ROBUST REDHORSE CONSERVATION COMMITTEE HABITAT TECHNICAL WORKING GROUP HABITAT RESTORATION MANAGEMENT PLAN

Bank Erosion

Point Source Discharge

Before **Habitat Restoration Project** **After**

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HABITAT RESTORATION MANAGEMENT PLAN FOR THE ROBUST REDHORSE

1.0 INTRODUCTION

The robust redhorse (*Moxostoma robustum*) was described by Edward Cope in 1870 from specimens collected in the Yadkin River, North Carolina. The species was essentially lost to science until 1991 when five specimens were collected by Georgia Department of Natural Resources, Wildlife Resource Division (WRD) biologists downstream of Sinclair Dam on the Oconee River near Toomsboro, Georgia. As of 2007, wild individuals are known to exist in the Oconee and Ocmulgee Rivers in Georgia, the Savannah River of Georgia and South Carolina, and the Pee Dee River of North and South Carolina. Stocked introductions have occurred in the Broad, Ogeechee, and Ocmulgee Rivers, Georgia, and the Broad and Wateree Rivers, South Carolina. The species is considered to be very rare and is classified as endangered by the Georgia Department of Natural Resources (Freeman, 1999).

The historic range of the species is believed to include Atlantic Slope drainages from the Pee Dee River, North Carolina, to the Altamaha River in Georgia. The robust redhorse inhabits Piedmont Plateau and Upper Coastal Plain sections of South Atlantic Slope rivers. Piedmont reaches are characterized by rock shoals, outcrops, and pools, particularly along the Fall Line. The Upper Coastal Plain reaches typically have sandy banks and beds interspersed with shoals and gravel bars. The Upper Coastal Plain reaches also have extensive networks of swamps, oxbows, and floodplains. Woody debris and fallen trees seem to provide preferred habitat for adult robust redhorse in the Oconee River (Conservation Strategy, 2003).

Recovery efforts have been initiated by a diverse group of stakeholders that comprise the Robust Redhorse Conservation Committee (RRCC). The RRCC was established in 1995 through a Memorandum of Understanding (MOU) among stakeholders including State and Federal agencies, conservation organizations, and the private sector (Conservation Strategy, 2003).

The Policies of the RRCC (Policies) describe goals, conservation, and administrative issues of the RRCC and were adopted by consensus during the annual meeting held October 16-18, 2002. The formation of technical working groups (TWG) is outlined in the MOU, the Conservation Strategy, and the Policies. TWG's are charged to determine needs including conservation actions, research, information exchange, and public education/outreach. TWG's may work to plan, coordinate, implement, and facilitate implementation of conservation actions agreed to by the RRCC and report periodically on progress to the RRCC within existing authority, policy review, and budgets. They may be formed and disbanded as needed and will address local or special interest issues. They represent the members of the RRCC who are actively engaged in research, protection, and restoration of robust redhorse in a specific geographic region. Conservation actions developed for the river basin/ ESU management plan are coordinated by the TWG and implemented using facilities and resources provided by its members.

During the 2002 RRCC annual meeting, the "Habitat Restoration" Policy was one of the many Policies that were adopted. The "Habitat Restoration" Policy charges the Habitat TWG to 1) identify critical habitat needs, 2) establish guidelines for evaluating habitat, and 3) establish guidelines for evaluating restoration activities.

2.0 PURPOSE

The purpose of the formation of the Habitat TWG is to oversee robust redhorse habitat restoration activities rangewide. The Habitat TWG is responsible for developing guidance that both prioritizes sites for restoration and facilitates suitable habitat restoration activities that can be applied to specific individual river basins. The guidance document, or Habitat Restoration Management Plan, should be initially reviewed and adopted by the RRCC, revised and/or appended every year, and reviewed and adopted by the RRCC after each revision. With the assistance of the Habitat TWG, the respective basin TWG's will be able to select sites, prepare proposals, secure funding, and conduct effective restoration activities within their basin.

3.0 STATUS, DISTRIBUTION, AND HABITAT REQUIREMENTS

3.1 EXISTING CONDITIONS

The robust redhorse is presently found in Piedmont and Upper Coastal Plain sections of the Oconee and Ocmulgee rivers, Georgia, the Savannah River, Georgia/South Carolina, and the Pee Dee River, South Carolina/North Carolina. The RRCC considers the wild robust redhorse in the Pee Dee, Savannah, and Altamaha (Oconee and Ocmulgee Rivers) drainages to be Evolutionary Significant Units (ESUs) based on current genetic information. The RRCC will continue to manage identified ESUs as distinct populations in order to maintain the genetic diversity of the species across its historic range (Conservation Strategy, 2003).

Introductions have occurred in the Broad River and a population is now believed to exist in this river and the downstream reservoir, Clarks Hill Reservoir, Georgia. Introductions are also occurred in the Ogeechee River, and the Ocmulgee River, Georgia (Conservation Strategy, 2003), the Broad and Wateree Rivers, South Carolina.

The recent discovery of robust redhorse in the Savannah, the lower Ocmulgee, and Pee Dee rivers, which have been extensively sampled for other species, suggests that this species can be difficult to collect, or may have been overlooked or improperly identified in the past (Conservation Strategy, 2003).

3.2 DISTRIBUTION

The historic range of the robust redhorse is the Atlantic Slope river drainages from the Pee Dee River in North Carolina to the Altamaha River in Georgia. Since the rediscovery of robust redhorse in 1991, individuals and possible populations have been found in rivers from all three states where historic populations existed. These areas include: the lower segment of the Yadkin-Pee Dee River system below Blewett Falls Dam (North Carolina/South Carolina); the Savannah River near the Augusta shoals area (below the Augusta Diversion Dam) and below the New

Savannah Bluff Lock and Dam (Georgia/South Carolina); and in the Oconee River below Sinclair Dam (Georgia).

3.3 LIFE HISTORY

Most of the information available concerning the life history of this species has been generated from research conducted on the Oconee River. The robust redhorse spawns during April, May, and June when water temperatures reach 21-23 degrees Centigrade, although spawning may occur over the range from 18 to 25 degrees Centigrade. Spawning is typical of *Moxostoma* and involves spawning triads with two males fertilizing the eggs of a single female, which are deposited in gravel substrate. Shallow water conditions in the Oconee River occasionally allow visual observation of spawning fish, but there are indications of spawning activity at greater depths as well. Adult fish are large (modal total length 66 cm, range from 42 cm to 72 cm). Wild juveniles less than 40 cm in length have not been collected from the Oconee River (Conservation Strategy, 2003).

The requirements for successful recruitment of robust redhorse are not fully understood. The requirements for successful emergence of yolk-sac larvae from gravel beds include absence of fine sediment. The subsequent food requirements and preferred habitats of juvenile robust redhorse are poorly understood. The recruitment rates in the Oconee River appear to be low, but need to be examined in the context of the population size and the long life span of the robust redhorse. Recruitment and population dynamics in the Ocmulgee, Savannah, and Yadkin-Pee Dee populations are not presently well documented. Possible migration of juveniles and adults are also not well understood. These are priority subjects of current research (Conservation Strategy, 2003).

Diet studies of adults are limited. The few specimens examined from the Oconee River suggest that adult fish feed primarily on bivalves, including the Asiatic clam (*Corbicula* sp.). The life span of robust redhorse is believed to be 25 to 30 years and the major known population is believed to be composed of numerous year classes (Conservation Strategy, 2003).

3.4 HABITAT REQUIREMENTS

Habitat alteration can lead to changes in the chemical, physical, and biological aspects of habitat that may be necessary for one or more life stages of the robust redhorse. This species requires clean gravel beds to spawn. Fine sediment mixed with gravel beds affects successful hatching and emergence of larval robust redhorse (Dilts, 1999). In some cases manganese has been shown to adhere to fine sediment, resulting in increased toxicity to early life stages of robust redhorse (Lasier, 2001).

4.0 RESEARCH STATUS AND NEEDS

See Appendix A.

5.0 PROBLEMS FACING THE SPECIES

Current research indicates that habitat modification is one of the primary factors affecting the decline of robust redhorse. Many of the factors listed below are causal or contributing factors to its decline.

5.1 SEDIMENTATION AND OTHER POLLUTANTS

Sedimentation can be due to point sources (e.g. municipal effluent), agricultural and urban runoff (non-point source pollution), dredging and filling, impervious surfaces, near-water and floodplain development, and erosion and unstable stream banks caused by land cover alteration, channel alteration, and riparian losses and alterations.

Historic land use practices including intensive farming and deforestation led to excessive erosion and subsequent sedimentation, and caused dramatic changes in riverine habitats. Sediment is considered the most important cause of water pollution in the United States (Waters 1995), and construction is considered the most damaging phase of the development cycle to aquatic resources (Brown and Caraco 2000).

Reproduction by this species appears to be sensitive to sedimentation (Dilts, 1998). Mollusks, presumed to be a major food source for the robust redhorse, would also have been severely impacted by sedimentation (Stansbery, 1971) (although Asiatic clams, a food source, have proliferated). Many of the environmental factors believed to have reduced populations of robust redhorse to the current levels are historic in nature, including sedimentation from poor land use practices, and chronic (and severe) water quality degradation.

Lasier et al. (2001) evaluated sediment-associated contaminants in the lower Oconee River to determine their sources and evaluate potential for reducing survival and growth of early life stages of robust redhorse. Manganese (Mn) and zinc (Zn) were found to be present in potentially deleterious concentrations in sediment pore water, but only zinc was found to inhibit growth in the selected surrogate, a freshwater amphipod, *Hyallela azteca*. Significant reductions in sediment-metal concentrations occurred between the fall of 1998, when amphipods were tested, and the spring of 1999 when robust redhorse egg and larval stages were evaluated. While manganese concentrations for sediments collected between fall 1998 and spring 1999 were reduced, pore water collected downstream of specific creeks discharging into the Oconee River did exhibit toxicity to early robust redhorse life stages. Toxicity is believed to be related to the concentration of manganese and reduction to the Mn^{2+} species. Lasier et al. (2001) suggested limiting soil erosion and sedimentation of fine soil materials into robust redhorse spawning gravel bars to alleviate the threat of Mn toxicity.

Although direct cause and effect relationships have not been determined, water quality degradation from point and non-point sources may also have contributed to historic declines. The implementation of the Clean Water Act, the Resource Conservation and Recovery Act, the National Environmental Policy Act, agriculture and soil conservation programs, reforestation, and many other regulatory programs, have improved riverine conditions significantly.

5.2 Agricultural and Urban Runoff (non-point source pollution)

Agricultural activities right up to the stream bank have resulted in degraded channels due to the loss of riparian vegetation, trampling by livestock, sedimentation, and input of excessive nutrients and pesticides and herbicides. Steam channels in agricultural areas often become incised, have limited substrate diversity, limited aquatic habitat, and an unstable condition. Agricultural runoff includes sediment, nutrients, and herbicides and pesticides.

Stormwater runoff typically contains dozens of pollutants. The direct water quality impact of stormwater pollutants depends on the type of pollutant or combination of pollutants (potential synergistic effects), as different pollutants impact streams differently. For example, sediments affect stream habitat and aquatic biodiversity; nutrients cause eutrophication; metals, hydrocarbons, deicers, and Methyl Tertiary Butyl Ether (MTBE) can be toxic to aquatic life; and organic carbon can lower dissolved oxygen levels.

As indicated above, direct cause and effect relationships have not been determined for the robust redhorse, however, water quality degradation, may have contributed to historic declines.

5.3 Dredging and Filling

5.3.1 Loss of Wetlands and Streams

Frayer, et al. (1983) estimated national annual wetland losses at an average of over 450,000 acres during the 20-year period from the 1950's to the 1970's. Another 644,000 acres of wetlands have been lost between 1986 and 1997, resulting in a net loss of 58,500 acres annually in this time period (Dahl 2000). Between the 1970s and 1980s, wetland losses within the Southeast region accounted for 89% of the net national wetland loss for the period, and North Carolina stood out among all the southeastern states for the highest acreage of wetland loss with an estimated loss of 1.2 million acres in palustrine forested and scrub/shrub wetlands (Hefner et al. 1994). Major conversions of coastal and freshwater wetlands have occurred due to agricultural and silvicultural expansion, industrial development, and urban encroachment. The greatest wetland losses have occurred in forested wetlands (1.2 million acres), and the greatest wetland losses are attributed to urban development (30%) (Dahl 2000). In spite of the continued losses, the rate of wetland loss has decreased by 80% in the U.S. in the past decade, and the U.S. Fish and Wildlife Service urges the American public to remain diligent in its commitment to wetland protection, so that the substantial progress that has been made in wetland protection is not lost in the future (Dahl 2000).

Dredging removes sediments from the bottom of the stream and is conducted to develop waterways for commerce, recreation, and defense and to disperse urban, industrial, and agricultural wastes (Ebert 1993). Stream channels are often piped for development activities. Numerous significant and negative consequences can result when headwater streams are lost (Meyer and Wallace 2001), and the effects of degradation accumulate; therefore, the condition of the stream in the lower reaches is closely dependent on the condition in the headwaters (Vannote et al. 1980). In addition, headwater streams can significantly reduce nutrient export to rivers (Alexander et al. 2000; Peterson et al. 2001).

The cumulative effects of stream and wetland losses will contribute to continued declines in aquatic and wetland dependent species and in water quality, and is a potential threat to the robust redhorse.

5.3.2 Channel Alteration

Streams are altered to increase some other benefit (e.g. flood control, navigation, reduced erosion, or increased area for farming or development), but may also change fish and wildlife habitat, disrupt patterns and timing of water flows, act as barriers to animal movement, or reduce or increase natural filtering of sediment and pollutants. Stream channels are altered by channelization, dredging, culvert and dam placement, construction of ponds and reservoirs, and watershed development. Channelization is extremely destructive; disrupting pre-existing equilibria and causing adjustments in channel morphology, affecting physical habitat, water quality, and aquatic communities, and impacts on associated watershed habitat (Hubbard et al. 1993). Dredging may remove benthic invertebrates, destroy fish and invertebrate habitats, resuspend sediments, alter water quality, and release toxicants, which can adversely impact aquatic organisms (Ebert 1993). Over time, watershed development can alter or eliminate a significant percentage of the stream network. Channel alterations may have contributed to historic declines of the robust redhorse and remains a potential threat to the robust redhorse.

5.4 IMPERVIOUS SURFACES

Land development can result in stream hydrology changes. Paving of watersheds results in impervious surfaces and compact soils, which significantly reduces their infiltration capabilities. Installing urban stormwater drainage systems exacerbates the problem by increasing the efficiency with which runoff is delivered to the stream (i.e., curbs and gutters, and storm drain pipes). Consequently, a greater fraction of annual rainfall is converted to surface runoff, runoff occurs more quickly, and peak flows become larger. Examples of hydrologic impacts are: increased runoff volume, increased peak discharge rates, increased bankfull flow, and decreased baseflow, and examples of physical impacts are: increased stream warming and changes in channel geometry (enlargement of the cross-sectional area of the stream channel through a process of channel incision, widening, or a combination of both). Enlargement of the cross-sectional area can increase sediment transport from the stream due to an increase in bank and/or bed erosion.

Although there are no studies specifically conducted on impacts of impervious surface on robust redhorse, a number of studies have examined the link between watershed urbanization and its impact on stream and wetland biodiversity (Center for Watershed Protection 2003), which demonstrate that a relatively small amount of urbanization has a negative effect on aquatic diversity, and that as watersheds become highly urban, aquatic diversity becomes extremely degraded. Many of the studies have determined that stream degradation occurs at approximately 10% coverage by impervious surfaces (Schueler 1994; Arnold and Gibbons 1996; Doll et al. 2000; Mallin et al. 2000; May and Horner 2000; Stewart et al. 2000; Paul and Meyer 2001); however, the influence of impervious cover is most evident at the subwatershed level (Center for Watershed Protection 1998).

5.5 Near-Water and Floodplain Development and Land Cover Alteration

Undeveloped floodplains strongly influence aquatic systems, support a combination of riparian and upland vegetation used by aquatic and terrestrial wildlife, supply a rich source of food to aquatic communities (Junk et al. 1989), and provide an important sediment trapping function (Palik et al. 2000). Without proper safeguards, the cumulative effects of land development can transform the landscape and negatively impact the environmental character and natural functions of the ecosystems. Some of the greatest impacts of development, both land-based and near-water development, affect water quality in our streams and rivers. Approximately one-third of North American freshwater fish species (Williams et al. 1989) and 72% of freshwater mussel species (Williams et al. 1993) qualify for classification as "endangered", "threatened", or "special concern" at the federal level, and habitat loss is a primary culprit, particularly for mussels. In North Carolina, 21% of freshwater fishes and 53% of freshwater mussel species are designated endangered, threatened, or of special concern at the state level (LeGrand et al. 2001). The decline in freshwater species is a direct reflection of declining quality of our streams and rivers and declining water quality may have contributed to historic declines of the robust redhorse and remains a potential threat to the robust redhorse.

5.6 Riparian Losses and Alterations

Although riparian zones constitute a small percentage of the landscape, they frequently perform important ecological functions and contain a disproportionately high number of wildlife species in comparison to most upland habitats (Fischer et al. 2000; Knutson and Naef 1997). Riparian areas perform many functions that are essential to maintaining water quality, aquatic species survival, and biological productivity. Riparian zone functions include: reduce pollutants and filter runoff, improve air quality and lower ozone levels, maintain stable water flows, help sustain natural channel morphology, help maintain water and air temperature by providing shade, stabilize stream banks, provide most of the organic carbon and nutrients to support the aquatic food web, provide sources of large woody debris for the stream channel, help reduce the severity of floods, facilitate the exchange of groundwater and surface water, provide critical wildlife habitat. Riparian best management practices (BMP), along with upland BMP, have been found to affect fish communities (Wang et al. 2002).

