EVALUATION OF PREFERENTIAL USE OF CLEANED GRAVEL BARS IN THE UPPER SAVANNAH RIVER

Final Report

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Lithophilic riverine fishes commonly employ a reproductive strategy whereby eggs are deposited directly into gravel substrate during spawning. If the substrate and water quality conditions are suitable, the eggs will hatch and larvae develop until they emerge. Members of the family Catistomidae often spawn as a trio of two males and one female. A dominant male selects a spawning site. A receptive female moves into position next to the male and is joined by a subdominant male. The trio then vigorously scours the substrate with their anal and caudal fins, simultaneously expressing milt and eggs into the resulting cavity. Sand and sediment are swept away by the current, leaving the embryos buried in the course substrate left behind. Course substrate provides a refuge against predators while allowing the exchange of fresh water over the eggs. For reproductive success, gravel must be well oxygenated and of a particular size range.

Availability of suitable spawning habitat may affect both population and community structure of fishes utilizing this strategy. Anthropogenic modifications to natural river flow regimes alter the quantity and quality of spawning habitat. Reservoirs behind dams serve as sinks for gravel from upstream sources, reducing the supply of gravel to downstream spawning habitat. Dams reduce the frequency and intensity of scouring events that clean fine sediments from courser substrate. Fine sediments from agricultural and other anthropogenic activities increase bed load, increasing the rate of re-sedimentation within course substrate. The result is that course gravel habitat within altered river systems is reduced, cemented and more rapidly re-sedimented than under natural flow regimes.

To date, habitat conservation activities in rivers have focused on prevention of further damage, rather than on restoration of limited habitat. Establishment of riparian buffer zones, bank stabilization and erosion control are all commonly employed methods for reducing the source of potentially damaging sediments. However, some specific river habitats have been restored through the removal of accumulated silt and sand. For example, the Georgia Department of Natural Resources restored springs on the Flint River used as thermal refuges for adult striped bass *Marone saxatilis* by pumping out accumulated sand and sediment, effectively deepening and widening the spring to historic proportions. Upstream sediment traps have been employed to reduce impacts on trout spawning habitat in Michigan. The Virginia Department of Fish and Game employed an experimental sediment removal system in 2008 to restore habitat Swift Run Creek following an acute bentonite spill. Although commonly employed, the strategy has not been thoroughly evaluated.

The lower Savannah River represents a unique opportunity to assess spawning habitat restoration by the removal of fine sand and sediment. As many as seven species of catostomids use main-channel gravel bars as primary spawning sites, including the imperilled robust redhorse

Moxostoma robustum (Cope), notchlip redhorse *Moxostoma collapsum* (Cope), the currently undescribed brassy jumprock *Moxostoma sp*., quillback *Carpiodes cyprinus* (Lesueur), highfin carpsucker *Carpiodes velifer* (Rafinesque), spotted sucker *Minytrema melanops* (Rafinesque) and northern hogsucker *Hypentelium nigricans* (Lesueur). The members of this assemblage all have been reported to require clean gravel deposits in shallow flowing water for successful spawning. This habitat type is rare in the main channel of the lower Savannah River, consisting of two shallow mid-channel gravel bars. The lack of a sufficient quantity of suitable spawning habitat has been suggested as one of the factors contributing to the decline of robust redhorse and other catostomid populations. The gravel bars also historically provided spawning habitat for the endangered shortnose sturgeon.

The objectives of this study were to evaluate the effects of mechanical removal of sand and fine sediments on the physical characteristics of mid-channel gravel bar habitat in the lower Savannah River. Specifically, we quantify the degree of imbeddedness and substrate size composition before and after restoration. In addition, the study evaluated the longevity of restoration by monitoring re-sedimentation rates in relation to discharge, and assess selection of restored habitat over control habitat by spawning fishes.

