SUMMARY REPORT FOR THE SECOND SAVANNAH RIVER ECOSYSTEM FLOWS RESTORATION WORKSHOP FOR THE SUSTAINABLE RIVERS PROJECT

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February, 2012

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Introduction

The Savannah River Basin Sustainable Rivers Project is founded on the idea of adaptive management, that as new and relevant research became available it would be used to revise previous recommendations. Since the 2003 Savannah River Ecosystem Flows Restoration workshop for the Sustainable Rivers Project, a number of studies have been conducted pertaining to the Savannah River. In anticipation of a second workshop in 2012, a synopsis of literature published since 2003, which is relevant to the Savannah River Basin Sustainable Rivers Project, is provided below.

Modifications to the original 2003 workshop flow recommendations were incorporated into tables 4-6 of the second draft final report of the April workshop. These tables represent the final product of the 2003 workshop. However, these tables do not specify the timing and duration of high pulse flows and floods and in general are not as detailed as tables 2-3. Attempts to merge the duration and timing of flows in tables 2-3 with the new flows in tables 4-6 mostly failed because they do not match. The duration and timing of these pulses and floods are very important depending on the species or ecosystem in question and may affect whether the 2003 flow recommendations are beneficial or harmful. The literature summarized in this report was compared to tables 4-6, however, the conclusions drawn in this literature review may change once the appropriate detail is achieved.

2003 Ecosystem Flow Recommendations, based on the second draft Final Report of April Workshop, Tables 4-6

			Low Flows (cfs)			Pulse (cfs)			Flood (cfs)	
	Month	**Shoals**	**Floodplain**	**Estuary**	**Shoals**	**Floodplain**	**Estuary**	**Shoals**	**Floodplain**	**Estuary**
Dry Year	October	2000	5500	6000						
	November	2700	6200	6200						
	December	2700	6200	6200						
	January	4000	7500	8000						
	February	4000	7500	8000						
	March	4000	7500	8000	12500-14500	16000-18000	16000-18000			
	April	4000	7500	8000	12500-14500	16000-18000	16000-18000			
	May	2700	6200	6200						
	June	2700	6200	6200						
	July	2700	6200	6200						
	August	2000	5500	6000						
	September	2000	5500	6000						
Average Year	October	4000	7500	8000						
	November	4000	7500	8000						
	December	4000	7500	8000						
	January	6000	9500	9500	16500-36500	20000-40000	20000-40000			
	February	7500	11000	11000	16500-36500	20000-40000	20000-40000			
	March	8500	12000	12000	16500-36500	20000-40000	20000-40000			
	April	6500	10000	10000	16500-36500	20000-40000	20000-40000			
	May	4500	8000	8000						
	June	4500	8000	8000						
	July	4000	7500	8000						
	August	4000	7500	8000						
	September	4000	7500	8000						
Wet Year	October	5500	9000	9000						
	November	5500	9000	9000						
	December	5500	9000	9000						
	January	8500	12000	12000	26500	30000	30000			
	February	10000	13500	13500	26500	30000	30000		50000	50000
	March	10000	13500	13500	26500	30000	30000			
	April	10000	13500	13500	26500	30000	30000			
	May	10000	13500	13500						
	June	5000	8500	9000						
	July	5000	8500	9000						
	August	5000	8500	9000						
	September	5000	8500	9000						

In-Channel and Floodplain Vegetation

Gordon and Wear (2011) conducted a study on the declining populations of the Shoals spider-lily (*Hymenocallis coronaria*) on the Augusta Shoals of the Savannah River. They examined the life history and environmental factors that may be leading to their decline by comparing the Augusta Shoals populations to populations on the less impacted Stevens Creek. They found that excessively high or low flow rates and water levels during the growing season were detrimental to successful seedling production. Flow rates $\geq 283\ m^3s^{-1}$ (~10,000 cfs) resulted in inundation of spider lily foliage and flowers. Post dam construction, high flows occurred more often in May, during anthesis, the period in which flowers are fully open and functional, than in pre-dam conditions. For the Shoals spider-lily, anthesis begins in late April to mid-May and continues sporadically until late June and occasionally into September. High flows in Stevens Creek during anthesis resulted in flowers losing anthers, the component of a flower which bears pollen, but subsequent flowering was not affected as plants recovered in one to two days. High flows were not observed in the Augusta Shoals during the study period although the authors concluded that when they do occur it is likely for a longer duration than at Stevens Creek which would increase anther loss and reduce opportunities for pollination. Extremely low flows in the Augusta Shoals were observed during a severe drought in the growing season of 2008 which resulted in seeds and seedlings drying out on exposed rocks. The flow at this time was estimated to be $\leq 51.0\ m^3\ s^{-1}$ (1800 cfs) after diversion of water in the Augusta Canal.

The Shoals spider lily also reproduces asexually through the production of ramets. A ramet is an independent member of a clonal colony and clusters of ramets are called clumps. There was no difference in clump size between the Augusta Shoals and the Stevens Creek populations which suggests that once seedlings become established the ramets are easily produced. The authors concluded that this asexual reproduction was a successful strategy for continuation of the population when flows are disruptive to pollination.

Severe browsing by deer during anthesis is a problem for one population in the Augusta Shoals, located between a mid-stream island and the eastern side of the Savannah River. Deer browsing resulted in complete flower loss in 2007. This population is easier for deer to access than other populations on the Savannah River because the presence of the island, the population's close proximity to shore, and the surrounding water is shallow. However, the authors caution that raising the water level to discourage deer access to this population may result in dislodging of seedlings and established clumps.

A positive relationship was found between channel gradient and population size. The Stevens Creek site had a channel gradient five times higher than Augusta Shoals and a much larger population. This is consistent with a study by Markwith and Parker (2007) on the Shoals spider-lily which found that channel width and stream gradient were positively related to shoal inhabitation and population size. However, Gordon and Wear (2011) did not find a positive relationship between channel width and population size. The channel width in the Augusta Shoals was 29 times greater than at Stevens Creek and had a much smaller population.

In summary, flow rates $\geq 283\ m^3\ s^{-1}$ (~10,000 cfs) or $\leq 51.0\ m^3\ s^{-1}$ (~1800 cfs) during the *H. coronaria* growing season (May 1 - October 31) combined with deer herbivory and habitat loss pose the most threat to the reproductive success of *H. coronaria*.

SUPPORT/TANGENTAL - *High flow pulses in April should be okay since this is only the beginning of anthesis and the growing season and loss of some flowers doesn't prevent others from growing. However, the low flow recommended for wet of 10,000cfs could be problematic* *but only if flows are sustained at 10,000cfs. The Shoals spider-lily needs low flows below 10,000cfs during anthesis (begins late April – mid-May and continues until late June and occasionally into early September) but since these flows are only recommended during the very beginning of the growing season and anthesis this should not prevent subsequent pollination efforts. Minimum flows recommendations for all types of years (≥ 1800cfs), are supported by this study. The authors caution against raising water level to discourage deer access, as suggested in the 2003 final report, as this may result in dislodging of seedlings and/or established clumps though don't specify at what flows this might occur.*

Palta et al. (2011) conducted a study on how flow alterations of the Savannah River affected diameter growth of bald cypress (*Toxodium distichum*). They expected backswamps to be wetter in the post-dam period but found that the levees and backswamps were drier post-dam than before impoundment. They also found that there was increased tree growth in the post-dam era. It was hypothesized that this could be caused by decreased incidence of root anoxia caused by shorter hydroperiods, fewer floods, and higher shallow groundwater levels. These factors seemed to encourage *T. distichum* growth. It was hypothesized that higher low flows created in the post-dam era help to prevent roots from completely drying out late in the growing season. Stress caused by extended deep flooding and drought was shown to have a negative effect on *T. distichum* growth.
SUPPORT – *Recommended low flow for dry years every 10-20 years (3000cfs from April-September for 3 years) would allow for floodplain tree recruitment and growth.*

Robust Redhorse (*Moxostoma Robustum*) and other Catostomid suckers

Weyers et al. (2003) conducted a laboratory experiment on the effects of pulsed, high velocity flows on larval robust redhorse (*Moxostoma robustum*) and v-lip redhorse (*Moxostoma collapsum*). The larvae were in tanks with stable low-velocity water flow (<10cm/s) and were exposed to either 0, 4, or 12 h per day high velocity pulses (>35cm/s). During the first 10-14 days after fertilization the pulses had little effect on robust and V-lip redhorse survival and growth. This was attributed to the protection provided by the interstitial spaces in the gravel nests and the adhesiveness of the sucker eggs which allowed them to attach to the gravel and to each other. However, during emergence, larvae exposed to 4 or 12 h pulses grew significantly more slowly and had lower survival than larvae exposed to 0-h pulses. During periods of high velocity flow larvae observed attempting to swim to the water surface to inflate their gas bladder were swept away in the current. Those carried by the current found it difficult to return down to the lower velocity areas in the gravel. Inability to inflate their gas bladder and expending energy during the struggle to swim down to lower velocity areas during these pulses could both lead to reduced larval growth and survival. Increases in the duration of pulses were found to cause a greater decrease in growth rate. V-lip redhorse larvae had better survival rates than robust redhorse larvae. This was attributed to their greater length at hatching which improves swimming ability. The results of this study indicate that pulsed, high velocity flows common with hydropower generation dams have negative effects on survival and growth of both of these catostomid species and that robust redhorse may have greater susceptibility to the negative effects created by these types of flows.

REFUTE & SUPPORT: *2003 recommended flood pulses occur during v-lip spawning times (mid March – early may) but only 1/month for 2-3 days in an average year. The greater survival rate of v-lip redhorse may mean that they are less susceptible to flow pulses. Since the robust redhorse spawns in May it will not likely be affected by the flood pulses.*

Grabowski and Isely (2006) conducted a study on the movements and habitat use of Robust Redhorse (*Mosostoma robustum*) in the Lower Savannah River. They found that seasonal migrations were correlated to water temperature and migration upstream occurred when temperatures were between 10-12°C. Robust redhorse were found to use most of the Savannah River below the New Savannah Bluff Lock and Dam (NSBLD). Robust redhorse migrated downstream to overwintering areas and upstream to spawn and were found to have high site fidelity to overwintering, spawning, and staging habitats. However, the results of this study suggest that this fish is mostly sedentary and only makes long-distance migrations seasonally. They also appear to be potamodromous (migration within freshwater only). The authors suggested that this extensive use of the Savannah River means that efforts to protect these fish should use a whole-system management approach.

The behavior of two individuals captured and released above NSBLD was found to be different from the behavior of fishes downstream. They did not make long migrations, preferring instead to remain in the Savannah Rapids and did not utilize the river below the shoals. In addition, one individual that was captured and released below the dam that subsequently passed NSBLD during the study adopted the same behaviors of the other two individuals inhabiting the area above the dam. It was unclear whether this was the result of an inability or an unwillingness to move out of the Savannah Rapids.

The only instance where these fish were found out of the main channel flow was during high water events when they were found in the floodplain adjacent to the river and occasionally in flooded tributaries, oxbows and other backwater areas. The authors attributed this movement to foraging in the floodplain in preparation for spawning. Because this species spawns in May to mid-June, foraging on the floodplain in March and April was hypothesized by the authors to improve their condition or fecundity.

SUPPORT- *High flow pulses during wet and average years would allow robust redhorse access to floodplain to forage during March and April before spawning in May.*

Grabowski and Isely (2006):

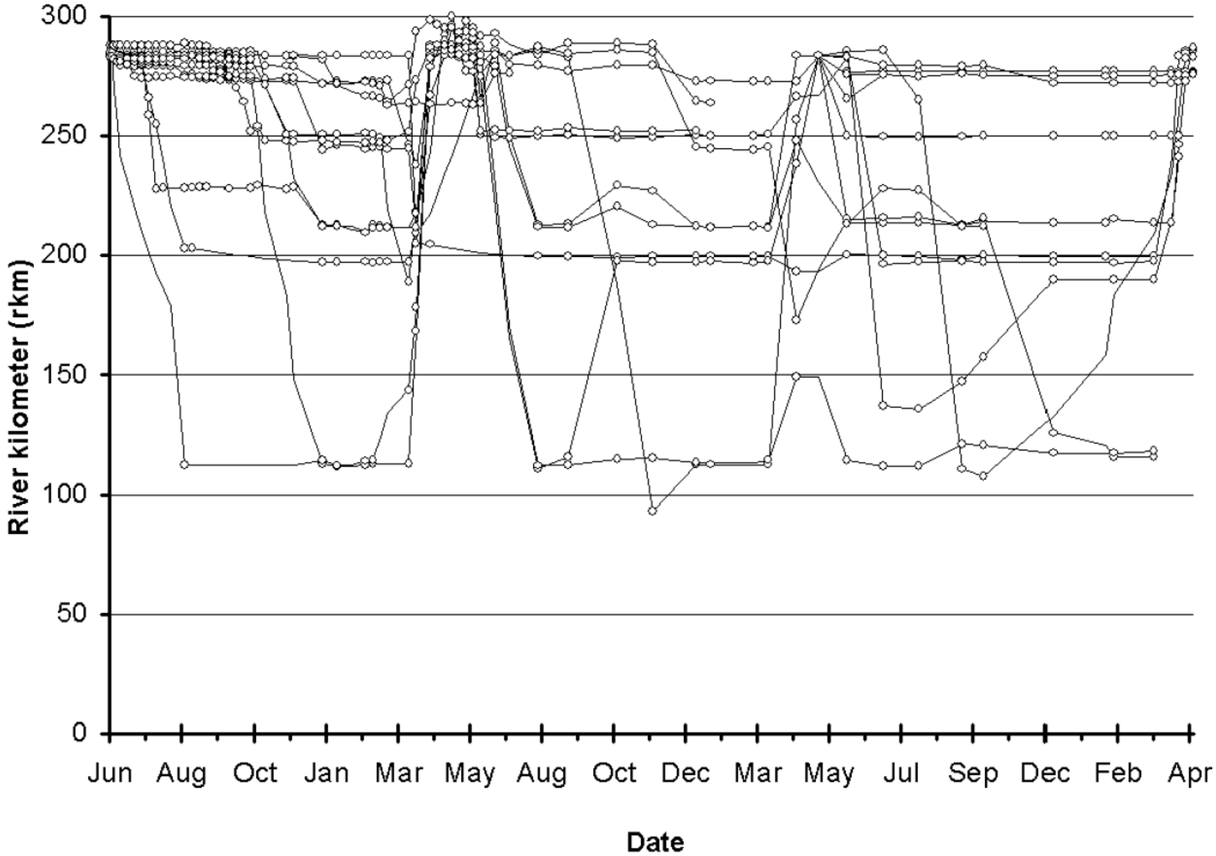

FIGURE 2.—River kilometer (rkm) positions of individual radio-tagged robust redhorses in the lower Savannah River below New Savannah Bluff Lock and Dam from June 2002 to April 2005. The solid lines connecting points indicate the movements of individual fish.

