RESEARCH

Effects of Channel Incision on Base Flow Stream Habitats and Fishes

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ABSTRACT / Channel incision is a widespread phenomenon that results in stream and riparian habitat degradation. Fishes and physical habitat variables were sampled at base flow from three incised stream channels and one reference stream in northwest Mississippi, USA, to quantify incision effects on fish habitat and provide a basis for habitat rehabilitation planning and design. Incised channels were sampled in spring and autumn; the reference channel was sampled only in the autumn. Incised channel habitat quality was inferior to the reference channel despite the presence of structures designed to restore channel stability. Incised channels had physical habitat diversity levels similar to a nonincised reference channel, but contained fewer types of habitat. At base flow, incised channels were dominated by shallow, sandy habitats, moderate to high mean local Froude numbers, and had relatively little organic debris in their beds. In contrast, the reference stream had greater mean water depth, contained more woody debris, and provided more deep pool habitat. Fish assemblages in incised channels were composed of smaller fishes representing fewer species relative to the reference site. Fish species richness was directly proportional to the mean local Froude number, an indicator of the availability of pool habitat.

Streams convey sediments as well as water to lower elevations. Channel incision (i.e., bed lowering by erosion) results from an imbalance of sediment supply and transporting capacity (Galay 1983). Sediment supplies can be abruptly reduced by closure of upstream reservoirs, imposition of erosion control activities throughout the watershed, and other causes. Stream sediment transport capacity can be abruptly increased by channel straightening or lowering base level. When the capacity of an alluvial stream to transport sediments exceeds supply, the channel will be eroded. In many cases erosion of the bed (channel lowering) is initially dominant over channel widening, but when a critical threshold is passed, widening can be explosively rapid, and increases in channel cross-sectional area of up to 1000% within a few years have been reported (Harvey and Watson 1986). Incision of a channel lowers base level for all of its tributaries, thus destabilizing the entire watershed landscape. Tremendous volumes of sediment are exported, substrates are buried or eroded away, and channel morphology, hydrology, and hydraulic characteristics are transformed.

KEY WORDS: Streams; Erosion; Sediment; Woody debris; Channel degradation; Habitat restoration; Fish; Diversity indices

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Physical changes in channel systems undergoing incision have been described (Galay 1983, Grissinger and Murphey 1983, Piest and others 1977, Simon 1989, Simon and Hupp 1986, Simon and Robbins 1987, Harvey and Watson 1986), but effects on aquatic habitats have not. Little attention has been paid to effects of incision on aquatic habitats relative to other impact categories (e.g., water pollution, reservoir construction, and channelization). However, because incision results in long-term morphologic transformation at the landscape scale, its potential for degrading biotic integrity is greater than point or nonpoint source pollution (Karr 1991), and recovery can be expected to be slow (Yount and Niemi 1990). Furthermore, a relatively small portion of the literature dealing with effects of disturbance on stream communities focuses on warmwater, sandbed systems. This article describes physical aquatic habitat and fish assemblages at base flow in three incised stream channels and one reference site in northwestern Mississippi, USA. All four streams were warmwater systems

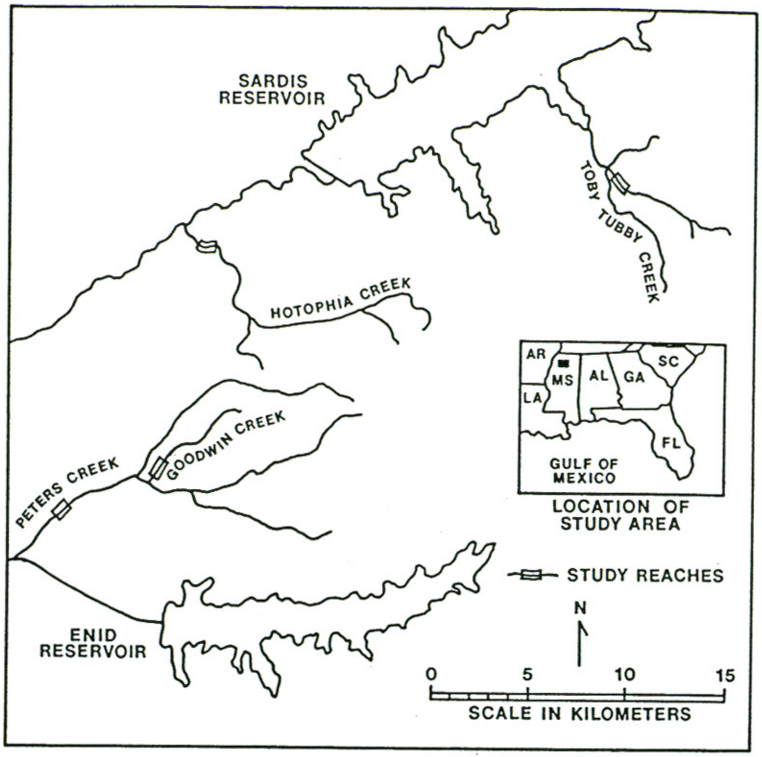

Figure 1. Study site locations. Each site was a 1-km-long reach. Peters, Hotophia, and Goodwin were deeply incised, while Toby Tubby was a nonincised reference site.

with predominantly sand beds. The utility of selected physical variables and diversity indices for describing incision effects on aquatic habitat quality are examined with an overall objective of quantifying deficiencies of incised channels to provide a basis for rehabilitation planning and design.

Unstable stream physical habitat may be characterized in two words: variable and harsh. Almost all stream environments display temporal variability, and unstable, incised streams are generally harsh habitats for fish because of their lack of cover, pool habitat, stable substrate, and heavy sediment loads. Many warmwater fish species are sensitive to the availability of pool habitat and cover (such as woody debris), and larger individuals of many species are particularly selective of slower, deeper habitats with cover (Meffe and Sheldon 1988). Although stream fish assemblages are structured by biotic (e.g., competition and predation) as well as physical factors, some investigators have suggested that physical factors are more important than biotic interactions in variable, harsh environments (Menge 1976, Peckarsky and others 1990, Ross and others 1985, Capone and Kushlan 1991). Schlosser (1987) proposed a conceptual model that predicted increasing fish species diversity with increasing water depth and temporal physical stability. Others have found that channels enlarged by excavation had depressed levels of physical heterogeneity (Scarnecchia 1988, Swales 1988) and, in some cases, fish species diversity (Gorman and Karr 1978). In light of these findings, we focused our investigation on effects of incision-related enlargement on physical habitat and fish species richness and diversity at base flow. We hypothesized that three of the major physical impacts of incision on fish habitat were reduced depth, increased hydrologic variability, and reduced bed stability and that these impacts would be manifest in the fish assemblages in the incised channels.

