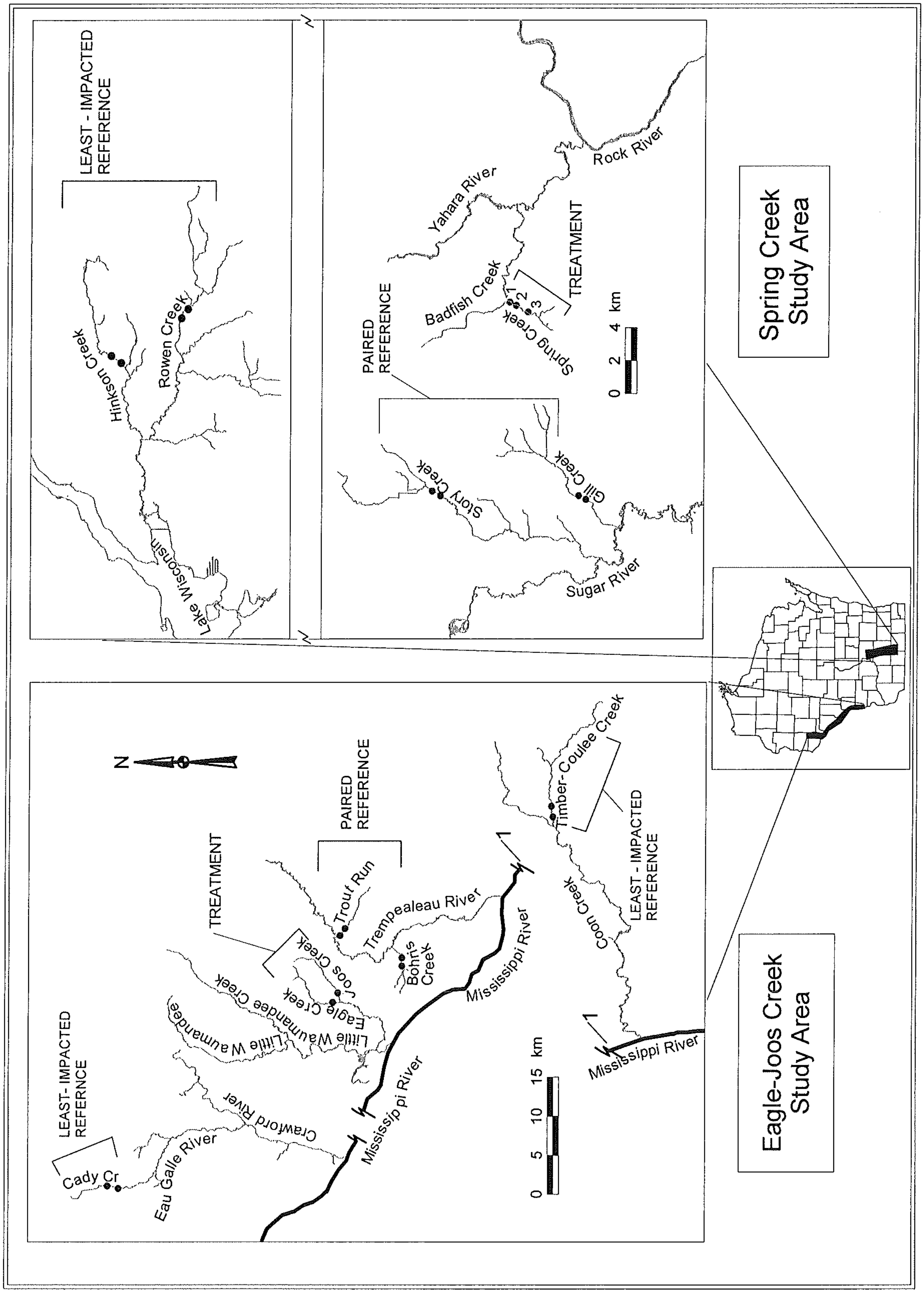

Figure 1. Study Watersheds With Approximate Locations of the Sampling Stations. In the Joos and Eagle Creek study area (left panel), the paired reference streams were Bohris Creek and Trout Run and the regional least-impacted streams were Timber Coulee and Cady Creek. In the Spring Creek study area (right panel), the paired reference streams were Story Creek and Gill Creek and the regional least-impacted streams were Hinkson Creek and Rowan Creek.

low gradient (generally less than 3 m/km), and located in agriculture-dominated watersheds with minimal urban influence.

TABLE 1. Stream Sampling Types and Number of Sampling Stations for the Study Watersheds.

Stream	Number of Stations	Stream Sampling Type
Spring Creek Study Area		
Spring	3	Treatment
Gill	2	Paired Reference
Story	2	Paired Reference
Hikson	2	Least Impacted Reference
Rowan	2	Least Impacted Reference
Joos-Eagle Creek Study Area		
Joos-Eagle	2	Treatment
Bohris	2	Paired reference
Trout Run	2	Paired reference
Cady	2	Least Impacted Reference
Timber Coulee	2	Least Impacted Reference

The treatment stream, Spring Creek, drains 1,492 ha and is a tributary to the Yahara River, which eventually flows into the Mississippi River through the Rock River. Spring Creek is classified by the Wisconsin Department of Natural Resources (WDNR) as a class III trout stream (WDNR, 1974) – a stream capable of supporting stocked trout during the spring, but lacking habitat or water quality suitable for trout survival throughout the year. Class III waters do not support natural trout reproduction and require annual stocking of legal-sized fish to provide a sport fishery. The land uses in the watershed in 1990 were 83 percent cropland, 3 percent pasture, 6 percent grass and woodland, 3 percent developed lands, and 5 percent wetland. The reported major NPS problems in the Spring Creek watershed included excessive pasturing along the stream banks with resultant losses of bank vegetation and hiding cover for fish, increased stream temperature, and extensive bank erosion (WDNR, 1994). Manure runoff from animal feed lots and heavily pastured areas created additional problems by contributing organic wastes that might have sporadically reduced stream dissolved oxygen levels. An estimated 92 percent of the total 2,940 metric tons of sediment annually delivered to the stream comes from upland crop farming (WDNR, 1994). Sediment inputs are believed to be responsible for the deep deposits of fine sediments and high degree of gravel and cobble embeddedness in the upper reaches of the streams and for the unstable substrates in the lower portion of the stream. The headwaters of the stream are channelized, which further modified stream hydrology and channel morphology.

In 1991, Spring Creek was designated as a priority watershed by the state of Wisconsin. In a priority watershed, land owners and local government are eligible to receive fund for sharing the cost of installation of BMPs. Since 1994 considerable resources have been allocated to reduce NPS pollution. As of 1999, BMPs had been installed in three of the five barnyards in the watershed (60 percent), along 488 m of the 1,772 m of degraded stream bank (28 percent), and on 1060 ha of the 1,274 ha of upland agricultural and developed areas (83 percent) (Table 2).

We established three treatment stations on Spring Creek near the bottom of the subwatershed to monitor the effects of subwatershed-scale BMP implementation on stream quality. Stations 1 and 2 were located adjacent to a large barnyard. The stream banks along these two stations were fenced to keep livestock off the banks and out off the stream in early 1995. Station 3 was located upstream of Stations 1 and 2, where the riparian land use was pasture and where stream bank fencing did not occur.

The paired reference streams, Story Creek and Gill Creek, drained 2,222 and 1,362 ha, respectively, at the furthest downstream sampling stations. They are tributaries of the Sugar River, which flows into the Rock River. Story Creek is a Class II trout stream (WDNR, 1974) – a stream capable of supporting a trout population with more than one age group, indicating substantial survival from one year to the next. Such streams also contain habitat and water quality adequate for natural reproduction but some stocking is necessary to fully utilize all available habitat or to sustain a fishery. Gill Creek is not classified as a trout stream currently but it has the potential to support trout when watershed conditions are improved. Two stations were sampled on each of these streams. There were no substantial land use changes in the paired reference subwatersheds during the study years.

