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Ten Years After: Stream Habitat Restoration Project in Retrospect

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Abstract

Long-term assessments of ecosystem rehabilitation project effects are rare. Herein we describe a study of the Hotophia Creek rehabilitation project in northwest Mississippi. The stream channel was subjected to channelization ca. 1963 and experienced rapid channel erosion between 1963 and 1985, with annual suspended sediment yield exceeding 1,000 t km^{-2}. More than $10 million were expended on erosion control measures within the 90-km^2 watershed between 1985 and 2000, with an attendant sixfold reduction in suspended sediment yield. Fish and physical aquatic habitat data were collected for one year prior to construction of a one-km long stream habitat rehabilitation project in 1992. Habitat rehabilitation consisted of extending existing stone spurs, placing stone toe, and planting willow cuttings. Post construction monitoring was conducted for the four years following construction, and at 10 years following construction. Parallel monitoring was conducted on an untreated reference stream and on untreated reaches upstream on Hotophia Creek. Effects of rehabilitation on habitat and fish communities were found to be positive in both the short and long term. For example, after 10 years, mean water depth in the reach subjected to rehabilitation was more than twice as great as for untreated reaches upstream. Woody riparian vegetation more than doubled and large woody debris density increased by an order of magnitude in both treated and untreated streams. Fish species richness and numbers were lower after 10 years, perhaps due to reduced sampling efficiency associated with greater water depth. However, fish populations shifted away from domination by large numbers of small, opportunistic generalists and toward dominance by large-bodied, pool-dwelling species typical of more pristine streams. Prior to rehabilitation, 51% of the fish captured were cyprinids (minnows), while 10 years later 61% of the fish captured were centrarchids (sunfishes).

Introduction

Sand-bed streams in the southeastern United States support high levels of biodiversity. However, many species are imperiled due to habitat and water quality degradation associated with erosion and sedimentation caused by channelization, watershed development, and other human activities (Warren et al. 2000). A fundamental change in watershed hydrology caused by deforestation and subsequent agricultural or urban development underlies most secondary causes of ecological degradation (Shields et al. 1995a). Rehabilitation of degraded warmwater streams ideally would include restoring watershed hydrology—shifting from a regime dominated by surface flows and characterized by flashy hydrographs, high peaks, and extremely low base flows to one characterized by more moderate fluctuations, subsurface flows, and higher base flow (Shields and Cooper 1994, Shields et al. 1998). Nevertheless, studies in degraded streams suggested that some ecological recovery could be triggered simply by increasing the availability of stable pool habitats (Cooper and Knight 1987, Knight and Cooper 1991, Shields and Hoover 1991). Accordingly, we developed and implemented two stream habitat rehabilitation projects in 1992 and 1993 that consisted of modifying existing stone erosion control structures and planting willow cuttings (Shields et al. 1995b, 1995c, 1998). Both projects were monitored before and after rehabilitation, as were untreated comparison streams. Observed effects on fish and their habitats were positive.

Table 1. Partial tabulation of federally-funded erosion control measures placed within Hotophia and Peters Creek watersheds, Mississippi.

Type of structure	Hotophia Creek	Peters Creek
Bank stabilization (km)	17.9[a]	15.2[c]
Riser (drop inlet) pipes	148[a]	77[c]
Low drop grade control	10[b]	17[c]
High drop grade control	3[b]	0
Small reservoirs	5[a]	4[c]
Debris basins	123[a]	100[d]
Estimated total cost ($\$10^6$)	9.8[e]	11.3[e]

[a] Sums of totals presented by U.S. Army Corps of Engineers (1996) for DEC project and by U.S. Army Corps of Engineers (undated) for original SCS work plan
[b] Simon and Darby (2002)
[c] Neill and Johnson (1989)
[d] Anonymous (1992)
[e] Cost estimates from Anonymous (1992) and U.S. Army Corps of Engineers (undated) for work to be completed subsequent to those publications. Total costs are therefore significantly higher.