Study Sites

One-kilometer reaches in each of four northwest Mississippi watersheds were selected for study (Figure 1 and Table 1) based on their locations, disturbance histories, and the availability of hydrologic and geomorphologic data. Watersheds were located in the East Gulf Coastal Plain Physiographic Province along the bluffline of the Mississippi River Valley. Chronology and nature of valley-fill deposits have been described by Grissinger and Murphey (1982, 1986). Mean annual rainfall was about 1400 mm. Three of the reaches (Peters, Hotophia, and Goodwin creeks) were deeply incised, flanked by cultivated fields (cotton, soybeans, and corn), and confluent with incised

Table 1. Study site watershed and reach characteristics

	Incised channels			Reference channel, Toby Tubby
	Peters	Hotophia	Goodwin	
Watershed area (sq km)	205	91	21	38
Land use (%)				
Row crops	11	8	14	31[a]
Idle or pasture	53	40	60	
Forest or water	36	52	26	69
Stream Order	5	4	4	4
Median daily mean discharge (liter/sec)	611	402	40	ungauged
Range of daily mean sediment Conc. (mg/liter)	1–4530	1–4460	10–2400[b]	ns
Channel top width (m)	55–85	37–58	20–70	7–9
Channel depth (m)[c]	2–6	3–7	4–5	1–2
Bed slope (m/km)	0.9	1.1	1.6	2.1
Sinuosity[d]	1.08	1.40	1.12	1.25

[a]All nonforested area, including some urban and suburban area.

[b]Includes only suspended sediment finer than sand.

[c]Difference between top of bank and thalweg elevations.

[d]Length of thalweg divided by straight line distance between reach endpoints. Sinuosity = 1.0 for a perfectly straight channel.

channels 400–4800 m downstream from the lower end of each study reach. The three incised reaches were selected to provide a range of channel sizes based on contributing drainage area (Table 1). The reference stream, which had a contributing drainage area intermediate to the incised channels, was selected using an approach similar to that described by Hughes and others (1986) modified for this study. The reference channel was assumed to be indicative of conditions that would have been present in the other three streams if they had not undergone incision during the 40 years prior to the study. The reference stream, which was not incised, flowed into a flood-control reservoir and was flanked by forested wetlands. The reference site did not experience annual backwater flooding, and all four of the study reaches were upstream of major waterbodies that served as potential sources of fish for colonization. Lentic fish species were found in all study reaches.

Disturbance histories of the study reaches were similar. European settlement of the area, which began about 1830, was followed by deforestation, cultivation, rapid erosion of hillsides, and accelerated valley sedimentation in all four watersheds (Happ and others 1940). Valley bottoms were covered by up to several meters of sediments eroded from hillslopes (Happ and others 1940, Grissinger and Murphey 1986), and swampy conditions developed due to impaired drainage. Landowners, acting as individuals and through drainage districts, attempted to reclaim valley lands by channelizing streams and constructing drainage ditches between about 1840 and 1930. Most of these efforts were ineffective, and a second round of channelization and construction of major flood-control reservoirs on receiving streams by federal agencies occurred between about 1930 and 1960.

The incised study reaches (Peters, Hotophia, and Goodwin creeks) responded to channelization and reduction of flood stages on receiving streams by rapid incision during the 25 years prior to the study (Whitten and Patrick 1981, Neill and Johnson 1989). During the study, incision continued in reaches upstream from the three incised study areas, but the study areas were typical of the more advanced stages of incised channel evolution (Harvey and Watson 1986): base-flow channels flanked by sandy berms occurred within the main channel that had been enlarged by erosion. The reference site did not incise, evidently because channelization was confined to upstream and base level was not lowered.

Efforts to halt channel incision and restore watershed stability were underway at the time of this study. Grade control structures were placed immediately downstream from two of the incised reaches (Hotophia and Goodwin, Figure 1) about ten years prior to this study, and bank protection works were constructed along all three of the incised reaches during the four years prior to the study. Furthermore, during the seven years prior to the study, numerous grade control structures, bank protection devices, and