The two regional least-impacted reference streams, Rowan Creek and Hinkson Creek, drain 2,494 and 1,810 ha, respectively, at our sampling stations and are tributaries of the Wisconsin River, which flows into the Mississippi River. Rowan Creek is a Class I and Hinkson Creek is a Class II trout stream at our sampling sites (WDNR, 1974). Class I streams are capable of supporting a trout population with more than one age group, have substantial survival from one year to the next, and contain adequate habitat and water quality for natural reproduction to support a sustainable fishery. There were two sampling stations on each of these streams. Neither stream

TABLE 2. Best Management Practices Implemented in the Spring Creek and Eagle-Joos Creek Study Areas.

	Spring Creek Study Area			**Eagle-Joos Creek Study Area**		
Year	**Barnyard* Management (number)**	**Shoreline Fencing (m)**	**Upland** BMPs (ha)**	**Barnyard* Management (number)**	**Shoreline Fencing (m)**	**Upland** BMPs (ha)**
Before 1991	0	0	0	0	0	0
1992	0	0	0	1	1,052	0
1993	0	0	0	0	0	0
1994	1	122	147	0	0	0
1995	1	366	424	0	0	0
1996	0	0	115	2	0	0
1997	0	0	69	0	0	0
1998	1	0	142	-	-	-
1999	0	0	163	-	-	-
Total	3	488	1,060	3	1,052	0
Eligible	5	1,772	1,274	17	8,565	1,267
Percent Installed	60	28	83	18	12	0

*Barnyard management includes manure storage and barnyard control systems.
**Upland BMPs include contour farming, reduced tillage, conservation crop sequence, strip crop, and critical area stabilization.

experienced major subwatershed land-use changes during our study.

Eagle-Joos Creek Study Area. The study streams are in west-central Wisconsin, are second- to third-order, have moderate gradients (5-9 m/km), and are located in forest dominated watersheds with intensive agricultural activities in the valleys along the streams.

The treatment streams, Eagle and Joos Creeks, drain 1,795 and 1,512 ha, respectively, at the study stations. They are tributaries of Waumandee Creek, which flows into the Mississippi River. Both Eagle and Joos Creeks are classified as Class III trout streams (WDNR, 1974). Watershed land uses in the watersheds are 58 percent woodland, 28 percent row crop, and 14 percent pasture for Joos Creek; and 57 percent woodland, 32 percent row crop, and 11 percent pasture for Eagle Creek (Wierl *et al.,* 1996). The major NPS problems in these watersheds are related to livestock. Overgrazing in the riparian area has removed bank grasses and woody plants, eliminating shading and overhanging vegetation, which has resulted in higher water temperature and less overhead hiding cover for fish. Livestock grazing also has destablized stream banks, leading to widespread bank erosion and excessive sedimentation of the stream bottom and channel widening. Two large riparian barnyards in Eagle Creek and one chicken farm in Joos Creek yield considerable amounts of organic wastes to the streams. Row crops in riparian and upland areas, which are grown to feed livestock, also contribute substantial sediment.

In 1990, Joos and Eagle Creeks were designated as priority watersheds and substantial funding was earmarked to install BMPs. However, by 1997, only 3 of 17 eligible manure storage facilities and barnyard-runoff control systems (18 percent), 1 of 11 contracted stream animal crossings (9 percent), 98 m of 8,565 m of eligible bank protection (1 percent), 1,052 m of 8,565 m of contracted fencing (12 percent), and none of 1,267 ha of eligible nutrient management and other upland BMPs had been implemented (Wierl *et al.,* 1996).

One sampling station from each stream was chosen to monitor the impacts of subwatershed BMP implementation on stream attributes. The stream banks along these two stations were fenced to keep livestock off the banks and streams in late 1991. At the Joos Creek station, bank stabilization structures were also installed along badly eroded areas.

The paired reference streams, Trout Run and Bohris Creek, drain 2,468 and 1,983 ha, respectively, at the furthest downstream sampling sites. They are tributaries of the Trempealeau River, which flows into the Mississippi River. Trout Run is a Class II trout stream (WDNR, 1974) and Bohris Creek is a nonclassified trout stream. Watershed land uses for these two streams are similar to those of Joos and Eagle Creeks and did not change during the study period. We had two stations on each stream.

The two regional least-impacted reference streams, Timber Coulee and Cady Creek, drain 3,026 and 3,432 ha, respectively, at our lower-most sampling stations. Timber Coulee is a tributary of Coon Creek, which flows into the Mississippi River. Cady Creek is a tributary of the Eau Galle River, which flows into the Chippewa River and from there into the Mississippi River. The primary land uses in these two subwatersheds are row crop agriculture (54 and 40 percent, respectively), pasture (14 and 37 percent), and woodlands (30 and 23 percent), and they did not change substantially during our study. Timber Coulee is a Class I and Cady Creek a Class II trout stream. There were two sampling stations on each stream.

Habitat and Fish Sampling

Sampling occurred during the late spring or summer of 1990 through 1999. Not all stations were assessed in each year of the study because a small number of sites were sampled in the initial years of the project and more sampling sites were added as more resources became available in subsequent year. In the Spring Creek study area, one station on Story Creek and two on Spring Creek were sampled for fish and habitat in 1993 and all stations on all five study streams were sampled from 1994 through1999. Data from 1993 to 1995 were considered as before BMP implementation. In the Joos-Eagle Creek study area, two stations on Bohris Creek and single stations on Joos Creek, Eagle Creek, and Trout Run were sampled from 1990 to 1997. One of the Timber Coulee stations was sampled from 1993 to 1997, and the remaining Trout Run and Timber Coulee stations from 1994 to 1997. The two Cady Creek stations were sampled from 1995 to 1997. Data from 1991 to 1992 were considered as before BMP implementation. Sampling always occurred from June 1 to June 15 in the Spring Creek study area and from July 14 to August 20 in the Joos-Eagle Creek study area, when low stream flows facilitated sampling effectiveness and large scale seasonal fish movements were unlikely to occur (Lyons and Kanehl, 1993).

A variety of fish and habitat variables were measured at each sampling station. Stations were 35 times the mean stream width in length or a minimum of 100 m, a distance sufficient to characterize the fish assemblage and to encompass about three meander sequences of the stream channel (Lyons, 1992; Simonson *et al.,* 1994a, 1994b). Actual station lengths ranged from 100 to 156 m. Water turbidity, dissolved oxygen, conductivity, and flow were measured at the downstream edge of the station. Lengths of runs, riffles, and pools and the mean distances between bends and between riffles were determined for the entire station. Thirty habitat variables, encompassing channel morphology, bottom substrates, cover for fish, bank conditions, riparian vegetation, and land use (Table 3), were measured or visually estimated along 12 evenly spaced transects using standardized procedures described in Simonson *et al.* (1994a, 1994b). These procedures yield data with known levels of accuracy and precision, typically ± 5 to 10 percent (Wang *et al.,* 1996). The entire length of each station was electrofished with either two single-anode backpack units in tandem or a single tow-bar unit with three anodes (Lyons and Kanehl, 1993; Simonson and Lyons, 1995). During the sampling, efforts were made to collect all fish observed, and all captured fish were identified and counted. Previous studies have shown that this sampling procedure adequately characterizes fish relative abundance and community structure and produces estimates with a standard error of approximately ± 10 to 20 percent (Simonson and Lyons, 1995).

Water temperatures were measured with a continuous-recording thermograph (Optic StowAway Temp, Onset Computer Corporation) at selected stations between late May and early September. Thermographs were installed at two stations on Spring Creek and one station on each of its four reference streams from 1993 to 1999 and at single station on each of the six streams in the Joos-Eagle Creek study area from 1994 to 1997.

Data Analysis

To summarize the habitat data, we first calculated the mean and variance for each variable for each station in each year. We then scored habitat quality using a system developed for Wisconsin stream fishes (Simonson *et al.,* 1994a). The overall habitat score was the sum of differentially weighted scores for the quality of riparian buffers, bank erosion, pool area, width to depth ratio, distance between riffles or bends, amount of fine sediment on the bottom, and cover for fish. Finally, we calculated the daily mean, maximum, and minimum water temperatures.