Grabowski and Isely (2007a) studied the spawning aggregations of five species of catostomids (Carpsuckers *Carpiodes sp.*, spotted sucker *Minytrema melanops*, robust redhorse *Moxostoma robustum*, notchlip redhorse *Moxostoma collapsum*, and northern hogsucker *Hypentelium nigricans*) on two mid-channel gravel bars in the Lower Savannah River to assess the extent of spatial and temporal overlap in the use these habitats. They found that these species were segregated based on specific flow, substrate, slope and depth preferences but that temporal and spatial overlap did still occur most likely because the quantity of suitable spawning habitat is low. They found that although robust redhorse was considered the least abundant species it was the least at risk for nest site superimposition because it spawns later in the spring than the other species and appears to be the only species to use the lower gravel bar to spawn.

Grabowski and Isely (2007a):

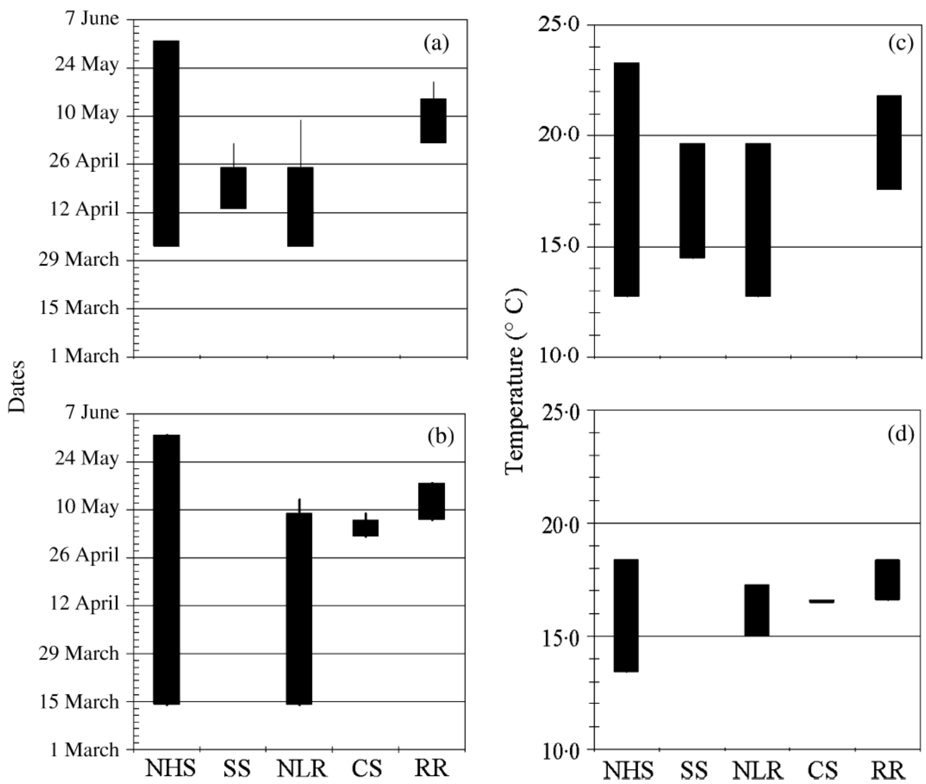

FIG. 3. (a), (b) Dates and (c), (d) temperatures when northern hogsucker (NHS), spotted sucker (SS), notchlip redhorse (NLR), carpsucker (CS) and robust redhorse (RR) were observed on the gravel bars in the lower Savannah River in (a), (c) 2004 and (b), (d) 2005. Vertical lines indicate the latest date larvae of that species were captured.

Grabowski and Isely (2007a):

Table II. Mean ± s.e. depth, velocity and slope, and mean ± s.e. and median substratum particle size of the Savannah River gravel bar locations from which catostomid species were captured or observed in spring 2004 and 2005

Species	n	Mean depth (m)	Mean velocity (m s^{-1})	Mean slope	Mean substratum diameter (mm)	Modal substratum diameter (mm)
Carpiodes sp.	2	1·25	0·63	0·04 ± 0·01	14·8 ± 1·2	5·7, 22·6
Hypentelium nigricans	30	0·74 ± 0·03	0·44 ± 0·03	0·05 ± 0·00	11·9 ± 0·5	11·3
Minytrema melanops	22	1·16 ± 0·03	0·17 ± 0·03	0·03 ± 0·01	9·4 ± 0·7	8·0
Moxostoma collapsum	56	0·98 ± 0·02	0·30 ± 0·03	0·04 ± 0·00	12·2 ± 1·1	16·0
Moxostoma robustum	96	0·74 ± 0·02	0·24 ± 0·01	0·07 ± 0·00	14·3 ± 0·3	32·0

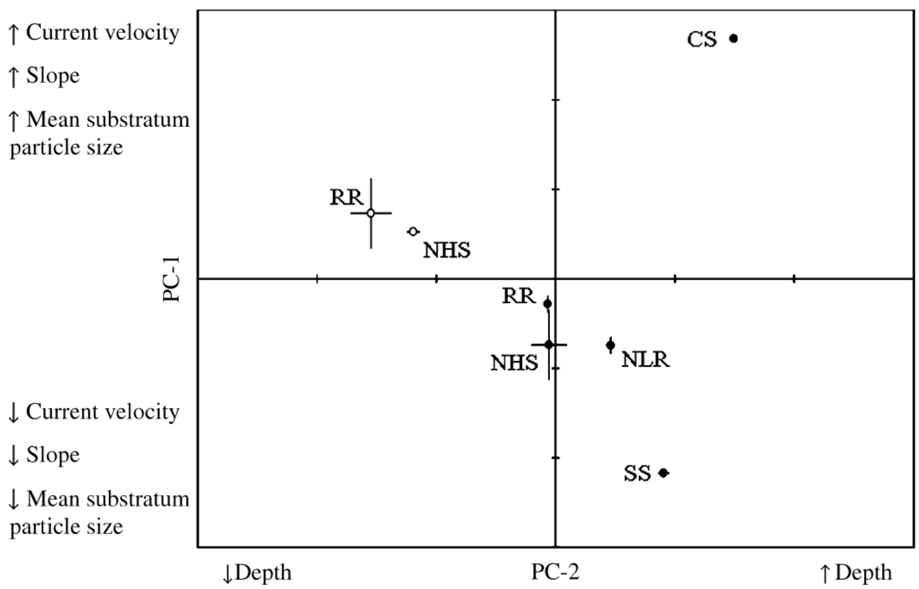

Fig. 4. Principle component analysis for habitat conditions in areas used by spawning notchlip redhorse (NLR), northern hogsucker (NHS), robust redhorse (RR), spotted sucker (SS), and carpsucker (CS) on the upper (●) and lower (○) gravel bars in the lower Savannah River in 2004 and 2005. Current velocity, slope and mean particle size loaded onto the first principle component while depth was the only variable loaded onto second component. Error bars are s.e.

Grabowski and Isely (2007a):

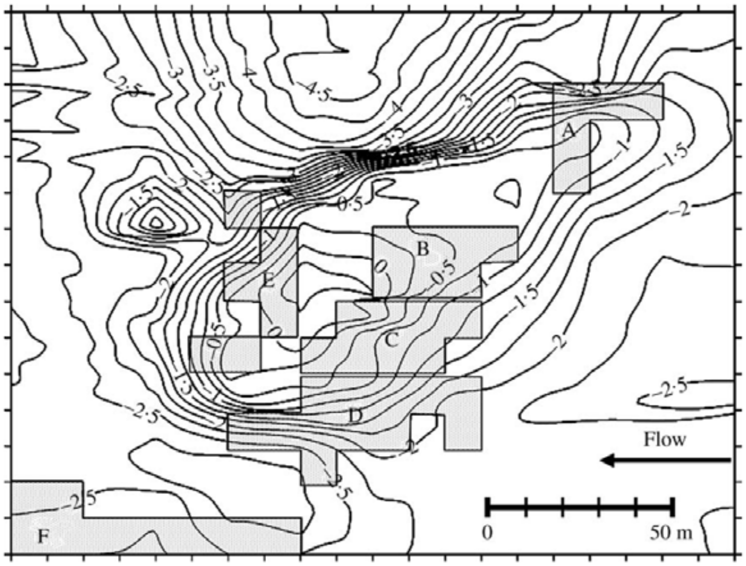

FIG. 1. Bathymetric map of the upper gravel bar at river kilometre 299·4 on the lower Savannah River. Contour lines represent a change in depth of 0·25 m. Depths indicate water depth under low flow conditions (*c.* 85 $m^3 s^{-1}$). The locations where catostomids were observed or captured (zones A–F) are delineated by shaded boxes.

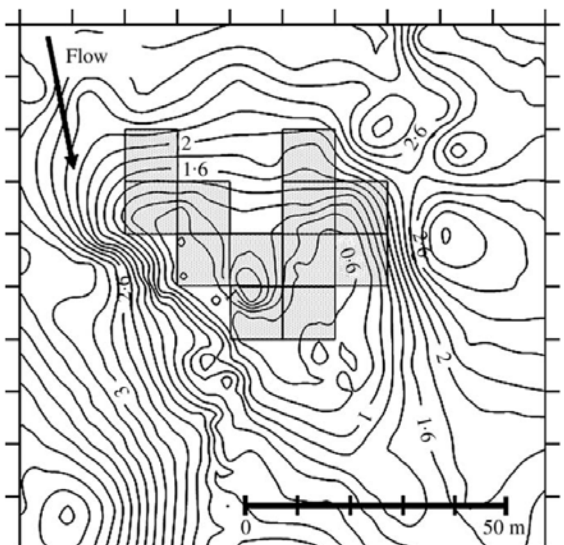

FIG. 2. Bathymetric map of the lower gravel bar at river kilometre 283·7 on the lower Savannah River. Contour lines represent a change in depth of 0·2 m. Depths indicate water depth under average flow conditions (*c.* 200 $m^3 s^{-1}$). The 10 m × 10 m areas in which catostomids were observed or captured are indicated by shaded boxes.

Grabowski and Isely (2007b) conducted a study on the effects of flow fluctuations on robust redhorse (*Moxostoma robustum*) spawning habitat on the lower gravel bar in the Savannah River. This study found that flow fluctuations during the spawning season left 50% of the nest sites on the lower gravel bar either dewatered or with current velocities at or near 0.0 m s^{-1} resulting in deposition of silt and fine sediments. The lower bar was found to be exposed when flows dropped below 200 m^3 s^{-1}(~7,062 cfs). Exposure of nest sites could lead to a decrease in embryo and larvae survival but there is evidence that exposure to zero velocities and siltation could be more perilous. In addition, nest site superimposition as a result of decreased available spawning habitat from exposure of the gravel bar is a concern. Post dam flows were found to drop more quickly than pre-dam and the authors hypothesized that this was an ecological trap which left embryos with less time to develop than before dam construction. REFUTE/SUPPORT: *During dry years, the low flow recommendation for May is 6200cfs, which would result in exposure of the lower gravel bar during spawning (lower bar is exposed when flows <~7062cfs). During average and wet years, the 2003 low flow recommendations for May are 8000 and 13500 cfs, respectively, which should act to keep the lower gravel bar inundated.*

Grabowski and Isely (2007b):

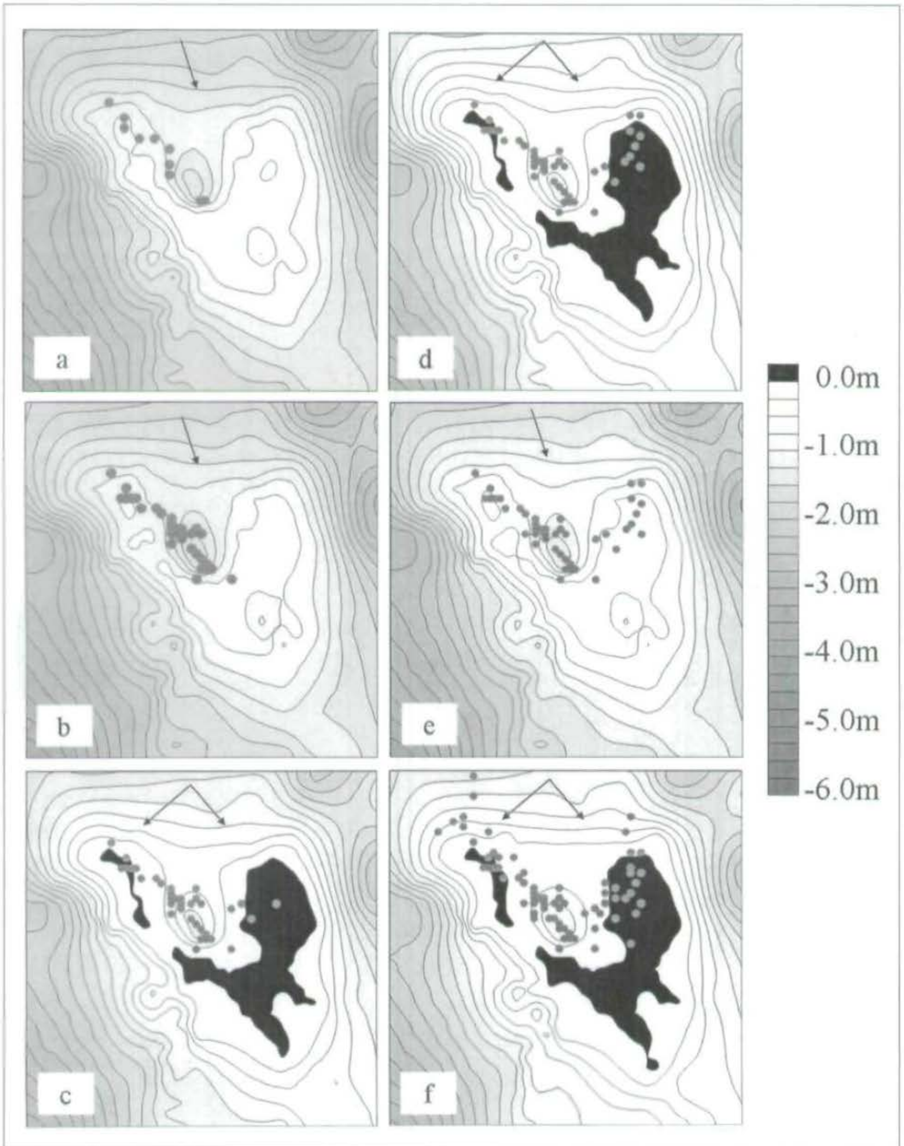

Figure 2. Location of *Moxostoma robustum* (Robust Redhorse) nest sites relative to water levels on the lower gravel bar in the Savannah River during 08 (a), 09 (b), 10 (c), 11 (d), 12 (e), and 16 (f) May, 2005. Black indicates areas that were exposed. Contour lines represent a change in depth of 0.25 m. Arrows indicate the direction of water flow over or around the lower gravel bar.