Study Area

The Savannah River drains one of the largest watersheds in the Southeastern United States. The 500-km long river drains an area of greater than 25,000 km^2 and forms the border between South Carolina and Georgia. The Savannah River flow regime is regulated by a series of eight main-stem dams. The farthest down-stream dam, New Savannah Bluff Lock and Dam (NSBLD), is located at river km 300 and serves to maintain water levels in the Augusta Pool. The study area consisted of two mid-channel gravel bars located in the upper portion of the free-flowing section (downstream of the NSBLD). The upper gravel bar is located at rkm 299.4 approximately 500-m below NSBLD. The upper gravel bar measures 200 m (length) x 150 m (width) and is composed of cemented course gravel over packed sand (Figure 1 A). The upper gravel bar rises over 3 m above the thalweg. The lower gravel bar is located at rkm 283.7, and is shorter (60-m long), narrower (70-m wide) and has a lower profile (2-m high) than the upper gravel bar (Figure 1 B). The lower bar is somewhat “Y” shaped. The upstream bifurcations direct channel flow over the bar at moderate flows but result in the formation of a pool above the gravel bar at low flows. Grabowski and Isely (2007; J Fish Biol 70:782-98) provide a detailed description of each gravel bar, including recent location of observations of spawning fishes.

Study plots on each gravel bar were selected at random from areas identified by Grabowski and Isely (2007) as recent spawning areas for catastomids prior to each observation period. Sites were limited to areas in water depths of <1.5 m from the top of each gravel bar. Two 4 x 4-m plots were selected at each site. Plots were subdivided into two 2 x 2-m treatment subplots and two 2 x 2-m control subplots. Plots and sup-plots were marked with surveyor’s flagging, and locations were identified using a global positioning system.

Methods

Restoration

Restoration consisted of mechanically removing material <0.5 cm in diameter within the top 15 cm of substrate. Material was removed using a commercially-available sediment removal system (Sandwand; Streamside Systems, Findlay, Ohio, USA). The sediment removal system consisted of 25-cm diameter hood fitted with a 5-cm mesh screen, a 1-cm diameter incurrent hydraulic pressure spray, a 7-cm diameter excurrent siphon, and a 1.5-m control arm (Figure 2). The incurrent pressure spray was powered by a 5-horsepower pump supplied by river water. The excurrent siphon was power assisted by a 10-horsepower pump. Discharge from the system was returned to the river downstream of the study area. The incurrent and excurrent pressures were adjusted to control the size of particles removed and depth of impact.

Prior to restoration, we collected a substrate sample from each subplot to a depth of 15 cm using a 7.2-cm diameter spoon-type auger sampler (model; manufacturer). Samples were sorted using a standard sieve series (ref) to sizes of 1 cm, 0.5 cm, 0.24 cm (#4), 0.1 cm (#10), 0.05 cm (#35), 0.025 cm (#100) and 0.0125 cm (#200), which correspond to course gravel, medium gravel, fine gravel, course sand, medium sand, fine sand, silt and fine silt. We then weighed each size fraction (wet weight, g). Following restoration, a second sample was collected to the depth of restoration from each treatment subplot, sorted and weighed as before. The total amount of removed materiel per unit volume was calculated by subtraction. Effluent from the sediment removal system was collected for 30 seconds, sorted and weighed.

Cementation was estimated using a penetrometer. We used a 100-kg weight placed upon a probe and measured the degree of penetration (0.1 cm). Cementation was measured before immediately after restoration, and at the end of the study on June 15, 2010.

Monitoring

We monitored sedimentation following restoration using sediment samplers similar to those described by Hartmann et al. (2007; Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 61:35–39). However, instead of using a PVC insert, we inserted a 10-cm diameter 0.5-L glass canning jar until the top of the jar was flush with the substrate. Jars were fitted with 1-cm mesh to exclude predators and large gravel. Sediment samplers were deployed 1 day. Upon retrieval, contents were examined for the presences of fish eggs and larvae, sieved and weighed as previously described. Sedimentation rates were calculated as the total weight of the sample per unit area (cm^2) per day.

