Factors Determining Abundance and Distribution of the Endangered Fat Threeridge mussel, *Amblema neislerii*, in the Apalachicola River, Florida

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Abstract

In the Apalachicola River, Florida, aggregated assemblages of native mussels (family: Unionidae) were dominated by the endangered fat threeridge (*Amblema neislerii*) and occurred mainly in moderately depositional, nearshore areas immediately downriver of point bars. In June 2007, *A. neislerii* was present at 23 of 25 areas surveyed between Navigation Miles 40 and 50. Catch per unit effort for all mussels at the 25 sites ranged from 0 to 1,080 (average = 312), and CPUE for *A. neislerii* ranged from 0.0 to 774 (average = 162). Mean *A. neislerii* density ranged from 0.2 to 12.7 individuals/m^2 (average = 3.7, standard deviation = 3.7) and total unionid density ranged from 2.4 to 36.0 (average = 11.9, standard deviation = 11.2). Total shell length for A. neislerii ranged from 11.7 to 76.4 mm, and there was evidence of strong recruitment with cohorts centered at 17.5 and 42.5 mm. Extremely low discharge, less than 6,000 cubic feet per second on the Chattahoochee gage in 2006 and 2007 resulted in considerable mussel mortality in shallow portions of the river and its distributaries during 2006. Never-the-less, most of the riverine assemblage of mussels had sufficient water. The past two years of low water killed virtually all bivalves in Swift Slough.

Despite concerns about its rarity, *A. neislerii* populations are moderately dense and include recent recruits throughout much of the Apalachicola River. This species is found in reaches of the Chipola River, although it is uncommon or absent in most connecting tributaries and sloughs. Until recent low water, it was collected in Swift Slough. A long-term monitoring plan, which focuses on intensive collecting at a few representative areas, coupled with sediment and water velocity modeling, will provide additional understanding of physical factors that affect abundance and distribution of *A. neislerii* in the Apalachicola River.

Introduction

Background. The Apalachicola River, formed by the confluence of the Flint and Chattahoochee Rivers, originates at Navigation Mile (NM) 106.3, just south of Lake Seminole in the tailwater of Jim Woodruff Lock and Dam. This is the largest river in Florida, with a mean annual discharge of 690 m^3/sec (Light et al. 1998). The Apalachicola-Chattahoochee-Flint (ACF) basin, in Georgia and northeastern Florida, drains approximately 210,448 hectares. The river enters the Apalachicola Bay at Apalachicola, Florida.

The river provides habitat for an endemic freshwater mussel (family: Unionidae) the fat threeridge, *Amblema neislerii* (Lea, 1858), which was listed as endangered on 15 April 1998 (Federal Register Volume 63, Number 50, pages 12664-12687). A review of the literature reveals that its abundance and distribution in the Apalachicola River has not been well understood or adequately portrayed. Part of the problem has been the difficulty of sampling mussels in medium-sized to large rivers. It was not until the 1980s, and in some cases later, that biologists routinely used power boats and divers to conduct both intensive and extensive searches for mussels. The following is a brief summary of pertinent literature on *A. neislerii* (also see Butler et al. 2003).

The first published reference to *A. neislerii* in the ACF basin was by Hyning (1925) who described it as ‘rare,’ after receiving an unreported number of *A. neislerii* from the Chipola River from a fisherman. Several years later, van der Schalie (1940) reported that *A. neislerii* was not found in tributaries but was at two sites in the Chipola River where it constituted 1.49 % of the unionid fauna. Clench and Turner (1956) reported that *A. neislerii* was rare in the watershed, although when present it could be locally abundant. They considered it to be extinct in the upper Flint River where it had not been taken since the latter part of the previous century and they found some specimens in the lower Flint, Apalachicola, and Chipola Rivers. They stated that *Crenodonta* (=*Amblema*) *neislerii* was ‘amazingly abundant’ in a natural impoundment in the lower Chipola River (referred to as Dead Lake) and suggested that 10-15 could be found in "every square meter" along a 200-meter reach.

In a survey conducted for the Office of Endangered Species, Heard (1975) collected mussels at 150 sites in the Gulf and Southeastern States; four sites were in the Apalachicola and three were in the Chipola River. He collected live *A. neislerii* only in the lower Chipola River (Dead Lake). He did not collect live *A. neislerii* in the Apalachicola River although he did find shells at one site. He did not provide specific information on his methods or location of sites.

Richardson and Yokley (1996) collected mussels in the Apalachicola River using quantitative methods (six 0.25-m^2 quadrats and total substratum removal) at each of three sites where adult *A. neislerii* or *Elliptoideus sloatianus* (threatened) had been found by previous investigators. *Amblema neislerii* was found at one site (NM 21.8) where it constituted 25% of the assemblage. Three live organisms were smaller than 50 mm total shell length. They concluded that appropriate search methods would likely yield additional evidence of recent recruitment for *A. neislerii*.

During 1991-92, Brim Box and Williams (2000) surveyed 324 sites in the ACF basin. They identified 33 species from a collection of 5,757 live individuals and 2,988 shells. Most sites were in the Chattahoochee and Flint Rivers upriver of Jim Woodruff Lock and Dam. *Amblema neislerii* was found at 11 sites in the watershed and 32 live specimens were taken at seven sites in the Apalachicola River.

The US Army Engineers District, Mobile (SAM), funded the first comprehensive mussel surveys of the Apalachicola River in association with maintenance activities for the Federal Navigation Project. In 1996, 1997, 1999, 2001, 2002, and 2003 approximately 100 sites were examined by divers and waders (Miller (1998), Payne and Miller (2002), Miller and Payne (2005a, b)). The surveyed sites were typically associated with potential dredged material disposal sites, slough locations, and other main channel areas within the Apalachicola and Chipola rivers. Over 4,500 live mussels were collected and 19 species were identified. Fat threeridge were detected at 22 locations and several of the locations included signs of recruitment. The fat threeridge was particularly abundant at the Chipola River cutoff (river mile 41.6), where a “dense band” of mussels was located. More than 60% of the mussels observed at this site were fat threeridge. At this same location 10% of the fat threeridge were less than 30 mm in total shell length, representing recent recruitment. The results of these surveys indicated that at moderately depositional areas, *A. neislerii* dominated and constituted approximately 36% of the mussel fauna. It should be noted that the purpose of studies conducted every year except 2003 were conducted mainly to assess impacts of maintenance dredging. Therefore, approximately half of the sites were located in erosional zones immediately upriver of point bars where mussels would not likely be found. Studies conducted in 2003 were designed specifically to investigate depth-distribution of *A. neislerii* at areas where *A. neislerii* was known to be abundant. The highest density assemblages were in water 1.2 m deep, and *A. neislerii* was collected to depth of 2.7 m.

In 2005 the Florida Department of Environmental Protection funded a mussel survey of the Apalachicola and Chipola Rivers and associated sloughs, side channels, and tributaries (EnviroScience 2006a). They used divers and waders and surveyed in a manner similar from that of the present survey. At seven sites in the Apalachicola River (between NM 106-70, 70-40, and 40-21), EnviroScience (2006a) reported that mean CPUE (per hour) for *A. neislerii* was 7.2 and mean CPUE for all mussels combined was 45.6. Habitat conditions at the riverine sites that they studied were similar to those sampled during the present survey. Although the majority of the sloughs either did not have mussels or supported very low densities, large numbers of *A. neislerii* were found in Swift Slough, a distributary of the Apalachicola River.

Recent low rainfall in the southeast has caused conditions in the Apalachicola River to be less than optimal for aquatic life. Since 1999 (with the exception of 2003 and 2005), average monthly minimum discharge at Jim Woodruff Dam for part of the year was less than 10,000 cubic feet per second (cfs). The Mobile District is required to maintain a minimum river flow of 5,000 cfs at Jim Woodruff Dam by releasing water from upstream reservoirs, including Lake Seminole, as specified in the 1989 draft water control plan. The Jim Woodruff Dam Interim Operations Plan, developed as part of Section 7 Consultation with the USFWS, would allow for a minimum flow (6,500 cfs) when conditions permitted. This additional flow would benefit aquatic biota in Swift Slough.