Stream habitat rehabilitation projects are increasing in popularity, but project outcomes are somewhat uncertain due to the complexity of stream ecosystems and the limited base of experience regarding long-term responses. Many writers have called for emphasis on post-project monitoring (e.g., Kondolf 1995), but reports of long-term effects on sand-bed streams are rare. Bryant (1995) proposed a “pulsed monitoring strategy” consisting of a series of short-term (3-5 years) high-intensity studies separated by longer periods (10-15 years) of low-density data collection. Downs and Kondolf (2002) identify and illustrate eight components of ideal monitoring: success criteria, baseline surveys, design rationale, design drawings, as-built drawings, periodic or event-driven monitoring, supplementary historical data, and secondary analytical procedures. Described herein are results of sampling one of the two previously mentioned rehabilitated streams 10 years after rehabilitation. Although space does not permit full presentation of all of the eight elements, this paper covers key aspects allowing transfer of experience gained from this project.

Sites and methods

Hotophia and Peters Creeks are located in northwestern Mississippi within the hilly region of the upper Yazoo River watershed. Due to their inclusion in federally-funded erosion control programs, both watersheds have been described in several publications (e.g. Whitten and Patrick 1981, Little et al. 1982, Knight and Cooper 1990, Simon and Darby 2002). All perennial channels within both watersheds were channelized at least once between ca. 1880 and 1965, and fluvial response between about 1965 and the present is consistent with conceptual models of incised channel evolution (Schumm et al. 1984, Simon 1989). Extensive erosion control works have been emplaced throughout both watersheds, and most of these structures were completed between 1986 and 1996 (Table 1). Three one-km long reaches were sampled for this study as shown in Table 2.

Table 2. Description of one-km long Study Reaches[a]

	Hotophia Creek Reach 1 (rehabilitated)	Hotophia Creek Reach 2 (untreated)	Peters Creek (untreated)
Drainage area (km^2)	91	91	205
Slope	0.001	0.001	0.0009
Sinuosity	1.4	1.3	1.1
Bed material	Sand	Sand	Sand and gravel
Bank height, m	3-7	3-7	2-6
Channel width, m	40-60	40-60	55-85
Structures	Low-drop grade control structure immediately downstream, stone toe, stone spurs	Stone toe protection along one bank	Stone toe protection along one bank

[a] Additional description of Hotophia Reach 1 and Peters is given by Shields et al. 1995b and 1998.

Figure 1. View of rehabilitation project reach immediately after construction (above) and in 2002 (below). Note stone toe and willow post plantings on left and spur dike extension on right side of top photo.

Rehabilitation activities were performed on Reach 1 of Hotophia Creek in January – February 1992. Prior to rehabilitation, aquatic habitat was typical of many incised channels in the region (Shields et al. 1994): base flow conditions were extremely shallow, pool habitats were rare and temporally unstable, substrate was dominated by shifting sands, and woody debris was in very short supply (Figure 1). Eroding banks were common, and riparian vegetation was sparse (Shields et al. 1998). Although stone structures had been placed for bank protection, they provided very little habitat. Rehabilitation consisted of extending existing stone spur dikes riverward to provide stony substrate and trigger formation of stable pool habitats. Willow posts were planted in the sandbar opposite the stone spurs, and a minimal stone toe was placed along the planted bars. The primary objective of the project was to increase the availability of stable pool habitat at base flow.

