Responses in Fish Community Structure to Restoration of Two Indiana Streams

ASHLEY H. MOERKE* AND GARY A. LAMBERTI

Department of Biological Sciences, University of Notre Dame, Notre Dame, Indiana 46556-0369, USA

Abstract.—Stream restoration has accelerated in the Midwestern United States during the past decade, but the effects of restoration on stream biota are rarely evaluated. From 1997 to 2000, we studied the responses in fish communities to the attempted restoration of two channelized streams (Juday Creek and Potato Creek) in northwestern Indiana, each of which received two new meanders to a 1-km reach of stream length. The restored meanders of Juday Creek also received major improvement to instream habitat, bank stabilization, and silt control. In contrast, Potato Creek received only reconnection of the stream to historical meanders. Fish were monitored for 3 years after reconstruction by use of electroshocking and salmonid redd surveys. In Juday Creek, trout size-class distribution broadened and redd construction increased in the restored reaches. However, most fish metrics for reconstructed reaches did not surpass the levels in the channelized reaches after 3 years. Continued sedimentation from upstream sources, which reduced habitat quality, likely counteracted the positive effects of the restoration. In contrast, unanticipated geomorphic changes in Potato Creek led to decreased current velocity and highly altered fish community structure. The American brook lamprey Lampetra appendix, a sensitive species, was not collected after restoration, and the fish community changed from rheophilic species to highly tolerant, slow-water species. Overall, changes in fish community structure revealed strengths and weaknesses in contemporary stream restoration approaches, findings that will aid future restoration efforts.

At a global scale, aquatic and riparian ecosystems are being impacted by human activity at a greater rate than at any other time in history (NRC 1992). The Midwestern United States exemplifies this trend. Since the 1870s, Illinois and Indiana have lost more than 85% of their wetland area, with land use now dominated by agriculture (Dahl 1990; USDA 1992). Rapid agricultural and urban development in the Midwest has contributed to surface water pollution, draining of wetlands, and stream channelization. All of these activities can adversely affect habitat diversity and biological communities in streams and reduce water quality for human uses.

Fish communities have often been used to detect stream impairment because they are sensitive to a range of biological, physical, and chemical disturbances (Karr 1981). The structure of a fish community is influenced on a local scale by water depth, current velocity, size of substrate particles, cover, and temperature (Rabeni and Jacobson 1993), which also may alter biological interactions. Anthropogenic activities such as channelization alter many of these physical features and eliminate the natural pool-riffle sequence of a stream, which may affect the abundance and distribution of juvenile and adult fishes (Bayless and Smith 1964; Jones 1975). Stream restoration often attempts to reverse anthropogenic degradation by increasing habitat diversity (Gore et al. 1995) and thus favors different organisms, including fishes of various sizes and species. Despite the need to restore degraded habitat and improve water quality of Midwestern streams (NRC 1992), little information exists on the effects of restoration practices. Many studies have demonstrated the impacts of habitat degradation on fishes in coolwater streams (e.g., Elser 1968; Tarplee et al. 1971; Chapman and Knudsen 1980) and conversely the effects of small-scale habitat improvement (e.g., Saunders and Smith 1962; Hunt 1976). However, quantitative assessment of ecological responses to larger scale stream restorations are rare (NRC 1992; Kondolf 1998). As a result, many well-intentioned projects have either failed or caused further damage to the ecosystem (Iversen et al. 1993; Kondolf 1998). Thus, improvements to contemporary restoration approaches require basic research to document ecological responses. Stream restoration can be viewed as large-scale experiments that may provide opportunities to assess our current understanding of stream ecosystem structure and function and to test our abilities to successfully repair degraded ecosystems.

Our objective was to determine the effects of
current restoration approaches on stream habitat and the structure of the stream’s fish community by evaluating two stream restorations that differed in degree of geomorphic manipulation. In 1997, restorations were attempted for portions of two channelized streams in northern Indiana, Juday Creek and Potato Creek, by adding two meanders to a 1-km reach of each stream. We define these reconstruction projects as “restorations” because both projects attempted to return stream reaches to more naturally structured and functioning lotic systems (as defined by Gore et al. 1995). To evaluate the effects of restoration on habitat and fish metrics, we sampled unrestored (reference) and restored reaches for 3 years. We expected to see the greatest improvement in fish and habitat metrics in the restored reaches of Juday Creek because that stream received more intensive riparian and instream habitat enhancements than did Potato Creek. Further, we expected to see little change in habitat and fish metrics in any unrestored, channelized reach because no restoration was applied to such reaches over the study period.