Purpose and Scope. The purpose of this paper is to describe the results of a mussel survey conducted on 7-11 July 2007 at 25 locations between NM 40 and 50 on the Apalachicola River. Survey design was based on discussions with representatives of the Mobile District, US Fish and Wildlife Service (USFWS), and the Florida Game and Freshwater Fish Commission (FWCC). No divers were used; all collecting was done by wading. The purpose was to collect information on density and relative species abundance of *A. neislerii* at sites that appeared to provide appropriate water depth, velocity, and substratum. In addition, the study was done to provide information that would be used to prepare a long-term mussel monitoring plan (see Appendix A). Information from the monitoring plan, in conjunction with results from a fluvial geomorphologic evaluation, will be used to obtain a more comprehensive understanding of reduced water level and project impacts (presence of Jim Woodruff Lake, operation of the lock and dam and maintenance dredging) on *A. neislerii*.

Study Area and Methods

Study Locations. Based on a reconnaissance field trip conducted by representatives of the Mobile District, USFWS, and FWCC, personnel of the USFWS identified 25 study areas between NM 40 and 50 along the Apalachicola River which either supported, or appeared likely to support *A. neislerii*. The USFWS randomly selected 10 sites for detailed study (Table 1, Figure 1, see also Table B1 and Figures B1-B4 in Appendix B). Detailed field studies were conducted at the 10 sites and partial studies were conducted at most remaining sites (23). In addition, one new site (DS01) was added at a disposal area of interest. This site was added because of a desire to obtain sediment and elevation data at a disposal area with little or no value to mussels. The 25 sites chosen by USFWS had one or more of the following characteristics: 1) stable, gently sloping banks primarily vegetated with newly established black willow, 2) dense and species-rich mussel assemblages, 3) firm substratum consisting of silty sand, and 4) signs of recent mussel mortality from low water in 2006 and 2007. Virtually every one of these areas was along a moderately depositional reach that was immediately downriver of a point bar. Eddies, which are swirling and reverse currents in rivers, are created when water flows past upstream obstacles such as point bars. These eddies create favorable conditions for mussel assemblages since they encourage deposition of fine particulate matter and glochidia larvae.

An elevation profile of the Apalachicola River reveals that the upper 25 miles has the steepest gradient (Figure 2a). There are three 10-mile reaches where slope is either nearly flat or slightly negative and water can pool: NM 70-80, NM 40-50 (Figure 2b), and NM 20 to 30. Although mussels are affected by local conditions of depth, water velocity, and substratum, larger-scale effects (i.e., river gradient) can influence local characteristics and therefore mussel distribution and abundance (e.g., Gangloff and Feminella 2007). The influence of large and small-scale physical effects on abundance and distribution of freshwater mussels could be further evaluated through the proposed mussel monitoring plan (Appendix A). It is likely that both effects are important, and further study would help define the relative importance of each. Those sampling for mussels could inadvertently bias their observations toward local effects, when in fact mussel distribution and abundance are largely being influenced by larger scale conditions, such as river gradient.

Based on 78 years of record, mean discharge on the Apalachicola River at Chattahoochee, FL, immediately downriver of Jim Woodruff Lock and Dam (USGS 02358000) was 15,700 cfs**.** Maximum daily discharge was 15,700 cfs and minimum discharge was 4,560 cfs (http://waterdata.usgs.gov/usa/nwis).

Methods

Detailed Studies. At the 10 areas where detailed studies were conducted, six evenly spaced transects were established perpendicular to shore. Mussels were collected with a 0.25 m^2 quadrat at three sites along each transect moving from near- to farshore. All sediment, shells, and live bivalves were excavated to a sediment depth of 15-25 cm from the quadrat and sieved through a screen (minimum mesh size equaled 6.4 mm). Live mussels and the Asian clam *Corbicula fluminea* were identified and counted. All live *A. neislerii* were measured, and the majority were marked and replaced in the substratum at known waypoints by USFWS personnel. A total of 18 quantitative samples were obtained at each site; therefore, 180 quantitative samples were taken. After processing, all live mussels and *C. fluminea* were returned to the river unharmed.

A 10- or 20-min timed search for mussels was conducted between two transect lines. All live mussels encountered by touch were placed in a mesh bag and taken to shore for identification and counting. *Corbicula fluminea* were not counted. After processing, all live mussels and Asian clams were returned to the river unharmed.

A theodolite was used to obtain distance and elevation data along each transect. Three readings were taken: one at a depth of approximately 1 m, one at the shoreline, and one part way up the river bank. Additional points were taken if there were abrupt elevation changes. At several locations transects were extended to include mouths of adjacent swales. Elevation data for four study areas are displayed in Figure 3.

A sediment sample was taken at the midshore location along each transect. Samples were returned to the laboratory for analysis of moisture (dried to $65^{o}C$), and organic content (dried to $550^{o}C$). A subsample was wet sieved for grain size distribution.

Additional Studies. At the remaining 15 areas only two transect lines were established perpendicular to shore. Sediment samples were collected, and elevation and distance measures were obtained along each transect. In addition, mussels were collected qualitatively for 10 minutes in the area bounded by transects. No quantitative samples for mussels were collected and none of the *A. neislerii* was marked.

Results and Discussion

Background on freshwater mussels

Although freshwater mussels can be found in virtually every type of lotic and lentic habitat in North America, they reach their greatest abundance and species richness in medium-sized to large rivers in the central and southeastern United States. Several features of their anatomy and life history makes them particularly successful in higher ordered rivers: 1) Their immature forms are dispersed to new habitats on the gills and fins of specific species of fish, 2) They are long-lived—30 or more years in many species; 3) As filter feeders they can separate organic from non-nutritious inorganic matter and expel the latter before it is taken into the stomach, and 4) they can withstand brief periods of desiccation and poor water quality. Large rivers, with species-rich fish assemblages, abundance of particulate organic matter, permanent supply of good quality water, and comparatively stable water levels, provide the best habitats for these long-lived, relatively immobile invertebrates (see Vannote et al. 1980). Sustained mussel populations are much less likely in ephemeral habitats such as small sloughs and tributaries, waterbodies lacking a species-rich fish assemblage, or at areas with excessive sediment accretion or erosion.

Freshwater dreisssenid and marine mussels attach to substratum with a bundle of byssal threads. Conversely, juvenile freshwater unionid mussels temporarily anchor with a single thread. After the thread is absorbed, the mussel buries into the sediments. Mussels move by extending their pseudopod (false foot), swelling the distal end to lock it into the substratum, and then contracting it to pull them through the sediment. Such movement is most efficient in silty sand or loose gravel.

Freshwater mussels can live for long periods on the surface of the substratum, or buried beneath several centimeters (cm) of sediments. However, typically they are found with only their anterior two thirds buried. In this position their incurrent and excurrent siphons, used to take in water and expel wastes, protrude into the water.

Usually mussels are found on shoals or gravel bars in large rivers where it is not uncommon to find 20 to 30 species and overall density approaching100 individuals/m^2 or more. Depending on availability of sediments, these shoals or bars can exist in cobble, gravel, or mixtures of sands and silts. Such shoals can be self-sustaining; shells become incorporated into the substratum and then attract invertebrates and fish carrying immature mussels. Because mussels rely on fish hosts for dispersal, juveniles can be deposited almost anywhere, even in unsuitable habitat. Regardless, the greatest survival will be in areas without excessive erosion or sedimentation. Finding a few live mussels in unsuitable habitat simply illustrates their ability to reach and then survive in these areas. Although mussels are most commonly collected in low-velocity water near shore, intensive searching by a diver will almost always yield a few specimens in the thalweg, fissures in bedrock, or partially buried in firm clay. The least suitable mussel habitat is unconsolidated gravel, sand, or silt that is vulnerable to dispersal during high discharge. More background information on freshwater mussels can be found in Fuller (1974), Russell-Hunter (1979), Cummings and Mayer (1992), Williams et al. (1993), and Strayer et al. (2004).

In the study area there are four major aquatic habitats: 1) the thalweg, 2) erosional zones adjacent to clay banks on the outside of bends, 3) sandy areas adjacent to point bars on the inside of bends, and 4) moderately depositional silty-sand substratum in straight reaches or downriver of point bars. Small- to medium-sized sloughs, which enter the river at various points, are another potential habitat for native mussels although most are either ephemeral or too small for unionids. Some larger sloughs, notably Swift Slough, have supported mussels during wet periods; however, the contribution of sloughs to overall mussel populations is minimal compared with the abundant high-quality riverine habitat. The value of Swift Slough for native mussels will be discussed later.