To summarize the fish data, we first determined the number of species, total fish density (number/100 m of stream length), cool- and coldwater-fish density (number/100 m), and the percentages of individuals that were tolerant and intolerant of environmental degradation (Lyons *et al.,* 1996). Fish data were then used to calculate an index of biotic integrity (IBI). The IBI is a widely used measure of the quality of the fish community, and an effective method to assess the overall condition or "health" of the stream ecosystem (Fausch *et al.,* 1990). The IBI applied here was specifically developed for Wisconsin coldwater streams and had values that could range from 0 to 100, with higher values indicating better fish communities (Lyons *et al.,* 1996).

TABLE 3. Descriptions of Habitat Variables Measured or Visually Assessed for the Study Streams. Most habitat variable descriptions are taken from Simonson *et al.* (1994a). An asterisk indicates variables that were measured and analyzed but not included in the results because changes in these variables do not directly indicate instream fish habitat improvement.

Variable	Description
	Stream Morphology
Depth (m)	Water depth measured at four equal distanced points per transect on 12 transects.
Distance Between Bends	Mean distance between bends divided by mean stream width.
Percent Pool	Percent length of station with deeper-than-average thalweg depths and little surface turbulence, slow water velocities, and eddies often present.
Percent Riffle	Percent length of station with shallower-than-average thalweg depths, obvious surface turbulence, and faster-than-average water velocities.
Percent Run	Percent length of station with average thalweg depths and little or no surface turbulence.
Sinuosity	Ratio of a 1000-m segment of stream (centered on station) divided by the straight line distance between the start and end of the segment.
Standard Deviation	Standard deviation of the mean thalweg depth for pool and run habitats.
Thalweg Depth (m)	The deepest water depth on each transect.
Width (m)	Stream width measured on 12 transects.
Width-to-Depth Ratio	Mean stream width divided by mean thalweg depth for run and pool habitats.
	Instream Cover for Fish (measured at four equal distanced points per transect on 12 transects)
Boulder (percent)	Rocks ≥ 0.25 m long found in or in contact with water ≥ 0.3 m deep.
Overhanging Vegetation (percent)	Thick vegetation overhanging water ≥ 0.3 m deep and ≤ 0.1 m above water surface.
Undercut Bank (percent)	Banks overhanging the water and meeting the criteria for overhanging vegetation cover.
Woody Debris (percent)	Large pieces or aggregations of small pieces of wood in or in contact with water ≥ 0.3 m deep.
Other Debris (percent)	All other types of debris found in or in contact with water ≥ 0.3 m deep that provide shelter or visual isolation for fish.
Macrophyte (percent)	Submerged and emergent vascular plants rooted in water ≥ 0.3 m deep that are thick or dense enough to provide shelter or visual isolation for fish.
Total Instream Cover (percent)	Sum of values for all cover categories.
	Riparian Land Use (within 5 m of stream edge) and Bank Condition (measured on 12 transects spaced three mean stream width apart)
Woodland (percent)*	Land dominated by trees > 3 m high.
Shrub (percent)*	Land dominated by trees and woody vegetation generally < 3 m high.
Meadow (percent)*	Land dominated by grass and forbs with few woody plants and not subject to regular mowing or grazing.
Residential (percent)*	Land modified for human use, including buildings, roads, parking lots, and recreational grounds.
Feed lot/ barnyard (percent)*	Land used to confine and feed high densities of livestock.
Wetland (percent)*	Land that is poorly drained and covered with standing water for much of the year, including swamps and marshes.
Cropland (percent)*	Land plowed and planted with row crops and harvested on a yearly basis, plus actively cultivated orchards and regularly mowed hayfields.
Bare soil (percent)*	Land covered by bare soil.
Pasture (percent)*	Land, either wooded or grassy, regularly grazed by livestock.

TABLE 3. Descriptions of Habitat Variables Measured or Visually Assessed for the Study Streams. Most habitat variable descriptions are taken from Simonson *et al.* (1994a). An asterisk indicates variables that were measured and analyzed but not included in the results because changes in these variables do not directly indicate instream fish habitat improvement (cont'd).

Variable	Description
Riparian Land Use (within 5 m of stream edge) and Bank Condition (measured on 12 transects spaced three mean stream width apart) (cont'd)	
Other (percent)*	Land that cannot be included in the other categories.
Buffer Vegetation (percent)*	Land covered with undisturbed vegetation (woodland, shrubs, meadow, wetland) within 10 m of stream edge.
Bank Erosion (percent)	Extent of stream banks (from toe to top; size variable) with bare soil that is susceptible to wind or water erosion.
Shade (percent)	The degree to which canopy vegetation intercepts sunlight to the stream channel.
Substrates and Stream Bottom Characteristics (measured at four equal distanced points per transect on 12 transects)	
Silt (percent)	Substrate of 0.004-0.062 mm particles.
Sand (percent)	Substrate of 0.063-2 mm particles.
Gravel (percent)	Substrate of 2.1-64 mm particles.
Rubble-Cobble (percent)	Substrate of 65-256 mm particles.
Boulder (percent)	Substrate of particles > 256 mm.
Bedrock (percent)	Substrate of solid, uniform rock.
Detritus (percent)	Substrate of partially decayed organic matter such as leaves, dead macrophytes, sticks, etc.
Attached Algae (percent)	Stream bottom covered with attached or filamentous algae.
Macrophytes (percent)	Stream bottom covered with submergent or emergent plants.
Sediment Depth (m)	Depth of fine sediments (sand or silt) that overlay or comprises the stream bed.
Embeddedness (percent)	The degree to which coarse gravel and rubble\cobble are surrounded by or covered with sand, silt, or clay.

We followed the BACI procedures recommended by Stewart-Oaten and Murdoch (1986) to test for statistical differences in fish and habitat variables related to BMP implementation. The two study areas were analyzed separately. First, we calculated the arithmetic mean for each of the variables that were obtained from the paired reference stations for each sampling year. Then, we subtracted this mean from the same variable that was obtained from each treatment station for the same year. Last, we performed a t-test on the differences between treatment and reference stations to compare if the mean difference before BMP implementation was statistically significant from the mean difference after implementation. Because the majority of BMPs in Spring Creek subwatershed were installed in 1995 and those in Eagle-Joos Creek in 1993, we used 1995 for Spring Creek area and 1993 for Eagle-Joos Creek area as the benchmarks for before and after BMP implementation. Results were considered significant if $P < 0.10$ because the continuous implementation of BMPs will substantially reduce the chance of type-I error.

Because water temperatures varied seasonally and annually in response to climate fluctuations, we analyzed our water temperature data slightly differently. First, for each station and year we regressed daily water temperatures on daily air temperatures obtained from nearby weather stations. Smaller slopes indicated more stable water temperatures that changed relatively little in response to changes in air temperatures. We then used the regression slopes as input into the BACI analysis. Water temperature data were not collected before BMP installation for the Joos-Eagle Creek study streams, so we only did the BACI analysis for the temperature data from the Spring Creek study area.

RESULTS

Spring Creek Study Area

Habitat quality in Spring Creek was improved after BMP implementation. Stream habitat rating scores and percentage fish cover increased and percentage bank erosion decreased significantly at Stations 1 and 2, where the banks had been fenced, relative to the paired reference streams (Figure 2). These three variables also showed the same trend at Station 3, which had not been fenced, but the changes were not statistically significant. Stream water depth increased and width/depth ratio decreased at all three Spring Creek stations after BMP implementation, but these changes were not statistically significant (Table 4). Seventeen other habitat variables were examined, but none showed consistent changes at the Spring Creek or reference stream stations.