Reach 1 of Hotophia Creek and Peters Creek were sampled in 1991-1995 and 2002, while Reach 2 of Hotophia Creek was sampled only in 2002. Procedures used to sample the study reaches in 2002 were similar to those used in 1991-1995. Fish and physical habitat variables were sampled concurrently at baseflow during the Spring (May-June) and Fall (Sept-Oct). Since pool-riffle sequences were absent or poorly developed, sampling reaches could not be located based on habitat units. Therefore four 100-m long zones distributed along each of the one-km long study reaches were sampled. Flow depth was measured with wading rod at five regularly-spaced grid points along five transects placed at uniform intervals within each zone. Bed material type was visually classified at each point where depth was measured. Thus water depth and bed type were sampled at (5 points x 5 transects x 4 zones) 100 points within each reach. Flow width was measured at each transect, and visual estimates were made regarding the number and size of woody debris formations, dominant type and size of bank vegetation, and percent canopy. Instantaneous discharge was measured at one transect within each reach using a wading rod and velocity meter. Fish were collected using a backpack-mounted electroshocker. In 2002, deeper regions of Hotophia Creek were sampled by placing the electroshocker in a small boat operated by two people assisted by others who waded in shallower regions nearby. Within each reach, the same four 100-m-long zones sampled for physical variables were fished for ~10 minutes of electric field application. Fishes longer than about 15 cm were identified, measured for total length, and released. Smaller fish, and fish that could not be identified in the field were preserved in 10 percent formalin solution and transported to the laboratory for identification and measurement.

Stage and discharge were recorded by the US Geological Survey within Reach 1 at Hotophia Creek (station 07273100) and within the sampled reach of Peters Creek (station 07275530) during water years 1987 – 2001. Daily mean suspended-sediment concentration and load were recorded during water years 1988 through 1997. In addition, biweekly grab samples (dipped from the surface at the channel centerline) from both sites were obtained and analyzed for suspended sediment concentration (total suspended solids, Clesceri et al. 1998) by the National Sedimentation Laboratory (NSL) during the periods April 1985 to present and December 1991 to present for Peters and Hotophia Creeks, respectively. The record of daily mean suspended sediment concentration was extended through water year 2001 using suspended sediment ratings developed using these grab sample concentrations, daily mean water discharge records, and a regression formula relating mean-daily suspended sediment load reported by the USGS to the grab sample suspended sediment concentration reported by the NSL.

Table 3. Average of mean-daily water and sediment discharge before (water years 1988-1991) and after (water years 1993-2001) habitat rehabilitation.

	Hotophia Creek			Peters Creek		
	Before	After	Change (%)	Before	After	Change (%)
Mean-daily water discharge	2.1	1.2	-71	4.6	2.8	-65
Mean-daily sediment load	304	44	-593	823	235	-251

Table 4. Effects of rehabilitation on physical aquatic habitat at comparable discharges

	Hotophia Creek (Reach 1—rehabilitated)			Peters Creek (untreated)	
	Before (Fall 1991)	Short term (Spring 1992)[a]	Long term (Spring 2002)	Short term (Spring 1994)	Long term (Spring 2002)
Instantaneous water discharge (m^3/s)	0.80	0.66	0.63	0.64	0.65
Mean (± std dev) water width (m)	18 ± 4	16 ± 3	16 ± 6	22 ± 8	16 ± 6
Mean (± std dev) water depth (cm)	16 ± 8	19 ± 17	54 ± 34	13 ± 6	22 ± 13
Fraction of bed covered with sand (%)	100	91	76	86	60
Average woody debris density, m^2/km^2	--	1,520	14,600	1,120	9,950
Bank line covered with trees or brush, %	----	19	55	15	36

[a] Rehabilitation works were placed in winter, 1992. The bed responded quickly to the stone structures, so widths and depths represent post-rehabilitation. However, woody debris and riparian vegetation responded more slowly, so Spring 1992 values of these variables represent pre-rehabilitation conditions.