Mussel distribution and abundance in the study reach. Typically, habitat suitable for *A. neislerii* was appropriate for all mussel species (Figure 4a); although this relationship did not hold at every site (Figure 4b). For example, *A. neislerii* populations were poor at DM09, DM22, and DM26, although total mussel populations were judged to be 'good'

(Table 2). Regardless, since it was a major component of the mussel fauna, A. *neislerii* abundance was positively related to the total abundance. Based upon qualitative sampling, *A. neislerii* was found at 23 of the 25 areas between NM 40 and 50.

Amblema neislerii was taken at all 10 areas surveyed using quantitative methods (Table 3). This species comprised nearly 37% of the mussel fauna and approximately 30% of the quadrats had at least one individual present. It is unusual to have an endangered species dominate the mussel assemblage. For example, the endangered *Lampsilis higginsii* comprises approximately 0.5% of the mussel fauna in the upper Mississippi River (Miller and Payne 2007, and references cited therein) and the Endangered *Plethobasus cooperianus* comprises approximately 0.1% of the mussel fauna at a dense and species-rich site in the lower Ohio River (Miller et al. 1986, Payne and Miller 2000).

Density of dominant bivalves in the Apalachicola River. Total mean density of *A. neislerii* ranged from 0.2 to 12.7/m^2 (Table 4). The maximum number of *A. neislerii* in a single quadrat at site DM14 was 13 individuals, corresponding to a density of 52/m^2. At the 10 sites surveyed, total mean density (all species) ranged from 2.4 to 28.9 individuals/m^2. Compared with other medium-sized to large rivers, total mussel density in the Apalachicola River is moderate to low. It is not unusual to find total densities of 50 to 100 individuals/m^2 at sites in the upper Mississippi River (Miller and Payne 2007), and lower Ohio River (Payne and Miller 1989). At a single site in the Sunflower River, MS, average mussel density at one site was greater than 200 individuals/m^2 (Miller and Payne 2004).

A summary of the mean density of *A. neislerii* in each area, as well as density trends from up- to downriver and from near to farshore, appears in Figure 5a. Although there are substantial density differences among the 10 study areas, there are only minor density differences moving up- to downriver (Figure 5b) or near-to-farshore within sites (Figure 5c).

Total mean density of the *C. fluminea* greatly exceeded that of native species at most areas and was greater than 1,000 individuals/m^2 at one location. There was no strong negative or positive relationship between numbers of *C. fluminea* and total number of mussels (Figure 6). The widespread concern that Asian clams exclude native mussels is not well-supported by data (Miller and Payne 1994).

Estimating population size of *A. neislerii* in the study area. Qualitative and quantitative data were used to predict density of *A. neislerii* from CPUE ($Y = 0.28X - 0.77$; $R^2 = 0.59$) for sites where only CPUE data were obtained (Table 5). If only a 1-m strip (to a water depth of approximately 50 cm) of live *A. neislerii* existed along the shore at each location surveyed between NM 40 and 50, then the total population size at all 25 sites would be 19,000 individuals. (Because of extremely high standard deviations (Table 4) the 95% confidence interval will exceed mean values in most cases. Therefore, there could be considerable error (either positive or negative) for predictions using these data). It is likely that this strip is wider than 1 meter and extends into deeper water. Results of a study conducted in 2003 indicated that while maximum densities were at 1.2 m, *A. neislerii* could be found up to 2.7 m deep (Figure 7). This is an additional 1.5 m of depth beyond that which was sampled during the present survey. Therefore, the total population of *A. neislerii* at these 25 locations probably exceeds 19,000 individuals. In addition, this figure does not include other sites both in and outside the study reach that also support *A. neislerii*.

Recruitment. There was evidence of strong recent *A. neislerii* recruitment (Figure 8). Of the 166 *A. neislerii* collected, total shell length ranged from 11.7 to 76.4 mm (mean = 50.6 mm). Cohorts of small mussels were centered at 17.5 and 42.5 mm. Furthermore, at least one individual with a shell length less than 20 mm was noted at 7 of the 10 sites. Additional sampling to increase the number of individuals collected would likely yield evidence of recent recruitment at all sites. Based on sampling conducted in 2007, as well as 1996, 1997, 1999, 2001, 2002, and 2003, *A. neislerii* regularly recruits in the river.

Elevation Profiles. There was no significant relationship between steepness of bank slope and CPUE of *A. neislerii* (Figure 9). Elevation profiles were relatively similar among sites whether they had poor, good, or very good mussel assemblages (Figure 3).

Relationship between sediment characteristics and mussel distribution. The relationship between CPUE for *A neislerii* and total mussels versus size of sediment particle appears in Figure 10a (% sediments < 0.075 mm in diameter), and 10b (% sediments >= 2 mm in diameter). Grain size distribution data indicate that mussels become slightly more abundant as the percentage of smaller-sized particles increases (Figure 10a). Conversely, mussels are most abundant when the percentage of larger-sized particles, >= 2.0 mm, is the least.

The relationship between CPUE for *A neislerii* and total mussels versus sediment characteristics appears in Figure 11a (% moisture content), and 11b (% organic content). These figures illustrate that there was a tendency for mussels to be most abundant in sediments with slightly higher moisture and organic content. Both sets of relationships further illustrate that mussels tend to be slightly more abundant in moderately depositional areas, for example in eddies located immediately downriver of point bars. Sediments in theses moderately depositional areas would be of slightly higher organic and moisture content and smaller diameter than sediments in erosional areas where these species tend to be less dense.

Effects of low water on mussels in the mainstem Apalachicola River. Low water in the Apalachicola River in 2006 and 2007 caused shallow, nearshore areas along many reaches to be exposed to the atmosphere. Observations by resource personnel indicated that many mussels were killed by either exposure, predation, elevated temperatures, or reduced dissolved oxygen. While mussels have the ability to move, many were trapped and did not reach deeper water. Regardless, most thick-shelled mussel species have the ability to withstand limited exposure and survive low water. If sediments are moist and ambient temperatures stay low because of shading or groundwater input, some can stay alive for weeks or longer.

Because of recent low water, considerable mussel mortality was observed at the mouths of sloughs and in associated swales along the margins of the main channel. It is unlikely that an uncommon event, such as high river discharge or wind, transported mussels into these areas. By 2007, the swale habitat at DM 14 and DM 21 was covered with grass, willows, and other terrestrial plants; the presence of partially buried shells indicated that this habitat had supported permanent mussel assemblages. Sloughs that enter the river where an eddy is present will be affected by the increased sedimentation caused by current reversal and swirling water. Such sedimentation is a natural river process, most observable at low water.

The value of Swift Slough for freshwater mussels. Swift Slough is a distributary that exits the Apalachicola River along the left descending bank at NM 40.3. It flows east and south, and then joins the Styx River, which enters the Apalachicola River at NM 35.4. Swift Slough disconnects from the Apalachicola River at 5,100 cfs on the Chattahoochee gage (Light 2006); therefore, at extreme low water most of the slough is dry except for pools of trapped water. If discharge in the Apalachicola River is high, Swift Slough carries considerable flow. High discharge can mobilize sand, silt, and freshwater mussels at the slough entrance and distribute them throughout the channel. Although *A. neislerii* and other mussels were found at several sites immediately upriver of the entrance to Swift Slough, these were low-density assemblages (Table 2).

EnviroScience (2006a) reported that in Swift Slough *A. neislerii* comprised 19.8% of the unionid fauna. Average CPUE (per hour) was 16.8 (maximum = 228) and average mussel density (all species) was 5.35/m^2. These data can be compared with results obtained during the present study. At virtually all sites between NM 40 and 50, *A. neislerii* dominated the assemblage and typically comprised nearly 37% of the native mussel fauna. Catch per unit effort for all mussels at the 25 sites ranged from 0 to 1,080 (average = 312), and CPUE for *A. neislerii* ranged from 0.0 to 774 (average = 162). Mean *A. neislerii* density ranged from 0.2 to 12.7 individuals/m^2 (average = 3.7, standard deviation = 3.7) and total unionid density ranged from 2.4 to 36.0 (average = 11.9, standard deviation = 11.2). The highest number of *A. neislerii* in a single 0.25m^2 quadrat was 13, corresponding to a density of 52 individuals/m^2. Catch per unit effort at 25 sites ranged from 0 to 774 for *A. neislerii* and from 9 to 1,080 for total mussels.