For sensitive streams (containing rare species or are of high quality), wider contiguous buffers (100–300 feet) are recommended (Knutson and Naef 1997; Center for Watershed Protection 1998; May and Horner 2000; Martin et al. 2000; Palik et al. 2000; Richards and Hollingsworth 2000; Stewart et al. 2000). Effective buffer sizes depend upon specific site conditions, such as slope and soil type. Riparian protection of sufficient size provides many functions that will help maintain robust redhorse habitat and is an important mitigative measure to protect the robust redhorse and its habitat from development impacts.

5.7 Waste Treatment Plant Discharge and Industrial Discharge

Wastewater treatment effluent can contain chlorine, ammonia, high levels of organic materials and nutrients, suspended solids, and metals and other pollutants. Occasionally an accidental spill occurs resulting in untreated waste discharge. Industrial discharge can result in the release of metals and other contaminants and dyes into the water. When water is released from power generating industries and some manufacturing plants, it is often several degrees warmer than the receiving waters. These point source discharges can have physical, chemical, and biological effects. Lasier et al. (2001) speculated that the elevated zinc concentrations found in the Oconee River were likely the result of permitted municipal and industrial effluents. As indicated above, direct cause and effect relationships have not been determined for the robust redhorse. However, water quality degradation may have contributed to historic declines.

5.8 Nutrient Loading

Nutrient loading can occur from both point and non-point sources such as wastewater treatment plant discharge sites, agricultural areas, and areas with large manicured grassed areas such as golf courses. Half of the rivers tested, as reported by The Heinz Center (2002), had total phosphorus concentrations of 100 ppb or higher, which is EPA's recommended goal for preventing excess algal growth in streams that do not flow directly into lakes. A survey of the Nation's waters by states and tribes showed that half do not adequately support aquatic life because of excess nutrients. Nitrogen and phosphorus are the primary causes of eutrophication and resulting algal blooms (EPA 2002). As indicated above, direct cause and effect relationships have not been determined for the robust redhorse. However, water quality degradation in general may have contributed to historic declines.

5.9 Atmospheric Emissions

Rising global temperatures are expected to raise sea level, and change precipitation and other local climate conditions, which could alter terrestrial and aquatic ecosystems.

The ecological effects of acid rain are most clearly seen in the aquatic environments (http://www.epa.gov/air/topics/comeap.html; accessed September 2003). In areas where buffering capacity is low, acid rain also releases aluminum from soils into lakes and streams, which is highly toxic to many species of aquatic organisms.

Toxic air pollutants include, but are not limited to, chlorine, hydrochloric acid, formaldehyde, toluene, acetaldehyde, benzene, perchlorethlyene, xylene, chromium, dioxin, lead, manganese, mercury, methanol, nickel, and triethylamine. The Heinz Center (2002) reported that three-fourths of the streams tested had one or more contaminants that exceeded aquatic life guidelines and one fourth of the streams exceeded the standards for four or more contaminants. Some of these pollutants may make it into aquatic systems resulting in water quality degradation, with similar potential affects to the robust redhorse as described above for pollutants.

5.10 Water Flow Alteration

The inherently natural flow regime of rivers is critical to ecosystem function and native biodiversity (Poff et al. 1997). Flow and channel modifications have been made for flood control, water supply, bank stabilization, formation and maintenance of navigation channels, mineral extractions, and land reclamation. River control structures include dikes, levees, and dams, and these structures can result in physical (e.g. channel length and velocity), chemical (e.g. dissolved oxygen, nutrients, pollutants), and biological changes (e.g. primary production, benthos, fishes) (Pennington and Shields 1993). Channel enlargement and realignment are channel modification activities designed to increase the channels capacity to convey water. Changes in stream flow can result in significant effects on fish habitat and chemical concentrations in streams. Altered instream habitat is considered one of the greatest stressors to mid-Atlantic streams, and many other streams throughout the U.S. (EPA 2003; and references therein). Water flow alterations may have contributed to historic declines of the robust redhorse and remains a potential threat to the robust redhorse.

5.11 SURFACE AND GROUNDWATER WITHDRAWALS

Communities' populations are growing, resulting in increasing demand for fresh water. Water is required by agriculture and municipalities and by industries as part of their processing activities. Permanent withdrawals can have detrimental and far-reaching impacts on aquatic organisms and habitats through processes such as reducing outflows of freshwater to estuaries, lowering of water tables, reducing or destroying riparian wetlands and littoral nursery habitats, altering physical characteristics of streams and rivers, and altering nutrient and carbon transport dynamics (Zale et al. 1993). Withdrawal can also result in the entrainment or impingement of aquatic organisms.

Rivers and shallow groundwater often are hydrologically linked; therefore, extraction of groundwater can result in reductions in connected surface flows. Declining water levels affect water quality; as wells are drilled deeper, water that is withdrawn has been exposed longer to surrounding rock layers. Higher concentrations of natural contaminants may eventually result as minerals in those rocks dissolve in ground water (Axness et al. 2002).

It is important to determine the maximum amount of water that can be removed at any given time without adversely altering the river system and its natural functions and processes. Instream methodologies to determine appropriate flows have been discussed in various publications (Zale et al. 1993; Annear et al. 2002). Water withdrawals are a potential threat to the robust redhorse and the cumulative effects of multiple withdrawals may be especially detrimental.

5.12 WATER DIVERSION

Water diversion has been defined as any man-made alteration that results in an increase in one stream discharge as a result of flow transfer from another stream (Christie et al. 1993) and has been implemented for hydroelectric projects and other power generating projects, irrigation, navigation, flood and salinity control, water supply, sediment reduction and movement, and pollution control. Christie et al. (1993) lists some of the environmental consequences from diversions: increased flow regimens and concommitment changes in channel morphology, turbidity, substrate, flow, pool-riffle ratio, water temperature, and water quality; introduction of aquatic organisms; larval fish transfer and mortality; altered riparian habitat; and increased potential for land-use changes in the downstream floodplain. North Carolina municipalities have been requesting an increasing number of inter-basin transfers of water to meet growth demands. As growth continues throughout North and South Carolina and Georgia, this could be an increasing threat to robust redhorse and its habitat.

5.13 INSTREAM AND FLOODPLAIN MINING

Instream mining operations remove accumulated sand and gravel directly from stream channels and floodplain mining from the floodplain. Sand and gravel are mined commercially in every state in the U.S.; however, due to numerous research studies that have demonstrated long lasting environmental effects from instream mining, many states have imposed strict regulations on instream mining, and some no longer allow it (Roell 1999). Some of the more detrimental effects of instream mining include channel degradation and erosion, headcutting, increased turbidity, stream bank erosion, and sedimentation of riffle areas. All of these changes can adversely affect fish and other aquatic organisms, either directly by damage to the organisms or through habitat degradation, or indirectly through disruption of the food web. Further, effects on stream geomorphology (e.g., channel incision) can result in infrastructure damage such as undermining bridge piers and exposure of buried pipeline crossings and water supply intakes (Kondolf 1997). Each mining operation not only exerts an individual effect on the stream, but effects of multiple mining operations within a river system may be cumulative. Of the listed effects of instream mining, those that may impart the greatest potential threat to robust redhorse include increases in sedimentation and the direct removal of spawning materials.

5.14 SURFACE MINING

Mining is defined as the taking of minerals from the earth (EPA 1995). Minerals are extracted by three basic methods: open-pit or surface, underground, and solution mining, but for quarrying of non-fuel, nonmetallic minerals, most mining is open-pit or surface mining. Quarrying is an open-pit mining process that cuts and loosens block or blasting of dimension stone or crushed stone. Processing may require the use of chemicals such as sulfuric acid, chromium, phenols, zinc, ammonia, hydrochloric acid, and phosphoric acid, and clay processing may involve the use of liquid chemical dispersants (phosphates, phosphoric acid, and hydroxides). Wastes generated from minerals processing include dusts, solid matter, and water effluents and processes used to remove mineral impurities can be a major source of water contamination. Waste material may include heavy metals and other chemicals. Some of these pollutants may make it into aquatic systems resulting in water quality degradation, with similar potential affects to the robust redhorse as described above for pollutants. Toxic sediment was collected in the Oconee River downstream of a mine site, which was speculated to be caused by chromium; however, the source of this metal to the watershed was unknown (Lasier et al. 2001).

5.15 DAMS, CULVERTS, AND OTHER BARRIERS

Infrastructure such as bridges, dams, pipelines, and culverts can create partial or total barriers to fish migration and impair the ability of fish to move freely in a watershed. Construction of infrastructure can cause the release of sediment or pollutants, a temporary fish passage barrier during construction, removal of bankline vegetation, and blocking of the flow or stranding of fish. Poor siting of road crossings for culvert installation can create a need for channel maintenance, and structural failure can cause extensive damage to habitat. River impoundment results in loss of kilometers of flowing stream and qualitative and quantitative changes in downstream (and potentially upstream due to loss of habitat and genetic connectivity) fish populations (Yeager 1993). The water release level from a dam will determine the physical, chemical, and biological attributes of the downstream ecosystem, the operating regimen will affect the hydrology of downstream reaches, and the presence of the dam will result in changes in sediment and nutrient transport (Yeager 1993).

Development of hydropower facilities affects robust redhorse populations by limiting access to probable historic spawning sites and reducing the amount of historic riverine habitat. Site specific flow regimes may be limiting factors below hydropower facilities but can be addressed through the FERC relicensing process for non-federal projects and by NEPA for actions involving federal projects. In addition, states with State Environmental Policy Acts (SEPA) may also address issues involving the robust redhorse for state projects. In many cases, dams will minimize sedimentation loading in immediate downstream riverine areas by acting as sediment traps from excessive anthropomorphic sources and thus locally improving water quality in tailwater reaches. However, it is preferable to prevent or minimize sediment input in the first place.

5.16 INFRASTRUCTURE (ROADS, UTILITY LINES) PLACEMENT AND CROSSINGS

Similar to other construction activities, infrastructure construction can result in impacts to aquatic communities due to the introduction of sediment or pollutants. Often utility lines are placed along streams reducing the amount of riparian buffer area, and stream crossings most often result in breaks in the buffer area. Crossings are usually aerial, open-cut through the stream channel, or directionally bored underneath the channel. Aerial and open-cut stream crossings necessarily require riparian vegetation removal, and open-cut methods often result in a large amount of sediment traveling downstream. The directional bore method can preserve the buffer area and result in minimal impacts to the channel. However, if a “frac-out” (material from the bore hole surfaces along a fracture of unconfined soils) occurs, a large amount of sediment can be introduced into the channel along with lubricant material (e.g. betonite). Infrastructure placement and crossings are a potential threat to the robust redhorse through paths as discussed above.

5.17 NON-NATIVE SPECIES

Non-native aquatic species are defined, for the purpose of this document, as species that have been moved outside of their native range whether originating in a foreign country or from within the United States. The introduction of non-native species such as the flathead catfish has influenced the abundance of native fish species (Evans, 1991), and may impact robust redhorse populations through predation on juveniles. Flathead predation on young robust redhorse is suspected to be a significant factor in limiting recruitment into the Oconee River or other river populations; however, the extent of predation is unknown. Flathead catfish have been introduced in nearly all of the large southeastern rivers within the historic range of the robust redhorse. Effective control of the flathead catfish may not be possible, and it is unclear whether removal efforts would have a significant long term impact on flathead catfish or robust redhorse populations. The flathead catfish is a potential concern for the RRCC conservation efforts.

The effect of predation by flathead catfish on robust redhorse has not been evaluated due to practical limitations in conducting such studies. However, general flathead catfish diet studies have been conducted. In the Altamaha River in Georgia, researchers found zero percent of catastomids (of the identified fish species) in flathead catfish stomachs (n=514) (Weller and

Robbins 1999). Quinn (1987) found the presence of catastomids in 2% of the flathead catfish stomachs (n=148) in the Flint River, however, catastomids made up the greatest percentage by weight in flathead catfish stomachs. Flathead diet studies from the Cape Fear River in North Carolina in 1979 found catastomids in 3% of flathead catfish stomachs (stomachs with food; n=66) (Guier, et al. 1981) and studies conducted in 1986 found zero percent (n=82) (Ashley and Buff 1987). Other recent flathead catfish diet studies that were conducted on North Carolina rivers, showed the presence of catastomids in 2% of the flathead catfish stomachs from Contentnea Creek (n=164) and zero for the North East Cape Fear River, Lumbar River, and Pee Dee River (n=87; n=47; n=12, respectively) (Kwak, unpublished data). It is important to note that although catastomids were found to be rare in the flathead catfish diet, it is possible that they may have already been decimated from the area due to the presence of flatheads.

The impact and interactions of other large, non-native fishes, such as smallmouth buffalo, blue catfish, and common carp with the various life stages of robust redhorse are also presently not well understood or defined in the river systems where these species coincide.

5.18 DISEASE

Robust redhorse from the Oconee River and Savannah River have been examined for the presence of parasites and infectious diseases by the US Fish and Wildlife Service's Warm Springs Fish Health Center. No evidence of infectious disease has been identified in fluid or tissue samples collected from wild fish (Heil 1997).

6.0 CONSERVATION ACTIONS TO BE IMPLEMENTED

6.1 CONSERVATION GOALS

6.1.1 Short-term goals (2002-2004)

Develop a comprehensive guidance document, the Habitat Restoration Management Plan, that will provide a methodology for prioritizing sites for restoration and facilitate and describe suitable robust redhorse restoration activities.

6.1.2 Long-term goals

Promote habitat restoration activities that support the Strategy's long-term goal to establish or maintain at least six self-sustaining robust redhorse populations distributed throughout the historic range.

6.2 CONSERVATION ACTIONS

The following conservation actions are steps to achieve long and short-term goals of the Habitat TWG:

1. Provide a guidance document that describes a suitable methodology for prioritizing restoration activities within river basins (see Appendix B).

2. Provide a list of grant opportunities for funding robust redhorse habitat restoration activities (see Appendix C).

3. Provide a list of appropriate habitat restoration activities for southeastern river systems (see Appendix D; at this time this appendix addresses a) restoration to improve erosion and sedimentation; and b) gravel augmentation).

7.0 LITERATURE CITED

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APPENDIX A

RESEARCH STATUS AND NEEDS

COMPENDIUM OF HABITAT-RELATED RESEARCH OF ROBUST REDHORSE (CHRRR)

This compendium is arranged by the date the research was published. The last page contains a summary of the research topics by life stage.

Walsh, S. J., D. C. Haney, C. M. Timmerman, and R. M. Dorazio. 1998. Physiological tolerances of juvenile robust redhorse, *Moxostoma robustum*: conservation implications for an imperiled species. Environmental Biology of Fishes 51: 429-444.

OBJECTIVE(S)

To describe physicochemical responses of larval robust redhorse. This might provide insight about historical distribution, micro-habitat requirements, and as a possible explanation of population decline.

METHOD

Lab-reared juveniles (4-12 weeks) or lab- and pond-reared juveniles (9-24 months) were used for an acute experiment. Juveniles were tested for tolerances of temperature (upper and lower limits), salinity, pH, and dissolved oxygen.

RESULTS

Juvenile robust redhorse appear to be moderately tolerant of a broad range of environmental physicochemical conditions.

They seem to be tolerant of a broad range of temperatures, depending at what temperature they were acclimated to, and other factors such as age or health.

They appear relatively stenohaline, but may be capable of tolerating short periods of high salinity. Larger individuals are more capable of tolerating higher salinity than younger robust redhorse. Also, those fish that were acclimated in hard water had higher tolerances than those in soft water.

Juvenile robust redhorse appeared to be moderately tolerant of acute exposures to pH values that are beyond the range found in the wild.

They can tolerate low dissolved oxygen. When oxygen levels were very low, aquatic surface respiration was observed.

POTENTIAL RESEARCH CONCEPTS

More physiological research is needed on eastern suckers because although physiological research has been conducted on western suckers, very little research has been conducted on eastern suckers. The eastern and western species evolved under different conditions and so may have evolved differently, and may exhibit different responses to similar situations.

Research is needed to address interactions of abiotic and biotic factors that affect robust redhorse, such as the interaction of temperature, low dissolved oxygen, flow, sedimentation, and other water quality variables on hatching success, and survival of early life stages.

Dilts, E. W. 1999. Effects of fine sediment and gravel quality on survival to emergence of larval robust redhorse, *Moxostoma robustum*. Master Thesis. University of Georgia.

OBJECTIVE(S)

To determine robust redhorse larval survival to emergence for different sediment conditions.
Since robust redhorse are lithophillous spawners, they are susceptible to fine sediment during the egg to emergence stage.

METHODS

A two year laboratory study was developed containing different gravel sizes mixed with different amounts of sand to imitate habitat found in the Oconee River, GA.

The control gravel mixture for the first year consisted (by volume) of 25.0-37.5 mm (10 %), 16.0-25.0 mm (40 %), 8.0-16.0 mm (30 %), and 2.0-8.0 mm (20 %). This mixture reflected relative abundance of size classes of gravel at known and suspected robust redhorse spawning areas. The second year 16.0-25.0 mm and 8.0-16.0 mm were mixed in reciprocal 3:1 ratios.

During the first year trial, the control gravel mixture had four treatments of fines (0, 25, 50, and 75 %). Eggs were buried at two depths (5 and 10 cm), because burial depth in the wild was unknown.

During the second year trial control gravel mixture had 6 treatments of fines (0, 5, 10, 15, 20, and 25 %). Eggs were buried at 5 cm, because rates of survival to emergence were similar between 5 and 10 cm.

Dissolved oxygen was measured at burial depth through a stand pipe in the gravel mixture container. Water temperatures were maintained between 21 and 23 °C.

Size of emergence was measured in Trial 1, but not in Trial 2.

RESULTS

Studies have not previously been conducted on catostomids, but seem to agree with finding of salmonid studies.

Robust redhorse larvae seemed relatively tolerant of fine sediments until about 15 %, but larval emergence was significantly reduced when fine sediments reach 25 %.

Gravel found in the Oconee River suggests that the gravel quality is not the limiting factor, but that it may be the fine sediment mixed in with gravel beds that affects successful hatching and emergence.