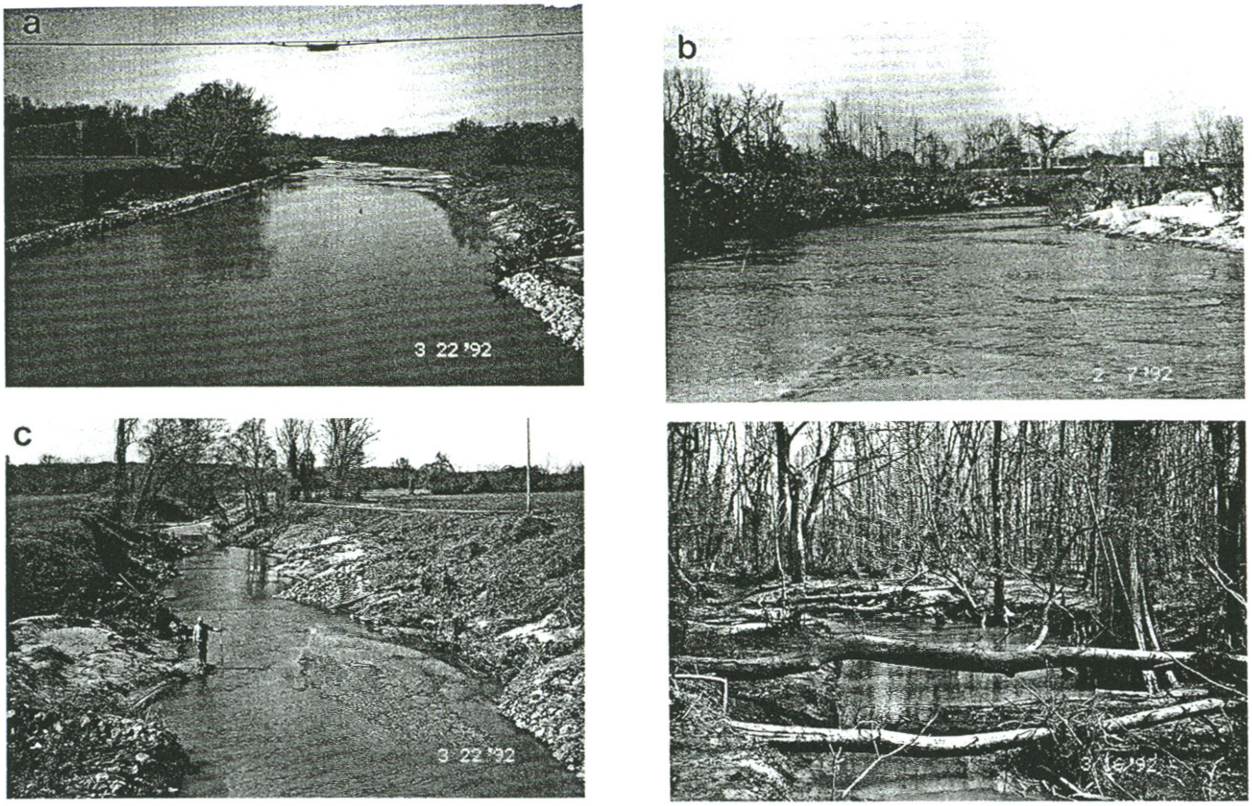

Figure 2. Photographs of study reaches. Peters **(a)**, Hotophia **(b)**, and Goodwin **(c)** Creeks were deeply incised, while Toby Tubby **(d)** Creek was a nonincised reference site.

drop inlet pipes were placed within the incising channel watersheds upstream of the study reaches.

Qualitative assessment of the three incised channel reaches indicated extremely poor physical habitat conditions. Base flow channels of moderate sinuosity were flanked by low (1 m or less) berms and flowed within deep (2–5 m), wide (20–85 m) incised high flow channels (Figure 2). Eroding banks were common. At base flow, velocities were moderate (0–30 cm/sec), but depths were extremely shallow (generally less than 20 cm), and substrate was primarily shifting sand. Woody debris and riparian vegetation large enough to provide canopy were infrequently encountered. Channel stabilization structures partially mitigated these conditions by providing stable, stony substrate, flow pattern heterogeneity, and small scour holes, but generally did not project far enough into the base flow channel to have much influence. The reference site was characterized by abundant woody debris of all sizes, frequent exchange of water and sediment with the floodplain, and dense (50%–70%) canopy. Incised channel hydrology tended to be flashy. Storm hydrographs were so sharp and brief that stages were constrained to a narrow range (15 cm) 80% of the time. Although the reference site was ungauged, weekly observations over several months indicated less flashy behavior: base flows (per unit watershed area) were generally greater, hydrograph peaks were lower, and high flow durations longer.

Study reach water quality was adequate for maintenance of healthy communities of aquatic organisms (Table 2). Cooper and Knight (1991) presented two years of weekly measurements of temperature, conductivity, dissolved oxygen, pH, solids (total, dissolved, and suspended), phosphorus, nitrogen, and indicator bacteria for eight sites in the Peters Creek watershed, including stations within our Peters Creek and Goodwin Creek study reaches. At normal and low flow, water quality conditions as indicated by all sampled parameters were not detrimental for aquatic life. Storm flows carried elevated (nearly 6000 mg/liter peak) suspended sediment loads and very low concentrations of residual pesticides, arsenic, and mercury. Less frequent sampling of the Hotophia and Toby

Table 2. Water quality conditions for three incised channels and one reference channel

Parameter	Incised channels Peters[a]	 Hotophia[b,c]	 Goodwin[a]	Reference channel, Toby Tubby[c]
Temperature (°C)	2.1–29.8 (17.5)	12.9–24.6 (18.5) 4.5–16.1 (10.1)	2.1–30.6 (18.0)	5.5–18.2 (12.0)
Conductivity (μmhos/cm)	22.0–130.0 (58.3)	15–67 (37) 21–72 (41)	22.0–99.0 (56.1)	22–185 (62)
Dissolved oxygen (mg/liter)	6.6–17.9 (11.2)	6.6–16.7 (11.1) 7.2–12.4 (9.9)	4.8–17.5 (11.1)	6.7–11.2 (8.3)
pH⁺	4.3–7.6 (6.8)	6.3–7.1 (6.9) 5.8–6.6 (6.3)	5.6–7.3 (6.6)	6.0–8.7 (6.7)
Total solids (mg/liter)	25–5,697 (163.0)	61–3.291 (873) 70–457 (157)	9–2.435 (113.4)	56–519 (187)
Dissolved solids (mg/liter)	42–95 (65.5)	15–3,273 (823) 35–58 (49)	9–92 (59.5)	26–122 (59)
Suspended solids (mg/liter)	0–5,640 (121.2)	10–72 (50) 16–438 (108)	0–2,398 (53.9)	4–483 (128)
Filterable orthophosphate (mg/liter)	0.009–0.723 (0.051)	0.00–0.02 (0.01) 0.001–0.026 (0.008)	0.008–0.342 (0.033)	0.051–0.093 (0.016)
Total phosphorus (mg/liter)	0.031–3.950 (0.163)	0.05–1.32 (0.35) 0.057–0.252 (0.107)	0.026–1.475 (0.095)	0.041–.449 (0.131)
Ammonium nitrogen (mg/liter)	0.000–0.650 (0.120)	0.05–0.28 (0.14) 0.037–0.262 (0.130)	0.000–0.638 (0.092)	0.012–1.659 (0.012)
Nitrate nitrogen (mg/liter)	0.014–0.598 (0.136)	0.02–0.15 (0.07) 0.060–0.198 (0.121)	0.015–0.868 (0.189)	0.221–0.653 (0.305)

[a]Means and ranges of weekly samples taken from the study site over two years by Cooper and Knight (1991).

[b]Means and ranges of quarterly samples taken for one year from three sites in the watershed by Knight and Cooper (1987).

[c]Means and ranges of five monthly wet season samples from three (Hotophia) and four (Toby Tubby) sites in the watershed.

Tubby study reaches indicated conditions there were also suitable for aquatic life. Similar data for the Peters and Hotophia sites were reported by Slack (1992).