Fish activity within each treatment and control subplot was monitored using video approximately weekly from April through June. We deployed an array of four digital video cameras at the center of each plot approximately 10 cm above the substrate. Cameras were arranged so that one camera monitored a single subplot, and subplot boundary markers were clearly visible. Cameras were deployed for one hour during daylight hours. Upon retrieval, video was reviewed and fish presence and behavior was documented. In addition, we positioned a 3-m tall observation tower similar to one described by Grabowski and Isely (2007) in the vicinity of the study plots and monitored fish activity visually while cameras were deployed.

Data Analysis

Differences in the frequency of fish use between treatment and control sites were analyzed using chi square analysis. Largest and smallest size categories were collapsed to meet minimum cell frequency requirements. Differences in the proportions of individual size fractions were evaluated using a paired t-test following transformation using an arcsin square root function. Differences in the size composition of sediment between treatment and control sites were analyzed using chi square analysis. The relationship between sedimentation of treated sites and flow was analyzed using least squares linear regression. Differences in cementation were evaluated using a Student's t-test. A significance level of 0.10 was used for all tests.

Results

Restoration

On April 7, 2010, a 3-man crew restored ~100 m^2 of mid-channel gravel bar habitat in ~6 hours. Restored area consisted of 4 – 4 m^2 subplots at the upper gravel bar, 4 – 4 m^2 subplots at the lower gravel bar, and 2 - 35 m^2 test areas (one at the upper gravel bar, one at the lower gravel bar) used to establish mechanical sediment removal apparatus operational parameters.

Gravel bar composition

Prior to restoration, the upper gravel bar was composed primarily of fine sand (mean = 72% by weight). Large gravel (4%), small gravel (6%), coarse sand (9%) and coarse silt (7%) were present as minor constituents (Figure 3a). Material removed from the upper gravel bar using a mechanical sediment removal system was composed primarily of fine sand (86%) and coarse silt (9%; Figure 4). Greater than 98% of removed material was finer than small gravel. Material size distribution of removed material was different than the distribution available. The mechanical sediment removal system selected for material <0.1 cm in diameter. Following restoration, the surface substrate was composed of similar proportions of large gravel (18%), medium gravel (25%), course sand (28%) and fine sand (23%; Figure 3a).

Prior to restoration, the lower gravel bar was composed primarily of large gravel (44%) and course sand (41%; Figure 3b). Small gravel (8%) was also present as a minor component. Substrate size composition of the lower gravel bar was different than the substrate size distribution of the upper gravel bar. The lower gravel bar had a greater proportion of coarse gravel (), and was composed of course sand rather than fine sand. Material removed using a mechanical sediment removal system was composed primarily of coarse sand (80%) and fine sand (18%). Greater than 98% of removed material was finer than small gravel. The mechanical sediment removal system selected for material <0.24 cm in diameter. Following restoration, the surface substrate was primarily composed of large gravel (68%; Figure 4). Small gravel (13%) and course sand (15%) were also present in substantial quantities.

Penetration

Restoration increases penetration (Figure 5) when compared to control levels. Mean penetration in restored sites was not different between gravel bars. Mean penetration of restored sites decreased over the course of the study.

Sedimentation

Sedimentation occurred at a rate of 5.5 – 55.7 $g \cdot cm^{-2} \cdot d^{-1}$ (29.9 ± 32.8; mean ± SD; Figure 6). No difference in sedimentation rate was detected between treatment and control samples, or upper and lower gravel bar samples. Sedimentation rate differed between dates. Sedimentation rate was higher on May 1, 3, and 12 than on May 10. We failed to detect a relationship between sedimentation rate and discharge. However, we were able to detect an inverse relationship between sedimentation rate and change in discharge. Sediment was composed primarily of fine gravel (17.9%) and fine sand (72.7%). Greater than 81% of sediment was finer than small gravel.