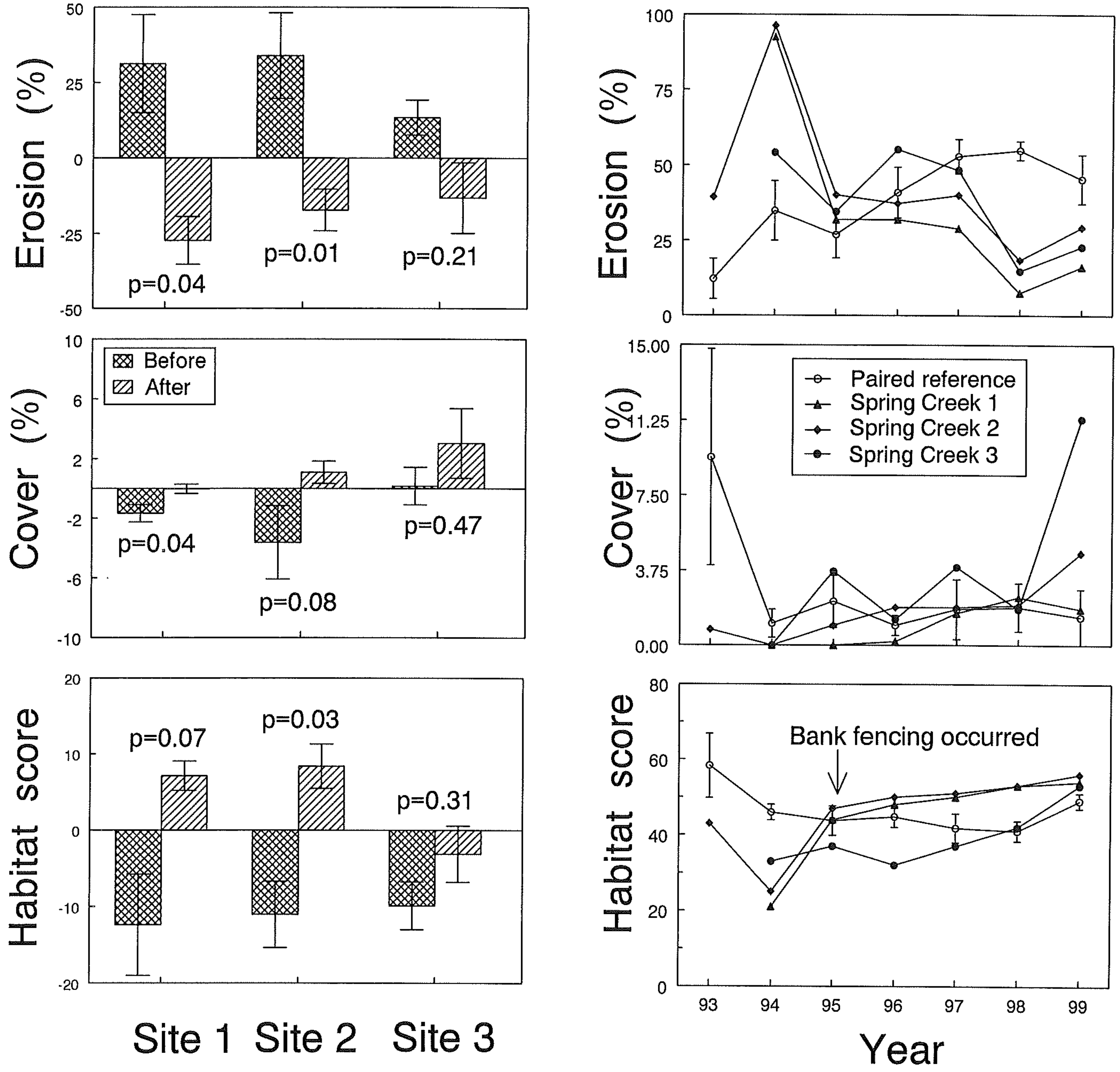

Figure 2. Mean Difference Between Treatment Stations and Paired Reference Stations Before and After BMP Implementation (left panels) and the Actual Values (right panels) for Habitat Score, Cover, and Bank Erosion for the Spring Creek Study Area. Error bars represent one standard error.

TABLE 4. Means and Standard Errors (in parentheses) of the Difference Between Treatment and Reference Values for Variables That Showed Improvement in Relation to BMP Installation. Statistically significant ($p < 0.10$) changes following BMPs are indicated by an asterisk.

Variables	Spring 1		Spring 2		Spring 3		Joos		Eagle	
	Before	After	Before	After	Before	After	Before	After	Before	After
Stream Depth (cm)	-4.4	-2.7	-2.7	-1.5	1.4	6.2	-7.0	2.1	-9.3	2.8
	(1.4)	(2.3)	(1.2)	(1.8)	(1.1)	(3.8)	(3.5)	(2.3)	(2.9)	(1.7)
Width/Depth Ratio	9.3	4.1	2.0	1.7	-1.7	-2.1	-2.1	-2.8	3.3	-0.6
	(2.2)	(1.5)	(1.3)	(0.6)	(1.7)	(1.3)	(1.4)	(0.6)	(0.1)	(0.6)
Regression Slope	0.0	-0.6	–	–	0.2	-0.5	–	–	–	–
(air vs. water temperature)	(0.2)	(0.2)	–	–	(0.1)	(0.1)	–	–	–	–
Tolerant Individuals (percent) (fish)	26.4	18.3	24.0	41.3	34.2*	10.0*	-6.2*	31.2*	-4.8*	17.5*
	(8.8)	(8.5)	(11.7)	(5.4)	(6.2)	(10.1)	(11.5)	(4.1)	(6.8)	(4.5)
Intolerant Individuals (percent) (fish)	-8.2	6.3	-9.6	-1.4	-12.0*	18.9*	-3.5*	-1.3*	-3.5*	-0.3*
	(11.5)	(4.1)	(9.5)	(7.3)	(8.5)	(6.2)	(0.3)	(0.2)	(0.3)	(0.9)
IBI Score (fish)	-20.8	-14.2	-20.9	-16.8	-14.2	-10.8	-8.9*	-18.3*	-8.9	-10.8
	(7.3)	(4.6)	(6.5)	(2.2)	(4.4)	(7.4)	(2.2)	(1.7)	(2.2)	(8.2)

The regression slopes between air and water temperatures decreased relative to the reference streams for Stations 1 and 3; no data were collected from Station 2 (Table 4). Water temperatures in Spring Creek were suitable for trout and other cool and coldwater species throughout the study, and daily mean water temperatures never exceeded 20°C. Daily mean water temperatures in Spring Creek were within the temperature range experienced by the two regional reference streams (Figure 3). The temperature in Spring Creek was usually 1 to 2°C higher than in Rowan Creek and 0 to 3°C lower than in Hinkson Creek.

Trout populations in Spring Creek improved after BMP implementation, whereas the reference streams did not show increases in trout abundance. Fingerling brown trout (*Salmo trutta*) (9 to 24 cm total length) were stocked in September annually in Spring Creek from 1987 through 1999. No trout were collected from Spring Creek in 1993 and 1994, but from 1995 through 1999 small numbers of stocked brown trout were found each year. In 1999, five young-of-the-year brown trout (less than 6 cm and less than 2 g) were captured from Spring Creek (one at Station 1, four at Station 3). These fish were much smaller than the stocked fish for that year (greater than 14 cm), indicating that they had been naturally reproduced. They represented the first naturally reproduced brown trout reported from Spring Creek (including data from unpublished WDNR surveys from 1980 to 1993). The two regional reference streams, Hinkson and Rowan Creeks, and one of the paired reference streams, Story Creek, yielded naturally reproduced brown trout or brook trout (*Salvelinus fontinalis*) every year. Numbers varied but no trends were evident. No trout were captured from the other paired reference stream, Gill Creek.

Overall fish abundance in Spring Creek increased after BMP installation. Catches of cool and coldwater fish, mainly mottled sculpin (*Cottus bairdi*), American brook lamprey (*Lampetra appendix*), and brown trout, and of all fishes increased significantly at Stations 1 and 2 relative to catches in the paired reference streams (Figure 4). The catch of cool and coldwater fish also increased at Station 3 but the change was not statistically significant. Index of biotic integrity scores and percentages of intolerant fishes improved at all Spring Creek stations, but the change was significant only for intolerant fishes at Station 3 (Table 4). The percentage of tolerant fishes also decreased significantly at Station 3.

Joos-Eagle Creek Study Area

Certain indicators of habitat quality at the Joos and Eagle Creek stations improved after BMPs were installed. Stream habitat rating scores and thalweg depth increased and stream bank erosion decreased significantly relative to values in the paired reference streams (Figure 5). Mean stream depth also increased and width-depth ratio decreased in Joos and Eagle Creeks, but these changes were not significant (Table 4). The remaining habitat variables did not show consistent changes at the treatment stations during the study period.