Percent fines may have affected robust redhorse in two ways, by lowering dissolved oxygen levels and causing larval entombment.

Gravel mixtures that contained > 50 % fines had lower dissolved oxygen. Larvae may have emerged earlier in higher concentrations of fine sediments, meaning that they would have emerged smaller (found in Trial 1). According to Ruetz (2000), this would imply that they would be more easily washed downstream in a hydro-peaking event.

The Oconee River is composed typically of 25-50 % fines (EA 1994a and 1994b). If this study is applicable to wild specimens, the results are that only 8 % of larvae emerge.

SUGGESTIONS

Several suggestions for management include: runoff control, soil stabilization projects, restorative process (removing excessive fine sediment from gravel beds), flushing flows, stream alterations, and construction of artificial spawning beds.

Jennings, C. A., B. J. Hess, J. Hilterman, and G. L. Looney. 2000. Population dynamics of robust redhorse (*Moxostoma robustum*) in the Oconee River, Georgia. Completed for the USGS Biological Resources Division. University of Georgia Research Work Order 52.

OBJECTIVE(S)

The objectives of this study were; to use capture-recapture data to determine if current population estimates were reliable, to determine the effectiveness of the sampling gear for this species, and to use population modeling to estimate long-term outcome of the robust redhorse in a small section of the Oconee River, Georgia.

METHODS

Fish collection was conducted using boat electrofishing. Existing robust redhorse capture data (1994-1999), as well as data collected for this study (1999-2000) were pooled and separated by year. Water temperature, dissolved oxygen, and turbidity were taken at time of collection.

Jolly-Seber models were used to estimate population size, survival rate, recruitment, and capture probability. ANOVA was used to evaluate differences in CPUE among years, and if there was a significant difference among years, the models were adjusted.

POPAN-5 software was used to estimate the potential long-term outcome of the robust redhorse population in the Oconee River. This was accomplished by evaluating the current population, survival rate, capture probability, number of new recruits, and the stochastic variation of the data.

RESULTS

According to the Jolly-Seber model, there was an estimated range of 335 to 607 individuals greater than 417 mm total length in the study reach. Survival rate was estimated between 0.10 and 0.99 and number of new individuals recruited to the population ranged from 29 to 191.

After 200 simulations were run, the population ranged from100 to 1,200 individuals. The population models suggest that the robust redhorse population will persist over the next 100 years, but the number of individuals will vary.

SUGGESTIONS

Research is needed regarding how to effectively sample juvenile robust redhorse since boat electroshocking does not appear to be effective for size-classes below 400 mm total length. Also, research is necessary to define habitat requirements and the availability of those habitats in the Oconee River.

Ruetz, C. R. III and C. A. Jennings. 2000. Swimming performance of larval robust redhorse *Moxostoma robustum* and low-velocity habitat modeling in the Oconee River, GA. Transactions of the American Fisheries Society 129: 398-407.

OBJECTIVE(S)

To determine if robust redhorse larvae can tolerate velocities similar to that present during hydro-peaking.

METHODS

Lab study using three size classes (averages of 13,16 and 20 mm) were subjected to prolonged swimming experiments. Prolonged swimming speeds were determined by calculating the velocity at which 50 % of fish tested failed to maintain their position in a swim tube for 1 hour.
Water temperature was kept constant in swim chamber for each size class tested, but was increased for each successive size-class test. Water temperatures during trials were 22.5, 24.2, 25.5 °C (to mimic Oconee River).

Low-velocity habitat modeling was conducted at four sites in the Oconee River to determine the down-stream effects of hydro-power peaking by the Sinclair Dam. Depth and mean water column velocities were measured at low and intermediate flows.

Logistic regression models developed from robust redhorse swimming performance experiments were used to predict the proportion of larvae that would be able to maintain their position in the water column for one hour.

RESULTS

Swimming speed of robust redhorse varied individually, but in general, increased with fish size and water temperatures.

Habitat modeling showed that low-velocity areas were present in the Oconee River, and there did not appear to be a strong correlation between low-velocity habitat and discharge. However, low-velocity habitats were dynamic during discharge and the ability of larval robust redhorse to find these areas is unknown.

Water velocity may not directly decrease the abundance of larval fish nursery areas, but may limit the access of these habitats to larvae.

Other limiting factors may include vegetation, substrate, woody debris or near substrate hydraulic conditions.

POTENTIAL RESEARCH CONCEPTS

There are few estimates for other catostomid swimming speeds, so it is difficult to compare with other species. Research on notch-lip redhorse and maybe some non-Moxostoma’s swimming speeds might be useful.

Study the ability of larval robust redhorse to move from one habitat to another during increasing water velocity.

What effect does vegetation, substrate, woody debris or near substrate hydraulic conditions have on this species?

Freeman, B. J., and M. C. Freeman. 2001. Criteria for suitable spawning habitat for the robust redhorse *Moxostoma robustum*. Report to U. S. Fish and Wildlife Service.

OBJECTIVE(S)

To determine the criteria for spawning requirements of robust redhorse by measuring the range of depth, velocities, and substrate composition in the Oconee River and Savannah River.

METHOD

Oconee River (1997, 1998, 2000)

Depth and velocity were measured using a wading rod and an electronic current meter. Velocities were measured with the probe at 60 % of water depth, measured from the water surface. Substrate composition was obtained using a freeze-coring device, which is a hollow stainless steel with pointed tip and liquid nitrogen is pumped into the device to freeze the core. The location and distribution of eggs were noted and samples were sent to the lab to be sorted by size and weighed. Depth and velocity were plotted to show ranges and value distribution (e.g. median) for each year.

Savannah River (2000)

Depth and velocity were measured the same as in the Oconee River. Dominant particle size was estimated visually using photographs that also included a ruler for scale.

RESULTS

Spawning occurred most often between late April and early May. Water temperatures were between 17 and 26.7 ° C, although some years, when temperatures were between 19-25 °C, no spawning was documented. This suggests that spawning is triggered and terminated by more than water temperatures.

All spawning was observed around a mid-channel gravel bar in the Oconee River. Depths and velocities of the spawning area differed among years as a result of different flow levels, however the ranges overlapped. Depth was observed between 0.29 to 1.4 m and velocity ranged from 0.26 to 0.67 m/s. Gravel was the dominant substrate in all spawning areas. Most particles were 12-50 mm in the Oconee River and were estimated at 15-30 mm in the Savannah River.
Criteria for suitable spawning habitat include:

water depth: 0.29 - 1.1 m
average water column velocity: 0.26 - 0.67 m/s
substrate: dominated by medium-coarse gravel (12 - 50 mm), with < 30 % sand (0.25 - 2 mm), and minimal fine particles (< 25 mm).

POTENTIAL RESEARCH CONCEPTS

More data from additional locations to verify the criteria listed above.

Spawning success in relation to substrate characteristics, depth and water velocity.

Inter-gravel flow in spawning locations in spawning locations to better understand habitat-related mechanisms.

Lasier, P. J., P. V. Winger, J. L. Shelton Jr., and K. J. Bogenrieder. 2001. Contaminant impacts to early life stages of the robust redhorse (*Moxostoma robustum*) in the lower Oconee River. Final Report. Species at risk Program, Biological Resources Division, U. S. Geological Survey.

There are two parts of the report. Part 1: Sediment-quality Assessment of the Lower Oconee River, and Part 2: Impacts and Toxic Thresholds of Sediment-associated Contaminants to Robust Redhorse (*Moxostoma robustum*) in the Lower Oconee River.

PART 1:

OBJECTIVE(S)

To evaluate sediment quality in the lower Oconee River and to identify potential sources of contaminants.

METHOD

Sediments, pore waters, and surface waters were collected from 12 sites around known robust redhorse spawning areas.

Hyalella azteca, a freshwater amphipod, was used to test samples for toxicity in the laboratory.

Third party laboratories determined concentrations of metals, organic compounds, and dissolved organic carbons.

RESULTS

Pore waters from the lower Oconee River were acutely toxic to *H. azteca*.

Sediments from several sites demonstrated chronic toxicity, and overall, caused reduced growth, which may be caused by metal contamination.

Toxicity of sediments appeared to be caused by zinc, which is most likely from permitted point sources. The toxicity of sediment collected from Avants Mine may have been caused by chromium; however the source of chromium is unknown.
Porewater toxicity was caused by elevated levels of manganese, which was not found in surface waters. There are no water quality criteria for manganese at this time.

PART 2:

OBJECTIVE(S)

To determine the toxic threshold of cadmium, copper, manganese, zinc and ammonia to early-life stages of robust redhorse; and to evaluate the toxicity of sediments and pore waters from the lower Oconee River to early-life stages of robust redhorse.

METHOD

Fertilized eggs were used from a single cross between one Oconee River female and male.

Tests were conducted on eggs, yolk-sac fry, and swim-up fry for the duration of 4-, 8-, or 12 day, and after 96 hours of exposure.

Eggs and larvae were exposed to pore waters and toxicant solutions using static renewal procedures.

Sediment exposures were conducted using an automated static-renewal procedure, which replaced water twice a day.

Dissolved oxygen, pH, conductivity and alkalinity were measured at the beginning of the exposures.

RESULTS

Toxicity assessment of sediments and pore waters from the lower Oconee River indicate that there are several locations that have toxic conditions to early-life stages of robust redhorse.

There were different sensitivities of eggs, but the differences were not consistent among metals.

Cadmium, copper and zinc are of concern because of potential effects of reproductive success.

Early-life stages appear to be sensitive to manganese. Manganese can be reduced to MN^{2+}, which can diffuse into areas that embryos and larvae are located for a period of time.

Several deformities were observed during the trials. These included abnormalities in yolk-sac development, spinal curvature, and head/mouth abnormalities.

SUGGESTIONS

To limit soil erosion and sedimentation of fine sediment into gravel beds used for spawning.

Weyers, R. S., C. A. Jennings, and M. C. Freeman. 2003. Effects of pulsed, high-velocity water flow on larval robust redhorse and v-lip redhorse. Transactions of the American Fisheries Society 132: 84-91.

OBJECTIVE(S)

To determine the effects of 0, 4, and 12 hours per day of pulsed, high-velocity water flow on egg mortality, hatch length, final length, and survival of larval robust redhorse and notch-lip (referred to as v-lip in the paper, formerly called silver) redhorse.

METHOD

This lab study used modified aquaria to simulate pulsed, high-velocity water flow (> 35 cm/s) and stable low-velocity flow (< 10 cm/s). Three experiments were conducted, two with robust redhorse (1999, 2000) and one with notch-lip redhorse (2000). Temperature, dissolved oxygen, zooplankton density, and water quality variables were kept the same among treatments.

Hatch rate success and larval length were recorded. Behavioral observations were conducted for about two hours every one to two days. The number of times larvae went around the tank because of high-velocity flows were recorded.

RESULTS

Hatch success was about 90 % (measured visually), and mean larval length for 24 hour larvae were similar among treatments. Larvae exposed to 4 and 12 hour pulsed, high-velocity flows grew significantly slower and had a lower survival rate than those in stable low-velocity flows.

Larvae in high flow systems that emerged from the gravel had difficulty swimming to the surface to inflate their airbladders. Larvae that attempted to inflate airbladders were caught in the current and carried around the tank. These larvae demonstrated an increased effort to swim and tried to escape the high flows to low-velocity areas. Much of the mortality occurred at this time.

The notch-lip redhorse that successfully inflated their bladders returned to the gravel substrate/hyporheic zone where they spent most of their time. Younger robust redhorse (10-20 days) used more of the water column to forage for food and only fed in low velocity areas. If they strayed into high velocity areas, they were caught in the flows and carried around the tank. As these robust redhorse larvae got older (> 20days), they stayed in the gravel when high velocities were present and only came out to forage during low velocity periods.

SUGGESTIONS

Institute long periods of stable, low-velocity water flow during the period of the robust redhorse early life stage.

Jennings, C. A., and D. C. Shepard. 2003. Movement and habitat use of hatchery-reared juvenile robust redhorse released in the Ocmulgee River, GA. Unpublished.

OBJECTIVE(S)

To determine how many stocked robust stayed within a proposed refuge site, located between two dams, and to assess general habitat characteristics associated with known robust redhorse locations.

METHOD

30 Phase II robust were tagged with internal radio-telemetry tags and stocked in the Ocmulgee River, between Lloyd Shoals Dam and Juliette Dam. Forty fish were taken to UGA's lab, 30 had artificial transmitters implanted, and 10 received no transmitters.

The study area between the two dams was 30 rkm, but the lower dam was a low-head dam that allowed fish passage downstream.

When robust redhorse were located, the area within a meter of the boat was sounded with a metal pole to determine general characteristics of the sediment (i.e., sand, mud, gravel/cobble, combinations).

Cover, such as boulders and woody debris, were documented as present or not present with in a 3 m radius of where the robust redhorse had been located.

Total area surveyed was 115 rkm (below Macon).

RESULTS

Mortality consisted of one Ocmulgee River fish, two laboratory fish. Discounting the one mortality, 20 of 29 (69 %) tagged fish remained between the two dams.

70 % of the group were found near gravel/cobble (23 of 30 individuals were located near gravel/cobble), and 70 % of the group were found near woody debris as cover, although

open water appeared to be the most abundant (25 of 30 individuals were located near woody debris).

Habitat changed from woody debris and boulders to mostly sand and mud below Macon, Georgia.

POTENTIAL RESEARCH CONCEPTS

Use older year classes' (bigger fish), which can tolerate larger transmitters. These larger transmitters would have longer battery life and could have mortality switches.

Grabowski, T. B., and J. J. Isely. 2006. Seasonal and diel movement and habitat use of robust redhorse in the Savannah River, Georgia and South Carolina. Transactions of the American Fisheries Society 135:1145-1155.

OBJECTIVE(S)
Objectives for this study were to characterize seasonal migration, diel movement patterns, and essential habitat of robust redhorse in the Savannah River. The effects of temperature and flow as cues for seasonal upstream and downstream migrations were assessed. The degree of site fidelity in relation to spawning, staging, and over-wintering habitats was also determined.

METHODS
A total of 24 wild-caught adults (18 males; 6 females) were surgically implanted with pulse coded radio transmitters. Most of these individuals (n=22) were captured on the gravel bar at river km 283.7, while another two were tagged above New Savannah Bluff Lock and Dam (NSBL&D) in the Augusta Shoals (Savannah Rapids).

Fish were relocated every two weeks for the first year of the study and monthly for an additional two years to evaluate seasonal movement and habitat use. Tracking frequency was increased to weekly during spring migration and spawning. We relocated fish every two hours within a set transect to determine diel movement and habitat use.

RESULTS
Individuals dispersed along the length of the river down to rkm 90. The majority of radio-tagged robust redhorse showed a high degree of over-wintering site fidelity, returning to the same 100 to 200-m lengths of shoreline each year. These over-wintering areas were distributed along the outside edge of river bends in water 3.0 to 5.0 m in depth. Observations using an underwater camera system showed coarse gravel streambed sediment and structurally complex habitats consisting of large woody debris.

Fish began to make upstream migrations in early to mid March of 2003, 2004, and 2005 when water temperatures were approximately 10-12°C. Most individuals made upstream migrations each year. Radio-tagged robust redhorse also demonstrated a high degree of spawning-site fidelity. Fish returned to either the gravel bar at rkm 283.7 or to staging and holding areas immediately upstream or downstream of it. Fish spent the remainder of spring and early summer in the vicinity of their spawning grounds before dispersing downstream in late June and early July to their over-wintering areas.

During high water, radio-tagged robust redhorse accessed the floodplain occupying flooded forest habitats particularly in areas at rkm 200-250 and 100-125. Individuals frequently moved far enough onto the floodplain to be just barely detectable with our telemetry receiver. This was the only time during the study when we observed robust redhorse out of the main river channel. One radio-tagged robust redhorse was able to pass NSBL&D during high flow periods in 2003. Fish 51 was last observed below the dam at rkm 276.2 on 28 June 2003 and not again until it was relocated above NSBL&D on 9 August 2004 at rkm 326.6 in the Augusta Shoals.
Radio-tagged robust redhorse above NSBL&D did not exhibit any seasonal movement patterns. These individuals remained in the shoal and pool habitat of the Augusta Shoals. Gaps in the data are presumed to occur when fish moved out of range of the receiver within the shoals as they were never located in the navigable portion of the river below the shoals between rkm 323.0 and NSBL&D.

Adult robust redhorse are sedentary fish. On average, radio-tagged robust redhorse moved between 0.5 and 1.0 rkm over a 24-hr period. There were no seasonal differences in the total activity of individuals. Daily use areas were approximately 1.0 rkm in length and length did not differ among season. Absolute time of day did not have any effect on robust redhorse activity. However, activity was influenced by photoperiod, with significantly more movement occurring during daylight hours than at night or during twilight hours.

SUGGESTIONS
Robust redhorse appear to be a potamodromous species whose successful management and conservation will likely require the maintenance of several distinct habitats (over-wintering areas, nursery habitat, spawning habitat) and corridors between them. Availability of suitable over-wintering habitat does not appear to be a limiting factor to the Savannah River population; however, spawning habitat availability appears to be limited. The potential benefits of providing adult fish ready access to the Augusta Shoals should be evaluated. Barring this, augmentation of spawning habitat below NSBL&D concurrent with monitoring should be considered. Information regarding the movement, distribution, and habitat use of juvenile robust redhorse is needed in order to fully assess the processes that are driving the population dynamics of this species.

Robust redhorse behavior and habitat preferences render them cryptic. This species spends the majority of its time in habitats that are inaccessible or difficult to sample effectively with common gear types such as boat electrofishers or gill nets. Assessing the presence or absence of this species in a given river system with any degree of certainty will require a large amounts of effort. There may be potential in using radio-tagged sentinel fish to assist in the location of spawning aggregations in these cases.

Grabowski, T. B. and J. J. Isely. 2007. Spatial and temporal segregation of spawning habitat by a riverine fish assemblage. Journal of Fish Biology 70:782-798.