In a later study, EnviroScience (2006b) divided the upper mile of Swift Slough into thirty-five 50-by-9-m reaches and randomly chose six for quantitative sampling. Two could not be effectively sampled because of poor substratum so they were sampled semi-quantitatively. Mean density of *A. neislerii* in the four reaches was estimated to be 4.4, 0.9, 1.4 and 0.0 individuals/m^2. The total number of *A. neislerii* in each reach was estimated to be 1,983, 431, 644, and 90 (the latter value was based on a conservative estimate of density at 90% confidence based on non-detection of species). The mean (787) was multiplied by 23, the number of reaches in which the density estimates applied (two of the six reaches were inappropriate for sampling). The total population size was estimated to be 18,101 (10,626 – 33,879 individuals). An additional 1,809 *A. neislerii* were estimated to be in the remaining 12 reaches. Values include live and fresh dead mussels, but not 'weathered dead' (EnviroScience (2006b)).

These high numbers surprised some resource personnel since it had been assumed that *A. neislerii* was nearly extirpated from the basin (see literature review above). Some resource personnel expressed the belief that Swift Slough was a major and significant source of *A. neislerii* in the Apalachicola River.

Since the slough was essentially dry in the summer and fall of 2006 and the spring and summer of 2007 it is not possible to make additional population estimates; however, results of the previous survey should be viewed with some caution (as the authors recommend). First, very small amounts of benthic habitat were actually examined. Only 2.5% of each of the four reaches, and only 0.3% (45 of 15,750 m^2) of the 1-mile section was sampled. This is significant because low density zones could have been missed since such a low percentage of the habitat was searched. Second, this was not a stratified design in which the number of samples collected was proportional to habitat types. It is unclear if the set of 45 samples were representative of conditions in that reach, or if the six reaches characterized the 1-mile segment. If non-representative areas were searched, then it would be incorrect to extrapolate these data to the entire reach of the slough. Finally, the number of samples required to estimate density with a specified confidence was not determined. Because of high variance-to-mean ratio, the number of quantitative samples needed to estimate density of desired precision and specified chance of being incorrect can be extremely high (see Green 1979). For example, results of studies in the upper Mississippi River by the Wisconsin Department of Natural Resources (2004) indicated that the number of 0.25 m^2 quadrats needed to reliably estimate density of *L. higginsii* can exceed several thousand. It is likely that too few samples were obtained in each reach of Swift Slough to estimate mean density with suitable precision or confidence. Of course the same criticism of course can be made for the sample design for this survey.

As a result of low rainfall during 2006 and 2007, discharge in the Apalachicola River declined and its connection with Swift Slough was severed. Investigations in 2006 and 2007 revealed that large quantities of coarse sand, to a depth of 30 cm or more, had been carried into the slough channel. The sand probably originated at the entrance to Swift Slough and the Apalachicola River. It buried most of the mussels that were censused in 2005 and 2006 by EnviroScience, Inc. Several visits to Swift Slough in early 2007 revealed only a few shells in the channel, although there were some live and dead mussels in shallow pools.

Observations made during low water in 2006 and 2007 caused some to hypothesize that large numbers of adult mussels, including *A. neislerii*, were carried into Swift Slough from the Apalachicola River during periods of high discharge. Any mussels transported down the channel probably originated at the very head of the slough, not in the Apalachicola River. There are no known high-density *A. neislerii* populations immediately upriver of Swift Slough. Catch per unit effort for *A. neislerii* at seven locations between NM 40.3 and 42.2 (closest sites to the mouth of the slough) were all less than 50 (Table 2). The next dense *A. neislerii* assemblage (CPUE = 354) was at NM 43.0, 2.7 miles upriver. It is unlikely that mussels from these populations were carried by high water down the Apalachicola River and then into Swift Slough. It is not unreasonable to assume that mussels colonize Swift Slough like they do all waterbodies; from host fish. It is of course possible that some mussels in the upper reach of the slough are mobilized during high water and dispersed downstream in the slough. Some mussels could survive this translocation, although it is likely that many would be buried in sediments.

The report by EnviroScience (2006a) illustrates the low value of sloughs for native mussels; only Swift Slough supported substantial populations prior to the drought. It is unclear exactly how many *A. neislerii* were in Swift Slough prior to the low water. Regardless, it is difficult to imagine that a 1-mile segment of ephemeral habitat contributed substantially to *A. neislerii* populations in the river. This species is abundant and shows good evidence of recent recruitment at many sites, regardless of the recent low water. There is no reason to believe that a 3,000 m slough could be of much value for a species that is remarkably abundant in moderately depositional habitats that are common in the main stem of the river.

Discussion

As illustrated by results of this and previous surveys high density, recruiting populations of *A. neislerii* exist in the Apalachicola River and probably always have. Although intensive searching nearly always yield a few specimens even in poor habitat, this species reaches its greatest numerical abundance in moderately depositional sites immediately downriver of point bars in the middle reach of the river. As described above, eddies typically develop in these areas, which could further concentrate fine-grained sediments, organic matter, and if present, glochidia larvae. If earlier workers had access to powerboats and divers and conducted intensive and extensive surveys at appropriate locations, they would have also concluded that *A. neislerii* was common-to-abundant. An alternative hypothesis is unlikely. It is difficult to believe that *A. neislerii* was previously uncommon in the Apalachicola River and that it has become more abundant during the last 30 years. Although Swift Slough has supported moderately dense populations, typically sloughs and tributaries do not provide long-term mussel habitat.

Amblema neislerii is most abundant close to shore and becomes less common moving offshore (Miller and Payne 2005b, EnviroScience 2006a). The pooled reaches between NM 80 and 70, 50 and 40, and 30 and 20 likely relate to hydrodynamic conditions that can affect mussel distribution (Benda et al. 2004). In the present study, high-density assemblages were found in the pooled section upriver of the constriction at NM 41.5 (see Figure 2b). Previous studies have identified high-density assemblages at NM 73.3 and NM 30, also pooled reaches (Miller and Payne 2005a). This relationship could be investigated during subsequent monitoring and modeling (see Appendix A). An examination of the hydrodynamic forces that operate at various scales throughout the entire river would provide a better understanding of the *A. neislerii* distribution and density.

In the Apalachicola River, like all rivers, mussel distribution is influenced by fish behavior, flow pattern, and velocity. If currents are too erosional, juvenile mussels cannot settle, and if they do, survival is poor. If immature mussels are dropped in reaches with excessive sedimentation, they can be buried and killed. Juveniles almost certainly are more susceptible than adults to sediment accretion and scour. Mussel collections and observations tend to be made mostly in summer and fall at low water. Yet recruitment, which affects adult distribution, usually occurs in periods of higher flow in the spring. The physical effects of water velocity, when integrated over many years, define water depth, sediment characteristics, bank slope and the nature of the riparian community. Regardless, unionid abundance and distribution in rivers is dependent upon flow characteristics at large and small scales (Strayer et al. 2004). The proposed long-term monitoring plan, which will include sediment and velocity modeling, will provide a better understanding of the distribution and abundance of *A. neislerii* in the Apalachicola River (See Appendix A).

Acknowledgements

Studies were funded by the US Army Engineer District, Mobile. Three individuals from the US Army Engineer Research and Development Center provided much needed assistance: Mark Antwine analyzed sediments, John Newton assisted in the field, and Charles Hahn measured distance and slope at each site. Brian Zettle and Joanne Brandt, Mobile District, provided background information, assisted with logistics, and advised on study design. Jerry Ziewitz, Karen Herrington, and Sandra Pursifull, Panama City Office of the US Fish and Wildlife Service, provided assistance in the field, help with logistics and permits, and suggestions on study design. Ted Hoehn assisted with logistics, helped with permits, and advised on study design.

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Table 1. Summary information on study areas in the Apalachicola River, 7-11 June 2007. See also Figure 1 and Figures B1 – B4, and Table B1, Appendix B. (Reach length measurements were provided by USFWS).