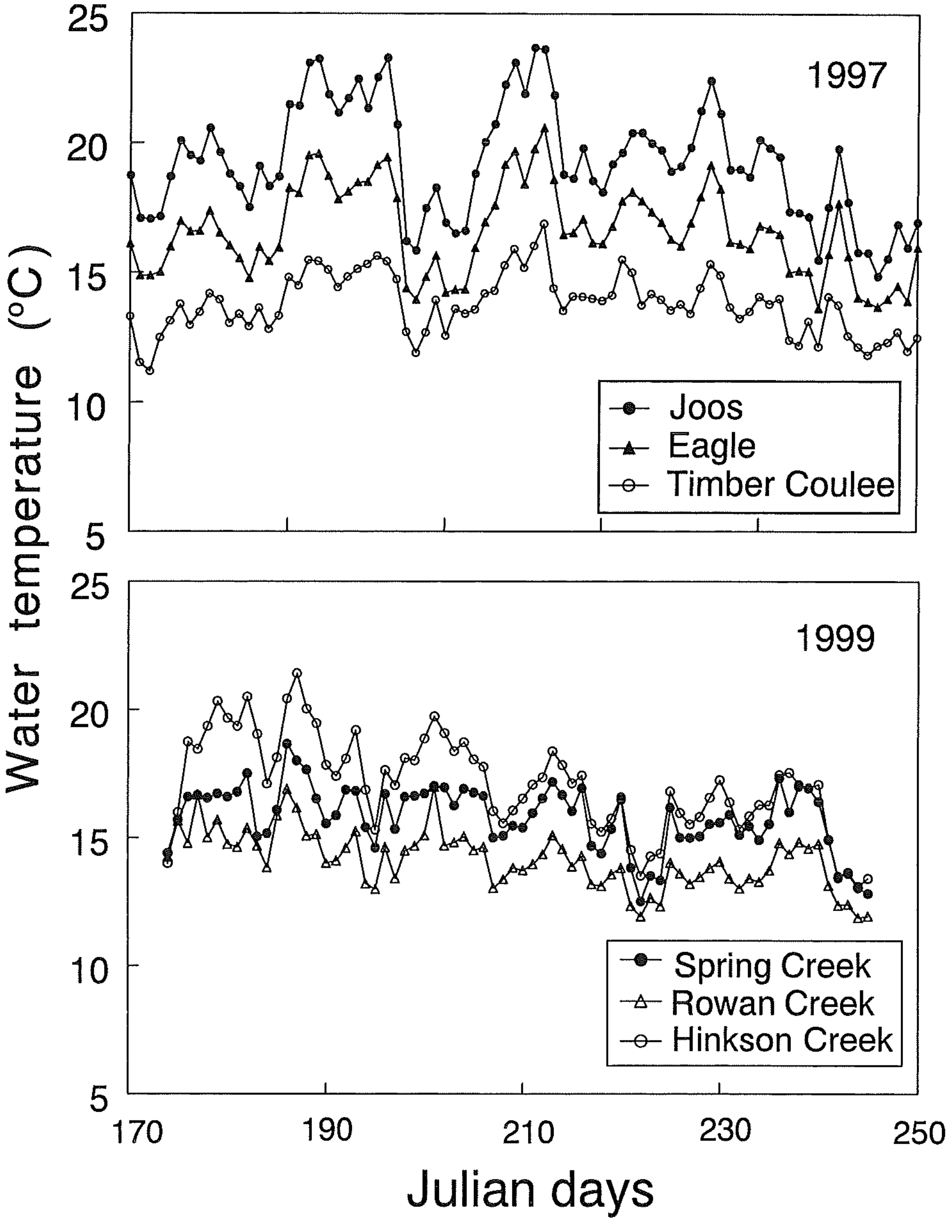

Figure 3. Daily Mean Water Temperature for Treatment and Regional Least-Impacted Reference Streams.

Water temperatures in Joos and Eagle Creek were marginal for trout. Joos Creek had the warmest temperatures, Eagle Creek and Bohris Creek temperatures were similar and cooler, and temperatures in Trout Run, Cady Creek, and Timber Coulee were the coldest (Figure 3). From 1994 to 1997, Joos Creek had 114 days in which daily mean water temperature exceeded 20°C, a maximum daily mean of 25.5°C, and a maximum instantaneous temperature of 29.8°C. In contrast, Eagle Creek had only four days with a daily mean greater than 20°C, a maximum daily mean of 20.6°C, and a maximum instantaneous temperature of 24.7°C. Similarly, Bohris Creek had four days with a daily mean greater than 20°C, a maximum daily mean of 20.8°C, and a maximum instantaneous temperature of 23.1°C. Daily mean temperatures in Trout Run, Cady Creek, and Timber Coulee were always less than 20°C.

Fish abundance did not improve after BMP implementation in Joos and Eagle Creeks. Total catch of all fishes did not increase (Figure 6). Differences in catches of cool and coldwater fish did change significantly between Eagle and Joos Creeks and the paired reference streams, Bohris Creek and Trout Run, but these changes were the result of declines in cool and coldwater fish at the reference stations for unknown reasons rather than increases at the Joos and Eagle Creek stations. Cool and coldwater fish

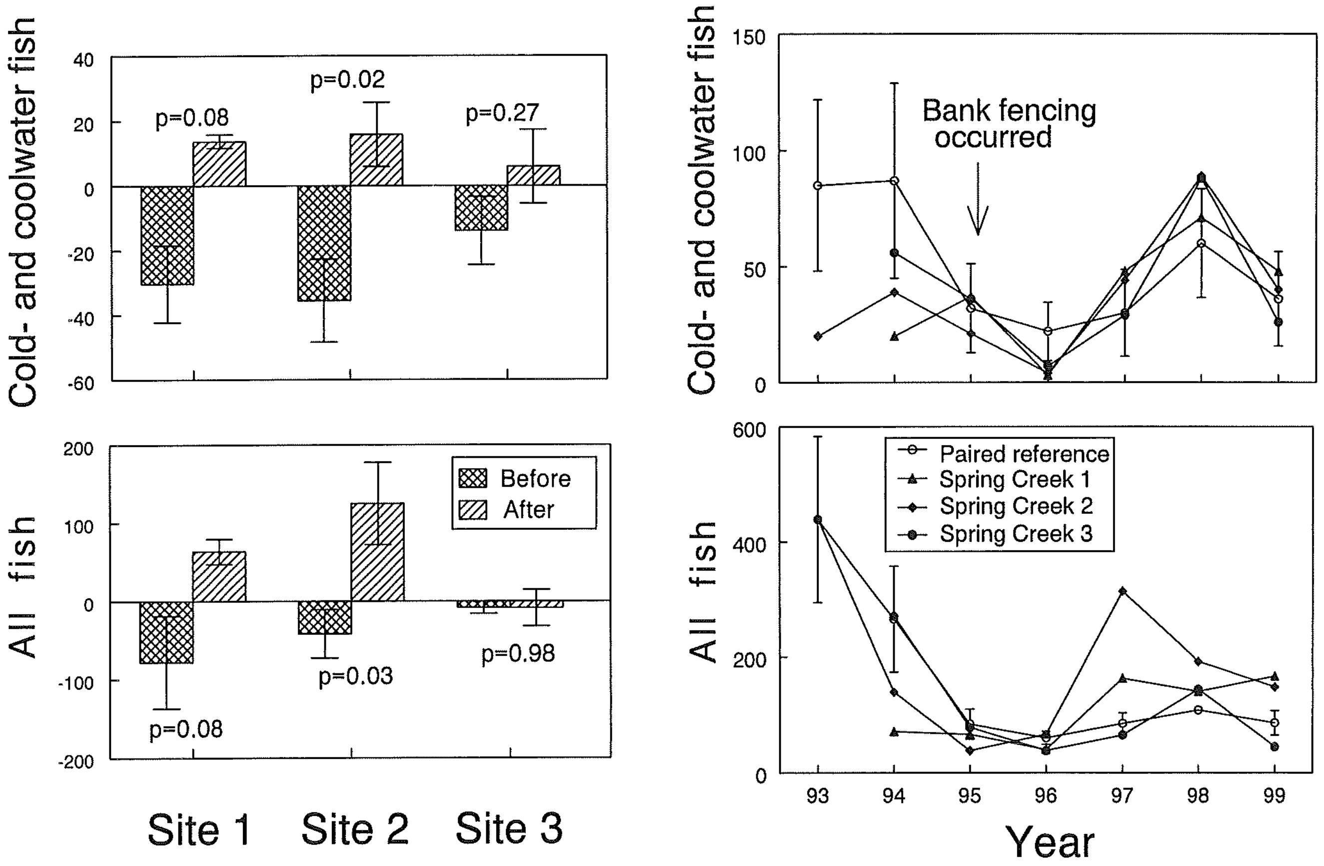

Figure 4. Mean Difference Between Treatment Stations and Paired Reference Stations From Before and After BMP Implementation (left panels) and the Actual Catch (right panels; number/100 m) of Cool- and Coldwater Fish and of all Fish for the Spring Creek Study Area. Error bars represent one standard error.

were essentially absent from Joos and Eagle Creeks over the entire study period (Table 5). The only cool and coldwater fishes captured were one brassy minnow (*Hybognathus hankinsoni*) in 1991 and two brassy minnows in 1994 at the Joos Creek station and five brook trout in 1994 and one brown trout in 1997 at the Eagle Creek station. The regional reference streams had abundant populations of trout and sculpins.