OBJECTIVE(S)

The objectives of this study were to document the specific spawning habitat requirements and determine the degree of spatial and temporal segregation of this habitat occurring among catostomid species in the lower Savannah River, including robust redhorse. The degree of intraspecific overlap in nest sites on each of the two gravel bars was also assessed.

METHODS

The study area consisted of the two mid-channel gravel bars in the lower Savannah. The upper bar is located at rkm 299.4 just below the tailrace of NSBLD. Observations were made every other day at the upper bar during spring in both 2004 and 2005. The lower gravel bar is both smaller than the upper one and lower relief. It is located at rkm 283.7 and observations were made every other day in spring 2005.

A combination of methods was used to assess how these habitats are partitioned and used by spawning catostomids. Visibility was such that fish could be observed from the surface with the use of polarized sunglasses. The positions of fish that were spawning, staging, and holding position near the spawning grounds were recorded with a GPS receiver while drifting over the deeper (>1.5 m) areas of the gravel bar in a boat. Fishes in shallower water were observed from a 3 m tall observation tower placed on the gravel bar. The positions of fish were marked with individually numbered weighted flags that were dropped upon the locations occupied by fish. Upon retrieval, the position of each flag was recorded using GPS and depth, current velocity, and substrate particle size distributions were recorded. Water temperature was measured everyday on site and recorded hourly approximately midway between the two gravel bars at rkm 289.7.

Prepositioned grid electrofishers (PGEs) were deployed to capture spawning and staging fishes. A GPS waypoint, depth, current direction, current velocity, and substrate particle size distribution was taken at each PGE prior to retrieval. The primary purpose in capturing fish was to confirm above-water species identifications and reproductive condition of individuals. Emergent larvae were captured as they left the gravel bar using 1000 ÿm mesh, square frame plankton nets with a 0.125 m^2 opening.

RESULTS

Spawning catostomids showed a considerable amount of temporal overlap in their use of Savannah River main channel gravel bars in 2004 and 2005. Northern hogsucker were present at each gravel bar throughout the duration of observations both years. Notchlip redhorse were observed over a 23-day period from 02 to 25 April in 2004 and a 56-day period from 14 March to 09 May in 2005. Larval *Moxostoma* sp. presumed to be notchlip redhorse were captured as late as 9 May 2004 and 13 May 2005. Two other species spawned on the upper bar during the period notchlip redhorse were present. Spotted suckers were observed or captured for 12 days between 13 and 25 April 2004 but larvae were captured one week after the last adults were observed. This species was not seen at either location in 2005. Carpsuckers were observed from 2 to 7 May 2005 and the last larvae were captured on 9 May. Robust redhorse were present 13 days in 2004. They were present earlier and remained for a longer period of time at the lower bar than at the upper one. Although this difference between the two bars was not as great in 2005, robust redhorse were again present earlier and longer at the lower bar than at the upper one. Larvae presumed to be robust redhorse were captured as late as 20 May in 2004. No larval robust redhorse were captured in 2005 after the departure of adults due to a dramatic increase in flows on the Savannah. However, a large number (n=97) of pre-hatching robust redhorse embryos at various stages of development were captured when ichthyoplankton nets were set behind actively spawning adults.

Overlap in the temperatures at which species were present appears to correspond to observed temporal overlap. In general, catostomids were present at the gravel bars through a wider temperature range in 2004 than 2005.

Spawning catostomids were not distributed uniformly on the upper gravel bar based on a 50 X 50 m grid, nor distributed uniformly among the 100 m^2 areas in which they did occur. While species demonstrated some spatial overlap among the zones of the upper gravel bar, their distributions were different from one another. Catostomids appeared to segregate spawning habitat based on microhabitat conditions of flow, depth, slope, and substrate size.

Robust redhorse and northern hogsucker were the only catostomid species observed on the lower gravel bar. More robust redhorse were observed or captured on the lower bar (n=226) than the upper bar (n=29). Their distribution on the lower bar was not uniform as they were found only along the upstream edge of the gravel bar. Their overall distribution along this edge also was not uniform with the largest concentration occurring along the Georgia edge of the bar. Northern hogsucker appeared to follow a similar distribution pattern. Spawning habitat used by robust redhorse on the lower bar was significantly shallower, steeper, higher velocity, and had coarser substrate than that used on the upper bar. However, areas used on the upper bar were the most similar in this regard to lower bar compared to adjacent areas.

SUGGESTIONS

Catostomid species in the lower Savannah River appear to segregate spawning habitat in space and time with minimal interspecific nest site superimposition occurring. Changes in flow or temperature regimes associated with extreme high or low water may increase the probability of overlap among species. Because of their late spawning season and apparent preference for the lower gravel bar, robust redhorse appear to have minimal risk of competition for spawning habitat with other catostomids.

However, there appears to be considerable overlap in nest sites within species, particularly robust redhorse. Individuals are concentrated into a relatively small area of suitable spawning habitat. Further investigations should focus on whether this habitat is truly limiting to the Savannah population and the impacts of density dependent (nest site superimposition, egg predation?) and density independent effects (water level fluctuations) on reproductive output. Providing fish with access to potentially existing spawning habitat in the Augusta Shoals or creating additional habitat in the lower Savannah River may be necessary. This study suggests that creating habitat that will attract spawning aggregations of robust redhorse will require more planning than depositing a barge-load of gravel. Fish appear to be selective in terms of current velocities, depth, slope, and potentially other factors (such as presence of spawning individuals) when choosing habitat. However, this study also suggests that it may be possible to construct habitat that will only attract robust redhorse and not be attractive to other spawning catostomid species.

Grabowski, T. B., and J. J. Isely. *In press*. Effects of fluctuations in flow regime on riverine fish spawning habitat: an aquatic ecological trap? Aquatic Conservation: Marine and Freshwater Ecosystems.

OBJECTIVE(S)

The objective of this study was to document the extent of dewatering robust redhorse nests experience occurring at various flows experienced during the 2005 spawning season.

METHODS

The robust redhorse spawning aggregation on the lower gravel bar in the Savannah River were observed during 07-18 May 2005. Nest sites were located on six days (08, 09, 10, 11, 12, and 16 May) during this period. The location of each nest site was recorded using GPS and marked with a surveyor flag. Water depth in the center of the nest site and current velocity at the upstream edge of the nest was recorded. Daily and archived river discharge in cubic feet per second (cfs) and gage height data were acquired from U.S. Geological Survey gauging station 02197000 located at New Savannah Bluff Lock and Dam in Augusta, Georgia.

RESULTS

Changes in discharge and gage height on the Savannah River appeared to be relatively minor during the period when robust redhorse were spawning on the lower gravel bar in 2005. River discharge ranged from 4580 to 7620 cfs translating to a change of approximately 1.2 m in gage height. However, mean of daily river discharge during 07-

17 May 2005 was lower than the mean of mean daily values for the past 98 years of record for that period ($t_{14} = -5.82$, $p < 0.0001$).

The robust redhorse spawning aggregation initially formed along the Georgia side of the upstream edge of the gravel bar on 08 May 2005. Over the next two days, active nest sites were spread along both the Georgia upstream edge and the center of the bar. On 10-11 May 2005, river discharge dropped below 5000 cfs, leaving approximately 26% of the observed nest sites exposed. An additional 29% of observed nest sites were still underwater in the central portion of the bar. These nest sites experienced approximately two full days of current velocities at or near 0.0 ms^{-1} and water depths ÿ 0.25 m. We observed the deposition of silt and other fine sediments over this area. These nest sites were abandoned by spawning adults during this period, but adults returned when water levels increased on 12 May. During the period of 12-16 May spawning robust redhorse spread out along the entire upstream edge of the gravel bar. River discharge dropped again on 16 May and left 27% of nest sites exposed and an additional 33% in near zero-flow conditions.

SUGGESTIONS

Nest site dewatering or degradation appears to have two major implications to the robust redhorse spawning aggregation on the lower gravel bar in the Savannah River. The first is the potential for increased mortality of embryos and larva in affected nests. It is unknown to what degree the early life history stages of robust redhorse can tolerate environmental changes such as decreased dissolved oxygen levels or elevated temperatures associated with dewatering or exposure to zero flow conditions. Further research is necessary to determine the precise impacts of nest dewatering on survivorship of early life history stages. The second major implication is the potential for increased mortality and loss of reproductive output associated with nest superimposition. Falling water levels reduce the amount of suitable spawning habitat available on the lower gravel bar, increasing the risk of disturbance of pre-existing nest sites by spawning adults. Maintenance of consistent flows, even if they are below 5,000 cfs, may help alleviate mortality associated with adults spawning in areas that will be rendered unsuitable by water level fluctuations. Maintenance of flows above 5,000 cfs during the robust redhorse spawning season may also decrease the risk of mortality associated with nest site superimposition.

Mosley, D. L. 2006. Habitat selection of robust redhorse *Moxostoma robustum*: Implications for developing sampling protocols. Master Thesis. University of Georgia.

OBJECTIVE(S)

The objective of this study was to gain an understanding of how juvenile robust redhorse use available habitat and to make inferences about where and how to sample them in the wild.

METHODS

The experiment was conducted in two identical mesocosms that simulated the lower Oconee River. The mesocosms included three habitat types: backwater, straight-channel, and bends (represent oxbows).

There were four flow classes for each mesocosm. Flow class 1 (-12 - -1 cm/s) corresponds to eddies, flow class 2 (0 – 15 cm/s) represents slow flows, flow class 3 (16 – 32 cm/s) signifies moderate flows, and flow class 4 pertains to backwaters. Fast flows (< 45 cm/s) were not available in either of the mesocosms.

Four 10-day trials (two winter, two early spring) were used to assess juvenile robust redhorse preference of available flow. Trial 1 began December 12, 2004, trial 2 began January 11, trial 3 began February 15, 2005 and trial 4 began March 9, 2005. Each trial used eight pond-reared, juvenile robust redhorse per mesocosm.

A frequency table of the flows, one for each mesocosm, was created from the flow data collected. The range, mode, and mean of the flows were also determined for each mesocosm.
Ten location observations were recorded for each fish each day. Consequently, the locations of the fish were not independent from one hour to the next. Therefore, the modal location reference for each fish within a day was found to analyze habitat use of the fish throughout the trials.

A Log-Linear Model analysis was used to evaluate the habitat use data, specifically to determine if the fish used habitats differently between mesocosms, seasons, flow class, and all combinations of the three.

RESULTS

During the winter the fish showed a preference for eddies and backwaters and avoided slow to moderate flows ($p<0.001$) based on the proportion of their availability. During the early spring the fish showed a preference for eddies, avoided the moderate flows, and used slow flows and backwaters in proportion to their availability ($p<0.001$).

SUGGESTIONS

Sampling for juvenile robust redhorse should be conducted in eddies and backwaters during the winter and eddies and slow flows during early spring. Eddies exist near the downstream-end of sandbars, in the transitional zone of two meanders in the lower Oconee River and may best be sampled with boat electrofishers. Seines of adequate mesh size, such as 8.50 mm or 6.35 mm, should be used when seining for juvenile robust redhorse on sandbars. Backwaters can be sampled with backpack shockers, barge electrofishers, or seines.

SUMMARY OF RESEARCH TOPICS BY LIFE-STAGE

RESEARCH TOPIC	EGG	LARVAE	JUVENILE	ADULT
Fine sediment[1]				
Metal toxicity[2]				
Pulsed, high-velocity water flow[3]				
Swimming performance[4]				
Physicochemical responses[5]				
Mesocosm[6]				
Radio telemetry (hatchery)[7]				
Radio telemetry (hatchery and wild)[8]				
Spawning habitat[9]				
Population estimates[10]				

[1]Dilts 1999

[2]Lasier et al. 2001

[3]Weyers et al. 2003

[4]Ruetz and Jennings 2000

[5]Walsh et al. 1998

[6]Mosley 2006

[7]Jennings and Shepard 2003

[8]Grabowski and Isely current

[9]Freeman and Freeman 2001

[10]Jennings et al. 2000

APPENDIX B

PRIORITY WATERSHED GUIDANCE

PRIORITY WATERSHED GUIDANCE

In developing the detailed watershed needs assessment methodology, the Habitat TWG determined that providing overall guidance and a general assessment framework was more appropriate than providing a highly prescriptive method. The reason is the uniqueness and complexity inherent in individual watershed analysis. Effective watershed assessment must allow watershed planners and managers to apply the most appropriate tools available for a specific situation. Examples of watershed protection and planning are provided below.

Center for Watershed Protection. 1998. Rapid watershed planning handbook: a comprehensive guide for managing urbanized watersheds. Center for Watershed Protection, Elliot City, Maryland.

Center for Watershed Protection. 2002. Watershed Vulnerability Analysis. http://www.cwp.org/vulnerability_analysis.pdf. Center for Watershed Protection, Elliot City, Maryland.

Washington State Forest Practices Watershed Analysis Manual
http://www.dnr.wa.gov/forestpractices/watershedanalysis/manual/

Oregon Watershed Assessment Manual
http://www.oregon.gov/OWEB/docs/pubs/ws_assess_manual.shtml

Coastal Conservancy. 2001. Watershed Planning Guide.
http://www.coastalconservancy.ca.gov/Publications/ws_planning_guide.pdf

Washington State Department of Ecology. 1999. http://www.ecy.wa.gov/pubs/99106.pdf

Watershed Analysis and Management (WAM) Guide for Tribes. 2000.
http://www.epa.gov/owow/watershed/wacademy/wam/

APPENDIX C

GRANTS FOR RESTORATION WORK

LISTING FOR CONTACTS FOR GRANT OPTIONS

American Sportfishing Association:
http://www.asafishing.org/content/conservation/fishamerica/

FishAmerica Foundation
http://www.fishamerica.org

Turner Foundation, Inc
2004 Native Fish Conservation Grant
National Fish and Wildlife Foundation
http://www.turnerfoundation.org/grants/index.asp

The National Science Foundation
4201 Wilson Boulevard, Arlington, Virginia 22230, USA
Tel: 703-292-5111, FIRS: 800-877-8339 | TDD: 703-292-5090
http://www.nsf.gov/home/grants.htm

Society of Research Administrators (SRA) International
1901 North Moore Street, Suite 1004
Arlington, VA 22209
Phone: (703) 741-0140
E-mail: Info@srainternational.org
http://www.srainternational.org/newweb/grantsweb/index.cfm

National Endowment for the Humanities
1100 Pennsylvania Avenue NW
Washington, DC 20506
Phone: 1-800-NEH-1121
Phone: (202) 606-8400
http://www.neh.gov/grants/index.html

Natural Resources Conservation Service
http://www.ga.nrcs.usda.gov/programs/

Grants.gov
Office of Grants Management
Email: Grants.Net@hhs.gov
http://www.grants.gov/index.html

Grants for Nonprofits
Jon Harrison
Michigan State University Libraries
100 Library
E. Lansing, MI 48824-1048
Voice mail: (517) 432-6123, ext. 123
Fax: (517) 432-8050
http://www.lib.msu.edu/harris23/grants/2sgalpha.htm

Sustainable Agriculture Research and Education (SARE) Program
Rosanne Minarovic
Cooperative Extension Service, Box 7602
North Carolina State University
Raleigh, NC 27695-7602
(919) 515-3252; (919) 515-5950 (fax)
Email: mailto:rminarov@unity.ncsu.edu
http://www.griffin.peachnet.edu/sare/

River Network
520 SW 6th Avenue #1130
Portland, OR 97204
Phone: (503) 241-3506 or 1-800-423-6747
Fax: (503) 241-9256
Email: mailto:info@rivernetwork.org
http://www.rivernetwork.org/howwecanhelp/index.cfm?doc_id=94

Farm Aid
PO Box 228
Champaign, Illinois 61824
Phone: 800-FARM-AID
Local: (617) 354-2922
Fax: (617) 354-6992
http://www.farmaid.org/org/mission/grants.asp

National Fish and Wildlife Foundation
Jean Harrigal
Green Pond, SC
Phone: (843) 844-2966
Email: mailto:harrigal@nfwf.org
http://www.nfwf.org/programs/grant_apply.htm

National Oceanographic and Atmospheric Administration
http://www.nmfs.noaa.gov/habitat/restoration/

The Foundation Center
79 Fifth Avenue
New York, NY 10003
Tel: 212-620-4230
Fax: 212-691-1828
http://fdncenter.org/for_individuals/funding_for/index.html

United States Army Corps of Engineers
Planning Assistance to States Program
Section 206 Aquatic Ecosystem Restoration Project
Section 1135 Project Modifications for Improvement of the Environment
Specifically Authorized Projects

For more information, contact the Planning Division for the U.S. Army Corps of Engineers. These offices are in Wilmington, NC, Charleston, SC, and Savannah, GA.

United States Environmental Protection Agency
Ariel Rios Building
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Phone: (202) 272-0167
http://www.epa.gov/epahome/grants.htm

United States Fish and Wildlife Service
Federal Aid: Landowner Incentive Program (States are eligible for grant that is for establishing or supplementing State landowner incentive programs. The grant funds habitat protection/restoration on private lands to benefit listed/proposed/candidate or other plant and animal species at risk) and State Wildlife Grants (States are eligible for grant that is for on-the-ground projects for animal species of conservation need.).

Private Stewardship Grant Program: Provides assistance directly to landowners for managing their lands in ways that benefit species and their habitats.

Partners for Fish and Wildlife Program: Private landowners are eligible for technical and financial assistance from FWS for habitat restoration. USFWS will pay up to 100% of project costs up to $10,000 per landowner.

USGS Science Support Partnership and Quick Response Funds: Monies for research needs that are co-developed by USGS and FWS; research conducted by USGS. Proposals are accepted usually around May 1st.

Flex Funds: Proposals are accepted annually usually around September/October.

Alice Lawrence
USFWS, Georgia Ecological Services
105 Westpark Drive, Suite D
Athens, Georgia 30606
Phone: (706) 613-9493 X 222
Email: Alice_Lawrence@fws.gov
http://www.fws.gov/grants

United States Forest Service
Challenge Cost-Share Agreements: involves non-profit organizations, state, and other federal agencies. Through a transfer of funds, restoration work can be accomplished by Ducks Unlimited, Trout Unlimited, and other non-profit groups.