Fish

We were successful in capturing video samples on 96 of 112 attempts. Samples ranged from 9 – 77 minutes in length. Fish were identified in 12 samples. Fish consisted of 1 – 6 juvenile northern hog suckers. No other fish were observed in video samples. Due to the small number of observations containing fish, we were unable to identify a difference in the frequency of occurrence of fish on control or restored sites, or on the upper or lower gravel bar. Six unidentified fish larvae and 8 unidentified fish eggs were collected from a total of 8 sediment samples (5 restored, 3 control) on 3 dates. Again, the rare occurrence of fish in samples precluded the analysis of treatment or location effects. Fish were observed in 12 of 16 visual observation periods. However, no fish were observed over the specific study plots representing control or treated areas. We did observe presumed spawning activity by northern hog sucker on the upper gravel bar on April 23 and May 1, by brassy jumprock on the lower gravel bar on May 1, and by robust redhorse on the lower gravel bar on May 9 and 10.

Discussion

Restoration of gravel bar habitat using a commercially-available sediment removal system proved efficient and effective. We estimate that a three-man crew is capable of restoring several hundred m^2 of habitat per workday. The apparatus was easily adjusted to target a specific particle size and depth of operation.

Prior to restoration, gravel bars were composed primarily of a thin layer of gravel over fine (upper gravel bar) or coarse (lower gravel bar) sand. Although the composition of the lower gravel bar contained a higher proportion of gravel, substrate at each study site was highly cemented. The sediment removal system not only removed a predetermined size fraction, but loosened the substrate to a specified depth, increasing the depth of penetration of an object using a fixed force. Although re-sedimentation occurred rapidly, the effects of restoration on increased penetration persisted for the duration of the 4-month spawning season. If sedimentation were to continue at the rate observed during the study period, the effects of the cleaning would disappear in roughly 12-24 months. Because gravel is concentrated in the first few centimeters of the surface of each bar, it is possible that restoration to a shallower depth may have a similar effect, reducing the time and therefore cost of restoration efforts.

As noted in previous studies at these sites, relatively minor changes in discharge resulted in changes in the area of exposed gravel. Gravel exposure changes flow fields and velocities resulting in differential deposition of material on a scale of <1 m^2. Although deposition was not directly related to discharge rate, decreases in discharge rate resulted in high levels of sedimentation. Sedimentation rates were variable within and between sites. Surprisingly, sediments were dominated by sand. We believe this is due to the suspension of fine material in the water column and the transport of sand as bed load. Although screening likely prevented the collection of larger material, little material larger than sand but smaller than the mesh size was collected. The lack of larger material was likely due to relatively supply, rather than flow constraints.

Although restoration clearly enhanced variables previously identified as important for successful reproduction, we were unable to document selection by spawning fish. Fish were generally present on the gravel bars during sampling; however, numbers were relatively low when compared with previous observations. Few fish were observed spawning during the season and no spawning fish were identified within treatment or control plots. Several factors may have contributed to the generally low use of gravel bar habitat. Water levels remained high through the entirety of the early spawning season, then fluctuated substantially thereafter. High and fluctuating water levels result in low and fluctuating water temperatures. Unseasonably low water temperatures result in reduced spawning activity by many species of fish. Generally high water levels impeded sampling. The inability to sample at high water levels may have precluded observations of spawning on submerged gravel. When spawning was observed, it was isolated to areas not located within the study plots. Spawning fish apparently select microhabitats based on a variety of variables available at that particular time. Although we selected areas that had been used for spawning in previous years, it is likely that the conditions existing during this study period differed enough from previous years that fish selected alternative sites for spawning. Although we were unable to document selection of restored habitat, we were able to document potential ecological benefits of Savannah River mid-channel gravel bar habitat restoration. Restoration reduced cementation and increased grain size, increasing the size of interstitial spaces. Combined, these effects reduce energy expenditures by spawning fish and increase the probability of survival of eggs and pre-emergent larvae. Other studies have documented the deposition (superimposition) of one spawn on top of another spawn. However, the cause of superimposition was not determined. We believe disturbances in the substrate may be recognizable by spawners. From an evolutionary point of view, superimposition should be a successful strategy because it reduces survival of competitors and reduces energy expenditures by the superseding pair. We believe restoration as demonstrated in this project should make Savannah River mid-channel gravel bars more suitable for spawning by lithophilic fishes including the endangered shortnose sturgeon.