Table 5. Physical aquatic habitat in rehabilitated and untreated reaches of Hotophia Creek

	Hotophia Creek reach 1 (rehabilitated)		Hotophia Creek reach 2 (untreated)	
	Spring 2002	Fall 2002	Spring 2002	Fall 2002
Instantaneous water discharge (m^3/s)	0.63	0.63	Not measured, but similar to reach 1	Not measured, but similar to reach 1
Mean ± std dev water width (m)	16.0 ± 5.5	15.5 ± 4.9	13.4 ± 3.1	12.7 ± 3.3
Mean ± std dev water depth (cm)	54 ± 34	67 ± 41	17 ± 12	25 ± 17
Fraction of bed covered with sand (%)	76	81	70	52
Average woody debris density, m^2/km^2	14,600	19,130	8,820	25,500
Bank line covered with trees or brush, %	55	44	56	55

Table 6. Effects of rehabilitation on fish populations. Means followed by different subscripts indicate distributions for the same stream but different time period are significantly different ($p \le 0.05$, One-way ANOVA or Kruksal-Wallis ANOVA on ranks if data were non-normal)

	Hotophia Creek (Reach 1—rehabilitated)			Peters Creek (untreated)	
Mean ± standard deviation	Before	Short term	Long term	Short term	Long term
Number of species per 100 m sampling zone	11 ± 2^{a}	19 ± 3^{b}	12 ± 2^{a}	11 ± 3^{a}	8 ± 2^{b}
Number of individuals per 100 m	40 ± 42^{a}	123 ± 82^{b}	21 ± 7^{a}	136 ± 100^{a}	82 ± 39^{a}
Number of individuals captured per min of electrical field application	10 ± 11	16 ± 12	2 ± 1	19 ± 13^{a}	9 ± 6^{b}
Fish biomass (kg/100m)	0.2 ± 0.2^{a}	2.7 ± 2.5^{b}	0.8 ± 0.8^{a}	2.1 ± 2.7^{a}	1.1 ± 0.9^{a}
% of numerical catch comprised of cyprinids	51 ± 2^{a}	49 ± 8^{a}	12 ± 18^{b}	49 ± 16	43 ± 17
% of numerical catch comprised of centrarchids	38 ± 8^{a}	32 ± 8^{a}	61 ± 16^{b}	36 ± 12	45 ± 17
Length of fish, cm	5 ± 3^{a}	7 ± 6^{b}	9 ± 10^{a}	8 ± 5^{a}	8 ± 6^{a}

Results

Suspended-sediment discharge fell sharply following rehabilitation in both streams, due at least in part to drier conditions (Figure 2 and Table 3). Hotophia Creek suspended sediment load dropped by a factor of six. Significant morphologic changes occurred within the rehabilitated reach of Hotophia Creek (Table 4). During the four years immediately following restoration, mean flow depth increased only slightly, although the depth and size of scour holes associated with the stone spurs more than doubled (Shields et al. 1995b). However, by 2002, the mean depth in the rehabilitated reach was 2.5 to 3 times greater than the same reach before rehabilitation, the untreated reach upstream, and Peters Creek (Tables 4 and 5). Both streams became narrower, and bed material became more heterogeneous.

Although 70% of the willow posts planted in the treated reach died during the first two years after planting due to poor soil conditions or competition from exotic species (Shields et al. 1995b) by 2002 woody debris density increased by an order of magnitude in both streams (Figure 1 and Table 5). Vegetation invaded stone revetments and sandy berms, consistent with the conceptual incised channel evolution model (Simon 1989), roughly doubling woody cover on banks in both treated and untreated reaches.

Fish communities in Hotophia Creek responded dramatically to habitat rehabilitation over the short term (1992-1995), with species richness, numbers, and biomass increasing by factors of 1.7, 3, and 14, respectively (Shields et al. 1998). Fish species composition shifted away from small cyprinids typical of shallow incised streams toward larger-bodied, longer-lived centrarchids typical of more pristine systems in this region (Shields et al. 1994, 1997, 1998). Between 1995 and 2002, species richness and fish density (both numbers and biomass) fell in both the rehabilitated stream (Hotophia reach 1) and the untreated reference stream (Peters Creek) (Table 6). However, relatively large-bodied pool-dwelling centrarchids comprised an average of 61% of the individuals captured from the treated reach of Hotophia Creek in 2002, while the highly tolerant cyprinids comprised only 12%, on average, of the catch (Figure 2). Prior to rehabilitation, centrarchids and cyprinids comprised 38% and 51% of the catch, respectively. Fish captured from the treated reach in 2002 were larger than fish collected from any other site at any other time (Tables 6 and 7).