Liz Caldwell
Oconee National Forest
1199 Madison Road
Eatonton, Georgia 31024
Phone: (706) 485-7110
Email: edcaldwell@fs.fed.us

APPENDIX D

ROBUST REDHORSE HABITAT RESTORATION TECHNIQUES

8.0 SUMMARY

The following summary briefly addresses habitat restoration techniques for the robust redhorse (*Moxostoma robustum*). It should be noted that in addition to the restoration techniques described below, preservation of riparian habitat on stable streams is another important recovery tool that should be supported by the Robust Redhorse Conservation Committee (RRCC). Various methods of preserving riparian habitat (ownership, restrictive covenants, conservation easements) should be encouraged. In many, if not all cases, restored habitat cannot provide the quality of environmental benefits provided by preserved, intact habitat.

Because sedimentation has been identified as a primary threat to the species**,** this document primarily focuses on restoration techniques that reduce sedimentation (Nichols 2003). Gravel bed augmentation was initially considered as a restoration technique, but was subsequently eliminated from further study after evaluating its continued maintenance requirements and, at least in some cases, lack of success as spawning habitat at other projects (Kondolf, in press).

Because each site is unique, successful projects begin with a careful evaluation of site characteristics. Enhanced planning occurs when a cooperative effort between land owners/managers, fishery biologists, plant ecologists, hydrologists, and engineering consultants is established. Factors to consider when evaluating potential sites include a) existing physical characteristics (source of problem, erosion potential, water velocities, slope, soil characteristics, type and condition of vegetation), b) intended goal, and c) cost (Muhlberg and Moore, 1998).

"Natural stream channel stability is achieved by allowing the river to develop a stable dimension, pattern, and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades. For a stream to be stable it must be able to consistently transport its sediment load, both in size and type, associated with local deposition and scour. Channel instability occurs when the scouring process leads to degradation, or excessive sediment deposition results in aggradation. When the stream laterally migrates, but maintains its bankfull width and width/depth ratio, stability is achieved even though the river is considered to be an "active" and "dynamic" system" (Rosgen 1996).

The first question to be asked on-site is if the stream is stable. If it is stable, or in a state of quasi-equilibrium, then it should be left alone and considered for riparian preservation. If it is not stable, the second step is to identify the source of the problem, and if is it causing vertical instability or lateral instability, or both.

9.0 VERTICAL INSTABILITY

If the stream is vertically unstable (incised), it is downcutting or already a vertically contained stream that has abandoned previous floodplains due to a lowering of local base level and is characterized by high streambanks bounded by alluvial terraces. A priority system composed of four methods has been developed to use when restoring or improving an incised river (Rosgen 1997). All of the following techniques should be designed, and installation supervised by personnel that have had Rosgen or similar training. At the time this document was prepared, the writers were not aware of an example of the Rosgen method being implemented on a regulated river.

Priority 1 is to re-establish the channel on the previous floodplain using the relic channel or construction of new bankfull discharge channel. The new channel should be designed to have a dimension, pattern, and profile of a stable form of a reference reach channel. The existing incised channel should be filled in or modified to form discontinuous oxbow lakes level with the new floodplain elevation. Advantages to a Priority 1 restoration include the re-establishment of a floodplain and stable channel that 1) reduces bank height and streambank erosion, 2) reduces land loss, 3) raises the water table, 4) decreases sediment load, 5) improves aquatic and terrestrial habitats, 6) improves land productivity, and 7) improves aesthetics. Disadvantages include 1) possible flood damage to urban, agricultural, and industrial development caused by floodplain reestablishment, and 2) downstream end of project could require grade control from new to previous channel to prevent head-cutting. Priority 1 requires relatively low costs and high probability of success.

Priority 2 is to convert the existing channel to a stream type with a floodplain, re-establishing a floodplain at the existing level or higher, but not at the original level. Construct the channel in the bed of the existing channel, converting the existing bed to a new floodplain, excavating the streambank walls if necessary. The resulting material can be hauled off or placed in the streambed to raise bed elevation and create the new floodplain in the deposition. Advantages to a Priority 2 restoration include 1) decreases in bank height and streambank erosion, 2) allows for riparian vegetation to help stabilize banks, 3) establishes floodplain to help take stress off of the channel during flood, 4) improves aquatic habitat, 5) prevents wide-scale flooding of original land surface, 6) reduces sediment load, and 7) downstream grade transition for grade control is easier. Disadvantages include 1) does not raise water table back to previous elevation, 2) higher shear stress and velocity during flooding due to a narrower floodplain, and 3) upper banks need to be sloped and stabilized to reduce erosion during flood.

Priority 3 is to convert the existing channel to a stream type without an active floodplain, but containing a flood prone area. Advantages to a Priority 3 restoration include 1) reduction in the amount of land needed to return the river to a stable form, 2) developments next to the river need not be re-located due to flooding potential, 3) decreases of flood stage for the same magnitude flood, and 4) improves aquatic habitat. Disadvantages include 1) high cost of materials for bed and streambank stabilization, 2) does not create the diversity of aquatic habitat, and 3) does not raise water table to previous levels.

Priority 4 is to stabilize the channel in place to decrease streambed and streambank erosion. The instream structures listed below may be used, but using the bioengineering restoration techniques listed below may be more suitable for a laterally instable versus a vertically instable stream. Advantages to a Priority 4 restoration include 1) reduced excavation volumes, and 2) minimal land needed for restoration. Disadvantages include 1) high cost for stabilization, 2) high risk due to excessive shear stress and velocity, and 3) limited aquatic habitat depending on nature of the stabilization methods used.

10.0 LATERAL INSTABILITY

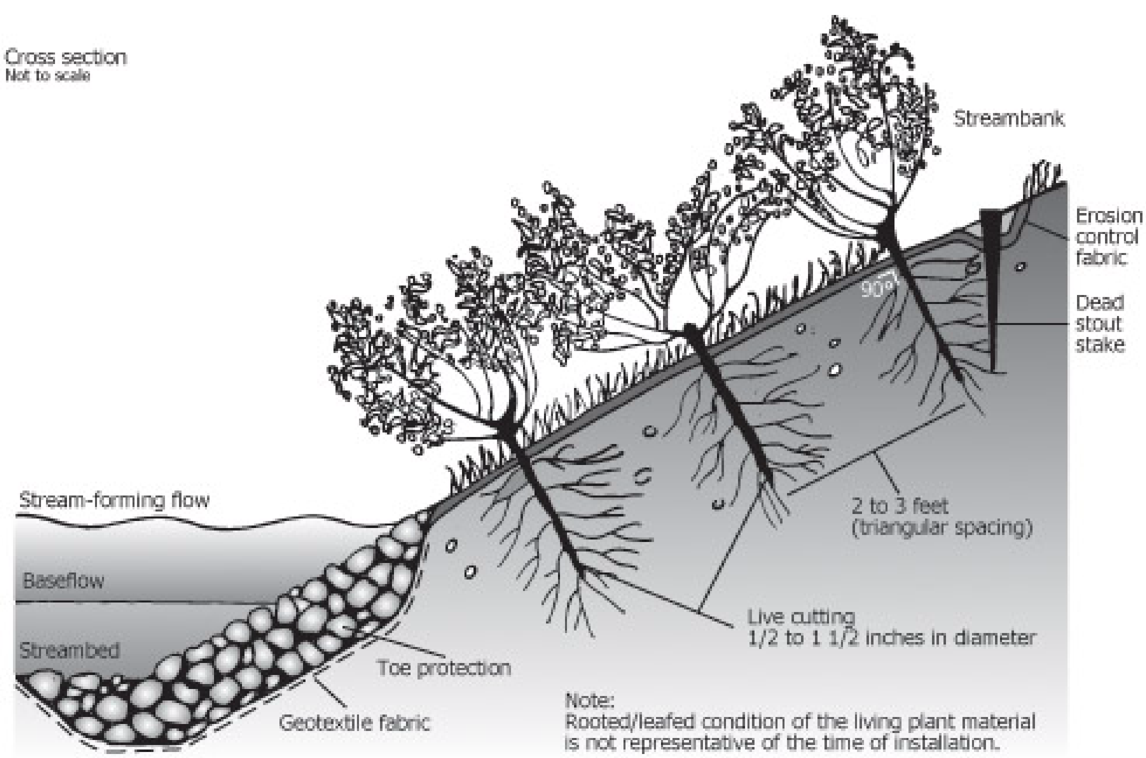
If the stream is laterally unstable, the stream has an accelerated rate and magnitude of bank erosion. The following bioengineering restoration techniques and instream structures may be used. If livestock access to the stream is the source of localized bank erosion, livestock exclusion (fencing the livestock out of the stream and providing an alternate water source) may be another important tool. The techniques described below are deemed to be applicable and functional for southeast systems. These descriptions and figures were primarily produced by Buck Engineering and Rosgen, 2001.

11.0 BIOENGINEERING STREAMBANK RESTORATION TECHNIQUES

11.1 LIVE STAKING

Live staking uses woody plant cuttings that root quickly when placed in soil. Once established, they provide vegetative cover and a very effective barrier to erosion. Alone, they are most effective as a preventive measure before severe erosion problems develop. They may also be used to stabilize areas between other bioengineering techniques. Willow species (*Salix*) are the most commonly used material for live stakes, although other commonly used species include dogwoods *(Cornus* sp.), elberberry (*Sambucus canadensis*), buttonbush (*Cephalanthus occidentalis*) and cottonwood (*Populus deltoides*). Live staking is economical and requires minimum labor to install.

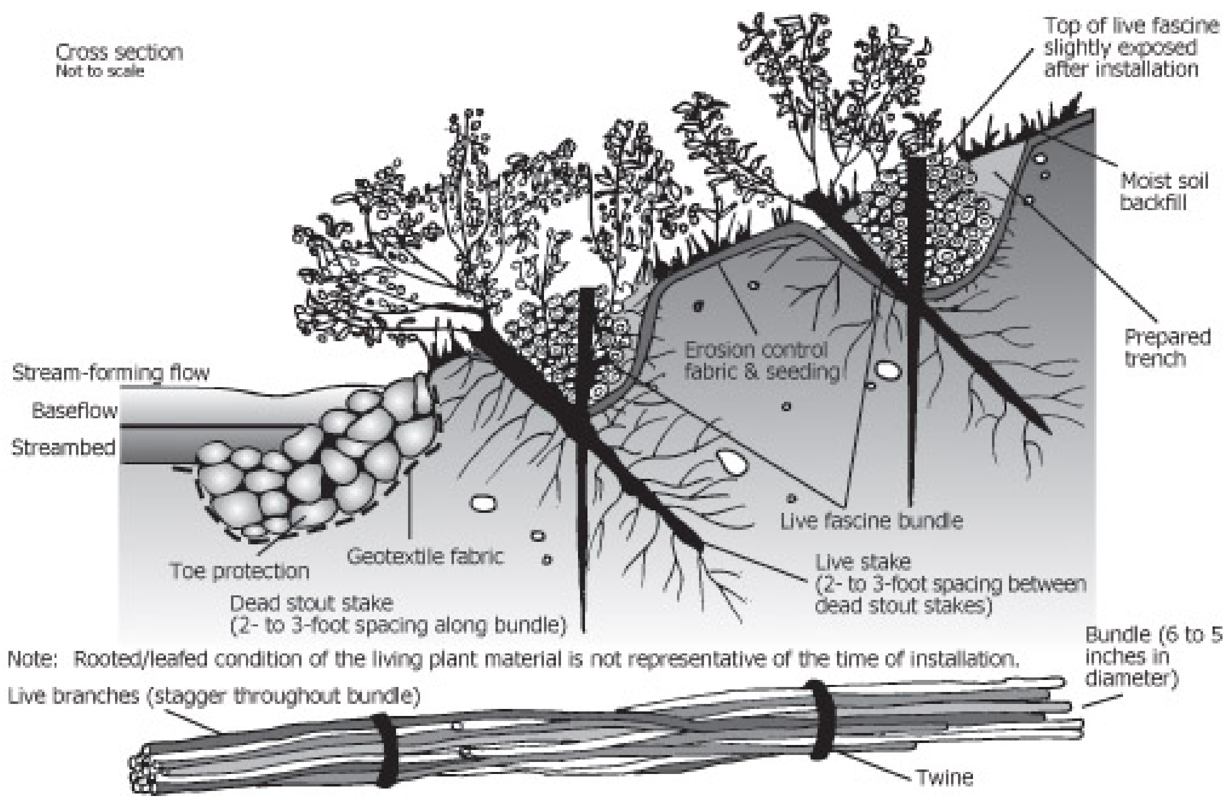
Figure 1: Live Staking



11.2 FASCINES

Live fascines are long (4 to 6 feet or longer) bundles of live branch cuttings bound with bailing twine. They are placed in trenches along the streambank, secured with stakes, and partially covered with soil. They may be constructed from dormant cuttings of materials that are on site, such as willow, shrub dogwoods, or other species that readily sprout. Once the cuttings take root, fascines offer protection for the bank and additional stability. They are particularly useful on steep, rocky slopes where digging is difficult.

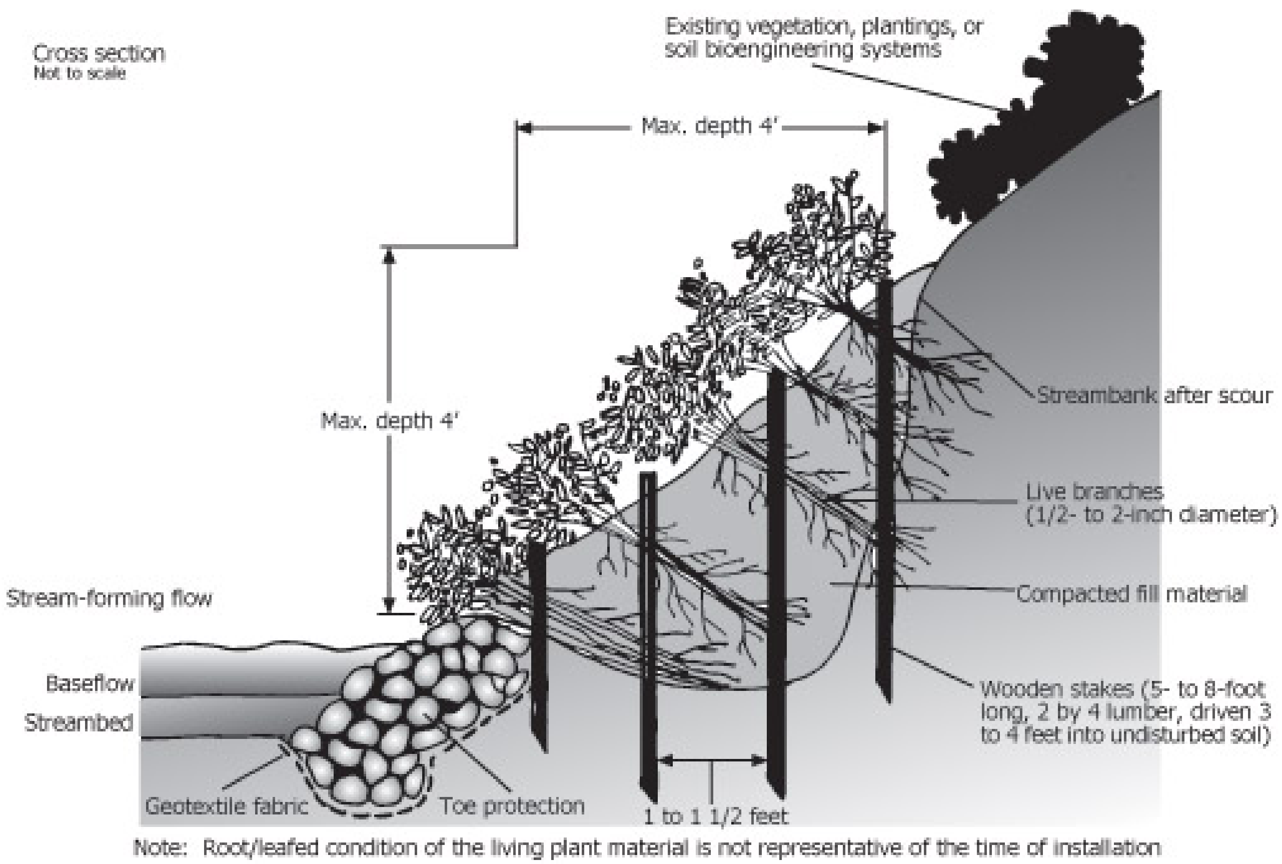
Figure 2: Fascines



11.3 BRANCHPACKING

Branchpacking involves placing alternating layers of live branches and soil into a washed-out streambank and can be used both underwater and above fast-moving water. They form an effective barrier that redirects water away from banks, and are often used for revegetating holes scoured in streambanks.