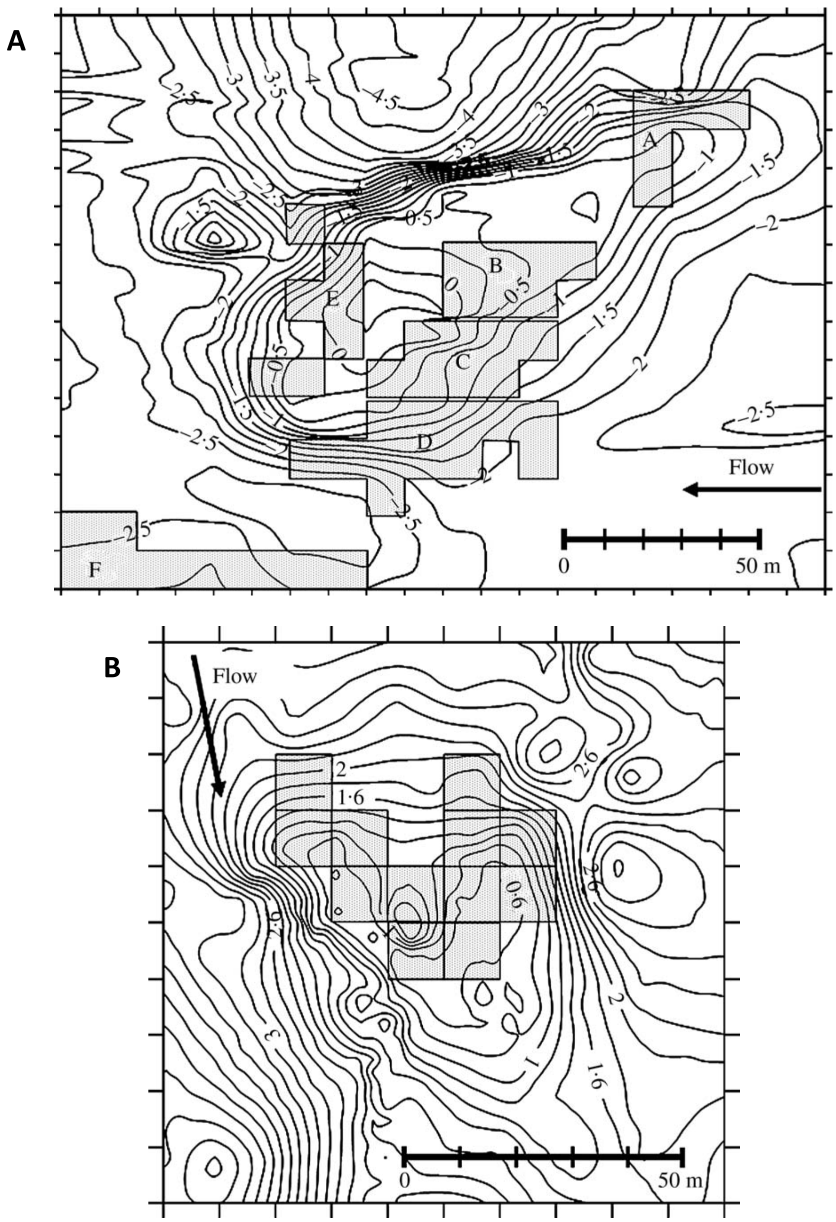

Figure 1. Bathymetric map of the upper gravel bar (A) at river kilometer 299.4 and lower gravel bar (B) at river kilometer 283.7 on the lower Savannah River. Contour lines represent a change in depth of 0.25 m (A) and 0.2 m (B) respectively. The locations where catostomids were observed previously are delineated by shaded boxes. Reprinted with modifications from Grabowski and Isely (2007; J Fish Biol 70:782-98).

Figure 2. Sediment removal system used to restore sites on exposed midchannel gravel bars on the Savannah River, SC and GA. The system consisted of a 25-cm diameter hood fitted with a 5-cm mesh screen, a 1-cm diameter incurrent hydraulic pressure spray, a 7-cm diameter excurrent siphon, and a 1.5-m control arm powered by two independent pumps. The system was deployed using a barge and was controlled manually (photo courtesy of Streamside Systems, LLC).