Methods

Physical aquatic habitat and fish fauna were sampled from each of the three incised reaches at base flow in spring and autumn. The reference reach was sampled only in the autumn. Depth, velocity, and bed type were sampled at grid points using a procedure similar to one used by Gorman and Karr (1978) and Schlosser (1987). Different segments of the 1-km-long study reaches were sampled in spring and autumn. Sixteen to 28 transects were established along the base flow channel perpendicular to the primary current vector. Transect spacing was dependent upon water surface width: spacing was always equal to width at the downstream transect. Starting 10–50 cm from the left descending bank, three to seven regularly spaced points were sampled on each transect. A total of 101–137 points were sampled at each site; more points were sampled from more heterogeneous reaches (Gorman and Karr 1978). Side channels and embayments were sampled only if they were hydraulically connected to the main channel at up- and downstream ends. Depth was measured with a wading rod, velocity was measured at 0.6 depth using a Marsh-McBirney current meter (brand names provided for information only), and bed type was visually classified as clay, sand, gravel, riprap, vegetation, debris, or other (e.g., man-made items). At each point, the current meter probe was oriented to measure maximum velocity regardless of its direction. Velocities were visually estimated based on the configuration of the wake around the wading rod (Gorman and Karr 1978) when depth was less than 4–5 cm. Where two or more bed types were closely mingled, the classification was based on the type that dominated the area covered by the "foot" of the wading rod (an 8-cm-diameter disk). Water surface width was recorded at each transect. Water surface elevations were measured using staff gauges placed at roughly 250-m intervals. Discharges were obtained from continuous

Table 3. Categories used for calculation of physical habitat diversity

Variable	1	2	3	4	5	6
Depth (cm)	0–8	8–20	20–50	>50		
Velocity (cm/sec)	0–5	5–10	10–25	>25		
Bed type	Clay	Sand	Gravel	Riprap	Debris	Other[a]

[a]Includes vegetation (primarily temporarily submerged terrestrial herbaceous species) and man-made objects such as refuse.

gauge records or were estimated based upon depth and velocity measurements made at the most uniform transects.

Depth, velocity, and bed-type data distributions were examined using summary statistics and plots. Depth and velocity were used to compute local Froude[1] and Reynolds[2] numbers (Statzner and others 1988). Depth, velocity, and bed type data were also used to compute habitat richness, diversity, and evenness using an approach similar to that of Gorman and Karr (1978). Each grid point was assigned to a habitat category using the scheme presented in Table 3. Four depth categories, four velocity categories, and six bed types were recognized for a total of 96 possible habitat types. Depth and velocity categories were chosen to be representative of distinct fish habitats based on experience gained from extensive ichthyofaunal surveys of these and other watersheds in the region (Cooper and Knight 1987, Knight and Cooper 1987, 1990). Habitat richness (number of habitat types observed) S, Shannon and log series diversity indices H' and α, and Pielou evennes indices E were computed for each data set (Magurran 1988) $\{H' = -\Sigma p_i \ln p_i$, $\alpha = N(1 - x)/x$, and $E = H'/\ln S$ where p_i = number of points (or individuals) in ith category or species divided by N, the total number of points (or individuals) sampled, S = total number of categories (or species) observed, and x satisfies the equation $S/N = (1 - x)/x[-\ln(1 - x)]\}$. Rarefaction (Magurran 1988) was used to correct S values for nonstandard sample sizes prior to computing the log series indices. Shannon diversity indices were compared using t tests.

Three samples of surficial bed sediments were collected during base flow from the center and quarter points of each of 12 transects within each study reach at base flow. Samples were returned to the laboratory for sieve analysis. Channel bed slopes and sinuosities (sinuosity = length of thalweg/distance between reach end points) were determined from surveys obtained using standard techniques, and stream orders (Strahler) were computed using US Geological Survey 7.5-min topographic maps. Ephemeral channels were included in drainage network analysis for stream order determination.

Fish were collected on the same day that habitat variables were measured using a Coffelt BP-4 backpack mounted electroshocker. Four 100-m stream subreaches within each 1-km study reach were fished for approximately 900 sec of electric field application. Fishes longer than about 15 cm were identified, measured for total length, and released. Weights were estimated using length–weight regression formulas developed from previous collections of fish from northern Mississippi. Smaller fish and larger fish that could not be identified in the field were preserved in 10% formalin solution and transported to the laboratory for identification and measurement of weight and length. Species richness, Shannon and log-series diversity indices, and Pielou evenness indices were computed for each data set.

Results

Physical Habitat Characteristics

Discharges for autumn sampling dates were 10%–60% lower than for spring, and velocities and water depths were also less in autumn (Table 4), but autumn stages were only 2–7 cm lower than in spring. Two data sets were somewhat distinctive: spring data for Hotophia Creek reflected a slightly higher discharge level relative to the other data sets, and autumn hydraulic conditions at Goodwin Creek were influenced by backwater from an ~75-cm-high beaver dam about 200 m downstream from the lower end of the sampled area.

The incised channels had shallower water depths and greater water width-depth ratios than the reference stream (Table 4). A plot of mean depth versus

[1]The Froude number = $V/(gD)^{0.5}$, where V is current velocity, g is the acceleration of gravity, and D is depth. It is a dimensionless term equivalent to the ratio of inertial to gravitational forces. Within the range of depths and velocities found in our data set, the distribution of Froude numbers computed using point measurements of depth and velocity is an indicator of the availability of pool habitat (Sullivan 1986). Other investigators have found relationships between Froude numbers and lotic fish densities (Statzner and others 1988), and between the Froude number and bed roughness, sediment concentration, and bed stability (Simons and Senturk 1977, Richards 1982).

[2]The Reynolds number = VD/ν, where ν is the kinematic viscosity. It is a dimensionless term equivalent to the ratio of inertial to viscous forces and is a measure of the turbulence of the flow. Correlations between lotic fish densities and Reynolds number have also been observed (Statzner and others 1988).