Study Areas

Juday Creek.—Juday Creek (41°42’N, 86°13’W), which is approximately 19 km long, lies within the Lake Michigan drainage and drains 98 km². Juday Creek is one of only a few remaining coolwater streams with reproducing trout populations in northern Indiana (Lamberti and Berg 1995), although only nonnative salmonids (i.e., brown trout \textit{Salmo trutta} and rainbow trout \textit{Oncorhynchus mykiss}) have inhabited Juday Creek in recent history. Row-crop agriculture and urbanization dominate watershed land use (Lamberti and Berg 1995). Because the study area has been channelized for many decades, stream biota have long been subjected to degraded habitat and water quality, including increased sedimentation. Restoration of Juday Creek was associated with a golf course development within the urban area, and the purpose of the project was to minimize the impacts of the golf course on stream biota while increasing instream habitat diversity and creating a self-maintaining stream channel.

In fall 1997, new channels were constructed in Juday Creek, banks were planted with native trees and grasses, fine sediment was retained, and instream habitat was enhanced. Approximately 800 m of new channel was excavated into two meanders to relocate the existing channel through regrowth woodland bordering the golf course (Figure 1A). Channels were excavated to specific cross-sections to create a pool-riffle sequence, and banks were sloped to minimize bank erosion. Gravel was added to the streambed to enhance spawning conditions, and boulders, rootwads, and logs were placed in the channel to decrease bank erosion, promote pool scouring, and provide habitat for fish and macroinvertebrates. Erosion control fabric, seeded with a mixture of native grasses and planted with tree saplings, was used to stabilize the stream banks of the restored reaches. An instream sediment trap (18 × 5 × 2 m) was excavated upstream of the restored channels and downstream of a designated reference reach. The sediment trap was dredged annually after construction.

Two unrestored and two restored reaches were designated for study (Figure 1A). One unrestored reach (U1), which was downstream of the restored reaches, was characterized by a straight run, sand and silt substrate, and dense overhanging vegetation. The two restored reaches (R1 and R2) had meandering channels, gravel and cobble substrate, abundant woody debris, and a moderate canopy. A second unrestored reach (U2) was upstream of the sediment retention basin; it had a straight channel, fine sediment, undercut banks, and a well-developed canopy. Riparian and instream habitat improvements were applied only to R1 and R2. U1 and U2 were considered reference (control) reaches. Mean wetted width was 5.37 m and mean depth was 0.39 m for all study reaches.

Potato Creek.—Potato Creek (41°32’N, 86°21’W) is located within Potato Creek State Park and flows into the Kankakee River (Mississippi River drainage). Watershed land use is dominated by row-crop agriculture. Although Potato Creek was channelized many decades ago, imprints of the stream’s natural meanders remained in the floodplain. The restoration consisted of reconnecting two historical meanders to the channelized stream, thereby lengthening the stream by approximately 300 m (Figure 1B). Water from the channelized stream was diverted into the old meanders and allowed to erode its own channel, thus requiring limited construction. Stream banks were not stabilized and no instream habitat structures were added to the new meanders.

Four reaches were studied in Potato Creek. The manipulated old reach and an upstream reference reach were studied for prerestoration conditions (Figure 1B). The old reach had fine sediment, a mature canopy, abundant large woody debris, and undercut banks. The reference reach had a mean width of 6.8 m and depth of 0.18 m, sand and
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Figure 1.—Pre- and postrestoration study reaches in (A) Juday Creek (South Bend, Indiana) and (B) Potato Creek (North Liberty, Indiana) from 1997 to 2000. Stippled areas near Juday Creek represent golf course holes. Distances are approximate. Arrows indicate direction of flow. The abbreviation REF refers to the reference reach; other labels are described in the text.