NM	Bank	Location	Bank	Waypoints	Survey Type	Length, m
40.3	RDB	DSDM01	RDB	143-144	Partial	No data
40.4	RDB	DM01	RDB	141-142	Partial	64.2
40.5	LDB	DM'09	LDB	134-139	Detailed	40.6
40.6	LDB	DM10	LDB	128-133	Detailed	78.4
41.0	LDB	DM11	LDB	186-187	Partial	85.2
41.3	LDB	DM12	LDB	168-169	Partial	192.3
41.7	LDB	DM13	LDB	166-167	Partial	68.5
42.1	RDB	DM'03	RDB	164-165	Partial	41.9
42.2	LDB	DM'02	LDB	162-163	Partial	238.5
42.7	LDB	DM'04	LDB	152-153	Partial	40.9
42.8	RDB	DM'05	RDB	145-151	Detailed	127.0
43.0	LDB	DM'06	LDB	156-161	Detailed	90.9
43.1	LDB	DM'07	LDB	154-155	Partial	67.4
43.4	RDB	DM'08	RDB	180-185	Detailed	144.2
43.9	RDB	DM15	RDB	201-206	Detailed	212.6
44.3	LDB	DM14	LDB	188-193	Detailed	77.0
44.5	RDB	DM16	RDB	170-175	Detailed	87.8
45.5	LDB	DM17	LDB	176-177	Partial	169.2
46.0	RDB	DM18	RDB	222-227	Detailed	66.5
46.4	LDB	DM19	LDB	196-197	Partial	159.5
46.9	RDB	DM20	RDB	207-208	Partial	No data
47.4	RDB	DM21	RDB	209-210	Partial	277.5
47.5	LDB	DM22	LDB	214-215	Partial	217.3
48.2	LDB	DM23	LDB	216-221	Detailed	107.9
48.7	RDB	DM24	RDB	228-229	Partial	101.0
49.6	RDB	DM26	RDB	230-231	Partial	309.9

Table 2. Results of qualitative sampling (10- or 20-min timed searches) for mussels at 25 areas between NM 40 and 50, Apalachicola River, 7-11 June 2007. Value judgments were based on frequency distribution of the data (also see Figure 4b).

		A. neislerii		**Total Mussels**	
NM	**Location**	**CPUE, hr**	**Value**	**CPUE, hr**	**Value**
40.4	DM01	0	Poor	9	Poor
40.5	DM09	30	Poor	210	Good
40.6	DM10	3	Poor	72	Poor
41.0	DM11	48	Poor	84	Poor
41.3	DM12	18	Poor	48	Poor
41.7	DM13	0	Poor	66	Poor
42.1	DM03	12	Poor	54	Poor
42.2	DM02	144	Good	516	Very good
42.7	DM04	6	Poor	48	Poor
42.8	DM05	120	Good	294	Good
43.0	DM06	354	Very good	474	Good
43.1	DM07	486	Very good	906	Very good
43.4	DM08	84	Good	108	Good
43.9	DM15	522	Very good	671	Very good
44.3	DM14	558	Very good	684	Very good
44.5	DM16	84	Good	102	Good
45.5	DM17	11	Poor	215	Good
46.0	DM18	72	Good	414	Good
46.4	DM19	276	Very good	462	Good
46.9	DM20	258	Good	576	Very good
47.4	DM21	774	Very good	1,080	Very good
47.5	DM22	54	Poor	126	Good
48.2	DM23	6	Poor	42	Poor
48.7	DM24	132	Good	348	Good
49.6	DM26	18	Poor	420	Good

Table 3. Results of quantitative (0.25m^2 quadrat) samples at 10 areas in the Apalachicola River, Florida, 7-11 June 2007.				
Species	**Abundance**	**Percent Abundance**	**Occurrence**	**Percent Occurrence**
A. neislerii	157	36.85	56	31.11
G. rotundata	95	22.30	45	25.00
L. teres	79	18.54	54	30.00
E. complanta	68	15.96	44	24.44
Q. infucta	7	1.64	4	2.22
V. villosa	7	1.64	5	2.78
T. paulus	5	1.17	4	2.22
E. icterina	4	0.94	4	2.22
E. crassidens	2	0.47	2	1.11
M. nervosa	1	0.23	1	0.56
P. grandis	1	0.23	1	0.56
Total Mussels	426			
Number of areas	10			
Transects / location	6			
Quadrats / transect	3			
Total number of quadrats	180			

Table 4. Mean density and standard deviation (Stdev) at 10 areas in the Apalachicola River, 7-11 June 2007.							
Area	**NM**	**Total Mussels**		***C. fluminea***		***A. neislerii***	
		Mean	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
DM05	42.8	6.0	8.5	31.3	38.9	2.7	5.1
DM06	43.0	9.6	7.0	33.6	25.0	6.2	7.2
DM08	43.4	3.6	5.3	344.4	389.7	1.6	3.4
DM09	40.5	12.4	7.6	1,008.4	738.9	1.8	2.5
DM10	40.6	2.4	3.9	255.8	223.6	0.2	0.9
DM14	44.3	14.9	19.5	324.2	176.4	8.0	13.7
DM15	43.9	28.9	19.0	312.4	240.2	12.7	12.6
DM16	44.5	2.4	4.8	13.6	12.3	0.7	1.8
DM18	46.0	12.0	8.6	215.3	117.0	0.9	3.0
DM23	48.2	2.4	2.8	16.7	22.6	0.2	0.9

Table 5. Estimated population sizes based on regression analysis of 25 areas between NM 40 and 50, Apalachicola River, 7-11 June 2007.				
	A. neislerii			**Estimated**
		Predicted		**Density**
Site	**CPUE/hr**	**Density**	**Length, m**	**Width = 1 m**
DM01	0.0	0.8	64.2	0
DM02	144.0	4.8	238.5	1,145
DM03	12.0	1.1	41.9	46
DM04	6.0	0.9	40.9	38
DM05	120.0	4.1	127.0	524
DM06	354.0	10.7	90.9	971
DM07	486.0	14.4	67.4	970
DM08	84.0	3.1	144.2	450
DM09	30.0	1.6	40.6	65
DM10	3.0	0.9	78.4	67
DM11	48.0	2.1	85.2	180
DM12	18.0	1.3	192.3	245
DM13	0.0	0.8	68.5	0
DM14	558.0	16.4	77.0	1,262
DM15	522.4	15.4	212.6	3,273
DM16	84.0	3.1	87.8	274
DM17	10.7	1.1	169.2	181
DM18	72.0	2.8	66.5	185
DM19	276.0	8.5	159.5	1,356
DM20	258.0	8.0	0	0
DM21	774.0	22.4	277.5	6,228
DM22	54.0	2.3	217.3	496
DM23	6.0	0.9	107.9	101
DM24	132.0	4.5	101.0	451
DM26	18.0	1.3	309.9	395
Total			3,066	18,906

Figure 1. Areas surveyed for mussels in the Apalachicola River, NM 40 – NM 50, 7-11 June 2007. For more details, see Table B1 and Figures B1 – B4, Appendix B.

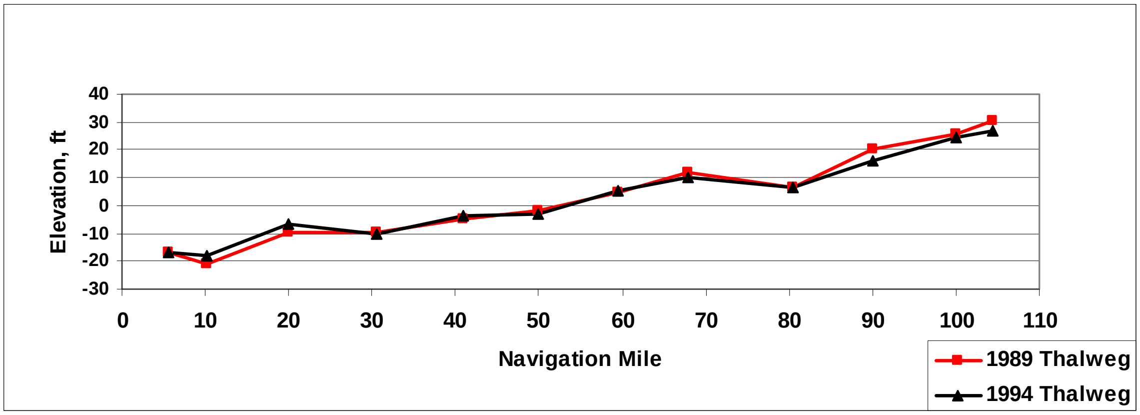

Figure 2a. Elevation profile of the Apalachicola River.