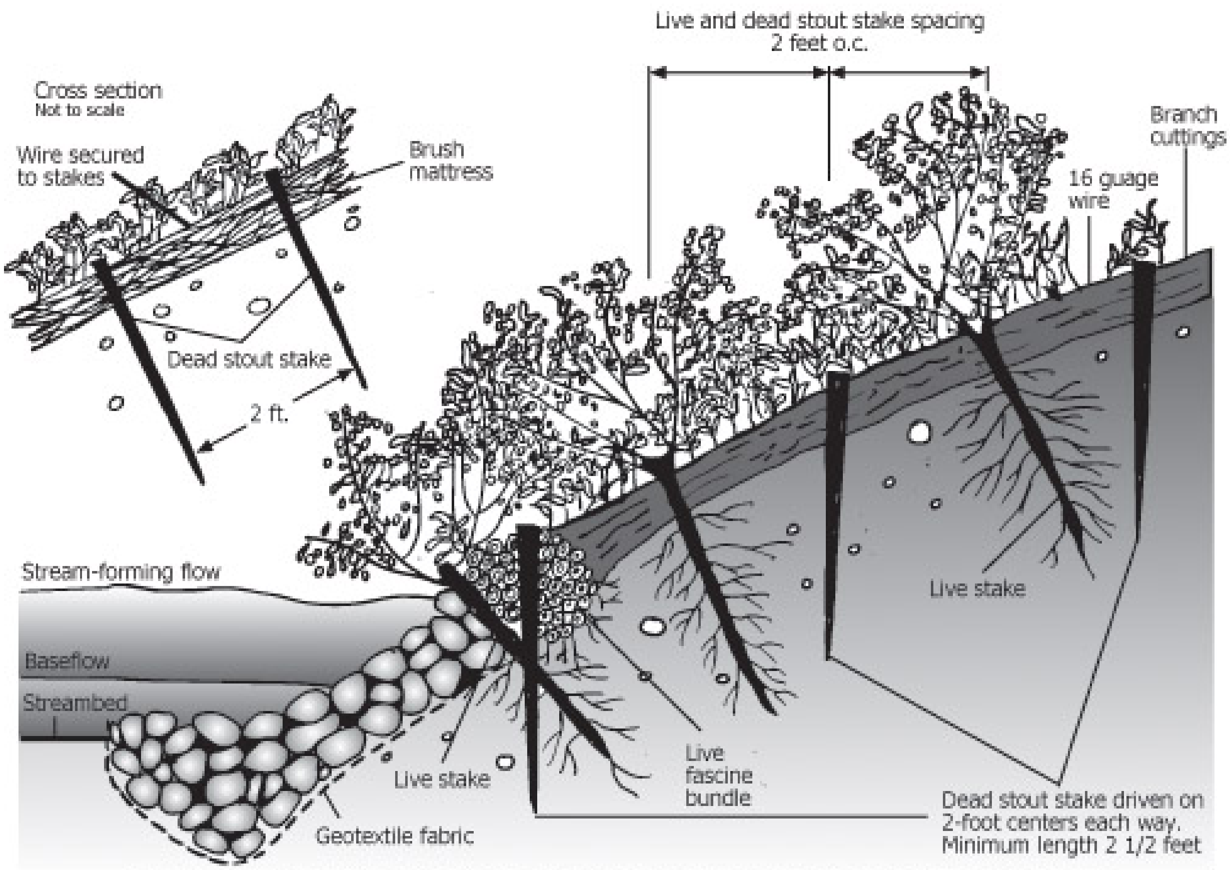
Figure 3: Branchpacking



11.4 BRUSH MATTRESS

Brush mattresses are a blanket of long branch cuttings wired together and secured to the streambank with stakes. They cover the bank and provide protection immediately after they are established. Brush mattresses are very effective at capturing sediment and rebuilding an eroding bank. Once the plants take root, they provide long-term erosion control and dense plant growth. However, they require a great deal of live material and are time-consuming to install.

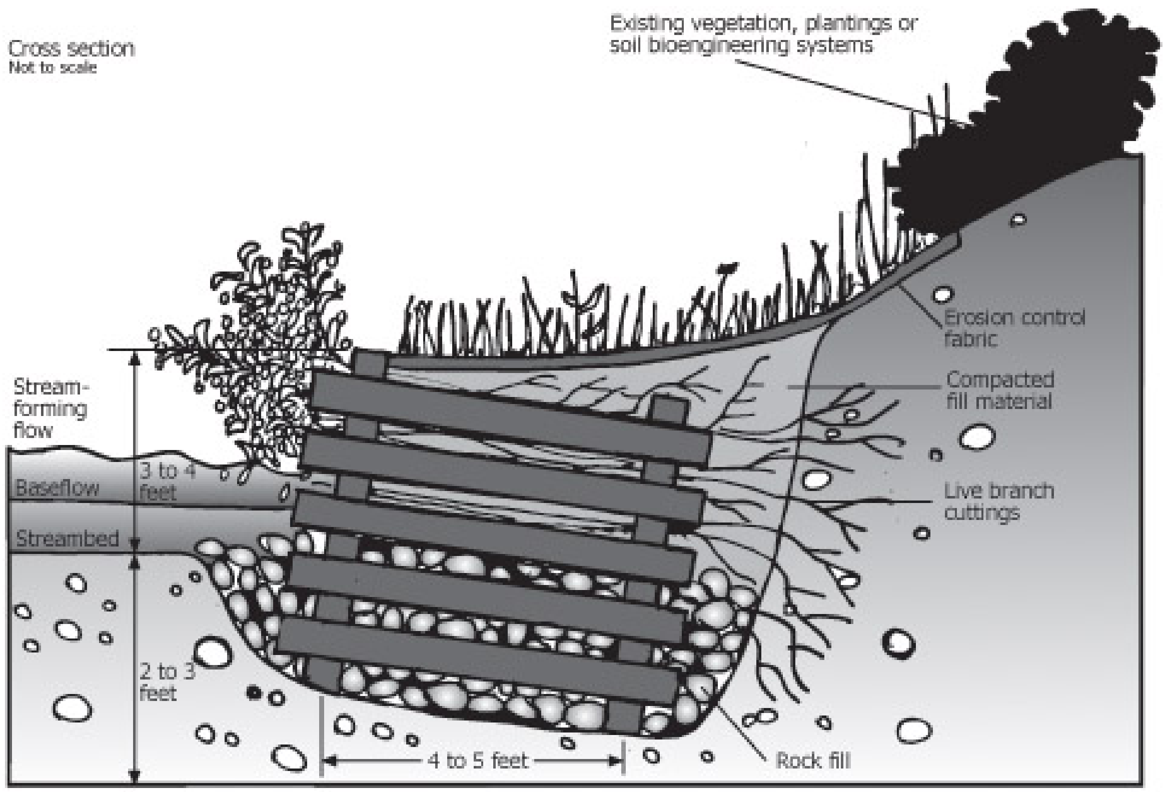
Figure 4: Brush Mattress



11.5 LIVE CRIBWALLS

Live cribwalls are rectangular structures of logs, rocks, and woody cuttings, and are filled with soil and layers of live branch cuttings. They are built into the streambank to protect eroding banks and are very effective on fast-flowing streams. Cribwalls provide long-term bank stability once the woody cuttings take root and grow. They are not recommended where the bed is severely undercut, in rocky terrain, or on narrow reaches where banks are high on both sides.

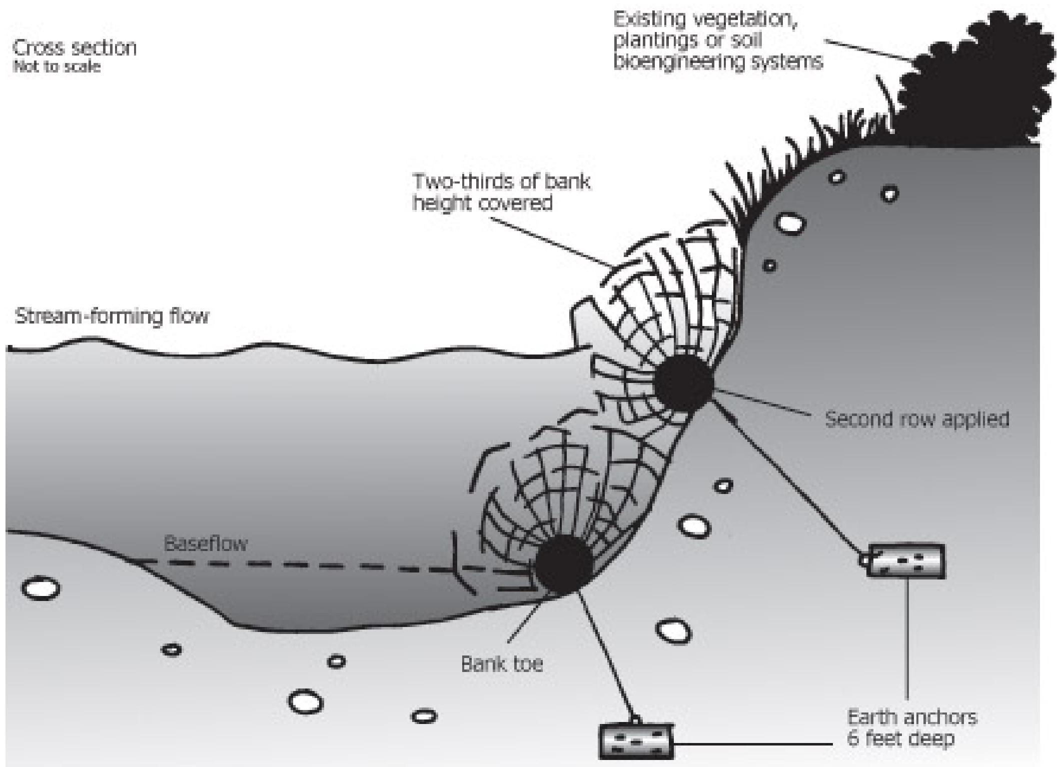
Figure 5: Live Cribwalls



11.6 Bank Revetments

Tree revetments are a relatively inexpensive, functional bank stabilization technique. Trees are installed parallel to the streambank with the top of the tree oriented downstream and overlap 1/3 to 1/2 of their length in a shingle fashion. The trees are tightly secured to the bank with cable and earth anchors. Revetments serve as a temporary protection measure, deflecting water flow away from the bank and therefore aiding in protection from scour and erosion. Over time, they trap sediment and help to rebuild bank structure and establish long-term bank stability. The revetments reduce water velocities, provide immediate cover for juvenile fish, and are a source of organic debris. Here in the southeast, Eastern red cedar is commonly used and works very well because of their dense branches. Tree revetments are appropriate on small to medium banks (less than 12 feet high) that are experiencing moderate erosion. Other types of revetments may be created using boulders, root wads, and logs.

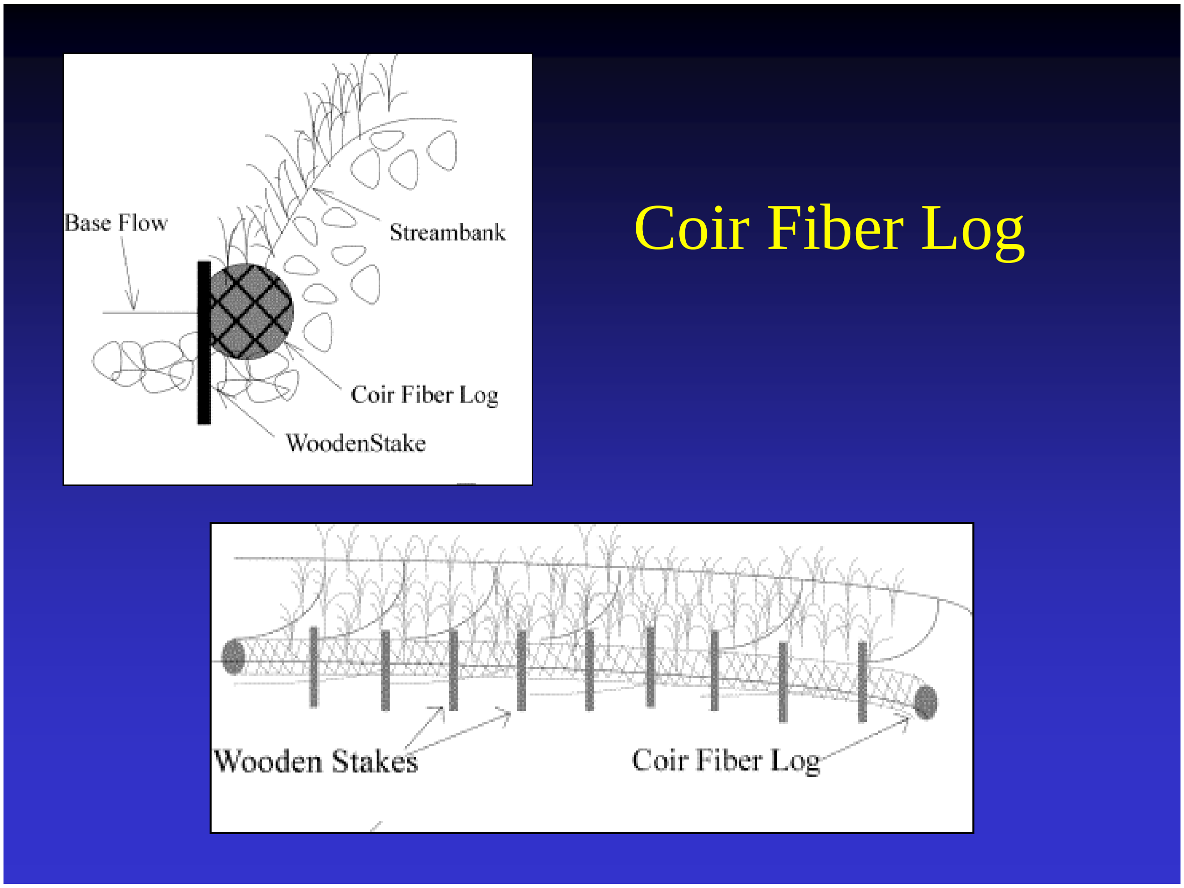
Figure 6: Bank Revetments



11.7 COIR FIBER LOG

Coir fiber logs are commercially-made erosion control products that consist of tightly bound cylinders of coconut fiber (coir) held together by a coir fiber netting. They are generally available in 10 to 20-foot lengths and are 10-12 inches in diameter. They are excellent for providing toe protection where scour is not severe. Once installed, the coir fiber log becomes saturated with water, and vegetation can be planted directly in them. Coir fiber rolls decompose over a three to six-year period, leaving the roots of colonizing vegetation to secure the toe of the streambank. They are relatively lightweight (10' in length= 75 lbs) and can be installed with a minimum of site disturbance. Some limitations to coir fiber rolls are that they are not appropriate in areas of severe scour and there must be sufficient sunlight for colonizing plant growth.

Figure 7: Coir Fiber Log



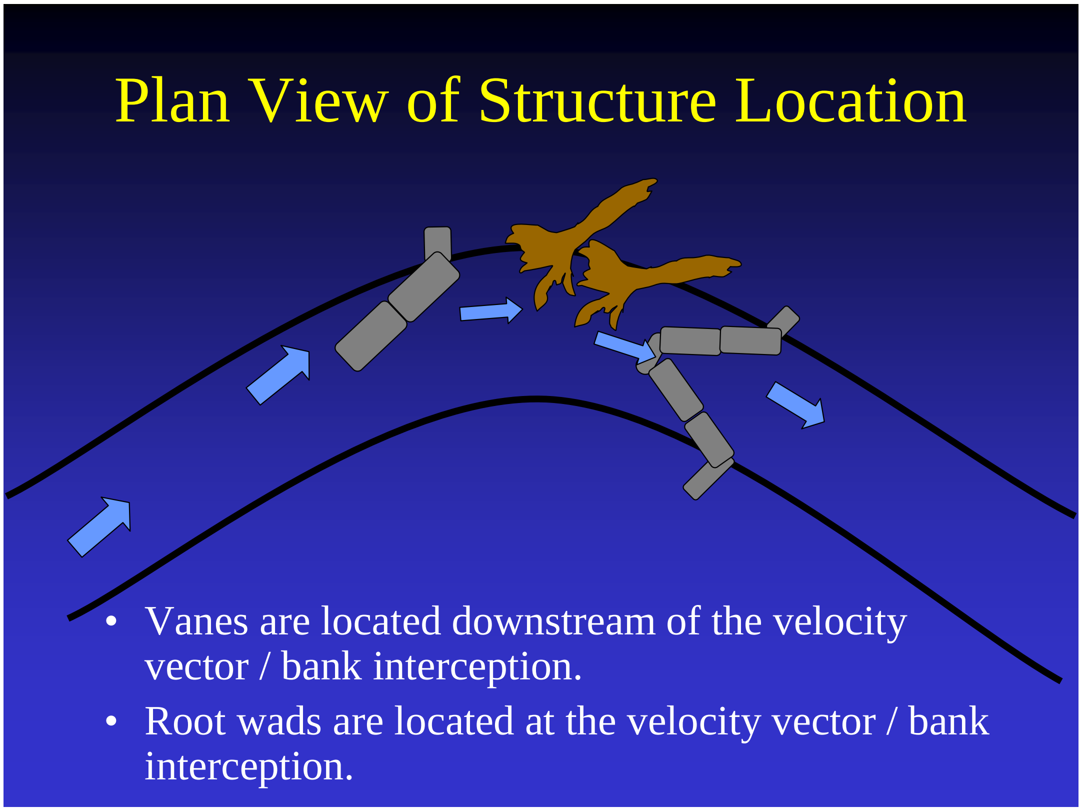
11.8 Erosion Control Matting

Erosion control blankets provide protective ground cover on slopes and in channels while permanent vegetation is being established. These temporary blankets are biodegradable and are typically made of wood fibers, straw, or coconut (coir).

11.9 Instream Structures

A problem with using some of the "hardening" methods (i.e. riprap, gabions, toe rock protection) is the increase in near-bank velocity, velocity gradient, stream power, and shear stress. These problems often lead to either on-site failures or problems immediately upstream or downstream of the structures. This, in combination with their high cost, resultant poor fish habitat, and non-natural appearance, led to the development of these structures listed below. These structures were designed to accomplish several goals, including: to establish grade control, reduce streambank erosion, facilitate sediment transport, enhance fish habitat, maintain width/depth ratio, maintain river stability, dissipate excess energy, withstand large floods, maintain channel capacity, be compatible with natural channel design, and be visually acceptable to the public. These structures should be installed so that they tie into the banks at bankfull and precisely follow the designated slope and degree of departure from the bank. For additional information on the following techniques, please see Rosgen, (2001).