The old reach was abandoned during the restoration; in its place were created two meanders (M1 and M2). The downstream meander, M1, contained a short riffle with cobble and gravel but otherwise was dominated by a run with fine sediments, eroding banks, and a moderate canopy. The upstream meander, M2, also had a short riffle composed of gravel and cobble but mainly consisted of a long pool with abundant large woody debris and a dense canopy. Beavers built a dam in M2 about 6 months after the restoration, but within 2 months it was abandoned and removed by park personnel.
Methods

Experimental design.—Habitat and fish surveys were conducted in restored and unrestored reaches of Juday Creek and Potato Creek both before and after restoration. Before restoration of both Juday Creek and Potato Creek, logistical constraints limited sampling to only one date. In addition, because restored reaches were undergoing active construction, it was not possible to sample those reaches before restoration. To address this deficiency in baseline data, we also evaluated reference (unrestored) reaches in the same streams throughout the study period. Tracking the changes in the reference reaches, supplemented by the pre-restoration data, helped us interpret the data from the restored reaches.

Habitat surveys.—Habitat surveys of Juday Creek and Potato Creek were conducted approximately 2 months before restoration and 33 months after restoration. Surveys were conducted at base flow by a team of 2–3 researchers. During each survey, the study reaches were divided into stream habitat units (riffle, run, or pool) based on standard criteria (Bisson and Montgomery 1996). In each habitat unit, length, mean width, and depth were measured and the dominant substrate and percent embeddedness were estimated (Platts et al. 1983). Current velocity was measured with a Montedoro–Whitney electromagnetic flowmeter, and dissolved oxygen was measured with a Hydrolab MIniSonde. Temperature was monitored continuously in restored and unrestored reaches by using StowAway XTI temperature loggers. The abundance of large woody debris (≥1 m long × ≥10 cm in diameter) was measured by counting each piece and noting the location. To determine substrate composition for all reaches, we took six substrate cores (10 cm deep × 5 cm in diameter) per reach. In the laboratory, cores were wet-sieved and then dry-sieved into 10 different size fractions (Cummins 1962). Sediments smaller than 2 mm were considered fine sediments.

Fish surveys.—Fish were sampled in Juday Creek by backpack electroshocking. Electroshocking was conducted 2 months before restoration and then at 9, 11, 21, 23, 33, and 35 months after restoration. A Smith–Root model 12 POW backpack electroshocker was used to sample a 60-m stream length chosen to be representative of each study reach. Block nets (mesh size, 5 mm) were set at the upstream and downstream ends of the sampling reach. Three sequential passes were made through each reach to deplete the reach of all fish. Fishes were identified, weighed, and measured and then were returned to the sampled reach. Fish abundances in restored and unrestored reaches were statistically compared over all sampling dates by using a repeated measures analysis of variance (ANOVA; SAS Institute 1991). Fishes were assigned to feeding guilds (Poff and Allan 1995) to compare feeding guild composition between restored and unrestored reaches over time. To assess the age-class structure of rainbow and brown trout and to achieve a larger sample size, we combined data from all reaches in Juday Creek. In addition to electroshocking, salmonid redds were counted biweekly from late October to February to encompass fall and winter spawning runs in all reaches.

In Potato Creek, fish were sampled with a backpack electroshocker 3 months before restoration and at 10, 22, and 34 months after restoration. Electroshocking methods were similar to those used in Juday Creek, except that 50-m reaches were sampled in Potato Creek. At 22 and 34 months, water was too deep to effectively electroshock the reference reach, so no data were available for that reach at that time. Fishes were assigned to current velocity and silt tolerance guilds (Poff and Allan 1995).

Results

Juday Creek

Habitat changes.—Habitat diversity and large woody debris abundance increased in both restored reaches shortly after restoration (Table 1). In addition, the percent of stream length consisting of pools increased and the substrate embeddedness declined in the restored reaches. Despite the presence of an upstream silt trap, loading of fine sediments reduced microhabitat diversity in both restored reaches over the 3-year study, although sediment deposition and loss of pool microhabitats was most evident in the upstream restored reach, R2 (Table 1). No difference in water temperature was found between the restored and unrestored reaches. Average and maximum summer (June–August) water temperatures in Juday Creek were 19.6°C and 24.6°C, respectively.