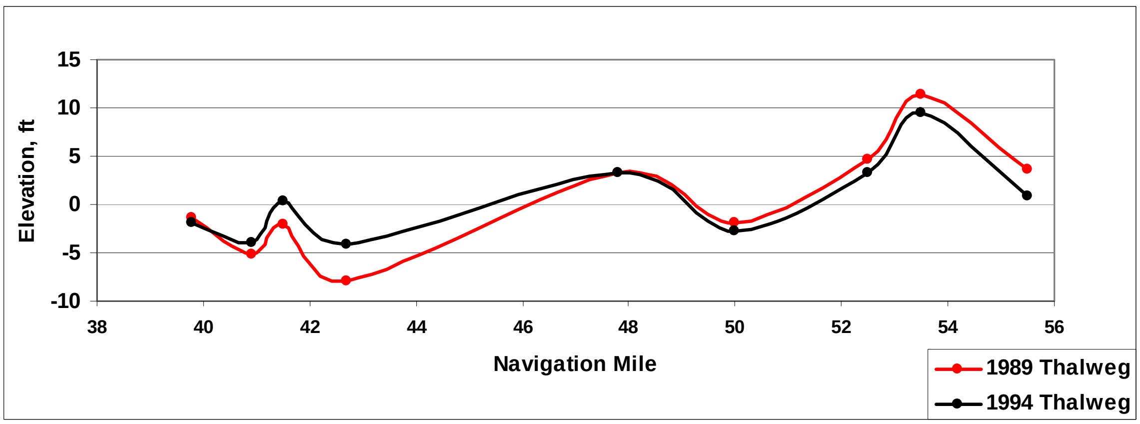

Figure 2b. Elevation profile of the study area, Apalachicola River.

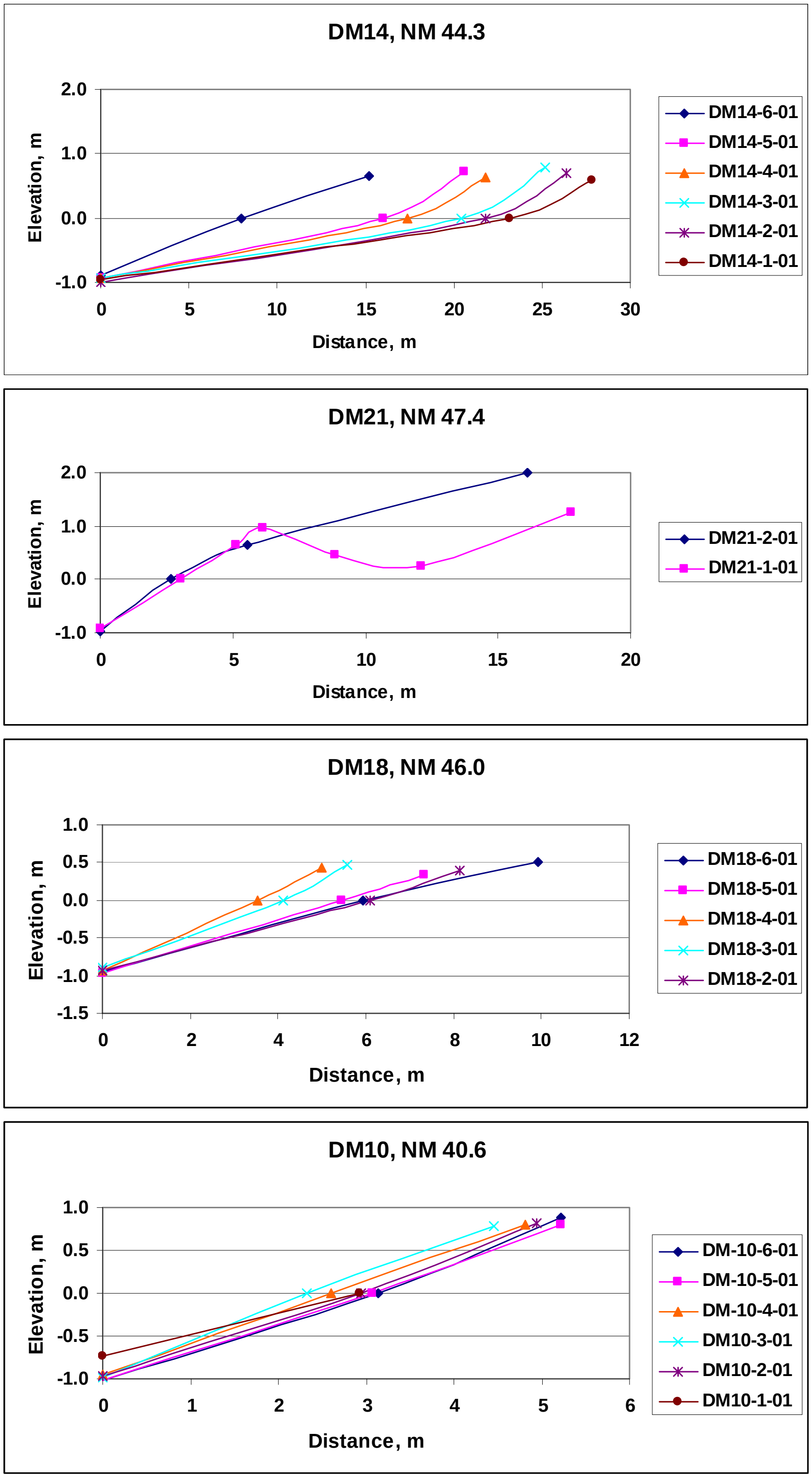

Figure 3. Elevation profiles at DM14 and DM21 (very good habitat), DM18 (good habitat), and DM10 (poor habitat) for *A. neislerii*.

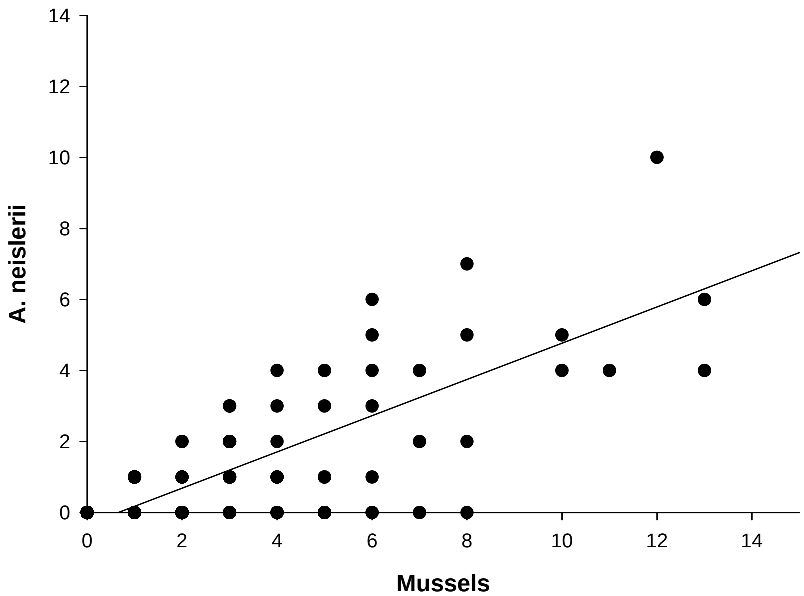

Figure 4a. Relation between total number of mussels and total number of *A. neislerii* (Y= 0.5X – 0.335; R^2 = 0.68).

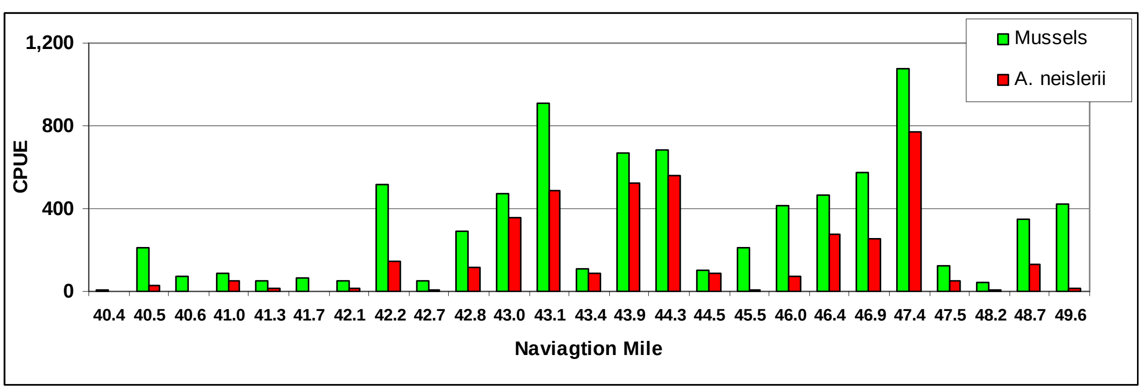

Figure 4b. Catch per unit effort for *A. neislerii* and all mussels at 25 areas, Apalachicola River, 7-11 June 2007.