Grabowski and Isely (2008) monitored the spawning aggregations of robust redhorse (*Mosostoma robustum*) on two mid channel gravel bars in the Savannah River to determine spawning population size and record movements and residence times of individuals within the spawning aggregations. Most individuals were tagged and recaptured on the lower gravel bar with the majority of recaptured individuals being male. Males were present in the spawning aggregations for at least 3-4 days. It was hypothesized that females had such a low recapture rate because they spend much less time in the spawning aggregations than males since they do not establish or maintain territories. They found evidence that males shift the location of their spawning territories daily. This was because the spawning aggregations disbanded each night and reformed each morning and secondly because changing flow levels would force males to change positions. It was also noted that the spawning aggregation on the lower gravel bar lasted for 12 days.

Jennings et al. (2010) conducted an experiment on the effects of fine sediments on robust redhorse survival to emergence (STE). Robust redhorse eggs were exposed to either 0, 25, 50, or 75% fine sediment by volume in the first year of the study. An inverse relationship was found between STE and increasing % fine sediments but the relationship was not linear. A threshold in STE decline was found between 0 and 25% fine sediment. In addition, it was found that mean larval length emerging from the 75% fine sediments treatment group was significantly smaller than the other three treatment groups. The second year of the study focused on achieving a higher resolution on the STE decline threshold and experimental gravel treatments were 0, 5, 10, 15, and 20% fine sediment by volume. Again, an inverse relationship was found between increasing % fine sediments and STE but the relationship was not linear, a threshold in STE was found at 15% fine sediment, where STE began to decline. STE ranged from 69.8% in the 0% fine sediment treatment to 9.1% in the 25% fine sediment treatment. At 20 and 25% fine sediment, STE was significantly lower than treatments with <20% fine sediments. The effect of % fine sediment on dissolved oxygen was also examined. In the first year of the study it was found that the 0 and 25% fine sediment treatment groups had higher mean dissolved oxygen than the 50 and 75% fine sediment treatment groups. There was no significant difference in mean dissolved oxygen between the five treatment groups in the second year of the study. In conclusion, it was predicted that STE of robust redhorse is 8.0% or less when % fine sediments are >25%.

Jennings et al. (2010):

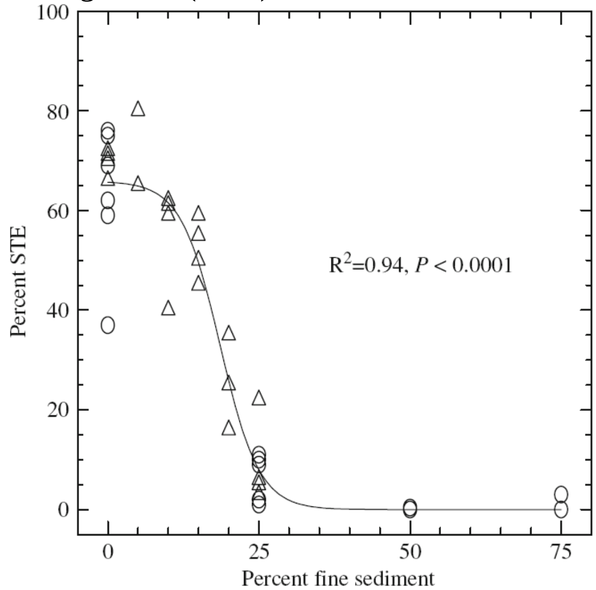

Fig. 3 The affect of increasing levels of fine sediment on survival to emergence of robust. Emergence rates observed in individual replicates during Year 1 are represented by (○) and those observed in individual replicates during Year 2 are represented by (△)

Aquatic Organisms Other than Catostomids

Baily et al. (2004) conducted a study on the diel and seasonal behavior of American Shad (*Alosa sapidissma*) when encountering the New Savannah Bluff Lock and Dam (NSBLD). They studied the within-season movement of American Shad during their spring spawning run, the proportion of the population that passed through the lock, the retention time in the tailrace and estimated the population size of American shad that reached NSBLD. There were two main concentrations of shad found in this study, the first was immediately below the dam and the second was located between RKM 294 and RKM 295. This stretch of river has tight bends and low grade sand banks protected by two current deflecting wing dikes with a deeper main channel and shallower flats than adjacent areas of the river.

They found that movements greater than 0.1km/h were more common at night. In 2001, the proportion of fish moving greater than 0.2 km/d increased with flow while there was no effect of flow in 2002 found on the proportion of fish moving greater than 0.2 km/d. There was no effect of flow found on the diel movement of fish in either year. The decreased proportion of fish that returned to the dam in 2002 than 2001 was attributed to decreased flow from drought that resulted in flows insufficient to attract or retain fish below the dam.

The fish showed great passage efficiency through NSBLD, 50% of the fish that returned to the dam in 2001 and 9% that returned to the dam in 2002, compared to similar studies and considering that the lower gates were open for less than 15h and 20h respectively. This high passage efficiency was said to be promoted by the bottom topography of the river directly below the dam. It is controlled by a mid-channel gravel bar which splits the river flow into two smaller channels, with the larger deeper channel leading directly to the lock entrance. The high passage efficiency was also said to be promoted by the turbulent flows found within 30m below the dam which could cause the fish to repeatedly swim upstream and downstream and was said to increase their chance of encountering the lock entrance.

Martin and Paller (2008) conducted a three year study in 1983 on ichthyoplankton transport in the lower Savannah River. They found that ichthyoplankton and larval recruitment and transport was controlled by timing and duration of pulses and mean spring discharge. Specifically, the best larval recruitment was achieved when a flood pulse occurred in April during the spring peak of spawning and when this flood pulse was most elevated for the longest time. It was also noted in Figure 4 of this paper that a river stage of 27.8 m resulted in extensive inundation of the floodplain.
SUPPORT – *Flood pulses are recommended during April for dry, average, and wet years in the river-floodplain section in April.*

Martin and Paller (2008):

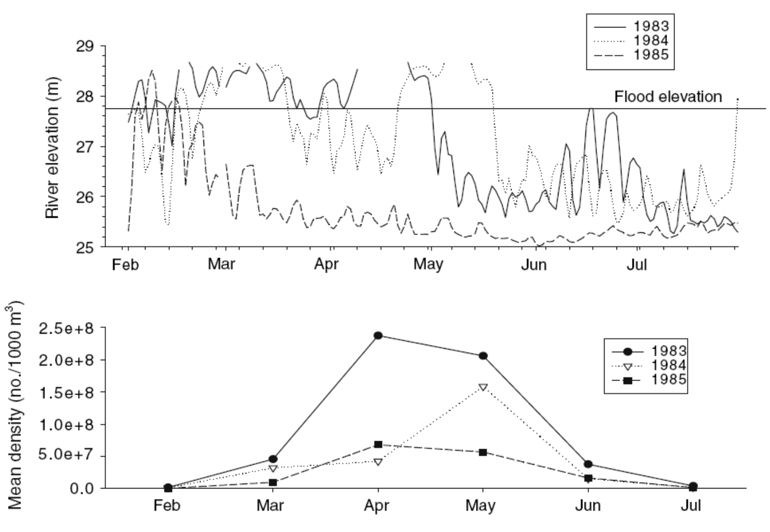

Fig. 4 Water levels and average monthly ichthyoplankton density in the Savannah River. Flood elevation represents the minimum river stage at which extensive inundation of the floodplain swamps occurred

A study by Bright et al. (2010) examined fish and invertebrate communities between three floodplain ecotones of the Savannah and Altamaha Rivers. These ecotones are the river-floodplain, upland-floodplain, and the interior floodplain ecotones which represent the ecotones between the river and floodplain and between the upland and floodplain. The purpose was to determine how water quality, fish abundance and species richness, invertebrate community structure and total invertebrate abundance and biomass varied across the floodplains. They found electrical conductivity to be significantly greater in the river-floodplain ecotone than the interior floodplain or the upland-floodplain ecotone. They did not find unique invertebrate fauna between the three ecotones and attributed this to the temporary nature of backwater swamp hydroperiods. Invertebrate biomass and abundance were found to be highest in the river-floodplain ecotone and smallest in the upland-floodplain ecotone with the floodplain interior ecotone being intermediate. This was attributed to higher conductivity in this area which is related to primary productivity and the period of inundation. The majority of fish were found in areas with the highest connectivity to the river and most of the fish were wetland adapted species. This led to the conclusion that they were not finding channel species that had moved into the floodplain but were finding wetland species that were returning to the floodplain. They also concluded that fish were found in the greatest numbers in areas of high river-floodplain connectivity because these areas contained the greatest abundance and biomass of invertebrate food sources. They did not find dramatic differences between the regulated Savannah River and the unregulated Altamaha River in regards to fish and invertebrates. The authors concluded that because they concentrated in the river-floodplain ecotone, river connectivity was the greatest influence on fish and invertebrate distribution.
SUPPORT: *Floodplain access for fish is recommended in dry, average, and wet years via high flow pulses and floods in wet years.*

Bright et al. (2010):

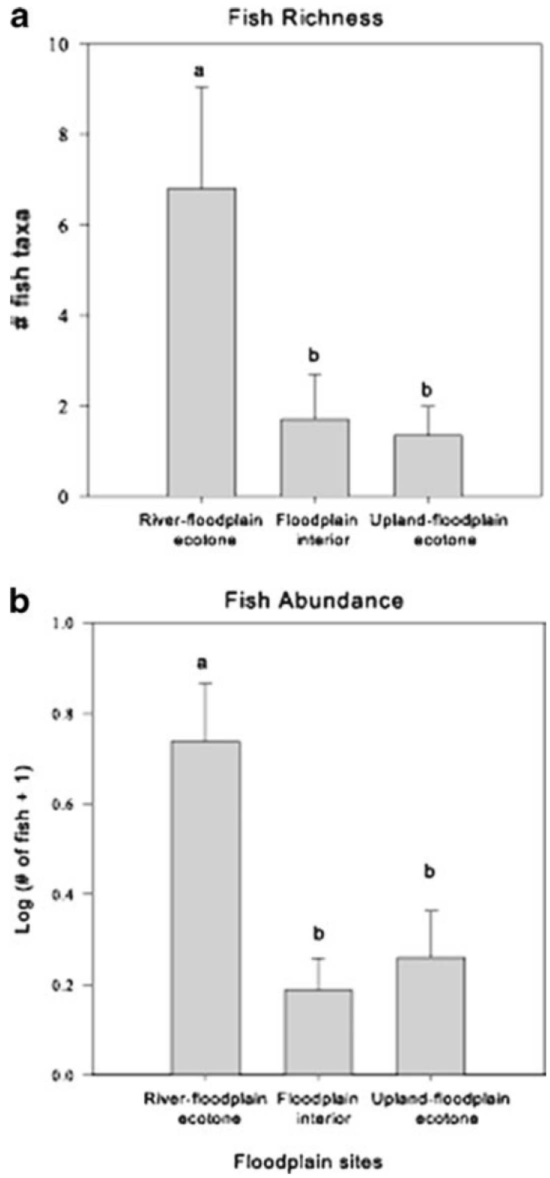

Fig. 7 Variation in **a** fish species richness and **b** fish abundance among the river-floodplain ecotones, the floodplain interiors, and the upland-floodplain ecotones of the Altamaha and Savannah Rivers. Different letters denote significant differences among habitat types (Tukey HSD tests, $p<0.05$). Error bars represent ±1 SE

Bright et al. (2010):

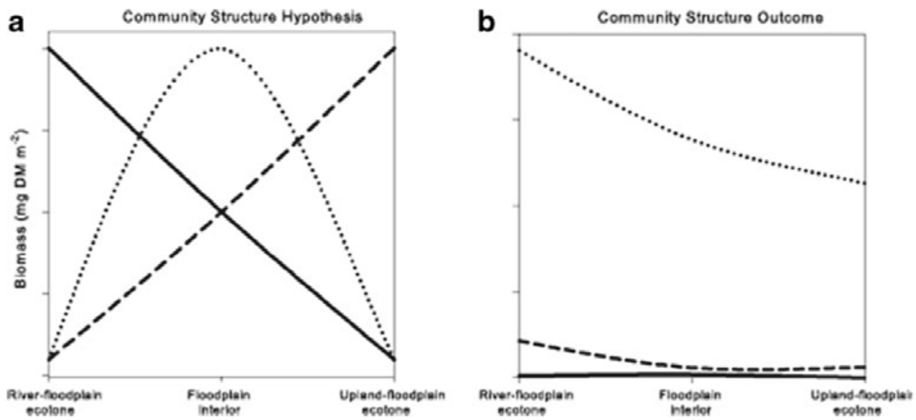

Fig. 8 **a** An idealized depiction of our original hypothesis (adapted from Wissinger 1999) that invertebrate community structure should differ across the floodplain, with lotic riverine organisms (*solid line*) dominating the river-floodplain ecotone, non-aquatic organisms (*dashed line*) dominating the upland-floodplain ecotone, and lentic wetland organisms (*dotted line*) dominating the floodplain interior. **b** A depiction of the outcome of our study based on actual biomass data, which shows that lentic organisms (*dotted line*) dominated all areas (although biomass declined with increasing distance from the channel), non-aquatic organisms (*dashed line*) were prevalent across the entire floodplain (although at low biomass), and lotic organisms (*solid line*) were very rare across the whole floodplain

The microhabitat use and seasonal movements of wild and hatchery-reared shortnose sturgeon (*Acipenser brevirostrum*) in the Savannah River was investigated by Trested et al. (2011). They found that hatchery-reared fish behaved like wild fish and occupied similar microhabitats and sections of river during all four seasons. This indicates that hatchery-reared shortnose sturgeon could be used as substitutes for wild sturgeon in behavioral studies. Both groups moved according to temperature, salinity, and water depth conditions. Wild shortnose sturgeon were captured in the tailrace of the NSBLD during the spawning season and remained in the area for up to 12 days and then migrated rapidly downriver to areas near brackish water. During the low-temperature periods of the winter sturgeon remained in the estuary. Upstream movements in February were at a rate of 9.2 km d^{-1}.