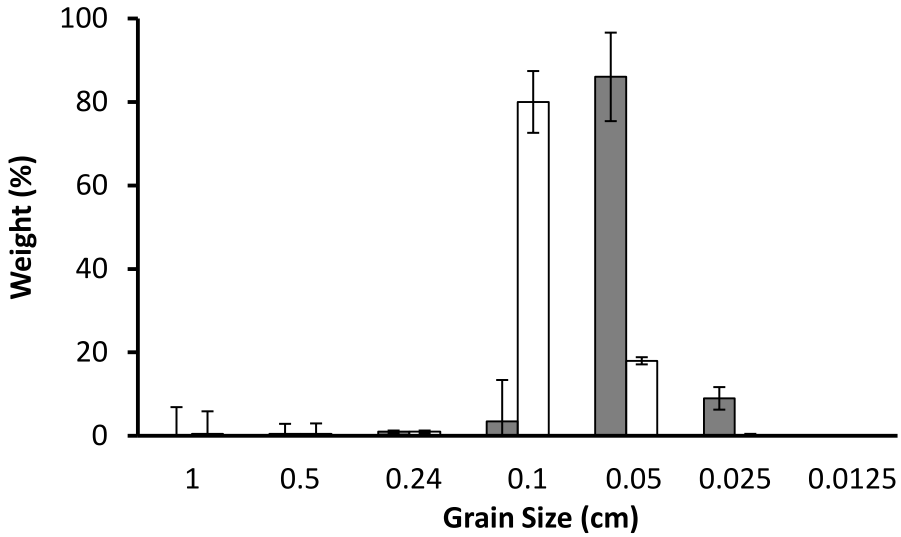

Figure 3. Mean (± 1 SD) grain size (cm) composition of material removed from restored sites on exposed mid-channel gravel bars on the Savannah River, SC and GA. Dark bars represent the upper gravel bar. Light bars represent the lower gravel bar.