Figure 8: Instream Structures



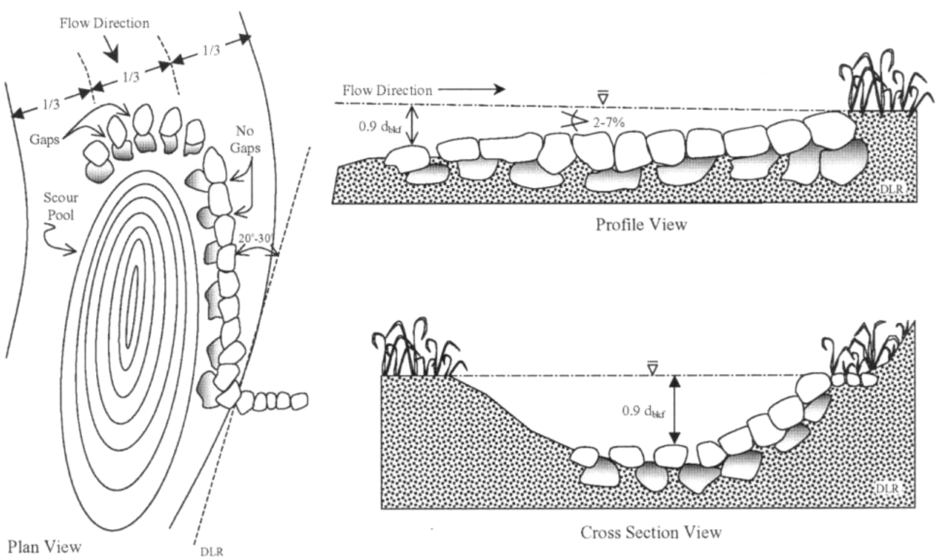
11.10 Root Wads

Root wads are a streambank stabilization technique but can also be used as a component to the J-hook method as described below. They provide immediate bank stabilization, protect the toe of the slope, and provide excellent aquatic habitat. They are especially well-suited for higher velocity river systems and riverbanks that are severely eroded. They provide toe support for bank revegetation techniques and collect sediment and debris that will enhance bank structure over time. Because of their size, root wads usually require the use of heavy equipment for collection, transport, and installation. The tree tops of the tree should be removed, leaving the trunk a minimum of 10 feet in length with root fans attached. Optimal root fans are a minimum of 5 to 6 feet in diameter. Root wads can be installed by two methods. The first is to excavate a trench into the riverbank deep enough to accommodate an 8 to 10 foot long tree trunk, embed the trunk at the level of the riverbed, perpendicular to the river, with the fans parallel to the bank. This placement requires that the riverbed be excavated to partially bury the root fan. The second method bores a hole into the riverbank to accommodate the tree trunk, or simply drives a pointed tree trunk into the bank. Again, the riverbed is excavated to allow the root fans to be partially embedded into the river substrate. Root wads should be positioned to undulate with the natural bank and installed so that the root fans overlap to provide continuous cover along the bank area (Muhlburg and Moore, 1998).

11.11 J-HOOKS

J-hooks were designed to re-direct velocity distribution and high velocity gradient in the near-bank region, stabilize streambanks, dissipate energy in deep, wide and long pools created below the structure, create holding cover for fish, and create spawning habitat in the tail-out of the structure. Material can vary using native boulders and logs. J-hooks are directed upstream, gently sloped, and are located on the outside of stream bends where strong downwelling and upwelling currents, high boundary stress, and high velocity gradients generate high stress in the near-bank region. The vane portion of the structure occupies 1/3 of the bankfull width of the channel, while the hook occupies the center 1/3. Sediment transport competence and capacity can be maintained as a result of the increased shear stress and stream power in the center 1/3 of the channel (Rosgen 2001).

Figure 9: J-Hooks

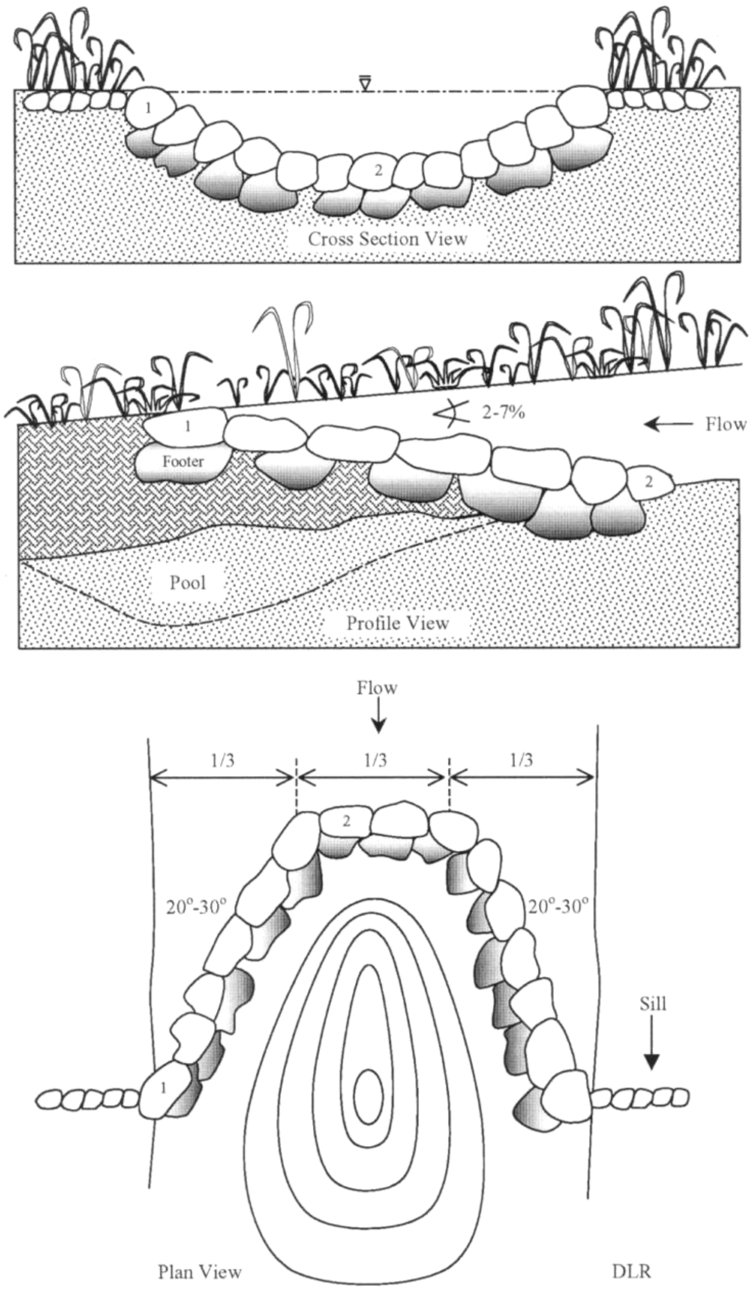


Plan, profile, and section view of the J-Hook Vane

11.12 CROSS-VANES

Cross-vanes were designed to take excess shear stress away from the near bank region and direct it to the center of the stream to maintain lateral stability, increase stream depth by decreasing width/depth ratio, increase sediment transport capacity, create instream cover and holding water, provide a natural sorting of gravel (where naturally available) on the upwelling portion on the downstream side of the structure for spawning habitat, and create grade control to prevent downcutting.

Figure 10: Cross-Vanes



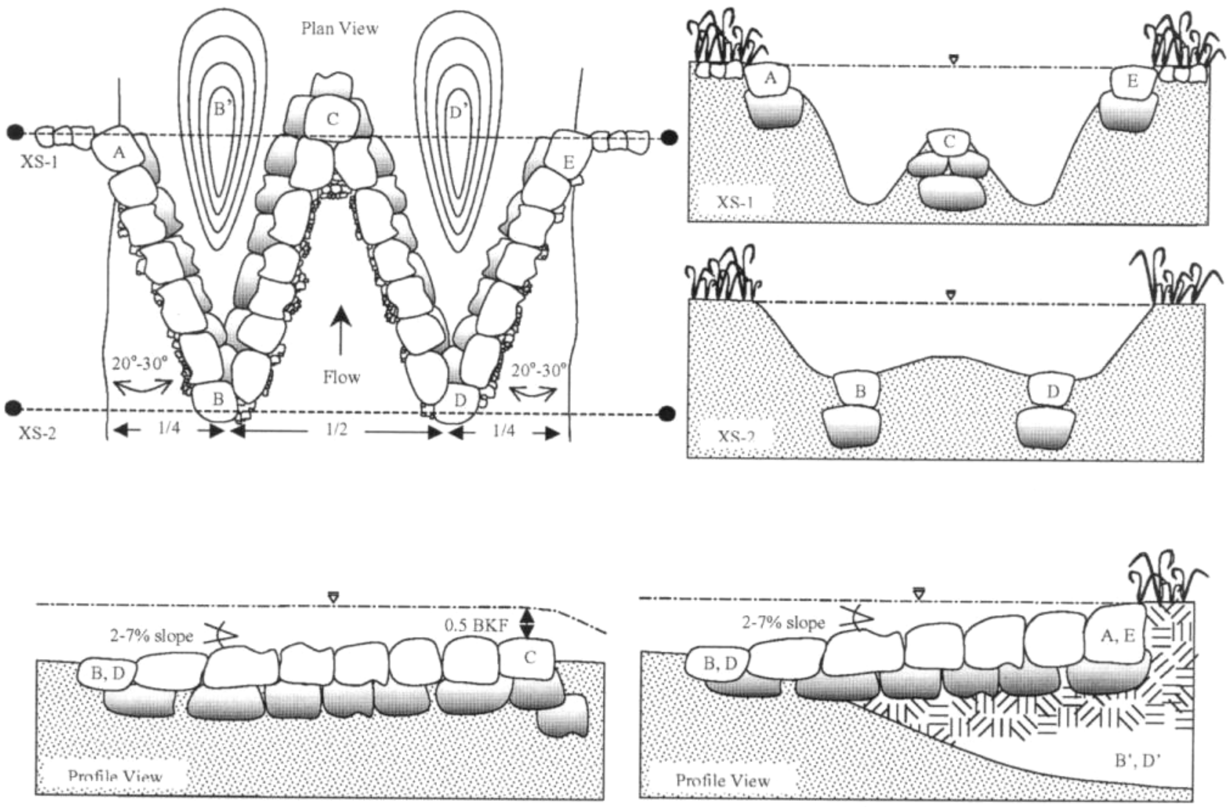
Cross section, profile and plan view of a Cross-Vane

11.13 W-WEIRS

This boulder structure is designed to create instream cover and diversity of velocity and depth and more useable area across the channel width. W-weirs are designed for river widths generally greater than 12 meters. They are similar to a Cross-vane in that both sides are vanes directed from the bankfull bank upstream toward the bed with similar departure angles. From the bed at

¼ and ¾ channel width, the crest of the weir rises in the downstream direction to the center of the bankfull channel creating two thalwegs (deepest part of the channel).

Figure 11: W-Weirs



Plan, cross section, and profile views of the W-weir

11.14 WING DEFLECTORS

Single wing deflectors are used to direct streamflows, increase velocities, form small pools for habitat, and direct high flows away from unstable banks. Double wing deflectors are used to form a deep scour pool in the center of the channel for habitat and to increase velocities and narrow the channel width by 40-80 %.

12.0 TREE/SHRUB PLANTING

All restored streams should be protected by a buffer of riparian vegetation.

Scientific research has shown that vegetative buffers are effective at trapping sediment from runoff and at reducing channel erosion. Both grassed and forested buffers are effective at trapping sediment, although forested buffers provide other benefits as well. These additional benefits include a source of temperature control, input of large woody debris that provides aquatic habitat diversity, and other organic matter necessary for aquatic organisms. To provide optimal habitat, native vegetative species should be maintained or restored in all buffers. A recent review of the scientific literature has yielded three options of guidelines for buffer widths in Georgia, with varying levels of protection. All three are defensible given the scientific literature. These widths vary from 100 feet plus 2 feet per 1 % of slope within the buffer, 50 feet plus 2 feet per 1 % of slope within the buffer, and a fixed width of 100 feet (Wenger 1999). As these buffers may seem extensive for some restoration projects, it should be noted that riparian plantings on a smaller scale can also serve as a localized bank stabilization method.

Common native trees used for stream restoration include:

Black Willow (*Salix nigra*)
Blackgum (*Nyssa sylvatica*)
Green Ash (*Fraxinus pennsylvatica*)
Other hydric oaks (*Quercus* spp.)
Persimmon (*Diospyros virginiana*)
Pumpkin Ash (*Fraxinus profunda*)- Coastal Plain only
River Birch (*Betula nigra*)
Sugarberry (*Celtis laevigata*)- Piedmont and Coastal Plain only
Swamp Chestnut Oak (*Quercus michauxii*)- Piedmont and Coastal Plain only
Sycamore (*Platanus occidentalis*)

Common native small trees/shrubs used for stream restoration include:

Ironwood (*Carpinus caroliniana*)
Red Chokeberry (*Aronia arbutifolia*)
Silky Dogwood (*Cornus amomum*)
Silky Willow (*Salix sericea*)
Spicebush (*Lindera benzoin*)
Tag Alder (*Alnus serrulata*)
Yellow-root (*Xanthorhiza simplicissima*)

Common species used in native riparian seed mixes include:

cardinal flower (*Lobelia cardinalis*)
ironweed (*Vernonia noveboracensis*)
joe-pye-weed (*Eupatorium fistulosum*)
sedge (*Carex* spp.)
soft rush (*Juncus effusus*)
soft stem bulrush (*Scirpus validus*)
switchgrass *(Panicum virgatum*)
Virginia wild rye (*Elymus virginicus*)

13.0 REFERENCES

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14.0 BEST MANAGEMENT PRACTICES

The Habitat TWG suggests the following measures to minimize impacts on the robust redhorse:

a. Cease construction activities from April 1st to July 1st, the spawning, egg, and larval development period of robust redhorse.

b. Implement at a minimum, BMPs endorsed by the State of Georgia, South Carolina, or North Carolina for erosion and sediment control and adequate stormwater management controls throughout the construction site. The site should be designed so that the river or stream does not serve as a stormwater or sediment detention area; stormwater runoff should be drained through an upland, vegetated buffer or permanent detention pond, rather than directly into the stream.

c. Temporary erosion control devices to protect water quality in the river or stream should be installed before any other work is performed. Establish appropriate perimeter controls at the edge of construction sites to retain or filter concentrated runoff from relatively short distances before it leaves the site.

d. Erosion control devices should be monitored weekly and after storms until disturbed areas have been permanently stabilized.

e. Phase construction for larger construction sites to reduce the time and area that disturbed soils area exposed.

f. Soils should be stabilized as rapidly as possible with native vegetation.

g. Borrow sites or sites for stockpiling fill dirt should be prohibited within 200 feet of the stream bank or elsewhere where runoff from the site would increase stream sedimentation.

15.0 GRAVEL AUGMENTATION LITERATURE

Danielle Pender, North Carolina Wildlife Resources Commission submitted the following two articles in her comments on the RRCC habitat restoration/conservation policy in July 2002. She recommended careful study prior to implementation of gravel augmentation as previous attempts may be short-termed and require continual replenishment efforts:

Gravel Removed from Failed Spawning, Red Bluff Daily News Article, Tehama County, California.

While the Tehama-Colusa Canal Authority is working to complete a revised EIR/EIS for its Fish Passage Improvement Project at Red Bluff Diversion Dam, dump trucks have been at work hauling gravel out of the nearby Tehama-Colusa Canal’s three-mile spawning channel. The gravel was originally added to the channel in the 1960s as mitigation for salmon spawning habitat lost due to the creation of the dam and its reservoir. While the gravel never was able to attract any salmon, it did prove to be a fertile ground for the propagation of pond moss. Whether it was the pond moss or the sound of irrigation pumps and tractors in the distance, the structure was never used by salmon. Indeed, it was the pond moss that found a niche in the spawning channel. It became so prolific that the U.S. Fish & Wildlife Service spent $60,000 a year on herbicides to keep it from stopping up the canal and causing overflows. Finally, this year the decision was made to remove the gravel and with it the prime pond moss breeding habitat, as well as eliminating any pretense of the channel’s usefulness for fish.

Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21:533-551.

Gravels were being artificially added to enhance available spawning gravel supply below dams on at least 13 rivers in California as of 1992. While these projects can provide short-term habitat, gravels placed in the main river have washed out during high flows, requiring continued addition of more imported gravel. On the Merced, Tuolumne, and Stanislaus rivers in California, a total of ten sites were excavated and back-filled with smaller gravel to create spawning habitat for Chinook salmon from 1990 to 1994. However, the gravel sizes imported were mobile at high flows that could be expected to occur every 1.5-4.0 years, and subsequent channel surveys have demonstrated that imported gravels have washed out.

Bill Bailey, U.S. Army Corps of Engineers, submitted the following August 2004 comments to the Habitat TWG in response to the Kondolf 1997 article mentioned above:

"I believe that portion of the article is talking about a situation that is much different than we have in our rivers. They are talking about dams producing excessive velocities that scour away the nesting substrate. The rivers erode to produce an overall larger sediment size. They discuss projects where the gravel was added back and state that the gravel gets washed away again. That would be expected as long as the high velocities continue to occur.

I don't believe we generally have that situation in our rivers. We will have it just below a dam, but the more widespread problem we encounter along the length of a river is siltation filling the voids in the nesting substrate. Instead of the problem being a substrate that is too large (discussed in the article), our substrates are typically too small (filled with fine-grained sediments). I believe we could either clean an existing gravel bar or add gravel to a site to restore a coarser-grained substrate.

I recognize that this approach may not be effective for long if turbidity is still high. In that case, the newly deposited or clean gravel will just fill in again. But the dams on our rivers also serve as sediment traps, with the water leaving the dams being much lower in suspended solids than what enters them. Locating a potential spawning site downstream of a dam would lengthen the usefulness of deposited or cleaned gravel. On the Savannah, the New Savannah Bluff Lock & Dam acts as a reregulation structure, evening out the flows (and velocities) in that portion of the river. Velocities downstream of that dam should have a narrower range than sections just below Thurmond Dam."