Trested et al. (2011):

Table 2
Seasonal mean (±SE) water temperature (°C), salinity (ppt) and river depth (m) recorded at observed locations for radio-tagged wild, diploid and sterile shortnose sturgeon monitored in the Savannah River, March 2002 to March 2003

	Treatment		
Variable	Wild	Diploid	Sterile
Spring			
Temperature (°C)	21.0 (± 0.1)^{y}	22.5 (± 0.4)^{z}	22.0 (± 0.2)^{z}
Salinity (ppt)	0.5 (± 0.1)^{z}	1.03 (± 0.3)^{z}	0.8 (± 0.2)^{z}
Depth (m)	5.9 (± 0.1)^{y}	6.9 (± 0.4)^{z}	7.4 (± 0.3)^{z}
Summer			
Temperature (°C)	28.6 (± 0.2)^{z}	28.5 (± 0.4)^{z}	28.4 (± 0.3)^{z}
Salinity (ppt)	0.3 (± 0.1)^{z}	0.1 (± .001)^{z}	0.1 (± 0.0)^{z}
Depth (m)	5.7 (± 0.3)^{z}	5.1 (± 0.3)^{z}	6.4 (± 0.6)^{z}
Fall			
Temperature (°C)	23.3 (± 0.4)^{z}	22.4 (± 0.9)^{z}	23.4 (± 0.7)^{z}
Salinity (ppt)	0.8 (± 0.2)^{y}	0.4 (± 0.2)^{yz}	0.1 (± 0.01)^{z}
Depth (m)	7.0 (± 0.4)^{z}	6.9 (± 0.5)^{z}	5.3 (± 0.3)^{y}
Winter			
Temperature (°C)	9.9 (± 0.2)^{z}	9.8 (± 0.2)^{z}	9.7 (± 0.2)^{z}
Salinity (ppt)	3.4 (± 0.4)^{z}	2.9 (± 0.4)^{z}	3.6 (± 0.4)^{z}
Depth (m)	10.0 (± 0.6)^{z}	8.6 (± 0.7)^{z}	9.0 (± 0.7)^{z}

Different letters indicate significant differences among treatments within season.

Pavel et al. (2011) monitored 34 adult shortnose sturgeon within the estuary of the Savannah River. They found that of the Front, Middle, and Back rivers, sturgeon used the Front River more than the other two combined. Fish were found travelling throughout the Front and Middle rivers, but none in the Back River. Fish were documented for the first time moving between the Front and Middle Rivers via man-made channels. The authors suggest that these artificial channels may play an important role in shortnose sturgeon access to estuarine foraging habitat or refugia from hypoxic conditions. The proposed harbor deepening of the Savannah River harbor, which includes alterations of these artificial channels, may limit shortnose sturgeon movement between the Front and Middle Rivers.

Habitat Distribution and Dynamics

Rosenquist et al. (2010) used time-series analysis methods to compare flow dynamics between the regulated Savannah River and the unregulated Altamaha River. Using these methods they found that flow-varying events are more frequent and of shorter duration on the Savannah River in the upper reaches near the impoundments than on the Altamaha. The Savannah River had more small amplitude events and displayed a clustering of flow-varying events with small wavelengths but with a wide range of amplitudes. They noted that the highest amplitudes in the Savannah are of lower wavelength than in the Altamaha. In summary, the Savannah had more flow-varying events and these events had a much shorter duration than the Altamaha.

A study by Dial Cordy and Associates, Inc. (2010) assessed the quantity and quality of shortnose sturgeon habitat (*Acipenser brevirostrum*) below NSBLD and the Augusta Diversion Dam. Between NSBLD and Hwy 301 bathymetric, depth, velocity and benthic substrate data were collected. It was found that cobble/gravel and boulder habitats most associated with shortnose sturgeon spawning comprised less than 1.4% of the study area. The "boulder" habitats consisted mostly of riprap while the "cobble/gravel" habitats occurred in only two locations in the river. These two gravel bars were the only habitats considered suitable or marginally suitable which were not located along the margins of the channel. 127.7 acres out of 2600 acres, or 4.9% of the area, below NSBLD contained benthic coverage considered marginally suitable or suitable habitat. Depths of 1.3-5.7 meters were considered suitable and were well represented in the study area below NSBLD. Suitable substrate sometimes overlapped with less suitable water depths which would decrease the overall suitability of that location for spawning. The average water velocity below NSBLD was 0.59m/s. Current velocities at or near the bottom of the river were also measured as benthic habitats are used by SNS for spawning. Most of the velocities were found to be suitable for spawning (between 0.3 and 1.3 m/s) but it was common for marginally suitable or unsuitable velocities to occur over suitable substrate. Considering depth in addition to benthic substrate, the total suitable or marginally suitable habitat comprises 125-127 acres, only a little less than the 127.7 acres when considering benthic substrate alone. The authors conclude that depth does not limit suitable spawning habitat but that that current velocity may.

Below the Augusta Diversion Dam in the shoals portion of the river only substrate characterization was conducted. Boulders and bedrock dominated the substrate. 40% of the sampling locations contained substrate considered suitable, 37% were marginally suitable, and

33% had unsuitable substrates. While current velocity and bathymetric data were not collected for this portion of the river, it was noted that many portions of this area had very high velocities and were very shallow, especially during low flow conditions, which may decrease the amount of habitat suitable for SNS spawning in this area.

Dial Cordy and Associates, Inc. (2010):

Table 4: Benthic substrate coverage in New Savannah Bluff Lock and Dam to U.S. Highway 301 study area

Class	Benthic substrate	SI[1]	Total Acreage	Percent Coverage
1	Mud, soft clay/fines	0.0	1.0	< 0.1
2	Silt, sand (diameter < 2.0 mm)	0.0	2505.2	95.1
3	Sand, gravel (diameter > 2.0 mm to < 64 mm)	0.5	91.0	3.5
4	Cobble/gravel (diameter > 64 mm to < 250 mm)	1.0	5.4	0.2
5	Boulder/riprap (diameter 250 mm to 4,000 mm)	0.8	31.3	1.2

[1]1.0 indicates highest suitability; 0.0 the lowest.

Table 5: Benthic substrate frequency in Augusta Shoals study area

Class	Benthic substrate	SI[1]	Number of Sites	Frequency (%)
1	Mud, soft clay/fines	0.0	0	0
2	Silt, sand (diameter < 2.0 mm)	0.0	7	12
3	Sand, gravel (diameter > 2.0 mm to < 64 mm)	0.5	0	0
4	Cobble/gravel (diameter > 64 mm to < 250 mm)	1.0	3	5
5	Boulder (diameter 250 mm to 4,000 mm)	0.8	20	35
6	Bedrock w/ fissures w/ gravel/cobble mixtures	0.6	21	37
7	Bedrock smooth w/ few fissures or gravel	0.2	6	11

[1]1.0 indicates highest suitability; 0.0 the lowest.

Jackson and Long (2011) quantified the sediment size distribution of two mid-channel gravel bars in the Savannah River to determine whether particle size distributions were affected by flow variation. This information would be used to decide whether conducting a pulsed release prior to fish spawning to clean the gravel in an effort increase the amount of suitable habitat would be advantageous. They also observed flow dynamics relative to spawning conditions and bedload sediment transport at different flow levels. In addition, interstitial dissolved oxygen concentrations in the spawning areas were measured. During sampling it was found that it was possible to wade on the gravel bars when flows were <6200cfs. Both gravel bars exhibited armoring with a single grain gravel layer overlaying a sand/gravel mix. At flows <7000cfs bedload movement of the gravel-covered areas of the upper bar did not occur. Macrophytic algae were observed growing on the submerged areas of both bars during the summer and fall and it was said that this would increase the flow necessary to create bedload transport on the bars. Both bars had a mixture of medium and coarse sands (30-58% of the sediment at the upper bar and 9-30% at the lower bar) and gravels typically between 8-32mm. Fine sands were only a small portion of the sediment while silts and clays were inconsequential.

There was little difference between the interstitial dissolved oxygen and water column dissolved oxygen which was said to indicate good exchange between river and interstitial water. Drops in water temperature were observed during high spring flow pulses, an effect of hypolimnetic releases from Thurmond Dam. A pulse which peaked on June 4, 2010 created water temperatures below those preferred by spawning robust redhorse. High spring pulses also resulted in increased turbidity, a result of entrainment and mobilization of fine sediments between the dam and the Savannah River at the Augusta gage by low turbidity water released from Thurmond dam. Repeated dewatering on both gravel bars, including common spawning areas as mapped by Grabowski and Isely (2007b), was observed. It was estimated that flows of 6200cfs are necessary to cover the upper gravel bar in 0.3m of water. The authors recommend that a flow of at least 6200cfs be maintained to keep nest sites inundated during robust redhorse spawning and larval development (April 15-June7) with some exceptions during drought years. They note that the current regime often drops below this level during the spawning season while the pre-dam period, except during dry years, would have provided sufficient flows during the this time. The authors concluded that using pulses to clean the gravel bars before spawning would not be beneficial as high flows tended to carry sand from upriver and deposit it on the gravel bar. Instead it is recommend to drop the winter peak flow as early as possible to medium flows which were shown to remove the sand and leave the coarser armoring gravel layer.

SUPPORT/REFUTE: *Jackson and Long observed dewatering of the bars during the Catostomid spawning period (see Grabowski and Isely 2007b). It was recommended that flows of at least 6200 cfs be maintained from April 15 to June 7 during spawning and larval development, which is provided for by the 2003 recommendations. 2003 recommended pulses at the beginning of the spawning period may not be beneficial because they may cause sand deposition on upper gravel bar.*

Jackson and Long (2011):

Figure 11. Single layer of armoring gravel overlying a mix of coarse sands and gravels at the upper bar.

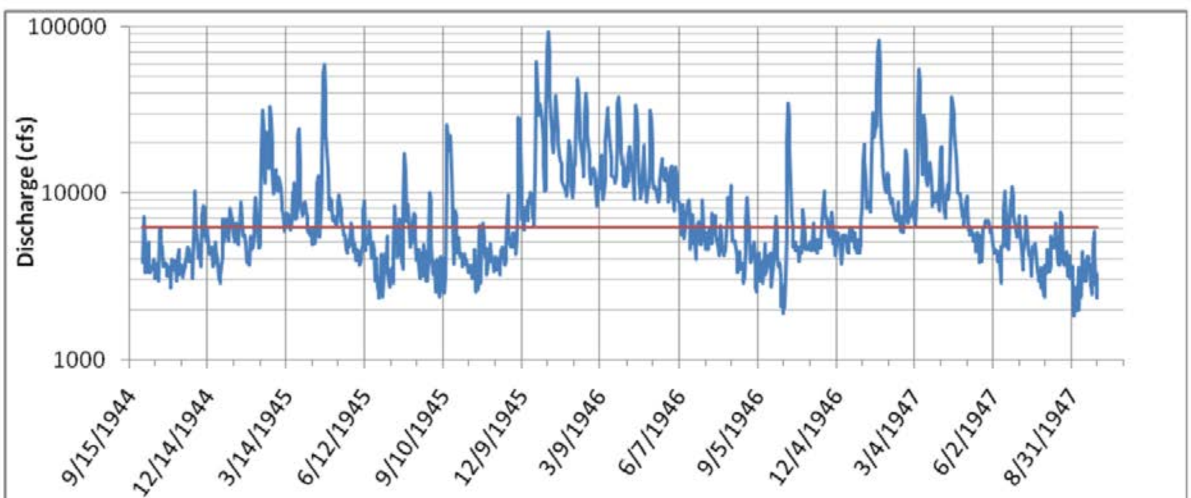

Figure 18. Example pre-dam flows from water years 1945-1947 with the recommended minimum spawning and larval development period (April 15 – approximately June 7) minimum flow of 6200 cfs shown in red.

Estuarine Water Quality and Habitat

Conrads et al. (2006) developed a Model-to-Marsh Decision Support System (M2MDSS) for the Lower Savannah River Estuary to help managers evaluate the potential effects of salinity intrusion. This model is used in a study by Conrads and Greenfield (2010) along with the Environmental Fluid Dynamic Code (EFDC) to simulate the effects of reduced flows on salinity intrusion on the Lower Savannah River Estuary. Both models showed an increase in the magnitude and duration of salinity intrusion when flow is reduced. To test a potential mitigation approach to counteract salinity intrusion, seven-day stream flow pulses of 4500ft^3/s were inserted into the M2MDSS model. The results of these pulses show a substantial decrease in the magnitude and duration of salinity intrusion. It is recommended that these releases should be timed to have the maximum effect, during the spring tide of the new moon, and it is suggested that this approach could also be used to counteract salinity intrusion as a result of climate change and harbor deepening.

Conrads et al. (2006):

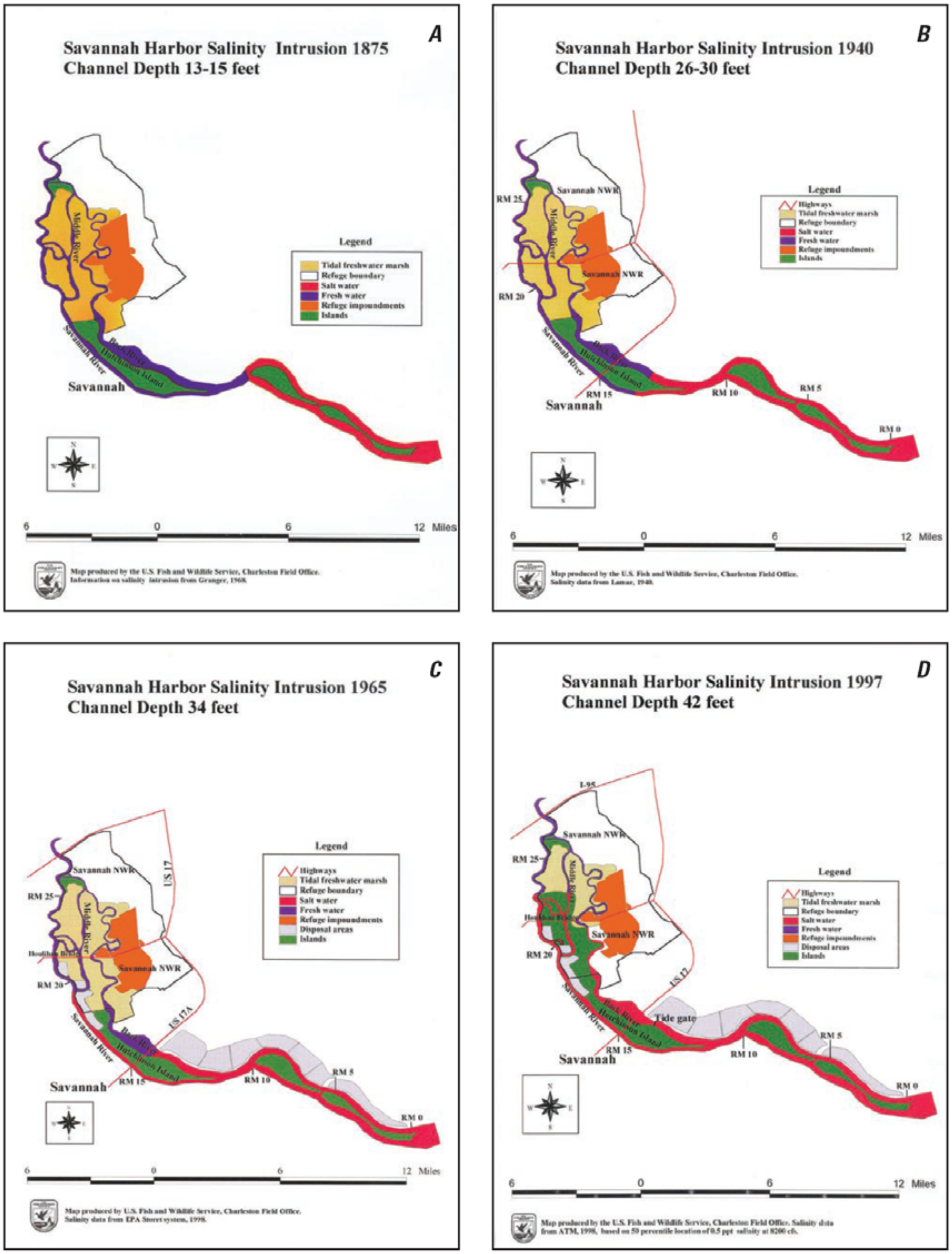

Figure 4. Location of the saltwater and freshwater interface for four channel depths: (*A*) 13–15 feet in 1875; (*B*) 26–30 feet in 1940; (*C*) 34 feet in 1965; and (*D*) 42 feet in 1997. Maps produced by the U.S. Fish and Wildlife Service, Charleston Field Office. Data references include: (*A*) Granger (1968); (*B*) Lamar (1942); (*C*) U.S. Environmental Protection Agency, STORET Database, 1998 (*http://www.epa.gov/STORET/*); and (*D*) Applied Technology and Management, 1998.