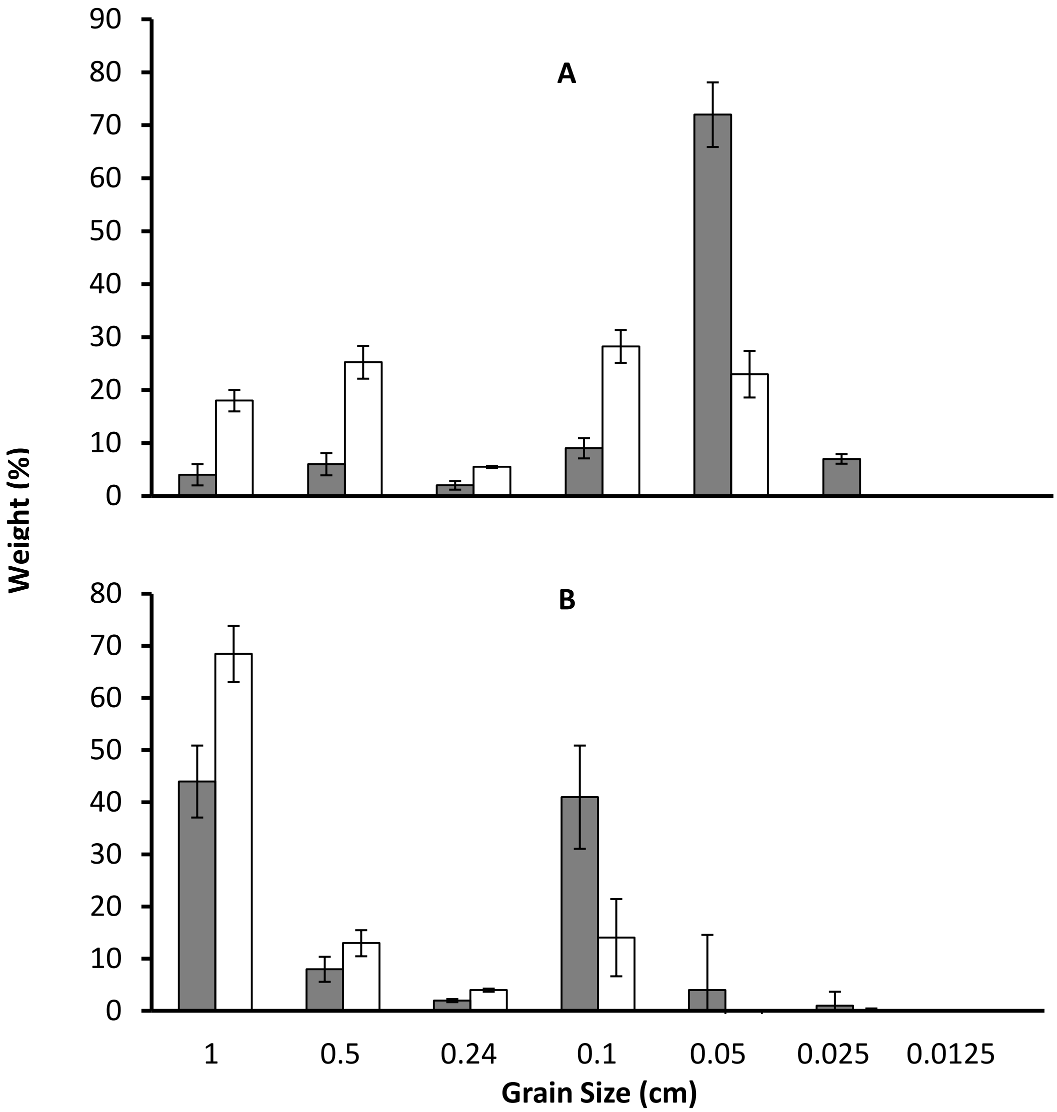

Figure 4. Mean (± 1 SD) grain size (cm) composition before (closed bars) and after (open bars) restoration on the upper (A) and lower (B) exposed mid-channel gravel bar on the Savannah River, SC and GA

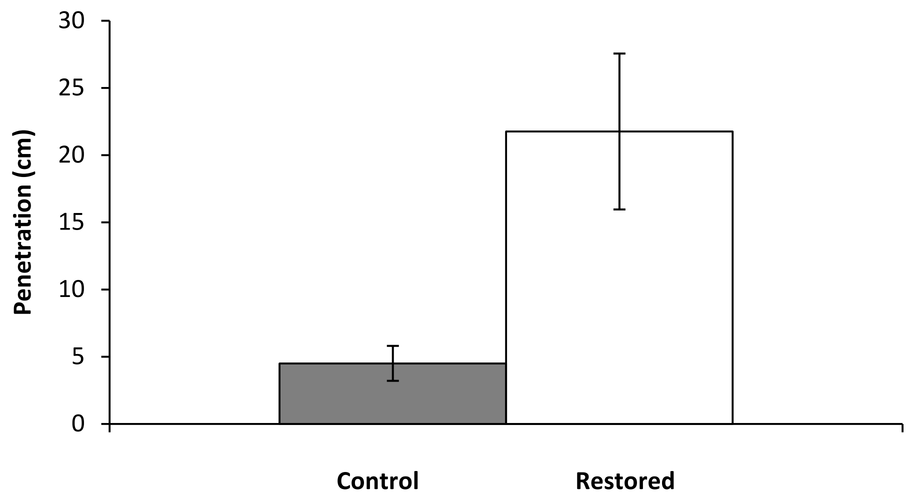

Figure 5. Mean (± 1 SD) penetration on control and restored sites on exposed mid-channel gravel bars on the Savannah River, SC and GA. Penetration at restored sites was significantly greater than at control (unrestored) sites.