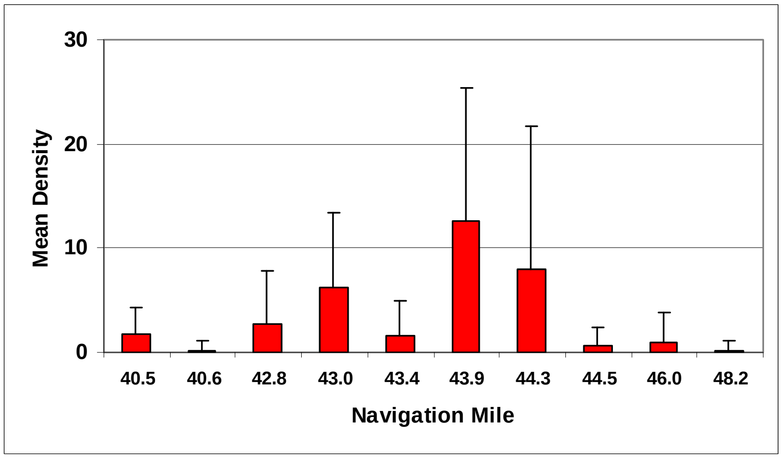

Figure 5a. Mean density of *A. neislerii* at 10 sites in Apalachicola River, 7-11 June 2007.

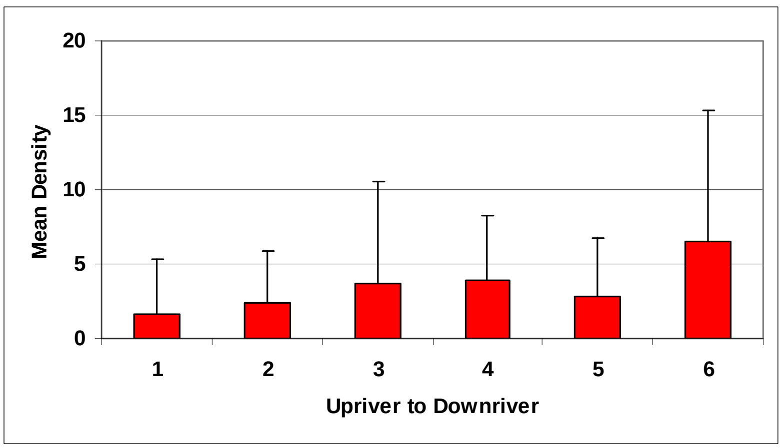

Figure 5b. Pooled within site variation in up-to-downriver density of *A. neislerii,* Apalachicola River, 7-11 June 2007.

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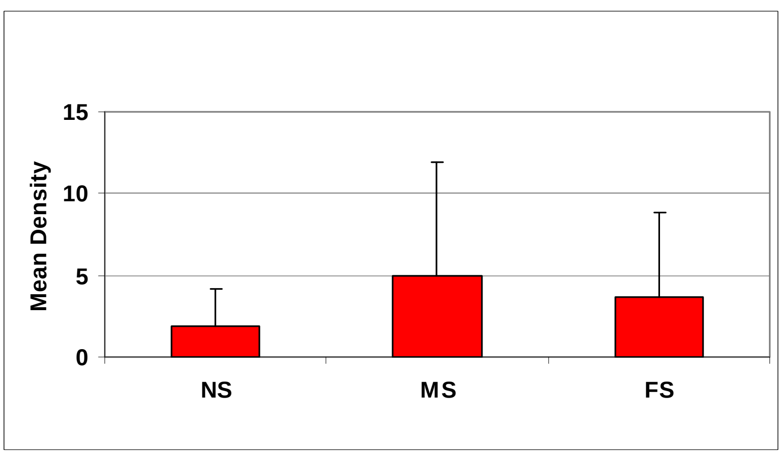

Figure 5c. Pooled within site variation in nearer-to-farshore density of *A. neislerii,* Apalachicola River, 7-11 June 2007.

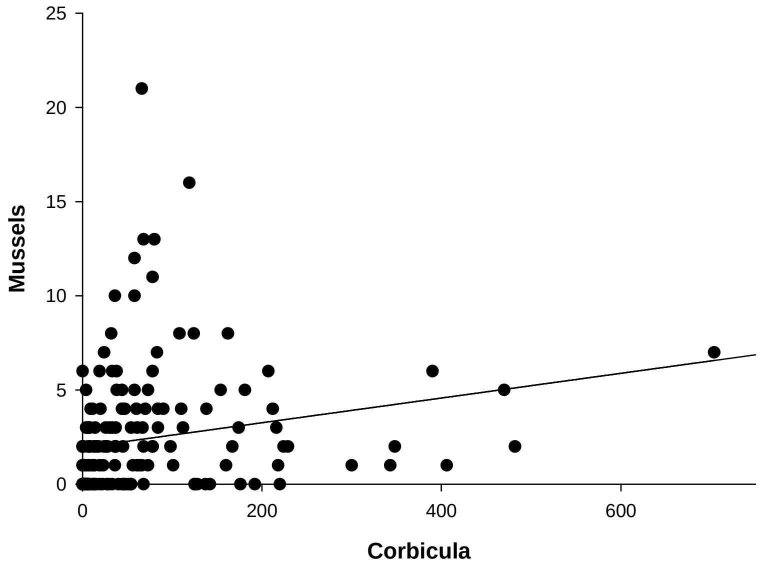

Figure 6. Relation between total number of *C. fluminea* and total number of mussels, Apalachicola River, Florida, 7-11 June 2007 ($Y = 0.006X + 1.9$; $R^2 = 0.38$).

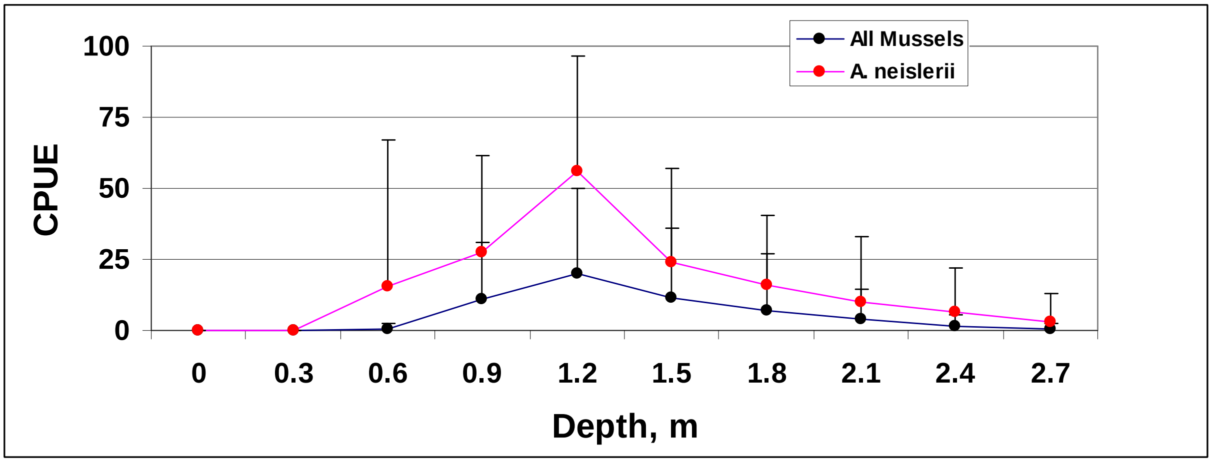

Figure 7. Relationship between abundance of all mussels and *A. neislerii* at multiple locations in the Apalachicola River, FL, 2003. During the survey period gage height and discharge at Blountstown (NM 78) was 3.63 ft, 9,420 cfs (18 Nov 03), 4.17 ft, 10,300 cfs (19 Nov 03), and 4.94 ft 11,500 cfs (20 Nov 03). (Taken from Miller and Payne 2005a).