Discussion and Conclusions

Expenditure of more than \$100,000 km^{-2} for erosion control structures and a period of drier weather has reduced suspended sediment yield from Hotophia Creek watershed by a factor of ~6 over the last decade. Determination of the relative importance of erosion controls in this decline is beyond the scope of this paper. Simon and Darby (2002) used channel erosion models and survey data to compute net bed-material erosion from Hotophia Creek; they found amounts leading to annual yields of 554 t km^{-2} for the period 1985-1992 and 164 t km^{-2} for 1992-1996, a greater than threefold reduction. However, they suggested that much of the reduction was due to natural processes tending to restore channel equilibrium and that sediment production was 1.6 times greater than it would have been without construction of grade control structures. They argued that some of the structures retained bed material in upstream reaches and exacerbated degradation downstream. Kuhnle et al. (1996) documented a ~60% reduction in sediment concentration in Goodwin Creek, a subwatershed comprising about 10% of the Peters Creek watershed and an attendant halving of fine sediment yield. However, they attributed most of the reduction to a halving of the area of cultivated land.

Table 7. Fish catches from rehabilitated and untreated reaches of Hotophia Creek. Bold font indicates significant differences between rehabilitated and untreated reaches ($p < 0.05$, Two-way ANOVA)

	Hotophia Creek reach 1 (rehabilitated)		Hotophia Creek reach 2 (untreated)	
Mean ± standard deviation	Spring 2002	Fall 2002	Spring 2002	Fall 2002
Number of species per 100 m sampling zone	**7 ± 3**	**6 ± 2**	**11 ± 1**	**8 ± 2**
Number of individuals per 100 m	**18 ± 6**	**25 ± 8**	**44 ± 19**	**44 ± 13**
Number of individuals captured per min of electrical field application	**2 ± 1**	**2 ± 1**	**5 ± 2**	**4 ± 1**
Fish biomass (kg/100m)	4.1 ± 0.8	0.4 ± 0.6	1.3 ± 0.8	0.8 ± 0.1
% of numerical catch comprised of cyprinids	**15 ± 21**	**9 ± 13**	**32 ± 12**	**30 ± 14**
% of numerical catch comprised of centrarchids	51 ± 18	69 ± 13	48 ± 12	40 ± 19
Length of fish, cm	13 ± 13	7 ±6	10 ± 7	7 ± 2

Baseflow channels of both the treated (Hotophia) and untreated (Peters) streams became narrower and deeper during the decade of observation, consistent with changes expected for systems with declining sediment load (Werrity 1997) and increasing bank vegetation (Hey and Thorne 1986). Rehabilitation works placed along Hotophia Creek in 1992 have been more effective in producing habitats more similar to nonincised streams than orthodox erosion controls placed upstream on Hotophia Creek or along Peters Creek. Fish populations have responded to habitat improvements in a fashion consistent with a conceptual framework proposed earlier (Shields et al. 1998). However, fish species and population density were much lower when sampled in 2002 than for 1992-1995. This may be indicative of the sharp reduction in sampling efficiency occurring for water depths greater than about 40 cm