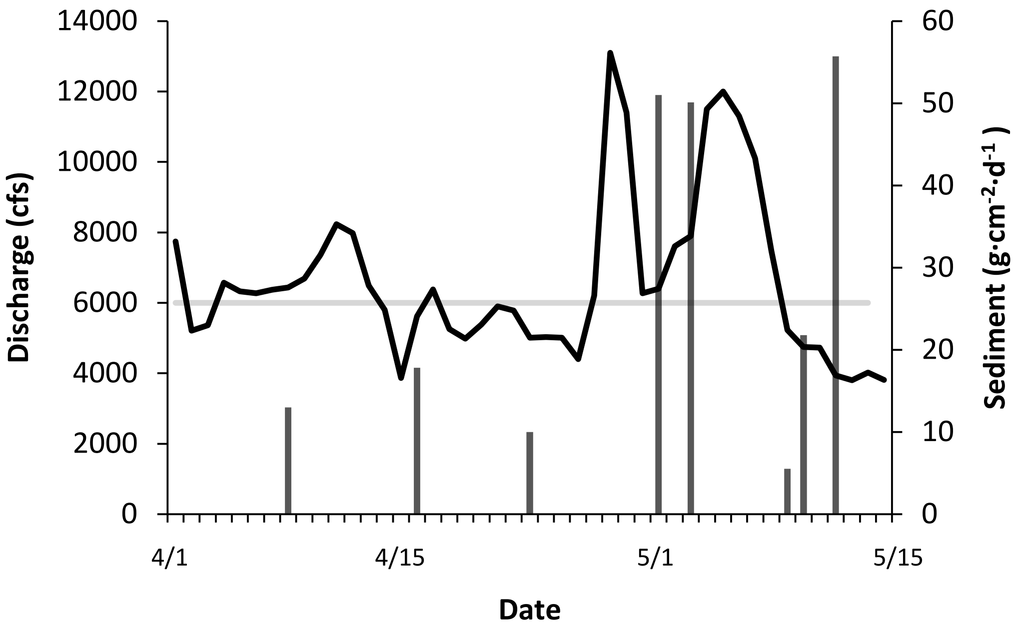

Figure 6. Daily discharge (cfs; solid line) near Augusta, GA, on the Savannah River, SC and GA (Date source: USGS 02197000 Savannah River gauge at Augusta, GA; http://waterdata.usgs.gov/nwis/uv?02197000). The reference line at 6,000 cfs represents the discharge below which gravel bars are exposed. Vertical bars represent mean sedimentation rate ($g \cdot cm^{-2} \cdot d^{-1}$) across location and treatment.

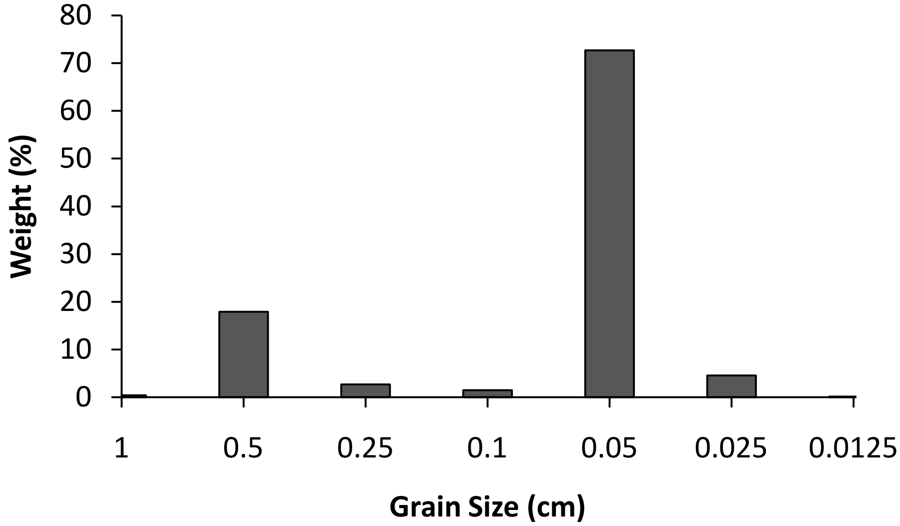

Figure 7. Mean (± 1 SD) grain size (cm) composition (% total weight of the sample) of sediment accumulating on control and restored sites on exposed mid-channel gravel bars on the Savannah River, SC and GA. No differences in sediment composition between control and treated sites, or upper and lower gravel bar were detected; therefore, results were combined.