Fish response.—Mean fish abundance did not differ significantly between restored and unrestored reaches over all sampling dates (Figure 2; \( F_{1,2} = 0.53, P = 0.54 \)). However, considerable variability was observed within the restored and unrestored reaches over the course of the study. At 35 months after restoration, fish abundance in
Table 1.—General habitat characteristics of Juday Creek (South Bend, Indiana) and Potato Creek (North Liberty, Indiana) 2 months before and 33 months after restoration. Habitat data are from surveys conducted in midsummer. Juday Creek after restoration is broken down into specific reaches (see text) when appropriate; ND = no data.\(^a\)

<table>
<thead>
<tr>
<th>Habitat changes</th>
<th>Juday Creek Before</th>
<th>Juday Creek After</th>
<th>Potato Creek Before</th>
<th>Potato Creek After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of habitat units</td>
<td>8</td>
<td>20</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Stream length comprised of pools (%)</td>
<td>1 U1: 1</td>
<td>R1: 33</td>
<td>7 U1: 1</td>
<td>73 U1: 1</td>
</tr>
<tr>
<td>Substrate embeddedness (%)</td>
<td>85 U1: 85</td>
<td>R1: 35</td>
<td>90 U1: 85</td>
<td>90 U1: 85</td>
</tr>
<tr>
<td>Fine sediments (%)</td>
<td>ND U1: 73</td>
<td>R1: 7</td>
<td>ND U1: 73</td>
<td>ND U1: 73</td>
</tr>
<tr>
<td>Mean current velocity (m/s)</td>
<td>0.390</td>
<td>0.370</td>
<td>0.245</td>
<td>0.005</td>
</tr>
<tr>
<td>Dissolved oxygen range (mg/L)</td>
<td>9.4–12.2</td>
<td>6.7–10.5</td>
<td>10.7–12.8</td>
<td>3.1–6.9</td>
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<tr>
<td>Large woody debris abundance (pieces/100 m)</td>
<td>14</td>
<td>20</td>
<td>27</td>
<td>87(^a)</td>
</tr>
</tbody>
</table>

* Immediately after restoration wood abundance declined, but beaver activity led to an overall increase in woody debris abundance.

R1 (162 fish/100 m) was more than twice that in R2 (75 fishes/100 m).

At 9 months after restoration, total fish biomass in R1 was about 1.5 times greater than in unrestored reaches and more than 4 times greater than in R2 (Figure 3A). Also, fishes in R1 were larger than in the other reaches (Figure 3B), a trend that persisted at 21 and 33 months after restoration. On all sampling dates, total fish biomass and mean individual size in U2 were greater than in U1.

Species richness of fishes did not show clear differences between reach types (Table 2). At 9 and 21 months after restoration, species richness was similar in restored and unrestored reaches (six to nine species, regardless of reach or time). At 33 months after restoration, richness in U1 and R1 declined to three and five species, respectively.

Before restoration, only nine fish species were found in the entire study reach of Juday Creek. At 9 and 21 months after restoration, two additional species, yellow perch and largemouth bass, were found in the study reach. Both species typically prefer lentic habitats, and they most likely colo-

Figure 2.—Mean fish abundance (±1 SE) in restored and unrestored reaches in Juday Creek as determined by triple-pass electroshocking of 60-m reaches. Data shown are from 1997 to 2000. The bold arrow on the x-axis indicates the date that restoration was completed.

Figure 3.—Fish biomass from electroshocking catches for restored and unrestored reaches of Juday Creek, presented as (A) total fish biomass and (B) mean individual mass. Data shown are from 9, 21, and 33 months after restoration (1998–2000).
Table 2.—Fish community composition and species richness in Juday Creek 2 months before and 9, 21, and 33 months after restoration. The following abbreviations are used: C, common; R, rare; and A, absent. Species comprising ≤5% of the sample were categorized as rare, those comprising >5% as common. Reach designations (U1, U2, R1, and R2) are described in the text. Data are from June electroshocking, except for the samples taken 2 months before restoration (~2 months), which are from August.

![Figure 4](image4.png)

**Figure 4.**—Feeding guild composition of fish in Juday Creek collected 2 months before restoration (1997) and 33 months after restoration (2000); NA = not available for sampling.

![Figure 5](image5.png)

**Figure 5.**—Number of salmonid redds observed during fall and winter spawning runs (1997–2000) in restored and unrestored reaches of Juday Creek.
trout were strongly represented in age-0 and -1 classes, and brown trout were strongly represented in age-0, -1, and -2+ classes (Figure 6B). A similar trend was found for salmonids at 35 months after restoration, but fewer age-1 trout were present.