Conrads and Greenfield (2010):

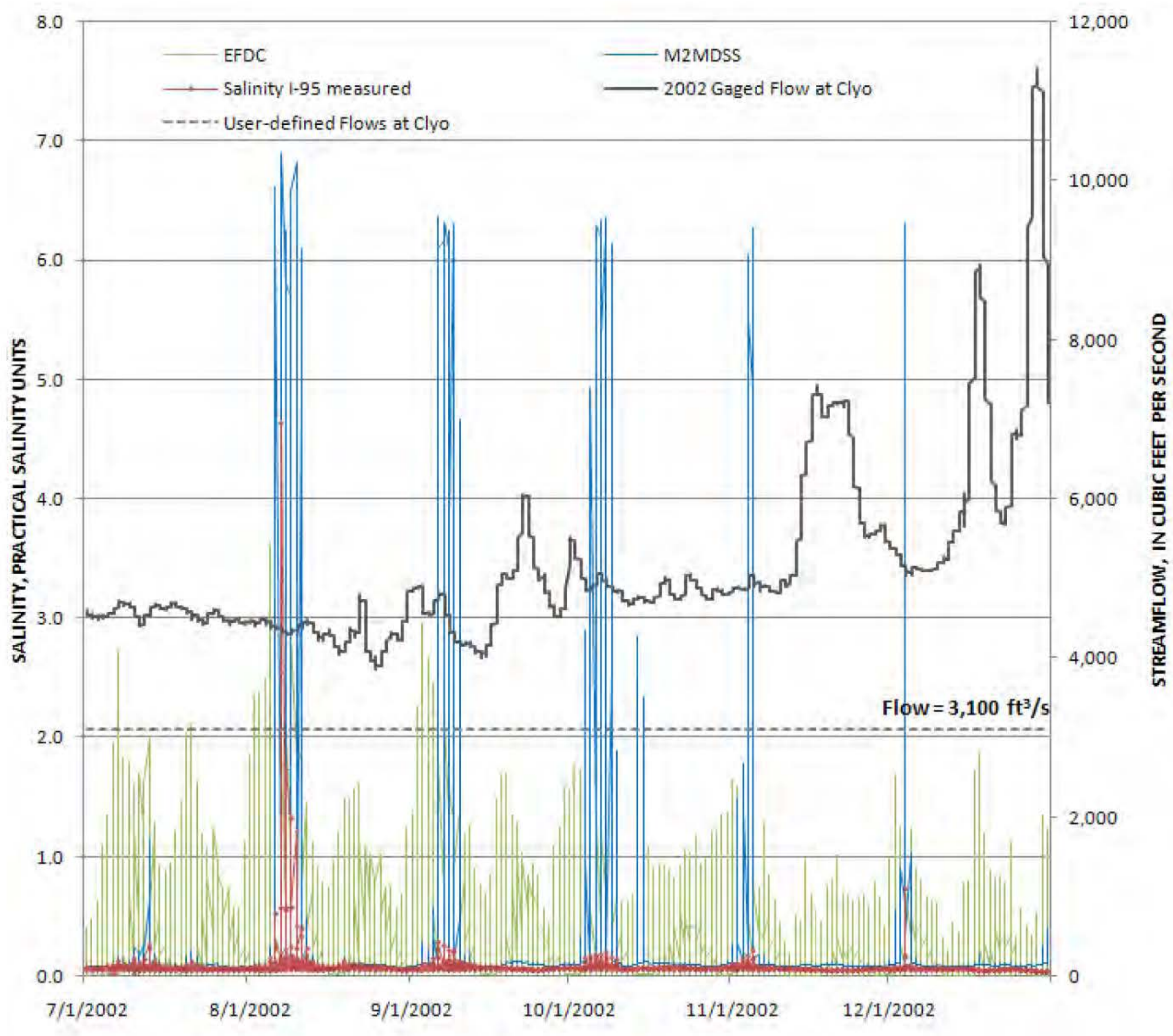

Figure 5. Hourly salinity response at I-95 to a user defined constant flow of 3,100 ft^3/s.

Conrads and Greenfield (2010):

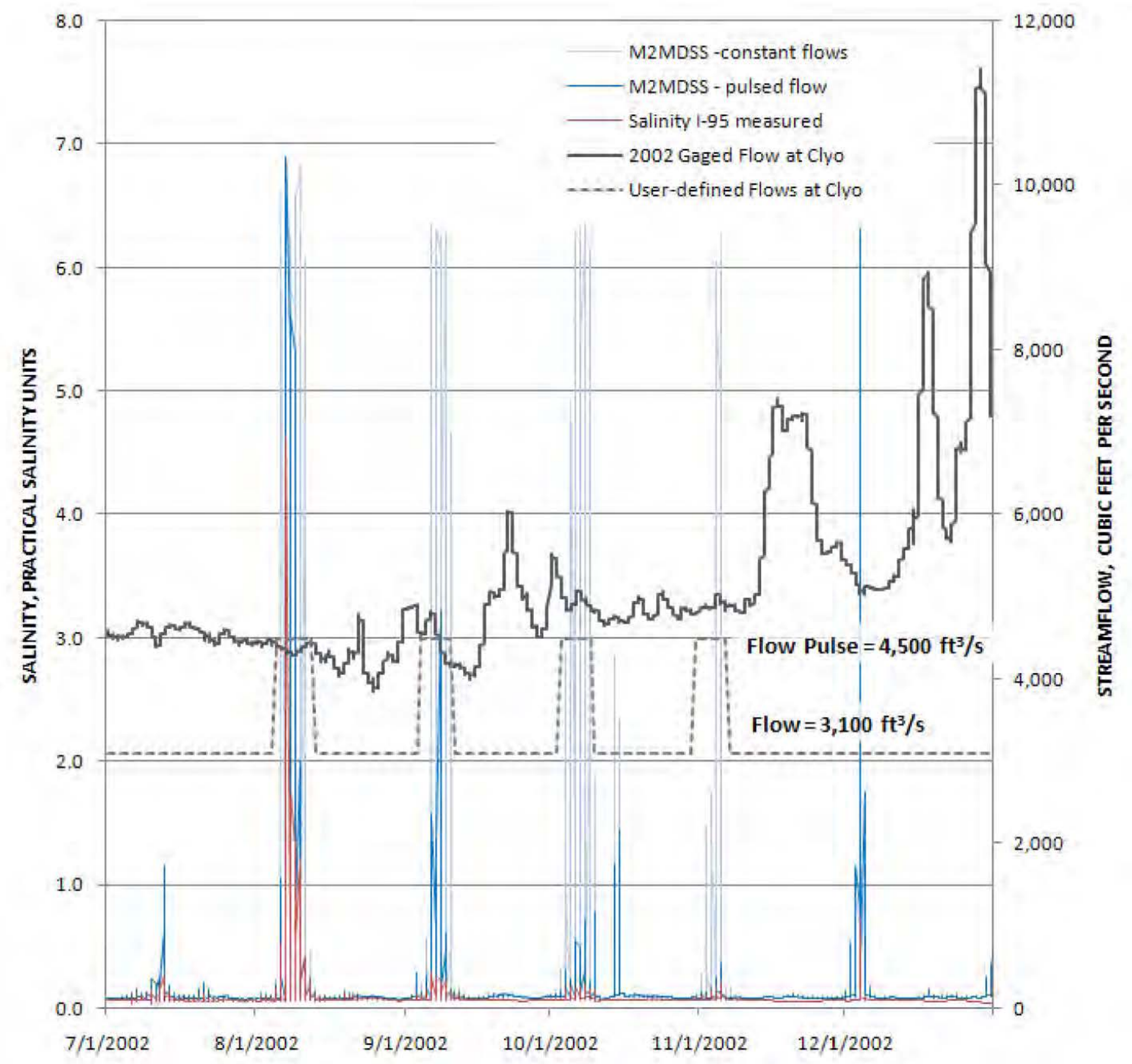

Figure 6. Hourly salinity response at I-95 to user defined hydrograph with streamflow pulsed inserted to minimize salinity intrusion.

Conrads et al. (2010a) conducted a study to evaluate the effect of climate change on salinity intrusion in the lower Savannah River estuary using artificial neural network (ANN) models. This was done in an effort to provide managers with the means to plan for mitigation efforts to minimize these effects. It was found that sea-level rise by 1 and 2 feet would increase the duration of salinity intrusion and shift the portion of the estuary below I-95 during low flow conditions from a tidal freshwater system to an oligohaline system. The authors recommended that managers mitigate these effects by timing withdrawals to occur during outgoing tides, increasing the storage of raw (untreated) water and timing the larger releases of regulated flows to facilitate moving the saltwater-freshwater interface downstream.

Conrads et al. (2010a):

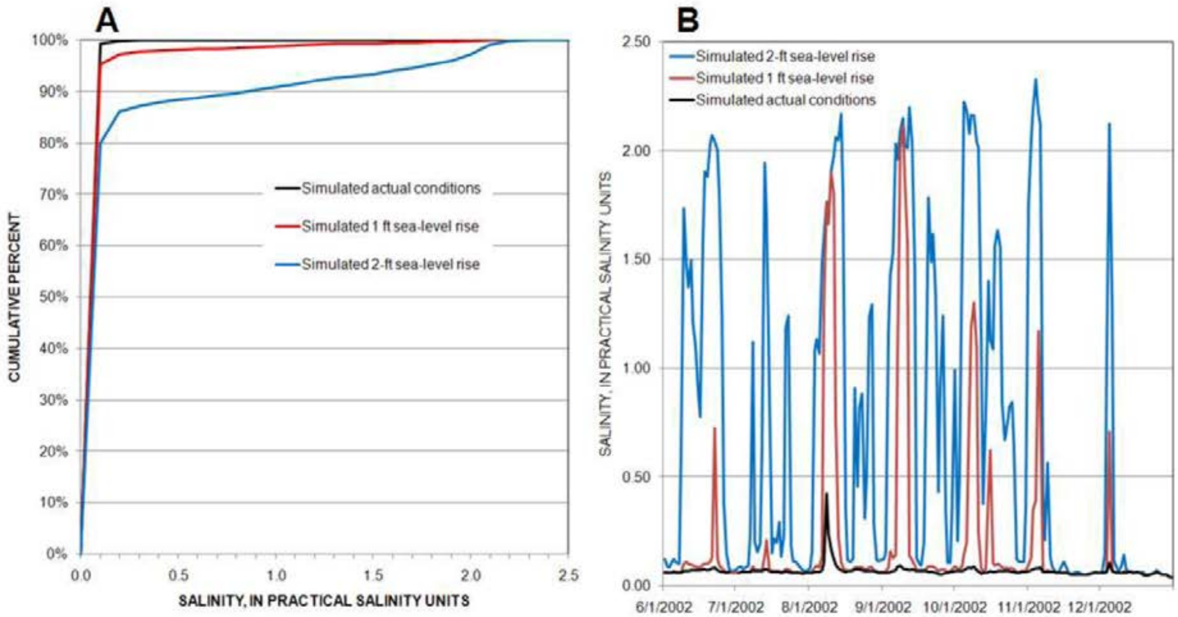

Figure 5. Salinity response to a 1-ft and 2-ft sea-level rise. Plot on the left (A) shows the cumulative frequency distribution for a 7½ year simulation. Plot on the right (B) shows the time series for the daily response during 2002.

Reinert and Peterson (2008) developed models to investigate the effects of potential shifts in the salinity regime on striped bass (*Morone saxatilis*). They found that as salinity increases in a system and as the salinity shift progresses upriver, egg and larval survival decreases. Upstream salinity shifts >1.67km would have progressively larger impacts on striped bass early life history survival and a 8.33km shift would decrease the estimated early life history survival probability (ELHS) by >28%.