Other fish variables also did not improve in Joos and Eagle Creeks following BMP implementation. Index of biotic integrity scores decreased significantly at the Joos Creek station relative to the paired reference streams and did not change at the Eagle Creek station (Table 4). Percentages of tolerant fishes increased in both treatment streams. Differences in percentages of intolerant fishes increased significantly in Joos and Eagle Creeks relative to the reference streams, but this was due to a decline in intolerant fishes at the reference stations rather than a gain in Joos and Eagle Creeks (Table 5). Over the entire study period, the only intolerant fishes captured at either the Joos or the Eagle Creek station were the five brook trout encountered in Eagle Creek in 1994.

DISCUSSION

Influences of BMPs on Stream Physical Habitat and Water Temperature

Our results demonstrate that BMP implementation in the Spring Creek and Joos and Eagle Creek subwatersheds improved overall stream physical habitat conditions. We are unaware of comparable studies concerning habitat, but our findings are consistent with previous evaluations of watershed-scale BMPs on water quality. In a preliminary evaluation of watershed-wide BMPs in a stream in south-central Wisconsin, Walker and Graczyk (1993) found declines in storm mass-transport of suspended sediment and ammonia nitrogen following watershed BMP implementation. In a Virginia stream, Park *et al.* (1994)

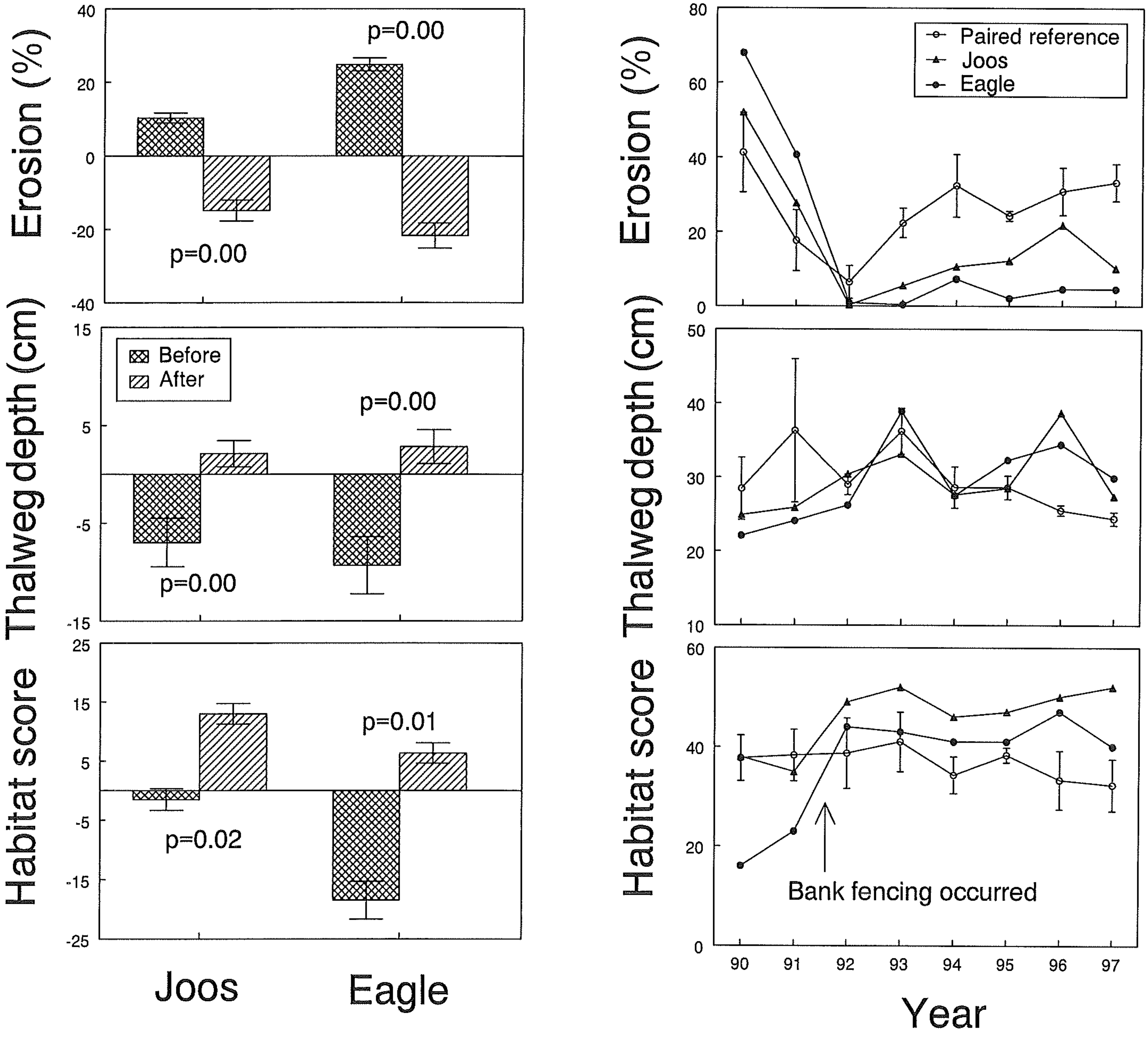

Figure 5. Mean Difference Between Treatment Stations and Paired Reference Stations Before and After BMP Implementation (left panels) and the Actual Values (right panels) for Habitat Score, Thalweg Depth, and Bank Erosion for the Joos and Eagle Creek Study Area. Error bars represent one standard error.

reported that watershed-scale BMPs reduced runoff, sediment, and nutrient (nitrogen and phosphorous) concentrations by approximately 5, 20, and 40 percent, respectively. Edwards *et al.* (1996) concluded that concentrations of ammonia nitrogen, Kjeldahl nitrogen, and chemical oxygen demand were significantly reduced by watershed-scale BMPs in an Arkansas stream.

In both of our study areas, obvious habitat improvements occurred where stream buffers and bank stabilization were installed as riparian BMPs. In Spring Creek, an observable habitat improvement also took place at a station without riparian BMPs. The Spring Creek results imply that both riparian and upland BMPs are valuable for restoring stream habitat. However, the results from Eagle-Joos and Spring Creeks together indicate that riparian area BMPs are effective only when watersheds are in reasonably good condition or are improved by watershed BMPs. Other studies, which did not examine BMPs per se, also indicated that stream habitat characteristics were determined by both riparian and watershed