**Potato Creek**

**Habitat changes.**—In Potato Creek, the number of habitat units (riffl e, pool, or run) decreased, the amount of stagnant water increased, and the abundance of large woody debris decreased shortly after restoration (Table 1). Subsequent beaver activity increased the abundance of large woody debris, but stagnant water and low amounts of dissolved oxygen persisted even after beaver activity ceased.

**Fish response.**—Fishes colonized the new meanders (M1 and M2) of Potato Creek 10 months after inundation at densities similar to or greater than that of the reference reach but less than pre-restoration densities (Figure 7). Overall, fish density in the reference reach declined by about 70% from prerestoration levels. From 10 to 22 months after restoration, fish density in M2 declined by 85%, whereas fish density in M1 was stable. At 34 months, densities in M1 were almost three times greater than prerestoration levels, whereas fishes were nearly absent from M2. Fishes could not be sampled effectively in the reference reach after 10 months because of increased water depths.

Ten species of fish were found in Potato Creek.
before restoration. At 10 months after restoration, richness declined to six species in all reaches, but at 22 months after restoration, richness increased to levels similar to those before restoration (Table 3). At 34 months, however, only two fish species were found in M2. Species losses and additions led to changes in community structure in the restored and reference reaches. Before restoration, blacknose dace and American brook lamprey were abundant, but at 22 months after restoration, blacknose dace were rare in M1 and absent from M2, and no brook lamprey were collected. In contrast, smallmouth bass and white suckers, which were rare in the old reach and absent from the reference reach before restoration, were common in all reaches at 22 months after restoration. By 34 months, central mudminnows were dominant in M1 and accounted for 50% of the catch, whereas M2 was nearly devoid of fish.

Before restoration, current velocity guild composition was similar between the old and reference reaches, and all guilds were represented in both reaches (Figure 8A). At 10 months after restoration, M1 was dominated by velocity generalists, whereas M2 was more diverse and similar to prerestoration composition. In the reference reach, slow-water species were more than 70% of the catch whereas fast-water species were absent. At 22 months after restoration, current velocity guild composition in M1 was similar to prerestoration conditions, whereas M2 was dominated by species that preferred slow or moderate current velocities. At 34 months, slow-water species made up more than 75% of the catch in M1. Overall, the number of fish species preferring moderate to slow water velocities increased and the fast-water species decreased in all reaches during the study period.

Before restoration, fish species that are highly tolerant of silt made up about 50% of the catches in the old and reference reaches (Figure 8B). At 10 months after restoration, the proportion of highly tolerant species in M1 declined to 20% because of an increase in the numbers of mottled sculpin, a species with low silt tolerance. In M2 and the

Table 3.—Fish community composition and species richness in Potato Creek 3 months before and 10, 22, and 34 months after restoration. See text for reach designations and the caption to Table 2 for other details. Data are from July electroshocking, except for samples taken 3 months before restoration (±3 months), which are from August. Reach REF was not sampled at 22 and 34 months because of increased water depth.

<table>
<thead>
<tr>
<th>Species and species richness</th>
<th>±3 months</th>
<th>10 months</th>
<th>22 months</th>
<th>34 months</th>
</tr>
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<tr>
<td></td>
<td>OLD</td>
<td>REF</td>
<td>M1</td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>C</td>
<td>R</td>
<td>A</td>
</tr>
<tr>
<td>Blacknose dace</td>
<td>C</td>
<td>C</td>
<td>R</td>
<td>A</td>
</tr>
<tr>
<td>American brook lamprey Lampetra appendix</td>
<td>C</td>
<td>R</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Central mudminnow Umbra limi</td>
<td>C</td>
<td>C</td>
<td>R</td>
<td>A</td>
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<tr>
<td>Creek chub</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Johnny darter</td>
<td>C</td>
<td>C</td>
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<td>C</td>
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<tr>
<td>Mottled sculpin</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Smallmouth bass Micropterus dolomieu</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>R</td>
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<td>White sucker</td>
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<td>C</td>
</tr>
<tr>
<td>Yellow bullhead Ameiurus natalis</td>
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<td>A</td>
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<td>A</td>
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<td>Species richness</td>
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<td>Species richness</td>
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<td>7</td>
<td>6</td>
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*Fish categorized as rare because only two individuals were found.
reference species in the community increased over time. At 22 months after restoration, highly tolerant species in M1 increased to prerestoration levels, accounting for 90% of the catch in M2. By 34 months, highly tolerant species were more than 80% of the catch in M1, and fish were nearly absent in M2. Overall, the proportion of individuals tolerant of silt increased throughout the study.