Table 4. Hydraulic conditions at base flow in three incised channels and one reference channel

	Season	Incised channels: Peters	Incised channels: Hotophia	Incised channels: Goodwin	Reference channel, Toby Tubby
Discharge (liter/sec)	spring	1301[a]	821[a]	120[a]	ns
	autumn	538[a]	713[b]	44[a]	348[b]
Stage difference (cm) spring-autumn		2	6.5	2.5	ns
Percent of time sampled discharge is exceeded[c]	spring	50	30	19	ns
	autumn	60	35	46	
Percent depths >30 cm	spring	5	31	13	ns
	autumn	9	9	22	42
Width/depth	spring	110.6	61.7	28.2	ns
	autumn	117.5	104.1	36.1	17.5
Depth (cm)	spring	15 ± 8	26 ± 18	19 ± 11	ns
	autumn	15 ± 11	17 ± 10	21 ± 19	35 ± 24
Velocity (cm/sec)	spring	19 ± 12	36 ± 19	13 ± 12	ns
	autumn	17 ± 17	24 ± 12	4 ± 9	19 ± 13
Froude number	spring	0.16 ± 0.10	0.25 ± 0.14	0.09 ± 0.09	ns
	autumn	0.15 ± 0.15	0.20 ± 0.09	0.04 ± 0.10	0.11 ± 0.08
Reynolds number	spring	32,290 ± 7,630	95,000 ± 73,230	26,870 ± 29,190	ns
	autumn	29,300 ± 41,690	46,570 ± 41,400	7,360 ± 12,410	70,170 ± 58,410
Median surficial bed sediment size (mm)		0.40–9	0.08–0.48	0.24–0.85	0.06–0.55

[a]Mean of instantaneous values from permanent gauge within study reach.

[b]Computed from current meter measurements.

[c]Based on frequency distribution of mean daily values for four water years.

mean velocity (Higler and Mol 1984, in Statzner and others 1988) indicates the distinctive character of the reference site (Figure 3). Although it was deeper, the reference reach had a mean velocity that was higher than two of the three incised channels. With the exception of the spring data from Hotophia Creek and the autumn data from Goodwin Creek, the reference site had the lowest mean Froude number and the highest mean local Reynolds number due to the presence of deeper pools and absence of riffle areas. However, coefficients of variation for these variables from the reference site were not larger than those from the incised channels.

All channels had sand beds, but incised channel substrates often contained poorly sorted mixtures of sand and gravel, while the reference channel had more clay. No gravel was found in the reference channel, and sands found there tended to be finer than for the incised channels. Gravel riffles were observed at both the Peters and Goodwin sites, but were more frequent and regularly spaced at the Goodwin site. Organic debris was more frequently encountered in the reference stream bed (Figure 4), and field notes taken during subsequent inspections of the study sites indicate large woody debris information density at the reference site was more than ten times greater than for the incised channels.

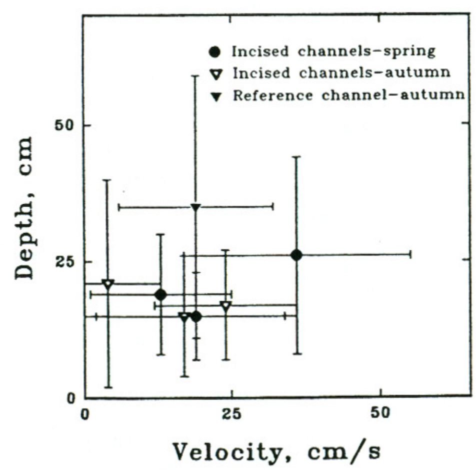

Figure 3. Mean depth and velocity for three incised channels and one reference channel at base flow. Depths were measured at regular intervals across 16–28 cross sections, and velocities were measured at 0.6 of depth at the same points. Error bars are ±1 SD.

Habitat diversity reflects two components: richness (the number of habitat types in a given area) and evenness or equitability (relative abundance of habitat categories). The reference channel contained more habitat types than any of the incised channels, but had

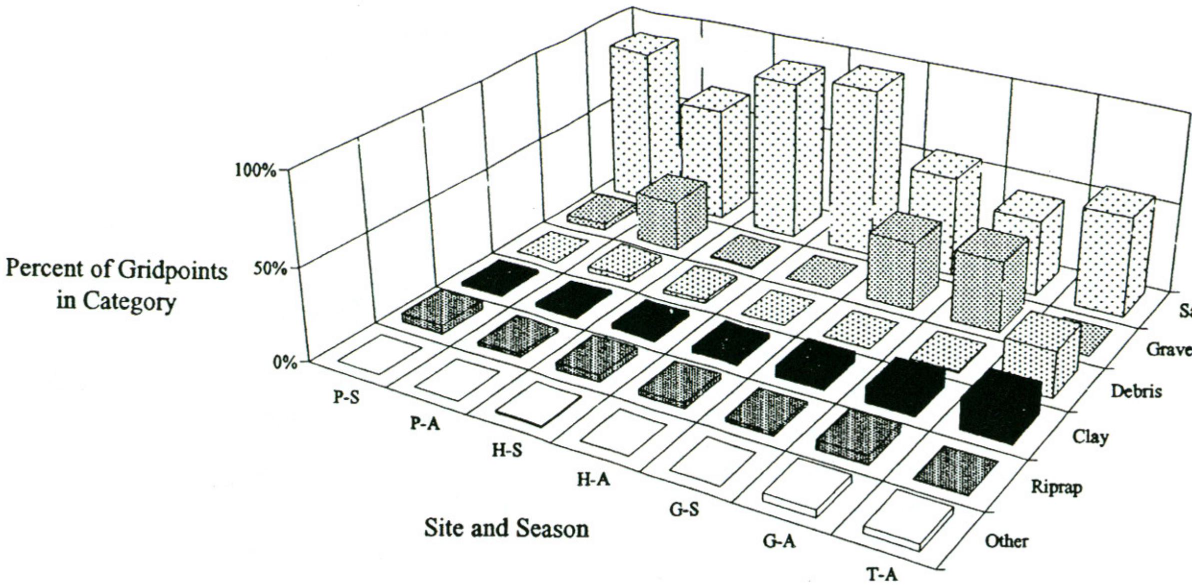

Figure 4. Frequency distribution of bed types in three incised channels and one reference channel at base flow. Labels on the *x* axis (Site) indicate both site (P = Peters, H = Hotophia, G = Goodwin, T = Toby Tubby) and season (S = spring and A = Autumn).

Table 5. Physical aquatic habitat diversity at base flow in three incised channels and one reference channel

		Incised channels			Reference channel,
		Peters	Hotophia	Goodwin	Toby Tubby
Number of points	spring	102	122	124	ns[a]
	autumn	132	101	137	138
Number of habitat categories (S)	spring	20	24	29	ns[a]
	autumn	33	16	29	38
S corrected for sample size	spring	17	17	24	ns[a]
	autumn	26	13	24	28
Shannon index (H′)[b]	spring	2.18 ± 0.14	1.84 ± 0.15	2.82 ± 0.13	ns[a]
	autumn	2.80 ± 0.13	1.90 ± 0.13	2.79 ± 0.12	2.70 ± 0.15
Pielou eveness (*E*)	spring	0.73	0.58	0.84	ns[a]
	autumn	0.80	0.69	0.83	0.74
Log series index (α)	spring	7.09 ± 1.72	7.09 ± 1.72	12.84 ± 2.62	ns[a]
	autumn	14.95 ± 2.93	4.63 ± 1.27	12.84 ± 2.62	17.28 ± 3.27

[a]Not sampled.