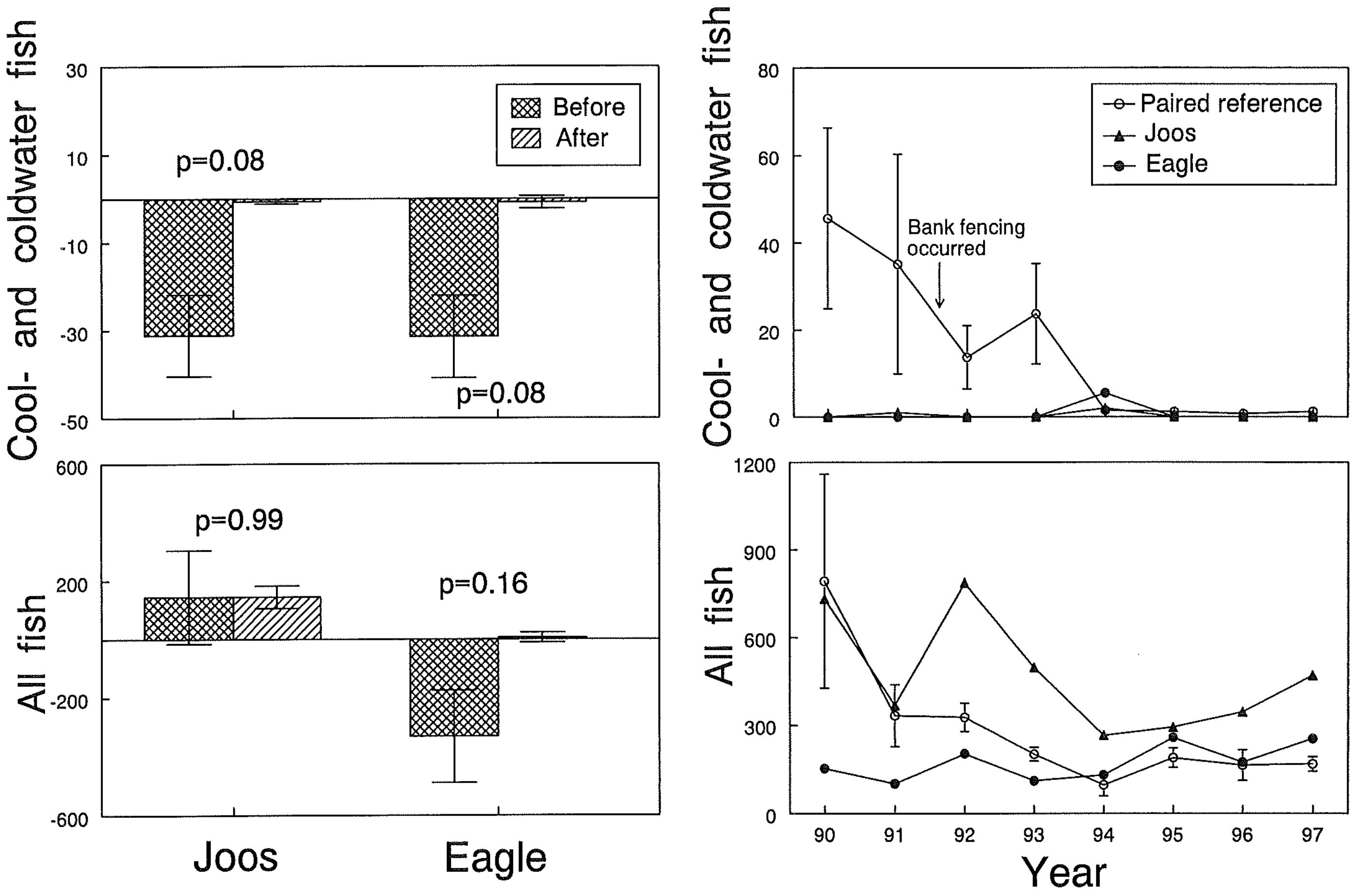

Figure 6. Mean Difference Between Treatment Stations and Paired Reference Stations Before and After BMP Implementation (left panels) and Actual Catch (right panels; number/100 m) of Cool and Coldwater Fish and of all Fish for the Joos and Eagle Creek Study Area. Error bars represent one standard error.

conditions. In a study of 46 stream sites in east-central Michigan, Richards *et al.* (1996) found that riparian attributes were more important for predicting sediment-related habitat variables whereas channel morphology was more strongly related to whole-watershed characteristics. In southeastern Michigan, Allen *et al.* (1997) reported that instream habitat structure and organic matter inputs were determined primarily by local conditions such as riparian vegetation, whereas nutrient supply, sediment delivery, hydrology, and channel characteristics were influenced by landscape features and land-uses upstream and away from the stream.

The thermal regime in Spring Creek was well within the range for supporting a trout population even before the installation of BMPs, which indicates that water temperature was not a controlling factor for determining stream quality in Spring Creek. However, although the changes were not significant, the regression slopes between air and water temperature did show a gradually decreasing trend after BMP implementation, implying that watershed land-use practices helped to stabilize stream water temperature. The lack of statistical significance may have been because of the continuous installation of BMPs during the post-treatment period coupled with a the delayed response between BMP implementation and stream temperature change. Changes in regression slopes were similar at sites with and without riparian BMPs, suggesting that any improvements in thermal regime were caused primarily by upland BMPs.

Although water temperatures at the Eagle and Joos Creek stations remained marginal for trout throughout the study, both stations appeared to have had the potential to support a coldwater thermal regime and fish community if additional BMPs had been installed in their watersheds. Both streams had cold headwaters that supported self-sustaining brook trout populations. These headwaters were more than 95 percent forested. In 1997, a site 9.5 km upstream of the study station in Joos Creek yielded 87 brook trout (WDNR, unpublished data). The maximum

TABLE 5. Mean and Range (in parentheses) of Annual Catch of Cool- and Coldwater and Intolerant Fish From the Study Streams for the Study Period. Cool and coldwater fish that are also intolerant species are indicated by an asterisk.

	Treatment Stream			Paired-Reference		Least-Impacted Reference		Treatment Stream		Paired-Reference		Least-Impacted Reference	
	Spring Creek 1	**Spring Creek 2**	**Spring Creek 3**	**Story Creek**	**Gill Creek**	**Hinkson Creek**	**Rowan Creek**	**Joos Creek**	**Eagle Creek**	**Bohris Creek**	**Trout Run**	**Timber Coulee**	**Cady Creek**
Cool and Coldwater Fish													
American Brook Lamprey* *Lampetra appendix*	0.8 (0-2)	0.7 (0-2)	1.3 (0-5)	12.4 (1-66)	1.8 (0-3)	3.4 (1-7)	2.9 (1-7)	0.0 (0)	0.0 (0)	6.8 (0-25)	1.2 (0-5)	0.8 (0-3)	0.0 (0)
Brook Trout* *Salvelinus fontinalis*	0.0 (0)	0.0 (0)	0.0 (0)	12.2 (2-26)	0.0 (0)	66.3 (34-140)	0.5 (0-1)	0.0 (0)	0.6 (0-5)	0.1 (0-2)	0.2 (0-1)	0.0 (0)	224.3 (108-357)
Brown Trout *Salmo trutta*	0.8 (0-2)	1.4 (0-4)	3.2 (0-7)	15.1 (4-40)	0.0 (0)	0.0 (0)	59.6 (31-112)	0.0 (0)	0.1 (0-1)	0.1 (0-1)	0.2 (0-2)	317.3 (210-376)	11.2 (0-33)
Brassy Minnow *Hybognathus hankinsoni*	1.0 (0-4)	2.1 (0-15)	3.2 (0-19)	0.3 (0-1)	0.0 (0)	7.8 (0-42)	0.0 (0)	0.4 (0-2)	0.0 (0)	2.9 (0-18)	10.9 (0-42)	0.0 (0)	0.0 (0)
Mottled Sculpin* *Cottus bairdi*	56.0 (5-109)	46.0 (5-116)	38.2 (5-93)	24.4 (16-44)	1.2 (0-3)	18.9 (7-34)	123.4 (93-146)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	284.0 (349-351)
Northern Redbelly Dace *Phoxinus eos*	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	3.8 (0-18)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Pearl Dace *Semotilus margarita*	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	26.0 (1-130)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Slimy Sculpin* *Cottus cognatus*	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	87.7 (12-154)	0.0 (0)
Intolerant Fish													
Blacknose Shiner *Notropis heterolepis*	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (0-3)	2.3 (0-8)	0.0 (0)	0.0 (0)
Iowa Darter *Etheostoma exile*	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (0-5)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (0-6)	0.3 (0-2)	0.0 (0)	0.0 (0)
Rainbow Darter *Etheostoma caeruleum*	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (0-1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)

water temperature in 1997 was 21.1°C at this site, compared with 29.8°C at the treatment station downstream. In Eagle Creek, a site 5.2 km upstream of the study station had 15 brook trout. The maximum water temperature there was 15.3°C in 1997, compared with 24.7°C at the treatment station. The BMPs planned for these watersheds, such as elimination of riparian pasturing, stream bank fencing, and conservation tillage crop farming, were designed to decrease and stabilize water temperatures. Upland BMPs, which reduce surface runoff and increase infiltration of rain and snowmelt, would increase groundwater inputs, which in turn would reduce maximum water temperatures in the stream (e.g., Lant *et al.*, 1995; McGee *et al.*, 1997). Riparian BMPs, which decrease stream width and increase shading would reduce the solar radiation reaching the stream and thus also reduce maximum temperatures.