Discussion

Juday Creek

Colonization by any organism is influenced by the distance to a source of colonists, the mobility of colonists, the reproductive capabilities of colonists, and the availability of food and habitat (Gore 1985; Gore and Milner 1990). For example, Latimore (2000) found that benthic macroinvertebrates required more than 300 d to recolonize and reach stable densities in the restored reaches of Juday Creek; she suggested this was because they depended on accumulation of detritus and establishment of periphyton. However, fish recolonization of restored reaches in Juday Creek did not seem to be restricted by the above factors. By 9 months after restoration, all fish species found in the unrestored reaches were also found in the restored reaches. Peterson and Bayley (1993) also reported rapid recolonization by fishes in a warm-water Illinois stream at abundances similar to those of the original community. They also found that the recolonized fish community was similar in structure to the original community, suggesting that an environmental factor, such as habitat structure, was responsible for organizing the recolonized community. Jungwirth et al. (1995) found that within 3 years, fish density and biomass tripled, and species richness nearly doubled in reconstructed reaches of Austrian streams, which they attributed to greater variation in depths, velocities, and substrate types in the reconstructed reaches. Although the Juday Creek restoration increased habitat heterogeneity, we found no increase in species richness, but this outcome probably happened because the fish community in Juday Creek is naturally depauperate (Lamberti and Berg 1995; A. H. Moerke, unpublished data).

However, total fish biomass and mean individual mass had increased in M1 by 9 months after restoration, whereas biomass in M2 remained at or below unrestored levels. Previous studies have shown that fish biomass or numbers of large fish are positively related to the volume of deepwater habitat in small streams (Shetter et al. 1946; Angermeier and Karr 1984; Gerking 1994). In Juday Creek, the presence of larger fish and a greater total biomass in R1, and of the smaller fish and a lower total biomass in R2, indicated that the two restored reaches provided different types of fish habitat.

In Juday Creek, trout populations also responded rapidly to the restoration by spawning only in the restored reaches. In a restored Danish stream, Gortz (1998) observed five times as many brown trout redds in restored river sections than in unrestored sections, which suggests that spawning gravels had been a limiting habitat in these streams as well. However, in Juday Creek, reduced spawning activity and an increase in fine sediments over time in R2 suggests that silt deposition likely affected the selection of spawning sites over time.

Trout size-class distribution in Juday Creek also broadened after restoration. Jungwirth et al. (1995) observed an increase in fish size-classes as well as a greater density of juvenile fish in restored stream reaches than in channelized reaches in an Austrian stream. Those authors suggested that low habitat diversity in the channelized reaches led to domination by one or two age-classes. The increased abundance of larger trout in Juday Creek also suggests that the enhanced habitat diversity of restored reaches offered more niches for different age-classes. However, age-0 and age-1 trout were underrepresented in 1999 and 2000, respectively. Drought during summer 1999 led to unusually low flows in Juday Creek (U.S. Geological Survey gauging station 04101370). At low flow, age-0 fish are exposed to harsher physical conditions in shallow areas and increased predation pressure in deeper areas (Schlosser 1982; Matthews 1999). Thus, the observed decrease in age-0 trout during summer 1999 and in age-1 trout during summer 2000 may have been related to drought-induced low flow, as well as to a deteriorating spawning habitat related to silt input.

The Juday Creek restoration initially created diverse habitats such as deep pools, backwaters, and shallow riffles to support numerous fish species of various sizes. Using a simulation model, Schaaf et al. (1993) demonstrated that small changes in habitat could result in large changes in estuarine fish populations because habitat bottlenecks were alleviated by restoration. Although habitat bottlenecks in Juday Creek were lessened initially, these newly constructed habitats do not appear to be self-maintaining. Thirty-three months after restoration, the decrease in total fish abundance, coupled with