[b]Shannon indices were compared using a two-tailed *t* test (Magurran 1988). The spring index for Goodwin Creek was different from the other two at the 99.9% significance level. Autumn indices were not significantly different, except for Hotophia Creek, which was different from the other three at the 99.99% level. The differences between spring and autumn indices for each stream were also tested, and only Peters Creek showed a significant change between seasons, perhaps because the area sampled in the autumn included a relatively narrow gravelly run.

an intermediate level of evenness (Table 5 and Figure 5). Accordingly, the Shannon index for habitat did not discriminate between the reference channel and the incised channels. The log series index, which has a higher level of discriminant ability than the Shannon index (Magurran 1988), was highest for the reference channel. The scheme we used to assign points to habitat categories lumped all points with depths >50 cm into one category (Table 3). If we had used a scheme that included a fifth depth category for depths greater than about 80 cm, habitat diversity values for the reference site would have been greater. Although

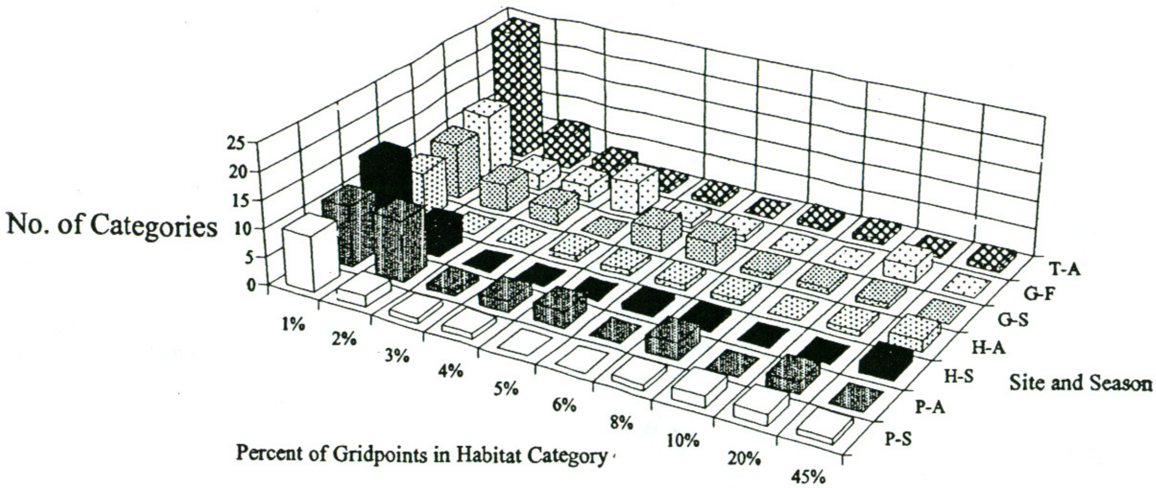

Figure 5. Frequency distribution of sampled points among habitat categories for three incised channels and one reference channel at base flow. Height of bars indicate the number of habitat categories that contained the indicated percent of the sampled points. For example, more than 20 of the 38 habitat categories detected at Toby Tubby in the autumn were represented by only 1% of the points. Labels on the *y* axis (Site) indicate both site (P = Peters, H = Hotophia, G = Goodwin, T = Toby Tubby) and season (S = spring and A = Autumn). Habitat categories are defined in Table 3.

depths in this range are usually required for large individuals, we could not identify a species or group of species that require or prefer depths this large.

Two major differences between our reference site and the incised channels were not quantified but were readily observable: the reference channel was less flashy (less rapid stage variation), and there were numerous hydrologic connections between floodplain beaver ponds and forested wetlands along the reference channel. In contrast, the incised channels were so deep and wide that overbank flow was a rare event. Inflows to the incised channels were either from similarly incised tributaries or ditches draining fields. Riparian zones were either absent or were disturbed areas of erosion or deposition. The forested wetlands along the reference channel and upstream reaches evidently acted as a reservoir to dampen discharge extremes and may have served as a source of allochthonous material.

Fish

Hotophia Creek, an incised channel, produced the fewest fish and had the lowest species richness, yielding nine and 12 species in the spring and autumn, respectively (Table 6). The reference site (Toby Tubby Creek) had the highest number of species (19). Five of the 19 species were represented by only one individual, and two species comprised 75.6% of the catch. Although the reference site had the highest species richness as well as the highest log series diversity index, it had the lowest Shannon and Pielou indices (Table 6). The low Shannon and Pielou indices were due to the uneven pattern of relative abundance: the log series index is more reflective of species richness than evenness.

Species composition varied considerably among the seven samples (Table 7), but some differences in relative abundance between the incised channels and the reference site were noted. Nine of the species taken from the reference channel were not found at any other site. Eleven percent of the fishes taken from the reference site were spotted bass, but only 0.2%–5% of the incised channel collections were spotted bass. Bluegill, bluntface shiner, and blacktail shiner (see Table 7 for species names) were present in reference channel collection and in five of the six collections from incised channels.

Seasonal effects on fish collections were evident. Only the incised streams were sampled for fish in both the spring and autumn. More individuals and more species were collected in the autumn than in the spring for all three incised streams (Table 6). Shannon and Pielou evenness indices varied, but the log series index was higher in the spring for all three streams. Although data presented here are too limited to draw conclusions regarding seasonal effects,

Table 6. Fish species diversity at base flow in three incised channels and one reference channel

		Peters	Hotophia	Goodwin	Toby Tubby
Number of individuals[a]	spring	261	57	230	ns[b]
	autumn	632	200	1,685	623
Species richness (S)	spring	13	9	14	ns[b]
	autumn	16	12	17	19
Most common species[c] (% abundance)	spring	longear sunfish (31) bluegill (16)	blackspotted topminnow (49) mosquito fish (21)	bluegill (27) green sunfish (21)	ns[b]
	autumn	bluntface shiner (38) channel catfish (16)	blacktail shiner (38) green sunfish (16)	bluntface shiner (43) Yazoo shiner (21)	bluegill (59) blacktail shiner (17)
Shannon index (H')[d]	spring	2.04 ± 0.06a	1.42 ± 0.14b	2.02 ± 0.06a	ns[b]
	autumn	2.15 ± 0.04a	1.98 ± 0.07a,c	1.85 ± 0.03c	1.44 ± 0.05b
Pielou eveness (E)	spring	0.79	0.65	0.77	ns[b]
	autumn	0.77	0.80	0.65	0.49
Log series index α	spring	2.64 ± 0.76	3.00 ± 1.00	3.27 ± 0.88	ns[b]
	autumn	2.54 ± 0.68	2.63 ± 0.78	1.69 ± 0.49	3.13 ± 0.77

[a]Each of the seven samples shown represents equal levels of electrofishing effort in four 100-m channel segments.