Reinert and Peterson (2008):

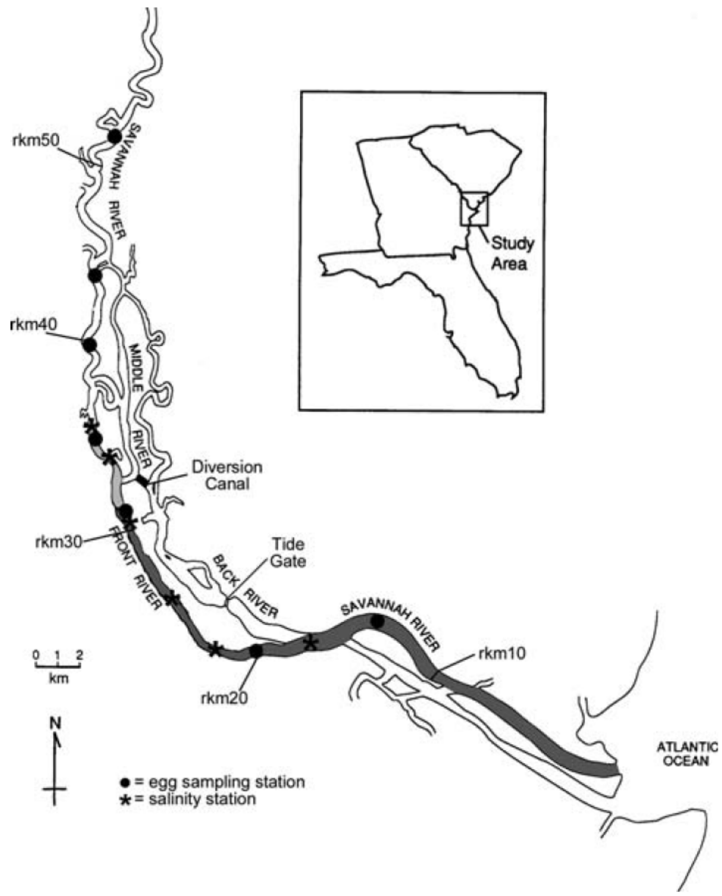

Fig. 1 Map of the Savannah River estuary, Georgia–South Carolina, showing the maintained river channel (harbor), tide gate, and diversion canal (filled). *Salinity-measurement stations. •Egg-sampling stations. Dark grey channel depth is 12.8 m MLW, and light grey channel depth is 11.6 m MLW. Proposed deepening will occur along the current 12.8 m channel. MLW = mean low water

Reinert and Peterson (2008):

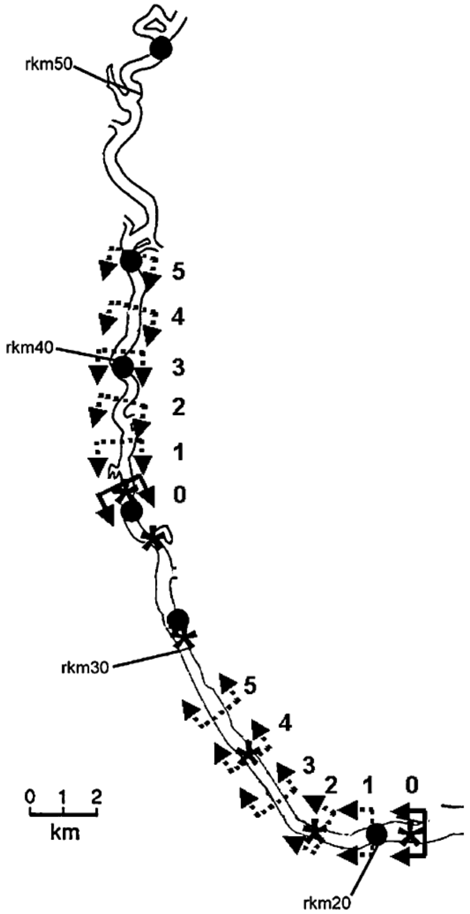

Fig. 4 Map of the Front River portion of the Savannah River estuary with graphic representation of modeled salinity shifts. Baseline salinity conditions specific to discharge and tidal phase were modeled in the area depicted between solid arrow brackets and denoted by "0." Progressive 1.67-km upstream shifts in the modeled salinity distribution are denoted by dashed-arrow brackets and labeled 1 through 5. *Salinity-measurement stations. •Egg-sampling stations

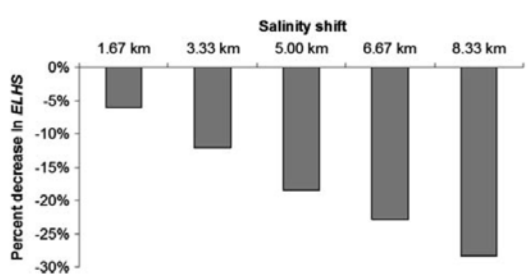

Fig. 6 Estimated relative change in striped bass ELHS for 1.67-km upstream shifts in the prevailing salinity conditions in the Savannah River estuary. Percentage decreases are relative to unchanged salinity

A study by Duberstein and Conner (2009) in tidal freshwater wetlands in the Savannah River investigated the degree to which trees utilized hummocks or hollows at three scales: landscape (bacskswamp vs. streamside), tree community, and species (within community). They found that hummocks were more prevalent in the backswamp setting and their role may be more important in this setting because trees in the backswamp setting used hummocks more than trees in the streamside setting. This is hypothesized to be caused by innate differences in hydrology. At the community scale it was found that hummocks are used more often than hollows and that certain tree communities will use hummocks when they are available but do not necessarily need them for survival. The authors concluded that hummocks are an important part of some forested wetlands because they provide refuge for seedlings that are sensitive to prolonged standing water and protection from erosion and floating or falling debris.

Duberstein and Conner (2009):

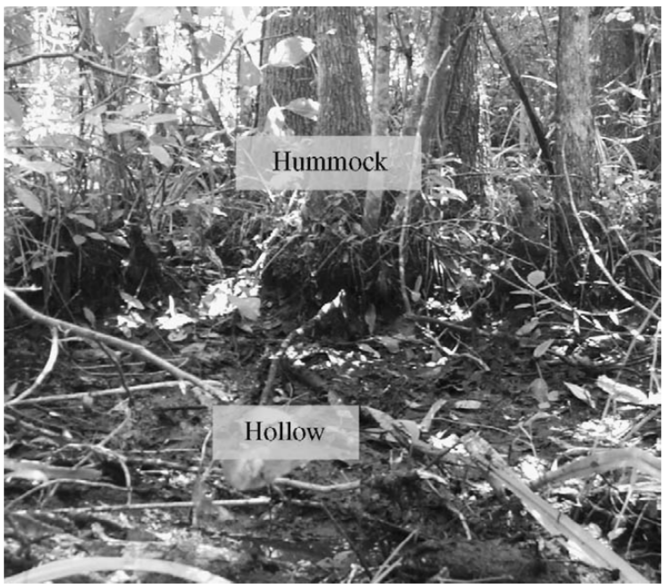

Fig. 1. Typical hummock and hollow microtopography found in the backswamp study area of the Savannah River tidal freshwater forests. This microtopography is also found in the streamside study area, though less pronounced.

Water Chemistry Issues

A study by Paller et al. (2004) found higher average methylmercury levels in the mouths of tributaries to the Savannah River than in the Savannah River itself. There was no significant difference found in total mercury between the tributaries and the Savannah River. It was hypothesized that methylmercury levels were higher in the tributaries because the tributaries drained wetlands where methylation of atmospheric mercury to methylmercury would be encouraged. It was subsequently found that mercury concentrations were higher in Asiatic Clams (*Corbicula fluminea*) which were collected in tributary outlets than those collected above these outlets. It was concluded that tributaries draining wetlands along the Savannah River provide a localized source of elevated levels of methylmercury in the stream biota.

Paller et al. (2004):

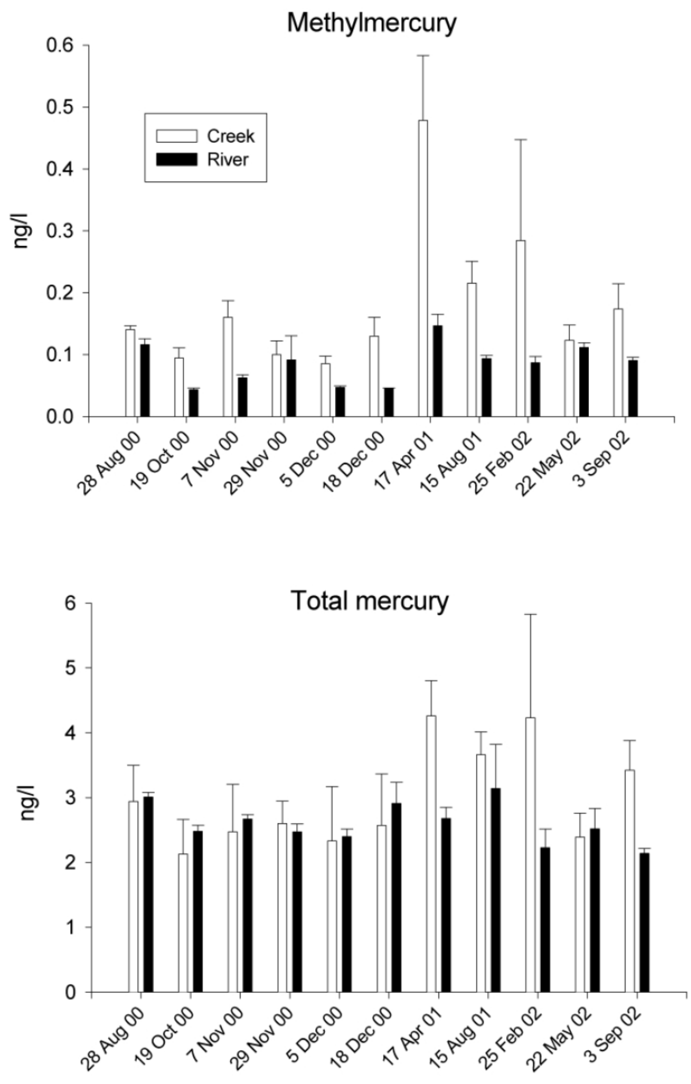

Fig. 2. Average aqueous methylmercury and total mercury levels for five Savannah River locations and five SRS Savannah River tributary creeks on 11 sample dates. Error bars represent standard errors.

Paller et al. (2004):

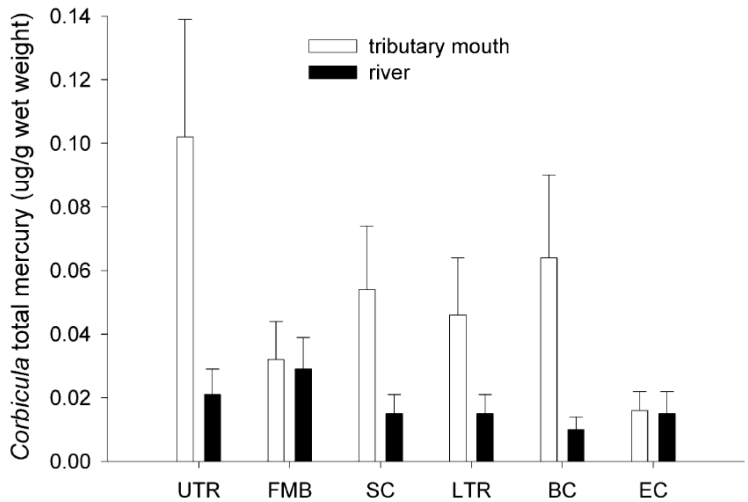

Fig. 5. Geometric mean mercury levels in *C. fluminea* collected from six Savannah River tributaries (Upper Three Runs, UTR; Fourmile Branch, FMB; Steel Creek, SC; Lower Three Runs, LTR; Brier Creek, BC; Ebenezer Creek, EC) and six Savannah River sites located just upstream from each tributary. Error bars represent 95% confidence intervals.

Paller and Littrell (2007) conducted a study on the long term changes of mercury concentrations in fish of the middle Savannah River. They found that total mercury concentrations were higher in largemouth bass (*Micropterus salmoides*) but that the temporal trend was similar between this species and other taxa (sunfish *Lepomis spp,* and catfish *Ameiurus spp.* and *Ictalurus punctatus*) with a general decline in mercury levels over a ten year period concurrent with a reduction in point source pollution. Tributaries have been found to be a source of methylmercury and it was found in this study that fish in tributaries had higher levels of mercury. It was also found that the mercury levels in fish were affected by river discharge. A sharp decrease in mercury in fish coincided with a drought which reduced inputs from and fish access to tributaries. It was suggested that moderate flows could create the greatest mercury levels in fish because it allows fish access to tributaries where high methylmercury levels may occur but offers limited dilution of methylmercury.

Paller and Littrell (2007):

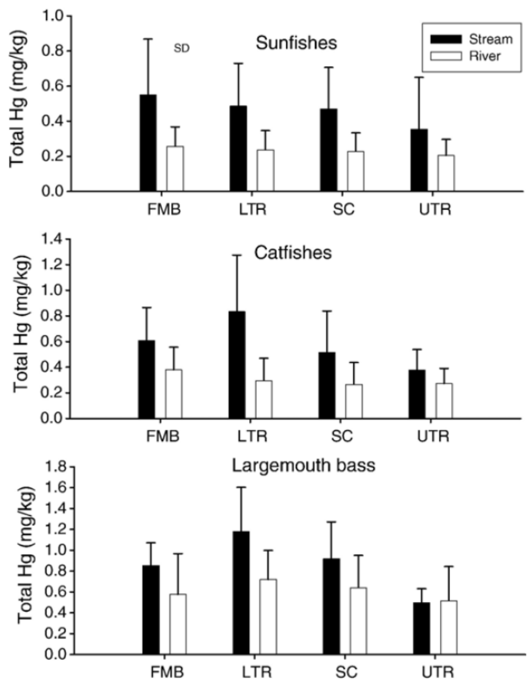

Fig. 3. Total mercury in fish from the Savannah River and four Savannah River tributary streams.

Paller and Littrell (2007):

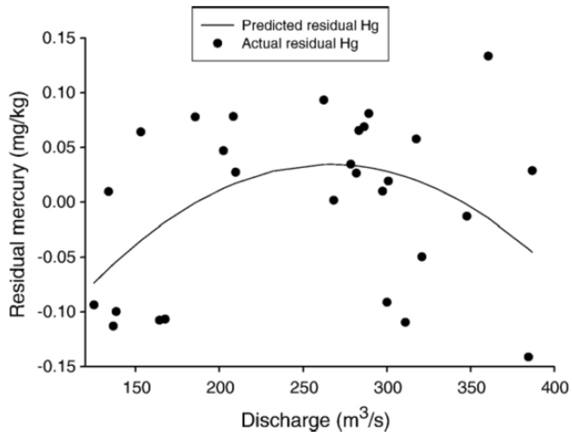

Fig. 5. Relationship between Savannah River discharge and residual variation in sunfish tissue mercury levels after statistical removal of variance associated with year.