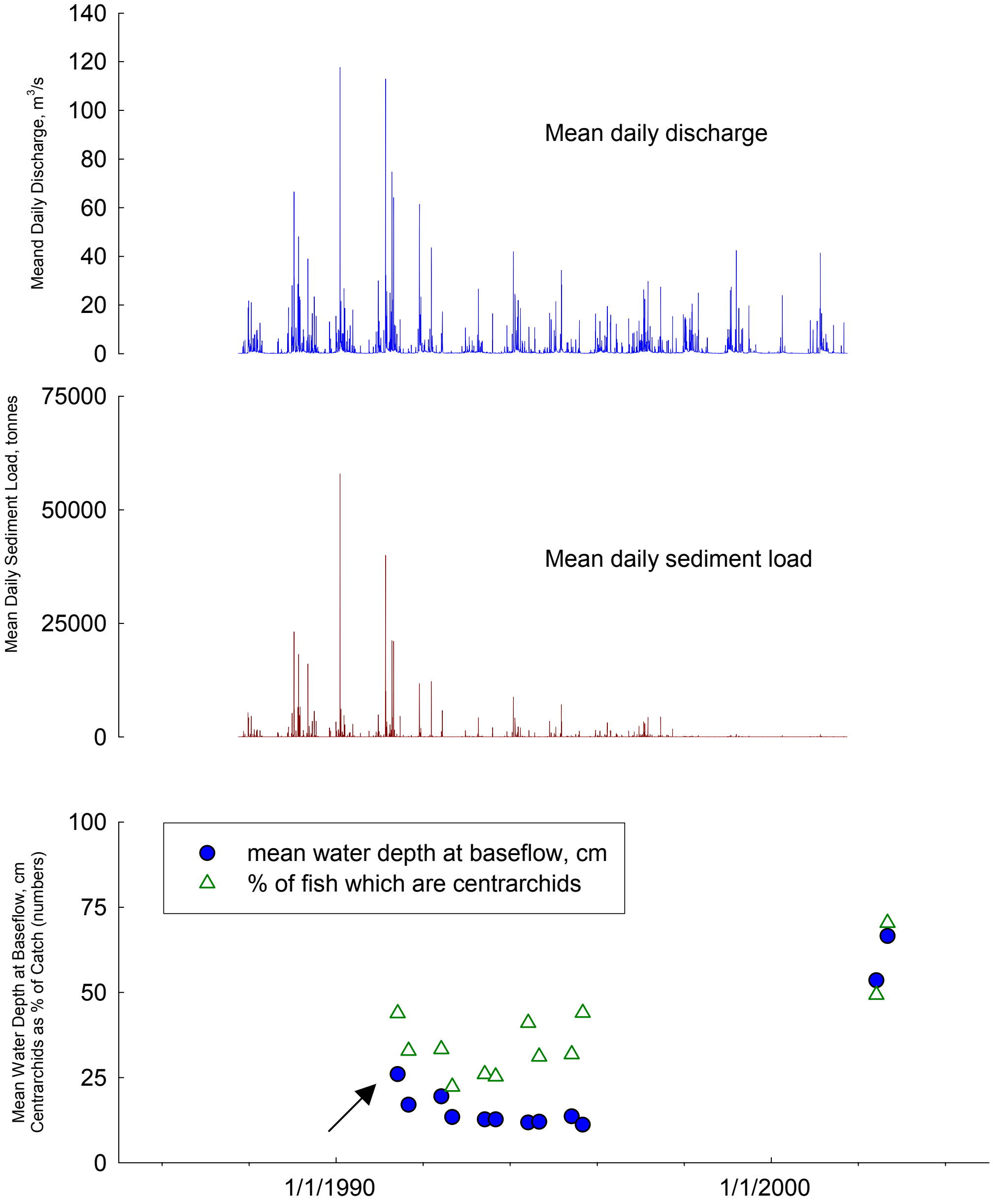

Figure 2. Mean-daily discharge, mean-daily suspended-sediment load, and mean water depth and percent of fish catch comprised by centrarchids (sunfishes) for treated reach of Hotophia Creek, Mississippi, 1987-2001. Rehabilitation works were constructed in 1992. Mean water depth for Spring 1991 (arrow) elevated by higher than normal discharge.

(Shields et al. 2000); additional samples must be collected using alternate means to more closely examine differences in species richness and population density.

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