Literature Search Method:

"Gravel spawning" turned up the most results; "spawning substrate" turned up records involving only fishery lake management using submerged trees or artificial vegetation such as synthetic carpet-like materials. Rebecca Peterson also tried "gravel augmentation", "gravel supplementation", and "gravel and rivers" with no results. I searched a natural sciences collective database that included ASFA and some other biological and environmental engineering databases. I searched Google Scholar as well.

As you can see from the abstracts below, most of this area of research revolves around salmonids in areas outside of the southeast. Some of the research projects allow the rivers to distribute the gravel, but most projects involve specific gravel configurations that are designed after a geomorphologically-modeled assessment to maximize use of suitable areas and minimize gravel entrainment. Long-term monitoring, gravel replenishment, and adaptive management are necessities in these projects. Initial spawning in these gravel augmentation projects has been documented in as little as 2 months after construction and use of these projects for spawning has been documented over several seasons.

Results:

1) Merz, J.E., and J.D. Setka. 2004. Evaluation of a spawning habitat enhancement site for chinook salmon in a regulated California river. North American Journal of Fisheries Management 24(2): 397-407. May 2004.

An evaluation of the effectiveness of a project to enhance spawning habitat for Chinook salmon was conducted in the Mokelumne River, a regulated stream in California's Central Valley. Approximately 976 m^3 of clean river gravel (25-150 mm) was placed in berm and gravel bar configurations along the 45 m enhancement site. Physical measurements taken before and after gravel placement indicate that the project significantly increased channel water velocities, intergravel permeability, and dissolved oxygen; reduced channel depths; and equilibrated intergravel and ambient river temperatures. These positive benefits remained throughout the 30-month monitoring period. Adults began spawning at the previously unused site within two months after gravel placement and continued to use the site during the three spawning seasons encompassed by the study. Bed material movement was documented by channel bathymetry surveys over two water years. Topographical channel surveys provide a useful tool for monitoring bed material transport and layering redd locations on contour maps. Although its usefulness in restoring salmon populations is poorly understood, gravel enhancement can be an effective means for improving salmon spawning habitat in rivers where upstream dams have effected low gravel recruitment.

2) Kondolf, M.G. 2000. Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals. Restoration Ecology 8(1): 48-56. March 2000.

Proposals to improve fish habitat for anadromous salmonids by modifying channel form or substrate must be justified based on geomorphology as well as biology, because geomorphic factors often cause such projects to fail. Proposals should address the geomorphic setting at the watershed scale, by specifying changes in flow regime or sediment yield through tools such as a sediment budget. Proposals should also address geomorphic setting and process at the reach scale, indicating the basis for design channel form and dimensions, calculating the frequency of bed mobilization, and assessing existing gravel quality for spawning habitat enhancement projects. Proposals should include explicit provisions for post-project performance evaluation, including adequate baseline data to permit project-induced changes to be quantified. Restoration projects also require clear objectives and adequate funding for long-term monitoring, and generally would benefit from an adaptive management approach to implementation and evaluation.

3) Khoroshko, P.N., and A.D. Vlasenko. 1970. Artificial spawning grounds of sturgeon. Journal of Ichthyology 10(3):286-292.

The improvement of existing spawning grounds for sturgeon and the creation of artificial spawning grounds is a question which is coming to be of extreme urgency in view of the increased amount of hydraulic engineering work. Three experimental stone-gravel spawning grounds were constructed for the 1st time in 1965 on the Volga in the area of the village of Tsagan-Aman and on the Kuban' in the afterbay of the Fedorovka hydroelectric power station.

Two years of observations on the conditions of exploitation of the artificially created spawning grounds have revealed the nature of their utilization by anadromous fishes. Recommendations on extension of the spawning area of sturgeon have been worked out on the basis of an analysis of the material collected.

4) Pasternack, G.B., C.L. Wang, and J.E. Merz. 2004. Application of a 2D hydrodynamic model to design of reach-scale spawning gravel replenishment on the Mokelumne River, California. River Research and Applications 20(2):205-225.

In-stream chinook salmon spawning habitat in California's Central Valley has been degraded by minimal gravel recruitment due to river impoundment and historic gravel extraction. In a recent project marking a new direction for spawning habitat rehabilitation, 2450 m^3 of gravel and several boulders were used to craft bars and chutes. To improve the design of future projects, a test was carried out in which a commercial modeling package was used to design and evaluate alternative gravel configurations in relation to the actual pre- and post-project configurations. Tested scenarios included alternate bars, central braid, a combination of alternate bars and a braid, and a flat riffle with uniformly spaced boulders. All runs were compared for their spawning habitat value and for susceptibility to erosion. The flat riffle scenario produced the most total, high, and medium quality habitat, but would yield little habitat under flows deviating from the design discharge. Bar and braid scenarios were highly gravel efficient, with nearly 1 sq meter of patches that were superior to the actual design. At near bankfull flow, negligible sediment entrainment was predicted for any scenario.

5) Rubin, J.F., C. Glimsater, and T. Jarvi. 2004. Characteristics and rehabilitation of the spawning habitats of the sea trout, Salmo trutta, in Gotland (Sweden). Fisheries Management and Ecology 11(1):15-22.

Characteristics of the natural spawning habitat of sea trout were studied in Sjalsoan, a small stream of Gotland, Sweden, from 1992-1999. Each year, trout spawned on 17 +/- 7 different areas (156 places per ha). Most of the spawning grounds were used every year. Overcutting was evident for at least 60% of the spawning grounds. Fish spawned on a gravel of 19 +/- 7 mm in diameter. From 1978-1992, 242 artificial spawning grounds were constructed by the Gotland Sport Fishermen Association in four Gotland streams. A sediment trap was dug upstream to the spawning grounds. The artificial spawning ground comprised of a downstream V-shape stream deflector of large stones with a log weir at the narrowest point of the deflector. Upstream of the dam, 15-60 mm diameter gravel was deposited to constitute the spawning ground substratum. To keep the installation efficient, maintenance is needed every year before the spawning season.

6) Kondolf, G.M., J.C. Vick, and T.M. Ramirez. 1997. Spawning habitat enhancement. Salmon Farming, April 1997, pp. 12-13.

From 1986-1995, over US $2.5 million has been spent or allocated for projects to modify channel conditions to improve spawning habitat for chinook salmon in the Merced, Tuolumne, and Stanislaus rivers, tributaries to the San Joaquin River, California. We evaluated the planning, design and performance of the riffle 1B reconstruction on the Merced River. This is typical of the nine individual riffle reconstructions completed to date, involving excavation of the existing channel bed (here, to 0.6 m) and back-filling with smaller gravels believed to be more suitable for salmon spawning. We reviewed project documents, interviewed agency staff, and conducted field surveys to document channel conditions in 1994 for comparison with the project as constructed in 1990. The project planning and design did not consider the site's geomorphic context nor processes of erosion and sediment transport under the current flow regime. As a consequence, spawning sized gravel placed in the channel was scoured and transported through the site as a flow with a return period of 1.5 years. The need for spawning habitat enhancement in the Merced River is questionable, but if such projects are to be built, we recommend that the project planning and design consider the site's geomorphic context and acknowledge the need for and provide funds for project maintenance, and that the performance of completed projects be systematically monitored and evaluated.

7) Mundie, J.H., and D.G. Crabtreem. 1997. Effects of channel cleaning on salmon fry. Salmon Farming, August 1997, pp. 15-16.

Prior to the cleaning of the Little Qualicum chum salmon channel, the sediments, of which 33% were greater than 64 micron, were distributed fairly evenly throughout the 56 cm gravel column and occupied 25% of the interstitial space. Filamentous algae, especially Didymosphenia, were abundant in summer and reduced the diversity of the zoobenthos relative to that of the parent stream. The mean number of salmonid food-organisms was 30,000/ sq. m (sampled with a 200 micron net); 57% were Chironomidae at the upstream end of the channel, increasing to 93% at the downstream end. Numbers of coho salmon fry per km of channel exceeded those of productive natural streams. Scarification of the channel resulted in removal of 88% of the sediments, reduction of arthropods by 98%, and reduction of emerging insects by 88% across the center of the channel and by 90% at the margins. Coho salmon fry showed no significant mortalities during cleaning and lived on marginal aquatic insects until the channel was re-colonized 8 weeks later.

8) McCulloch, Michael. 2002. Campbell River (Elk Falls) Canyon Spawning Gravel Placement, 2002. Funding provided by BC Hydro Bridge Coastal Fish and Wildlife Restoration Program, 6911 Southpoint Drive- E16, Burnaby BC, V3N 4X8, Project No. 02.CA.54 and Ministry of Water, Land and Air Protection, Fisheries Seciton 2080A Labieux Road, Nanaimo BC, V9T 6J9. Prepared by BC Conservation Foundation, #3-1200 Princess Royal Avenue, Nanaimo, BC V9S 3Z7, March 2002.

94 m^3 of spawning gravel was placed in two key locations with a heavy lift helicopter for steelhead, coho, and chinook habitat enhancement in July 2002. Two snorkel surveys were conducted 3-4 months later to evaluate habitat use. At the time of the October survey, overall use of the substrate by spawning sockeye and Chinook was considered high; during the November survey the introduced gravel was being used by spawning coho and post-spawn Chinook were observed guarding redds. A very high abundance of rainbow parr and cutthroat adults were associated with the gravel pads, likely feeding on salmon eggs displaced from redds.

9) Wheaton, J.M., G.B. Pasternack, and J. Merz. 2001. Integrating empirical geomorphology, CAD and 2-D hydraulic models as design tools for salmonid spawning gravel rehabilitation projects. American Geophysical Union, Fall Meeting 2001, abstract #H52B-0399.

Recent salmon restoration and rehabilitation efforts have focused on reintroducing spawning gravels to rivers whose sediment supplies have been blocked or altered by dams, land-use changes and altered flow regimes. Few of these projects have considered the fluvial processes that govern how spawning habitat can be created, enhanced and maintained given the finite supply of spawning gravels introduced by such projects. Reach scale 2-D hydraulic models could solve this problem, as they have already proven to be a useful tool for assessing salmonid spawning habitat quality and quantity. Habitat data collected on the Mokelumne River in California suggests that optimal spawning conditions for fall run Chinook salmon occur at velocities near 0.87 m per second and around 0.38 m depths. We employed the FESWMS 2-D model, basic fluvial geomorphic principles and CAD software to design a range of alternatives for a gravel enhancement project on the Mokelumne River below Camanche Dam. The pre-project baseline condition was modeled and compared against ten in-stream gravel placement alternatives, which included alternate bars, flat riffles, braids, and more complex geometries. Pre project hydraulic geometry analysis showed b-f-m values of 0.32, 0.41 and 0.07 respectively, suggesting that depth responds quickest to changes in discharges on this reach of the Mokelumne River. A global habitat suitability index was used to quantify and map spawning habitat potential, while a sediment mobility index was used to guard against gravel entrainment at below bankfull flows. The final design consisted of a complex geometry gravel placement that produced the most potential spawning habitat of the design scenarios. In August of 2001, East Bay Municipal Utility District constructed the project with approximately 850 cubic meters of gravel based on the final design. Since the global habitat suitability index is based on velocity and depths, it is entirely stage dependent. The final design was estimated to produce an additional 0.16 square meters of spawning habitat per cubic meter of gravel over the pre project conditions at a discharge of 11.5 cubic meters per second. Velocity and depth cross sections were collected before the project to calibrate and validate the model and again after the project to evaluate the model's performance as a design tool. Salmonid spawning gravel rehabilitation projects can achieve higher rates of success and sustainability by utilizing empirical geomorphology, CAD and 2-D hydraulic models to predict the river's response to the addition of gravel.

10) Wheaton, J.M., G.B. Pasternack, and J. Merz. 2002. The use of spatial complexity in a spawning gravel rehabilitation project. American Geophysical Union, Fall Meeting 2002, abstract #H72B-0855.

A shortage of spawning habitat on dammed and regulated rivers has led to the popularity of gravel augmentation and spawning habitat restoration projects among river managers. Spatial complexity has been cited as an important feature of aquatic ecosystems, but has yet to be widely adopted in the design of spawning habitat rehabilitation projects. Spatial complexity in rivers is formed by geomorphic and hydrodynamic processes, and its importance reflected in habitat utilization. In August of 2002, over 2,786 metric tons of spawning gravels and 7 large boulders were placed in a 155 meter reach comprised of a short (22 m long) riffle, long (95 m long) glide and second riffle (38 m long) on the Lower Mokelumne River, California. Spatial complexity was incorporated into the design as part of a new, integrated, scientifically based spawning habitat rehabilitation approach developed and implemented over the past two years. At the reach scale, gravels were used to elevate the bed and increase slopes over newly constructed riffles from 0.0012 to 0.004. At the geomorphic unit scale (sub-reach), flow was routed through a complex assemblage of geomorphic units including three broad riffles (to encourage divergent flow and deposition of gravels at high flows), three small pools (whose widths were constricted by bars to encourage convergent flow and scour at high flows) and three boulder complexes. Boulder complexes were used to encourage localized scour and create shear-zones, channel constrictions, pour-overs and standing waves. Pool exit slopes at pool-riffle transitions were shaped to promote intragravel flow and encourage concentrated flow to diverge across riffles. Although optimal spawning habitat is generally found in riffles, proximity of optimal spawning habitat to pools, large woody debris, boulder clusters and overhanging cover provides equally important refuge from predation and holding areas where the female can quickly move between the redd and refugia without leaving the nest unprotected. Incorporating such complex features into a design can improve the quality of habitat beyond the predictive capability of models that use numerical habitat suitability indices. Such models can constrain the uncertainty of a design but need to be combined with conceptual models and practical limitations of construction to achieve spatial complexity. Results are presented to illustrate the exploitation of complexity as a component of an integrated approach to constructing spawning habitat rehabilitation projects.

11) Pasternack, G.B., J.M. Weaton, and J. Merz. 2002. Lessons from a spawning gravel rehabilitation program. American Geophysical Union, Fall Meeting 2002, abstract #H71F-10.

Altered sediment and flow regimes in dammed and regulated rivers limit available spawning habitat to salmonids. River managers have attempted rehabilitation of spawning habitat with gravel augmentation and riffle construction projects, but often neglect well-established conceptual models of geomorphic and ecologic processes, let alone apply them in a predictive manner. Application of such models could not only improve rehabilitation projects, but also serve to further test and evaluate the underlying scientific theories against the rigors of real-world uncertainties. For the past two years a new science-based approach to rehabilitate spawning gravels for salmonids has been under development and testing to overcome these deficiencies. The approach includes a balance of science-based quantitative tools from multiple disciplines and qualitative local knowledge relevant to the region in which it has been applied. In 2001 and 2002 it was used to design and implement the placement of 907 and 2787 metric tons of gravel, respectively, on separate reaches of the lower Mokelumne River in Central California. A long-term monitoring program to quantify outcomes and assess sustainability is on-going. Lessons from these efforts are providing for adaptive management and will be presented.

APPENDIX E

FUTURE PROJECTS

ROBUST REDHORSE CONSERVATION COMMITTEE
HABITAT TECHNICAL WORKING GROUP

FUTURE PROJECTS

The following is a list of projects that the Habitat TWG feels are important and would like to see accomplished in the future:

1. Develop a compendium of the contractors that are certified/ bonded to do streambed/streambank stabilization/restoration work in Georgia, South Carolina, and North Carolina.

   NOTE: This activity was completed in 2004. The latest list of contractors who have expressed a capability to the Athens Georgia office of the USFWS to design or perform stream restoration work can be found on the following page.

2. Obtain or conduct an assessment of potential habitat restoration actions on the Oconee River, targeting enhancement of existing spawning sites. The RRCC would identify known and suspected spawning sites on the river. An assessment of these areas and the watershed above would be used to determine the effects of ongoing and likely future development in the watershed on river flows. The assessment would also include identifying point and non-point source pollution (e.g., sedimentation, wastewater discharge). The end product should identify measures to potentially reduce those sources, and develop conceptual level designs for specific measures that would restore or enhance the spawning habitat.

LIST OF CONSULTANTS WHO HAVE EXPRESSED A CAPABILITY TO PERFORM STREAM RESTORATION WORK

16.0 MAY 2006

This list represents consultants with whom the US Fish and Wildlife Service has worked on stream restoration projects or who have provided the Service data indicating they are fully trained in natural channel design.

Acer Environmental, Inc. (Greg Smith)
1885 Lawrenceville-Suwannee Rd., Suite 150
Lawrenceville, GA 30043
Phone: 770-682-9731
Fax: 770-682-6164

Appalachian Environmental Services (Mickey B. Henson)
P.O. Box 52
Webster, NC 28788
Phone: 828-586-1973
Fax: 828-631-0343

Arcadis
801 Corporate Center Drive, Suite 300
Raleigh, North Carolina 27607
Phone: 919-854-1282
Fax: 919-854-5448

Biohabitats, Southeast Bioregion
321 E. Main St., Suite 106
Canton, GA 30114
Phone: 770-704-0098
Fax: 770-704-6479

Buck Engineering (Will Harmon) (acquired by Michael Baker Corporation)
8000 Regency Parkway, Suite 200
Cary, North Carolina 27511
Phone: 919-459-9003
Fax: 919-463-5490

Buck Engineering (Steve Glickauf) (acquired by Michael Baker Corporation)
200 Arizona Ave, Suite 114
Atlanta, GA 30307
404-653-0182
sglickauf@buckengineering.com

CH2MHill (Dale Jones)
115 Perimeter Center Place NE
Suite 700
Atlanta, Georgia 30346
Phone: 770-604-9182 X416
Fax: 770-604-9183
Cell: 678-520-6944

Eco-South, Inc. (Kent Campbell)
P.O. Box 1587
Covington, GA 30015
Phone: 770-385-1849
Fax: 770-786-1528

Environmental Services, Inc. (Steven M. Jones)
2169 West Park Court, Suite A
Stone Mountain, GA 30087
Phone: 770-469-8121
Fax: 770-469-1364

Register and Associates (Mark Nelson)
3949 Jodeco Road
McDonough, GA 30253
Phone: 678-432-2636
Fax: 678-432-2464