A two year study by the Southeastern Natural Sciences Academy (SNSA 2008 and Moak et al. 2010) in the Savannah River Basin was conducted on the effects of the urban corridor of the Central Savannah River Area (CSRA) on water quality. The Augusta urban corridor begins near the fall line, RM 208, immediately below Thurmond Dam and extends to RM 179. Based on macroinvertebrate data, water quality was found to increase with distance downstream from the Augusta urban corridor. Specifically, with decreasing river mile, light attenuation increased as did conductivity, temperature, dissolved oxygen, organic carbon and EPT taxa. After RM 202, pH decreased with increasing river mile. The authors attribute the general trend of increasing water quality with distance downstream to the poor quality initial water source into the Savannah River, the hypolimnion of Thurmond Lake. The carbon content of this water and therefore the upper reaches of the Savannah River are said to be poor and recalcitrant. The authors conclude that the chain of lakes upstream of CRSA exacerbate this effect by removing virtually all particulate organic carbon, leaving clean but barren water to feed the Savannah River. Macroinvertebrate data collected in this study support this conclusion. Their densities increased near and within tributaries, EPT taxa increased with decreasing river mile, and top macroinvertebrate predators did not appear until reaches were floodplain-influenced. This was said to be because floodplain interaction and surface water inputs draining watersheds supply nutrients and other allochthonous materials. This indicates a trend in increasing organic carbon quality and water quality from downstream of Thurmond Dam to RM 61 with the free flowing floodplain-influenced portion of the river having the highest quality.

An artificial pulse in 2006 which consisted almost entirely of releases from Thurmond Dam and a natural pulse in 2007 which consisted almost entirely of watershed drainage below Thurmond Dam occurred in the same month and were of the same magnitude in terms of discharge. These pulses resulted in very different fluxes of material and, with the exception of sodium, chloride, and alkalinity, the 2007 flood had much larger fluxes of material particularly of iron and manganese and the only mainstem BOD_5 (five-day biochemical oxygen demand) detections for the entire study.

The authors compared the dynamics of DO and specific conductance at RM 148 with floodplain inundation for the 2006 and 2007 pulses. They found that as the river rose to overbank height DO rose and then decreased with floodplain inundation then as the river stage began to fall and water drained off the floodplain and back into the river DO increased again. Specific conductance data showed that the flood pulse diluted the water initially but as the floodplain drained back into the river specific conductance rose again. Spikes occurred in the troughs of the descending limb of the flood pulse, indicating entrainment of floodplain material into the river.

The authors noted that floodplain inundation occurred at USGS gauge 021973269 near Plant Vogtle at ~16.5 ft or ~17,200 cfs, at USGS gauge 02197500 near RM 119 at ~11.50 ft or ~14,000 cfs, and at USGS gauge 02198500 near RM 61 at ~9.00 ft or ~11,700 cfs.

SUPPORT: *Based on the data collected in this study, the 2003 high flow pulse recommendations should be of high enough magnitude to inundate the floodplain as was shown to be beneficial in this study.*

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SNSA (2008):

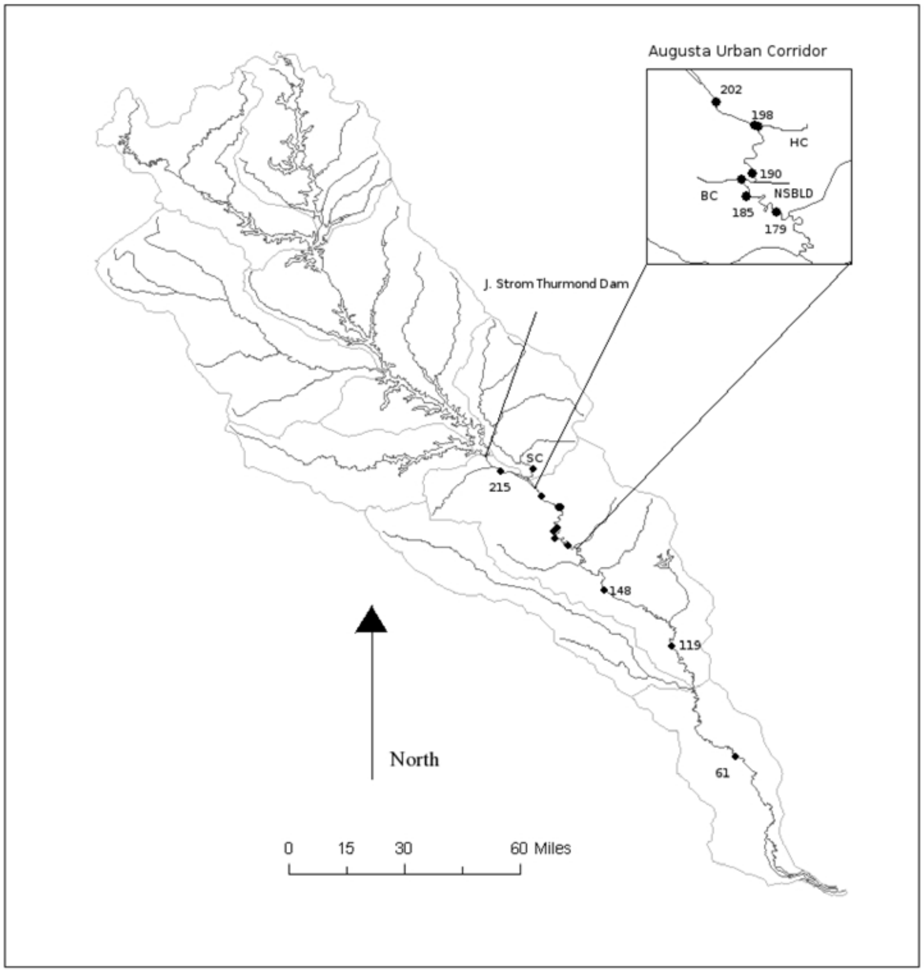

Figure 1-1. Savannah River Basin Map

SNSA (2008):

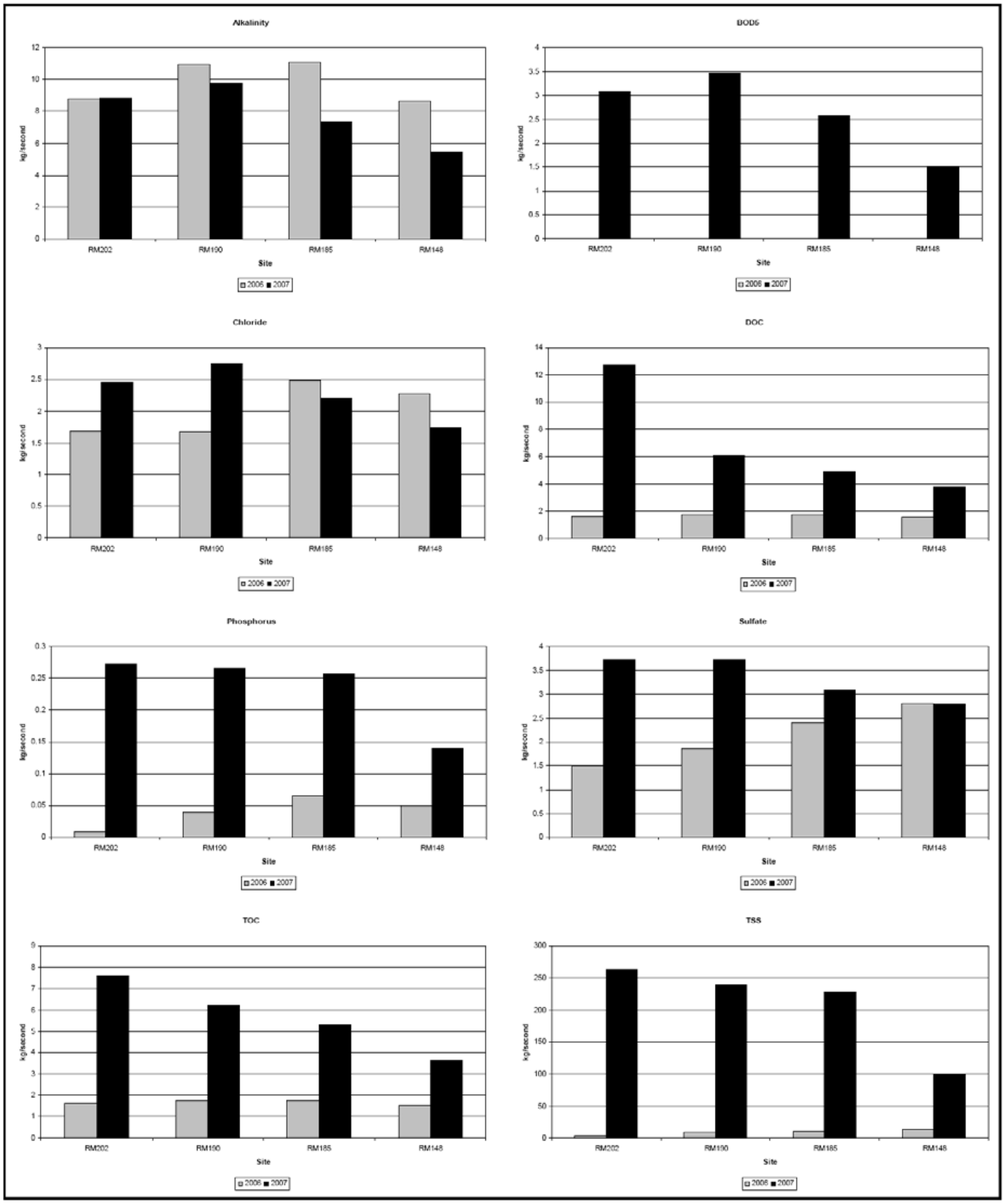

Figure 3-33. Mass flux comparison of March 2006 and 2007 flood events

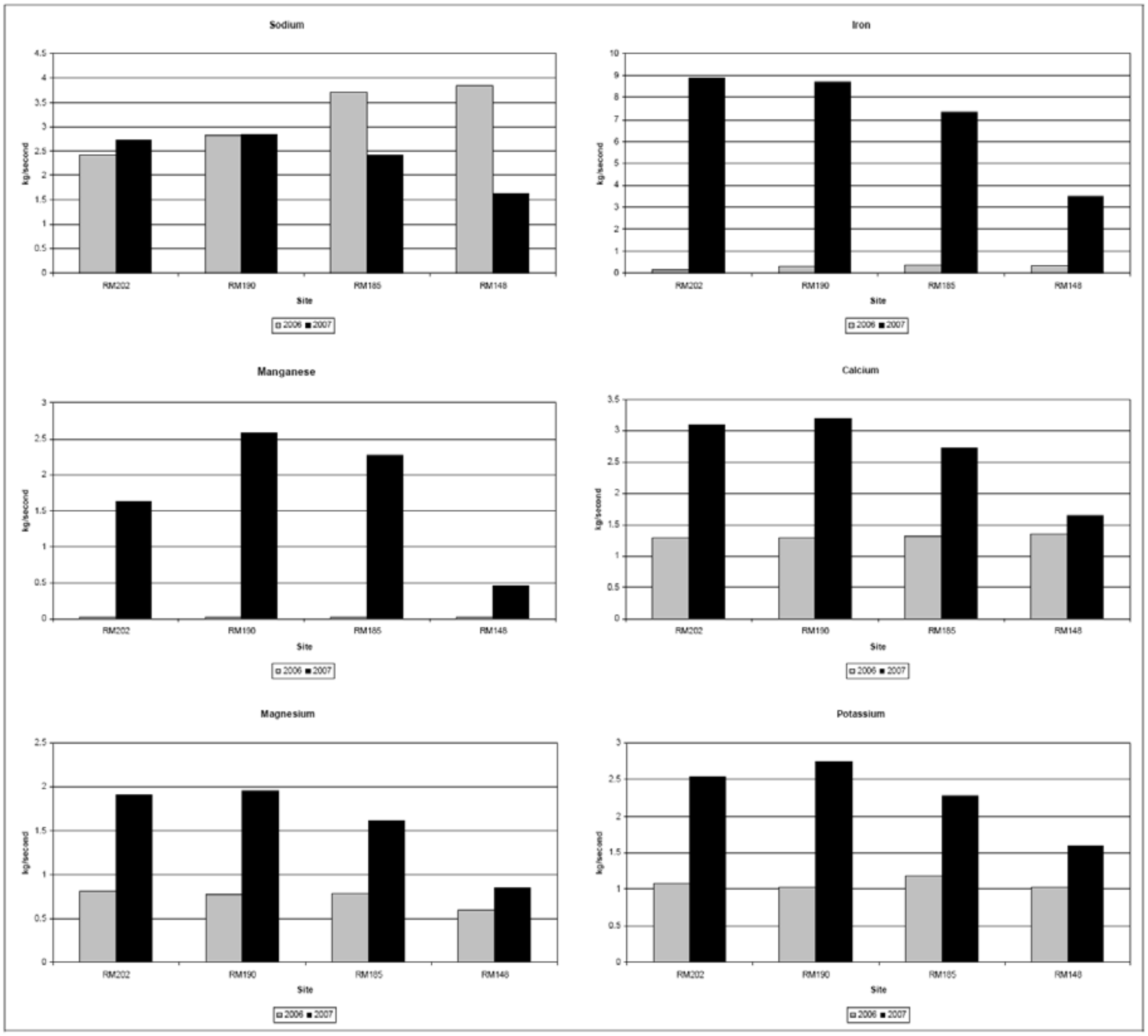

Figure 3-33 (continued). Mass flux comparison of March 2006 and 2007 flood events

SNSA (2008):

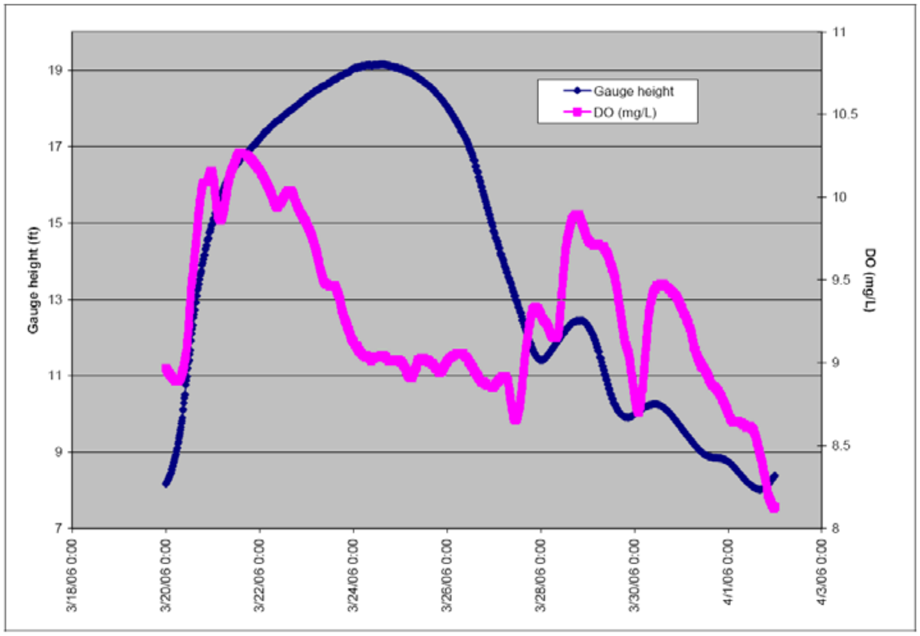

Figure 3-38. Discharge and dissolved oxygen at RM 148 during the 2006 spring pulse.