[b]Not sampled.

[c]See Table 7 for species names.

[d]Shannon indices were compared using a two-tailed t-test (Magurran, 1988). Indices with the same following letter are not significantly different at the 99% level.

they are consistent with samples we have collected from similar sites over the last seven years and are typical of stream fish samples from variable environments (Ross and others 1985). Spring collections from streams in northern Mississippi are depressed by higher velocities and turbidities following spring rain and do not include young of the year produced between spring and autumn samples.

Relationship between Fish and Habitat

Perhaps the most dramatic difference between fish catches from the incised and the reference channels was in size of the individuals. Fish size appeared to be associated with depth (Figure 6). The reference site had almost twice as much area with depths greater than 30 cm than any of the incised channels (Table 4). Sizes of the larger individuals taken from the reference site spanned a wide range and were not simply representatives of a single year class.

Fish species richness, S, tended to be greater for sites with lower mean local Froude numbers (Figure 7) and more pool habitat. Species richness also was greater for sites with higher levels of habitat richness, but Shannon indices of species diversity and habitat diversity were apparently unrelated. Schlosser (1982) found relationships between diversity of fish species and aquatic habitat were weakest in areas that experienced higher levels of temporal variability and human disturbance, while Ross and others (1985) suggested that, ". . . specific habitat use by fishes may be less structured in physically harsh than in benign systems." Other investigators (Shields and Hoover 1991, Scarnecchia 1988, Swales 1988, Tramer and Rogers 1973) failed to detect significant relationships between various metrics of habitat and fish species diversity in altered streams. However, they did report differences in species richness, composition, and population structure for channels with varying levels of disturbance and habitat diversity.

Discussion

The incised streams contained less woody debris, pool habitat, and fewer types of habitat than the nonincised channel, although they provided comparable levels of physical diversity. Other investigators studying channelized and unstable streams have reported depressed levels of physical diversity relative to less disturbed or partially recovered stream reaches (Zimmer and Bachman 1976, Scarnecchia 1988, Swales 1988, Gorman and Karr 1978, Hortle and Lake 1982, Schlosser 1987, Shields and Hoover 1991, Shields and Smith 1992).

We observed, but did not quantify hydrologic differences between incised sites and the reference site: the reference site had numerous hydrologic connections with floodplain waters and was less flashy. Literature describing effects of channel incision on hydrology is scarce. Shankman and Samson (1991) found that incision of the upper reaches of the Obion River

Table 7. Fishes collected from three incised streams and one reference stream in northwestern Mississippi in spring and autumn 1991[a]

Genus and species	Common name	P-S[a]	H-S	G-S	P-A	H-A	G-A	T-A
Ameiurus natalis	Yellow bullhead	17		5	3	2	70	
Carpiodes carpio	River carpsucker	4			24			
Cyprinella camura	Bluntface shiner	40	1	40	209	16	731	3
lutrensis	Red shiner			1			24	
venusta	Blacktail shiner	21	28	9	69	75	98	103
Dorosoma cepedianum	Gizzard shad	4	1		3			2
Erimyzon oblongus	Creek chubsucker			3			12	1
Etheostoma histrio	Harlequin darter							4
whipplei	Redfin darter						8	
Fundulus olivaceus	Blackspotted topminnow	3		21	5	15	94	8
Gambusia affinis	Mosquito fish					15	20	
Hybognathus nuchalis	Miss silvery minnow				23			
Ictalurus punctatus	Channel catfish	4			86			1
Labidesthes sicculus	Brook silversides							1
Lepisosteus oculatus	Spotted gar				3			
Lepomis cyanellus	Green sunfish	23	12	48	15	31	29	
gulosus	Warmouth							5
macrochirus	Bluegill	41	11	62	45	17	7	368
megalotis	Longear sunfish	81	1	25	56	12	122	
microlophus	Redear sunfish							2
punctatus	Spotted sunfish							8
Luxilus chrysocephalus	Striped shiner			3			20	
Lythrurus umbratilis	Redfin shiner						4	
Micropterus salmoides	Largemouth bass							18
punctulatus	Spotted bass	12	1	1	10	2	4	68
Minytrema melanops	Spotted sucker							6
Moxostoma poecilurum	Blacktail redhorse		1					
Notemigonus crysoleucas	Golden shiner							1
Notropis atherinoides	Emerald shiner					3		
rafinesquei	Yazoo shiner	5	1	3	55	3	360	
Percina sciera	Dusky darter				1			16
Pimephales notatus	Bluntnose minnow	6		3	25	9	73	1
Pomoxis nigromaculatus	Black crappie							7
Semotilus atromaculatus	Creek chub			6			9	
Totals		261	57	230	632	200	1685	623

Key to column heads is as follows: P, H, and G are incised channels (Peters, Hotophia, and Goodwin creeks, respectively). T is a nonincised eference channel (Toby Tubby Creek). S = summer and A = autumn.

ı western Tennessee reduced flood frequency harply (mean number of days of flooding per year educed from 114 ± 89 to 9 ± 7), but annual maxiıum stage was unaffected. Several studies of the ef-ːcts of channel deepening and widening due to chanelization are available. Before-and-after case studies f North Carolina streams showed that storm hydroraphs were sharper after channelization: in one case ıean storm hydrograph width (= time above base ɔw) decreased 35%. Similar effects of channelization ı floods in an Iowa river were predicted based on nulation modeling (Campbell and others 1972). ıse flows of a North Carolina stream were slightly ːvated after channelization because groundwater ntributions were increased (Mason and others 90), and similar findings were reported for a channelization project in Ireland (Wilcock and Essery 1991). Hydrologic factors may be as important determinants of habitat quality as those we measured. Horwitz (1978) showed fish species richness to be inversely related to hydrologic variability, and Schlosser (1985) documented the sensitivity of minnows and sunfishes to hydrologic instability.