0 trout during summer 1999. Thus, the observed decrease in age-0 trout during summer 1999 and in age-1 trout during summer 2000 may have been related to drought-induced low flow, as well as to a deteriorating spawning habitat related to silt input.
changes in species composition and spawning activity in R2, suggested that habitat complexity led to low dissolved oxygen. As our study progressed, reaches became dominated by pool species such as white suckers and smallmouth bass, whereas riffle species such as blacknose dace and brook lamprey disappeared. Nearly 3 years after restoration of Potato Creek, fish community attributes continued to decline until only a few fishes tolerant to low dissolved oxygen levels and high silt concentrations were present. Meffe and Sheldon (1988) also found that local fish community structure was predictable from habitat structure and that current velocity and stream depth were the primary determinants involved. Our study confirmed that at the reach scale, the composition of the fish community closely tracked the changing habitat conditions (i.e., current velocity, stream depth, and dissolved oxygen) in Potato Creek.

**Summary and Implications**

The Potato Creek and Juday Creek restorations attempted to recreate historical channel sinuosity, as well as to restructure the channel to increase habitat complexity and thus biotic diversity. However, the two restorations involved vastly different degrees of geomorphic manipulation, which likely produced the different fish community responses. In general, fish population and community metrics for Juday Creek suggested nearly complete fish colonization by 9 months after restoration, although metrics seldom exceeded the levels of unrestored, channelized reaches. In contrast, the Potato Creek restoration led to dramatic and generally unfavorable geomorphic changes that resulted in low fish densities, altered community structure, and domination by slow-water, silt-tolerant species. In both restorations, fish community characteristics appeared to be linked to habitat complexity, but neither restoration led to the predicted positive changes of the fish community in the restored reaches. A target taxon for the Juday Creek restoration, trout populations, did respond positively to the newly constructed reaches, but later evidence suggests declines in recruitment.

For Juday Creek, our study suggests that sedimentation will be a chronic problem and that successful restoration may be achieved only if sediment input is controlled at the watershed scale. The Potato Creek project indicates that simple reconnection of a stream to historical channels, without adequate attention to geomorphology and hydrology, may be insufficient to achieve successful restoration. Our study of these two restorations suggests that (1) further research is needed to identify geomorphic features critical to successful stream restoration, (2) site-specific efforts may be ineffective if watershed conditions such as fine sediments and local species pools are not considered, and (3) stream restoration techniques can be improved by addressing future designs the factors that affect stream communities at multiple spatial and temporal scales.

Traditionally, aquatic resources have been managed at relatively small scales such as the stream reach (e.g., 100 m long). When degradation is suspected, stream management strategies (e.g., bank stabilization, installation of instream structures, addition of gravel to encourage salmonid spawning) often address only local impacts and are ineffective at rectifying problems originating at the watershed scale. In general, site-specific approaches for restoring streams often attempt to consider processes operating at the watershed scale (Rabeni and Sowa 1996; Kauffman et al. 1997; Norris and Thoms 1999). Streams that have been degraded by poor watershed land use cannot be restored by focusing solely on instream conditions (Rabeni and Sowa 1996; Kauffman et al. 1997). Factors degrading stream communities need to be identified, and management activities should be targeted to the highest level at which the negative influence occurs (e.g., the watershed; Rabeni and Sowa 1996).

Our study also demonstrated that a single set of measurements may not be appropriate for evaluating all restorations; rather, metrics must be carefully chosen to fit the specific restoration. For example, current velocity guilds detected fish community changes in Potato Creek because the reconstruction dramatically altered flow, whereas no changes were detected in Juday Creek when using this metric. Furthermore, the use of multiple pop-
ulation- and community-level metrics to evaluate biotic response allowed us to draw conclusions that would not have been possible had only a few population-level variables been evaluated. Finally, a thorough assessment of habitat quality was needed to interpret changes in fish community structure.

In 1992, the National Research Council recommended that 400,000 stream and river miles in the USA be restored by approximately the year 2012, and Science (Anonymous 1999) recently predicted that river restoration would be one of the seven scientific fields that will rise to prominence in the next decade. Clearly, the need to repair aquatic ecosystems is urgent, but quantitative information on the outcome of stream restorations is scarce (NRC 1992; Kondolf 1998) and should be addressed. Methods of stream restoration, adequacy of monitoring programs, and scale of current restoration efforts need to be thoroughly evaluated if the restoration of streams is to succeed in the U.S. Midwest and elsewhere.

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