Influence of BMPs on Fishes

Our results suggest that a certain minimum amount of BMP implementation was needed before stream fish communities would improve. The exact threshold level was unclear from our data, but seemed to fall somewhere between 30 and 50 percent of BMP implementation goals. Overall fish density, abundance of cool and coldwater fish, and survival and reproduction of brown trout increased in Spring Creek where most types of BMP installation exceeded 50 percent of goals. Conversely, there were no consistent fish community changes in Joos and Eagle Creeks where BMP installations were generally less than 30 percent of goals.

The type of BMP implementation also appeared to be important in determining fish community response. In Spring Creek, fish community changes differed between stations with and without riparian BMPs. At Stations 1 and 2, which had both riparian and upland BMPs, there were significantly increased densities of all fishes and of cool and coldwater fish. At Station 3, which had upland but no riparian BMPs, the percentage of intolerant fishes increased significantly and the percentage of tolerant fish declined. Riparian BMPs alone did not change fish communities at the Joos and Eagle Creek stations, despite significantly improved stream habitat.

Studies evaluating watershed-scale BMPs for improving biological communities are scarce. However, stream bank fencing, one of the riparian BMPs in our study, has attracted some attention (Rinne, 1999). For example, Stuber (1985) reported that after three years of stream bank fencing to exclude grazing by livestock from a Colorado stream, the stream bank vegetation recovered, the stream channel became narrow and deeper, and trout standing crop was twice the standing crop in the reference unfenced areas. Carline and Spotts (1998) measured several physicochemical and biological variables before and after a variety of riparian BMPs were implemented in four small catchments in Pennsylvania. The riparian BMPs included a combination of stream bank fencing, bank stabilization, and installation of rock-lined animal crossings. Several years after BMP implementation, macroinvertebrate density increased considerably in two of the four streams and fish biomass increased in one stream.

These two previous studies seem to contradict our findings from Joos and Eagle Creeks, where localized riparian fencing and bank stabilization improved habitat but not fish communities. However, DeBano and Schmidt (1989) describe two potential watershed scenarios that may account for the apparent discrepancy. In a review of watershed restoration techniques and opportunities, they presented one scenario where much of the watershed remained in reasonably good condition but the riparian area was highly degraded by concentrated livestock overgrazing or other farming activities. In such situations, which perhaps existed in the Colorado and Pennsylvania streams, they predicted that riparian BMPs alone would be effective for restoring habitat and biological communities. In their other scenario, which described the situation in our two study areas, both the riparian and the upland areas away from the stream were damaged by agricultural activities. In this case, they predicted that watershed BMPs alone (as in Spring Creek Station 3) or watershed plus riparian BMPs (Spring Creek Stations 1 and 2) might improve fish communities, but riparian BMPs alone (Joos and Eagle Creek Stations) would not. Our results are consistent with their predictions.

Challenges for Evaluation of Watershed-Scale BMPs

Statistically sound experimental design is crucial for evaluating watershed-scale implementations of BMPs to improve stream physical habitat and biological communities. The ideal experimental design recommended by both statisticians and fisheries scientists (e.g., Green, 1979; Stewart-Oaten and Murdoch, 1986; Stewart-Oaten *et al.,* 1992; Underwood, 1992, 1994; Rinne, 1999; Stewart-Oaten and Bence, 2001) is sampling paired treatment and reference watersheds and collecting pre- and post-treatment data on habitat and biological communities. However, it has been difficult to achieve this design in field studies. For example, Rinne (1999) reviewed 30 studies that examined effects of grazing and stream bank fencing on stream fishes in the western United States and concluded that none had an optimal experimental design and analysis. He reported that only three studies had pre-treatment data, and 21 studies had reference sites; however, in 17 studies, the reference site was on the same stream as the treatment site so that watershed-wide effects of grazing and fencing confounded the comparison of treatment with reference data. Only two studies had multiple years of pre- and post-data from different treatment and reference streams, and neither of these studies analyzed their results statistically. As another example, the 20 projects selected by the Section 319 National Monitoring Program had better experimental designs, including 16 projects with paired treatment and reference streams with before and after data and four projects with reference and treatment sites on the same stream. However, most of the projects deal only with water quality, and those with biological components have not yet produced final reports (http://h2osparc.wq.ncsu.edu/319glossy/glossy.html).

Even with ideal experimental design, two factors make adequate evaluation of watershed-scale BMPs especially difficult. First, it has proven challenging to have enough BMPs implemented in a watershed so that a response in the stream could be reasonably expected. This derives in large part from the voluntary nature of nearly all watershed restoration programs. For example, overall implementation rates in Wisconsin's Priority Watershed Program, one of the largest and most sophisticated voluntary nonpoint pollution abatement programs in the United States, have averaged 25 percent or less for most BMPs (WDNR, unpublished data). Our findings from the Joos and Eagle Creeks study area suggest that this level is insufficient to improve fish communities. Wolf (1995) critically reviewed the Wisconsin Priority Watershed Program and concluded that there had been little improvement in water quality, probably because of a lack of adequate participation by landowners in the program.

Because BMP implementation rates cannot be specified in advance and are generally low, it is difficult to pick a study watershed where enough land-use changes are certain to occur for a meaningful evaluation of stream responses. Because several years of pre-treatment data are needed to apply a BACI design, investigators run the risk of investing substantial resources in an evaluation of a watershed that receives few BMPs and then having nothing to evaluate in the post-treatment phase. However, if investigators wait until BMP implementation is certain, then there is usually not enough time to collect sufficient pretreatment data (Rinne, 1999). As an example, we chose our two study areas after considering numerous alternative Priority Watersheds. Our two study areas were judged to have the best chance of all the current Priority Watersheds in the state for high rates of BMP implementation. In our study watersheds, County Land Conservation Department staff made concentrated and above-normal efforts to get farmers to install BMPs. Yet BMP implementation rates remained low in the Joos and Eagle Creek study area.

Second, the amount of time required for a stream to respond to BMPs can be a problem. There may be a substantial lag between BMP installation and changes in the stream, and often five or more years of post-treatment data are needed to document a response. Coupled with at least two years of pretreatment data, this means that most evaluations require seven or more years of monitoring. Maintaining sufficient funding and staffing over this time span is often difficult. Moreover, during long studies other changes in the watershed may occur that are unrelated to BMP installation. Farmers may decrease or increase the amount of their land in production or the size of their livestock herds owing to shifts in the economy or in national farm policy. The types of crops or livestock and the way in which they are raised can also vary dramatically over time. Housing and commercial developments may permanently replace agricultural lands in developing regions. Such changes may not be congruent between treatment and reference watersheds, thus confounding the BMP evaluation. Fortunately, we had relatively few land-use changes that were unrelated to BMPs in our study areas, but this was largely a matter of luck given the rate at which farming practices are changing and urbanization is increasing in the rural areas of the United States.

SUMMARY

By sampling multiple paired treatment and reference streams before and after BMPs were applied, we were able to demonstrate that sufficient BMP implementation in a subwatershed could improve stream ecosystem quality. In Spring Creek, where relatively large amounts of BMPs were installed in both upland and riparian areas, habitat, thermal regime, and fish communities benefited. Habitat improvements were more pronounced at stations with both riparian and upland BMPs than at a station with only upland BMPs, but thermal changes were similar among stations. The stations with upland and riparian BMPs had increases in fish abundance whereas the station with only upland BMPs experienced a shift towards more intolerant and fewer tolerant fishes. In Joos and Eagle Creeks, where few BMPs were installed, no changes occurred in the fish assemblage or thermal regime. Habitat improved in localized areas where riparian BMPs were applied.

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