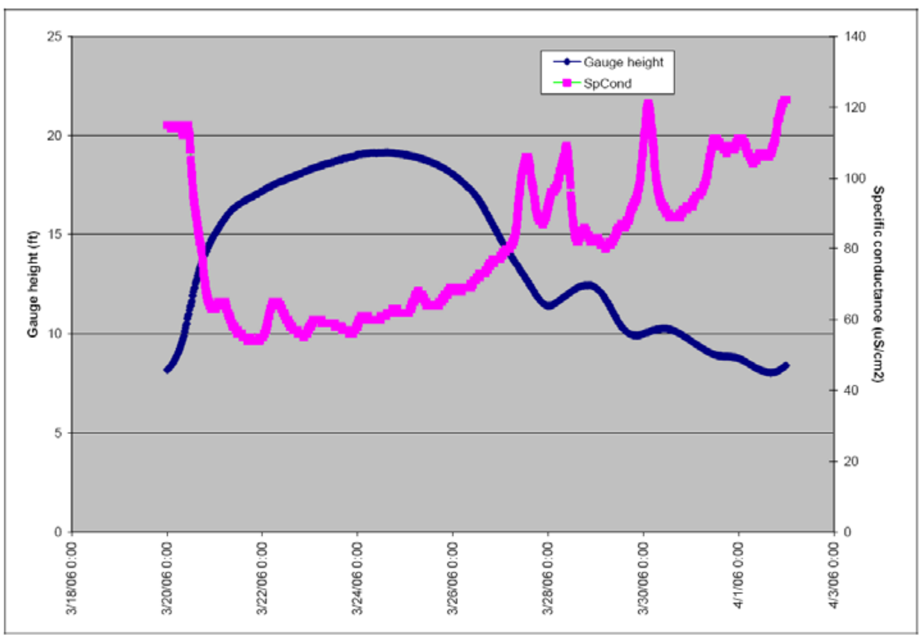

Figure 3-39. Effect of floodplain inundation on specific conductance at RM 148 during the 2006 flood pulse.

SNSA (2008):

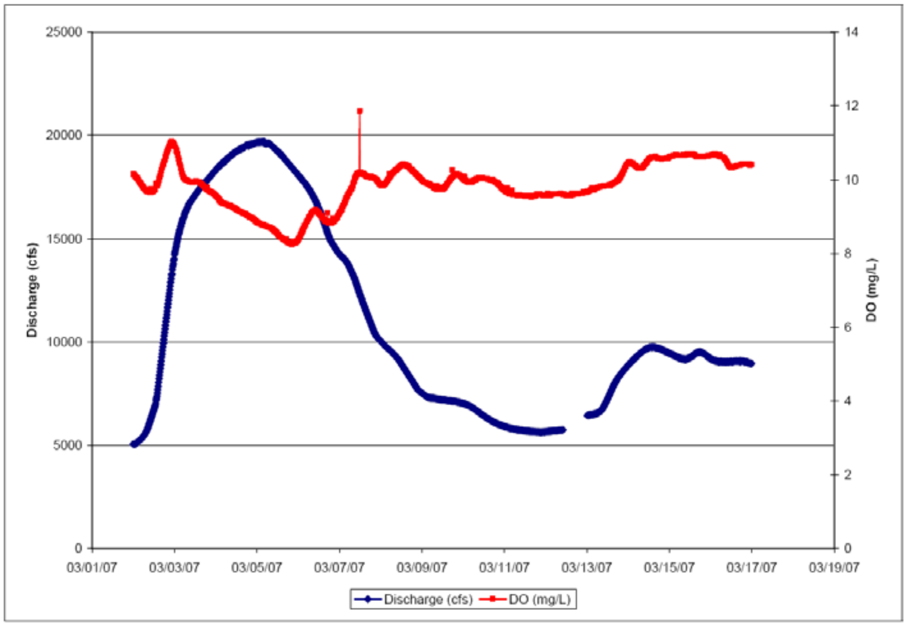

Figure 3-40. Effect of floodplain inundation on dissolved oxygen at RM 148 during the March 2007 flood pulse.

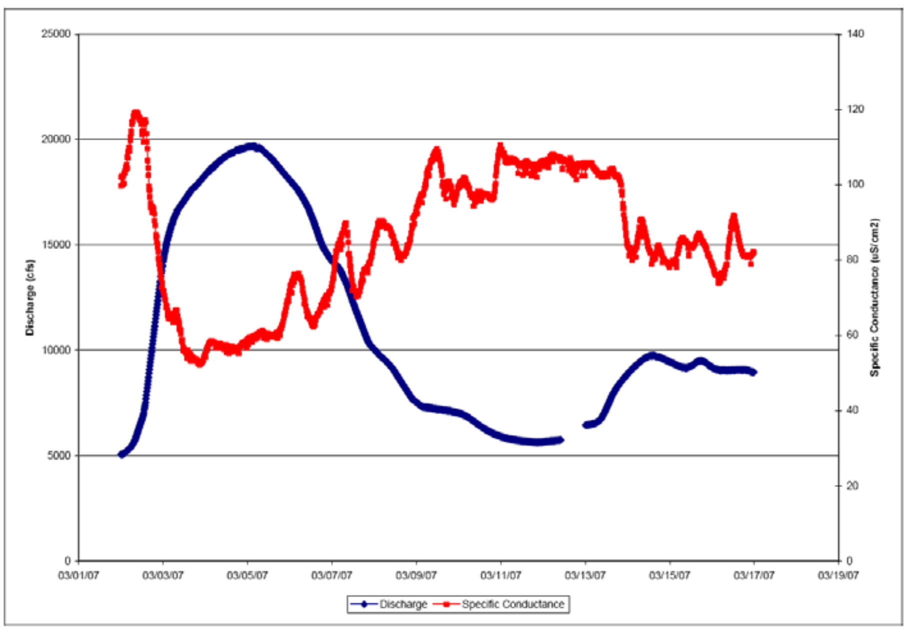

Figure 3-41. Effect of floodplain inundation on specific conductance at RM 148 during the March 2007 flood pulse.

Moak et al. (2010):

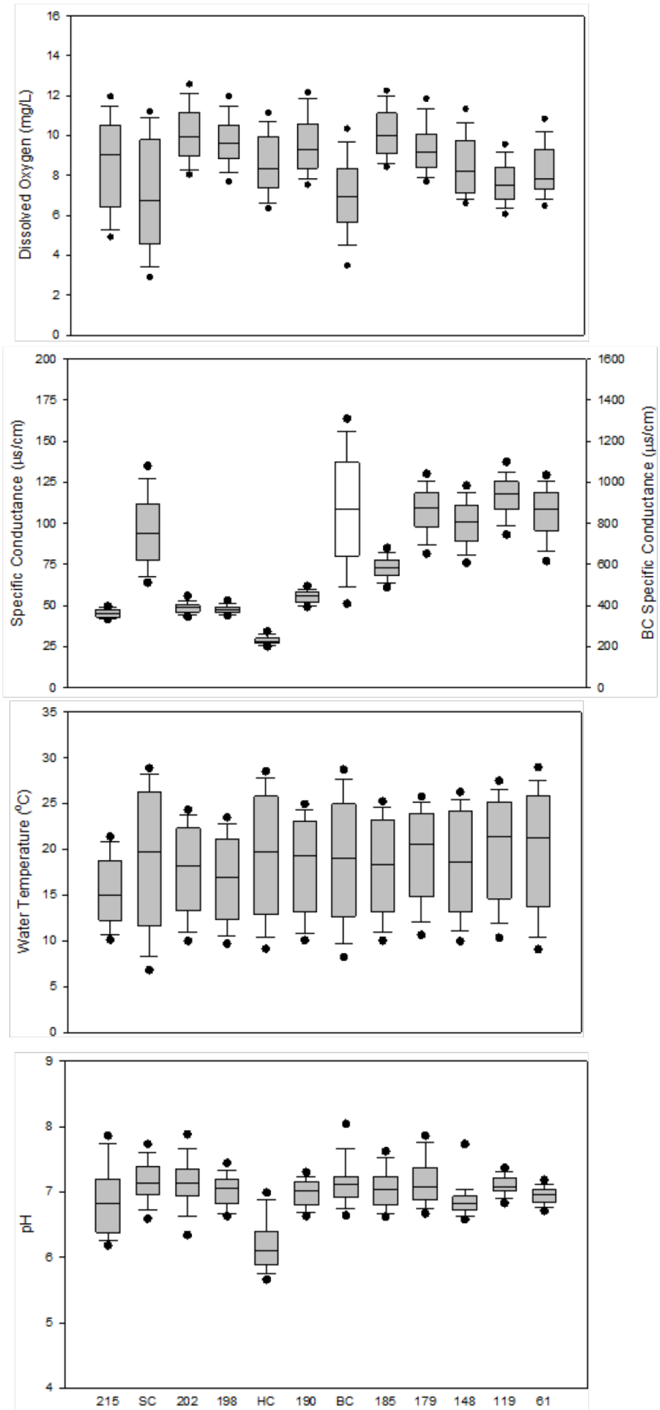

Figure 2. Box plot of continuous monitoring data (Box = 25th and 75th percentiles, line = median, whiskers = 10th and 90th percentile, and closed circles = 5th and 95th percentile outliers; SC = Stevens Creek, HC = Horse Creek, BC = Butler Creek).

Moak et al. (2010):

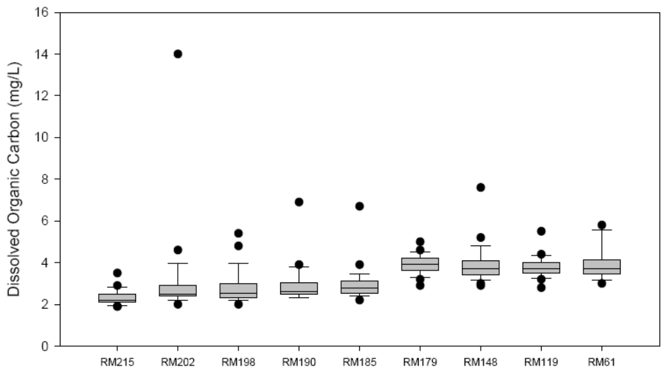

Figure 3. Box plot of dissolved organic carbon concentrations by river mile.

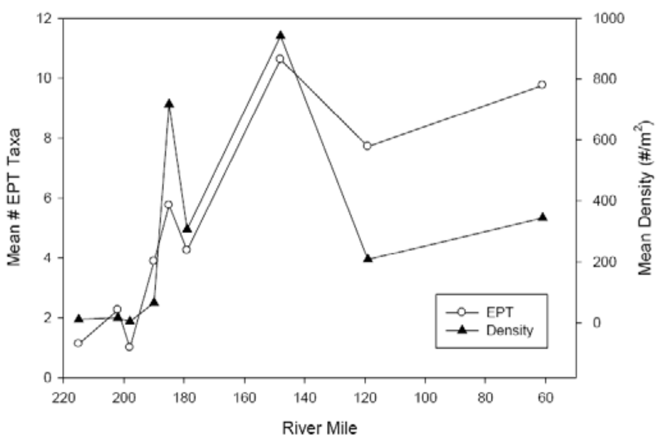

Figure 4. Mean number of EPT taxa and density by river mile.

Summary

The majority of the literature supports the 2003 flow recommendations with a few exceptions. The study by Gordon and Wear (2011) noted that flows of 10,000cfs were enough to completely inundate *H. coronaria* and strip the flowers of their anthers, which would prevent pollination. However, it was stated that if flooding of this magnitude occurred only periodically during the growing season (April-October) it would not prevent pollination for the entire season as the loss of some flowers does not prevent subsequent ones from growing. This supports the 2003 flow recommendations for the Augusta Shoals, which only recommend low flows up to 10000cfs during wet years, so long as flows of this magnitude are not sustained for extended periods in the growing season. The same is true for the 2003 recommended high flow pulses for all years. As these pulses occur only for the early part of anthesis and the growing season and are of short duration (except for wet years when the duration is 2 weeks) these pulses should not have a lasting effect on pollination as flowers will continue to form later in the growing season. Lastly, the authors caution against raising the water level to discourage deer access, as recommended in the 2003 final report, as this may result in dislodging of seedlings and/or established clumps. The authors, however, did not mention at what discharge this may occur.

The 2003 recommended low flow for dry years in the River-Floodplain section would allow for bald cypress recruitment and growth (Palta et al. 2011), however, it would also result in exposure of the lower gravel bar during robust redhorse spawning in May. The 2003 low flow recommendation for May in dry years is 6200cfs while Grabowski and Isely (2007b) found that flows below 7062cfs left the gravel bar exposed. However, the 2003 recommended low flows for average and wet years in May, 8000 and 135000cfs respectively, would provide enough discharge to keep the lower gravel bar inundated according the Grabowski and Isely (2007b). Jackson and Long (2011) recommend flows of at least 6200cfs from April 15-June 7 to keep the upper gravel bar inundated for robust redhorse spawning and larval development, a condition which is met by the 2003 low flow recommendations for dry, average, and wet years.

The 2003 high flow pulses for dry, average, and wet years in the river-floodplain section are supported with one exception. Pulses increase river-floodplain interactions, which SNSA (2008) and Moak et al. (2010) found contributed to increased water quality with distance downstream. The 2003 high flow pulse recommendations for dry, average, and wet years would be sufficient to cause floodplain inundation based on SNSA (2008) and Moak et al. (2010). They found that inundation of the floodplain occurred at flows of 17,200 cfs at USGS gauge 021973269 near Waynesboro, 14,000cfs at USGS gauge 02197500, and 11,700cfs at USGS gauge 02198500 near Clyo, GA. Findings by Bright et al. (2010) support high flow pulses because it would allow floodplain access for fish and support invertebrate populations. Martin and Paller (2008) concluded that ichthyoplankton and larval recruitment transport was greatest when flood pulses occurred in April at the height of spring spawning. However, Jackson and Long (2011) found that high spring pulses resulted in increased turbidity and drops in water temperature at the upper gravel bar. They stated that using pulses to clean the upper gravel bar before the robust redhorse spawning period (April) may not be beneficial because high flows tend to carry sand from upriver and deposit it on the upper gravel bar. Instead, they recommend dropping the winter peak flow as early as possible to medium flows which would remove the sand and leave the coarser armoring gravel layer on the upper bar. Finally, the 2003 recommended floods for wet years are supported by Bright et al. (2010) because they encourage river-floodplain connectivity which would support invertebrate and fish populations.

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