Pool habitat was much more common in the reference stream. Pool availability appears to be a necessary condition for larger individuals of some warmwater species (e.g., centrarchids) (Schlosser 1987, Meffe and Sheldon 1988, Lobb and Orth 1991). Schlosser (1982) noted fish species richness increased upstream to downstream along a headwater stream due to addition of deeper habitats. Creation of pools by grade control structures (weirs) has been shown to have pos-

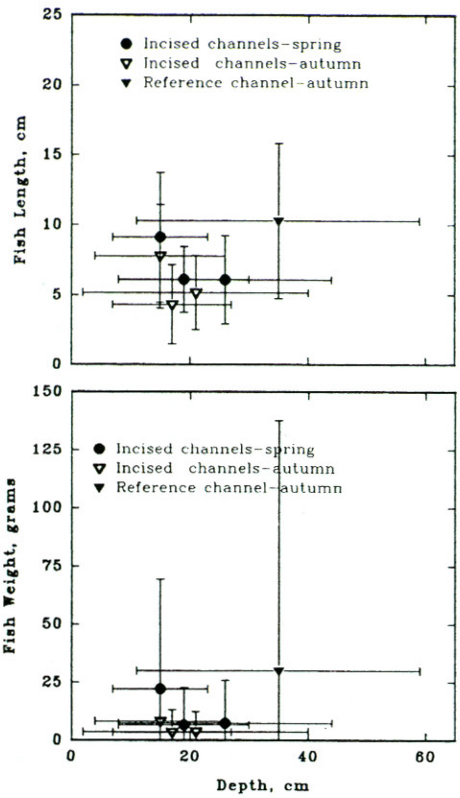

Figure 6. Mean fish length and weight versus mean water depth. Error bars are ±1 SD.

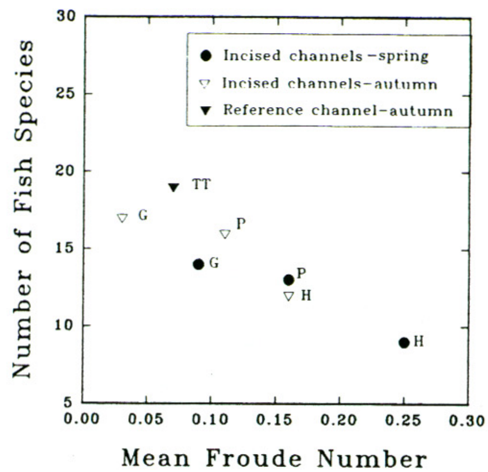

Figure 7. Fish species richness versus mean local Froude number. Equal effort was expended in collecting each of the seven fish samples. Froude numbers were computed by dividing velocity by the square root of depth times the acceleration of gravity.

itive impacts on incised channel fish assemblages in other Mississippi watersheds (Cooper and Knight 1987, Shields and Hoover 1991). Schlosser (1982) noted fish assemblage age structure in reaches with large, stable pools were characterized by fewer, larger individuals relative to shallow, temporally variable areas. Foltz (1982) found catch per unit effort was related to the cube of mean depth in a study of a South Carolina Piedmont stream draining an agricultural watershed.

Much of the physical diversity and pool habitat in the reference channel was directly associated with woody debris formations. Fish species that were unique to the reference site were those typically associated with deep, quiet pools or known to prefer greater depth, velocity, and woody debris. For example, the harlequin darter typically inhabits large obstructions in clear, high-gradient streams with enough current to prevent the accumulation of sediment (Pflieger 1975). Robinson and Buchanan (1988) describe habitat for such fish as the spotted sucker, black crappie, warmouth, spotted sunfish, and redear sunfish as deep, clear waters with large woody debris and no noticeable current. Neither of these habitat types were common in the incised channels. Abundance of woody debris was the only physical variable significantly correlated with fish numbers, biomass, and species richness in a study comparing channelized and unchannelized sections of an Australian River (Hortle and Lake 1983).

The levels of fish species richness we found were reasonable in light of existing knowledge regarding extant freshwater fish species in the state (~200; Ross and Brenneman 1991), in this region of the state (~90), and in lotic habitats in this region (~50). Previous electrofishing surveys of the watersheds containing the three incised study reaches revealed a high species richness despite physical habitat degradation. Surveys during 1986–1990 produced 14,392 individuals representing 42 species from Peters Creek and 3401 individuals representing 29 species from Goodwin Creek (Cooper and Knight 1987), and there were 31 species taken from 11 sites within the Hotophia Creek watershed over a three-year period (1986–1989) (Knight and Cooper 1990). However, headwater reaches that had suffered less instability in historic times had more diverse fauna; the study reach, which is at the lower end of the watershed, yielded only 18 species.

Although our observations generally agreed with published findings of others, generalization of this work to other locations must be done guardedly. For example, incised channel systems that cut into gravel or bedrock strata extensive enough to dominate channel bed types have morphology and biota considerably different from our study sites. Their rate of degradation will likely be much slower, and the presence of coarser bed material (Shields and Hoover 1991) and their relatively greater temporal stability (Reice et al., 1990) will influence fish assemblage structure.

The incised channels we sampled have experienced rapid change over the last century. We cannot be certain if their present condition represents a state of dynamic equilibrium that will persist for a long period or not. Conceptual modeling of incised channel evolution (Harvey and Watson 1986) and the magnitude of efforts within and upstream of these reaches to ensure stability by constructing grade controls and bank protection suggests that their current status will change slowly over the next 10–50 years, if at all. If this is correct, habitat resources may be maintained in a degraded state for the foreseeable future. A program of experiments to test simple modifications of currently employed stabilization practices that will result in habitat rehabilitation has been initiated (Shields and others 1992).

Conclusions

Conclusions based on these results must be viewed as preliminary due to the brevity of the period of record. Incised channel habitat quality was inferior to the reference channel despite the presence of structures (bank protection and grade control weirs) designed to restore channel stability. Although the incised channel habitats were as heterogeneous as a nonincised reference channel, they contained fewer types of habitat. Channel incision affected base flow aquatic habitats in the study reaches in at least two ways: deep pool habitats and organic debris (wood and leaf mats) were virtually absent. Fish assemblages in incised channels were composed of smaller fishes representing fewer species. Fish species richness was directly proportional to the mean Froude number, an indicator of the availability of pool habitat.

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