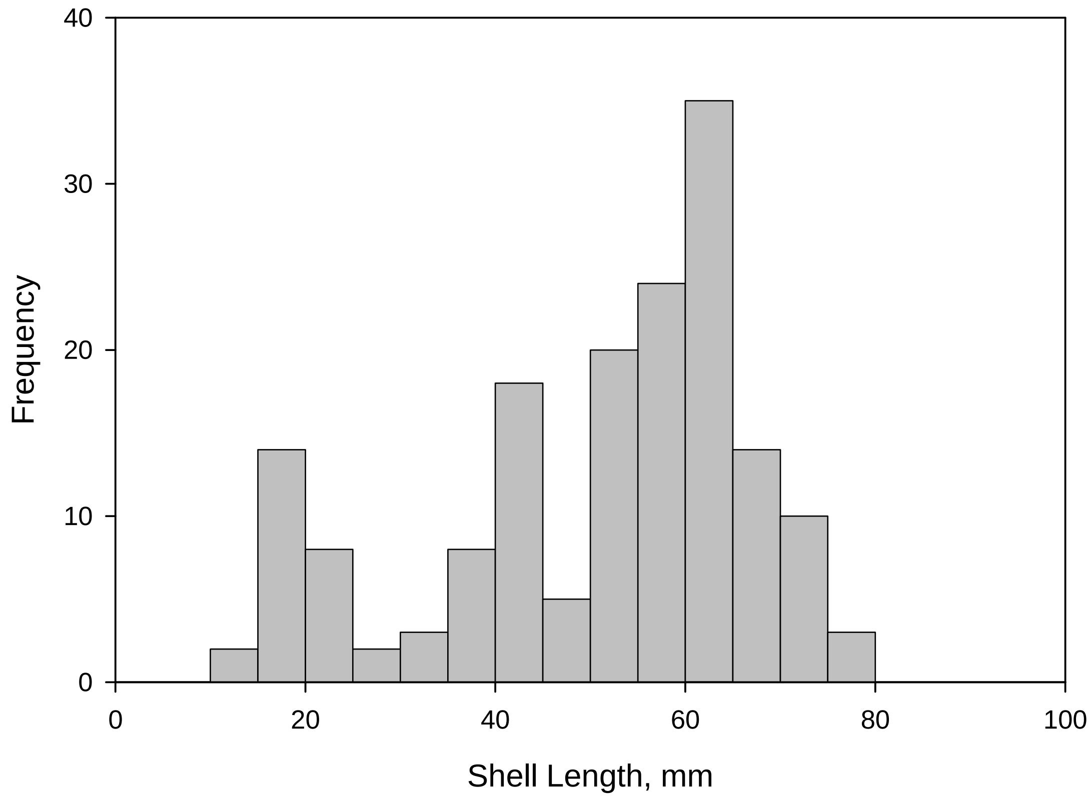

Figure 8. Length-frequency histogram for *A. neislerii*, Apalachicola River, FL, 5-7 June 2007.

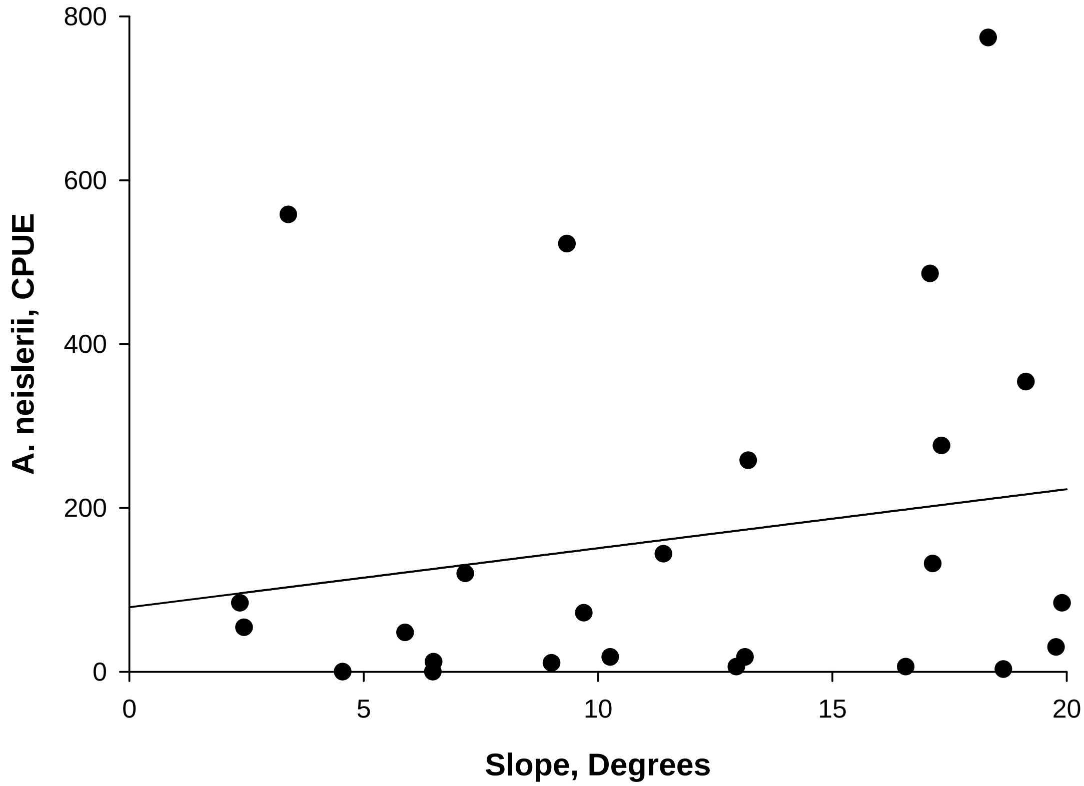

Figure 9. Relationship between bank slope and CPUE for *A. neislerii,* Apalachicola River, FL, 7-11 June 2007 (Y = 7.19X + 78.9; R^2 = 0.038).

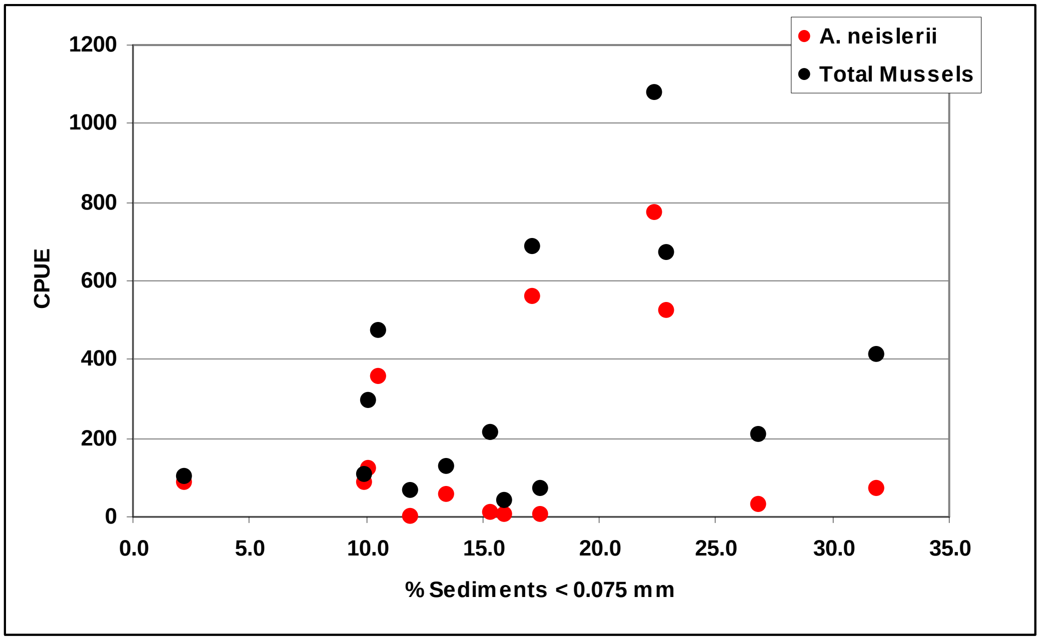

Figure 10a. CPUE for *A. neislerii* and total mussels versus percentage of particles < 0.075 mm.

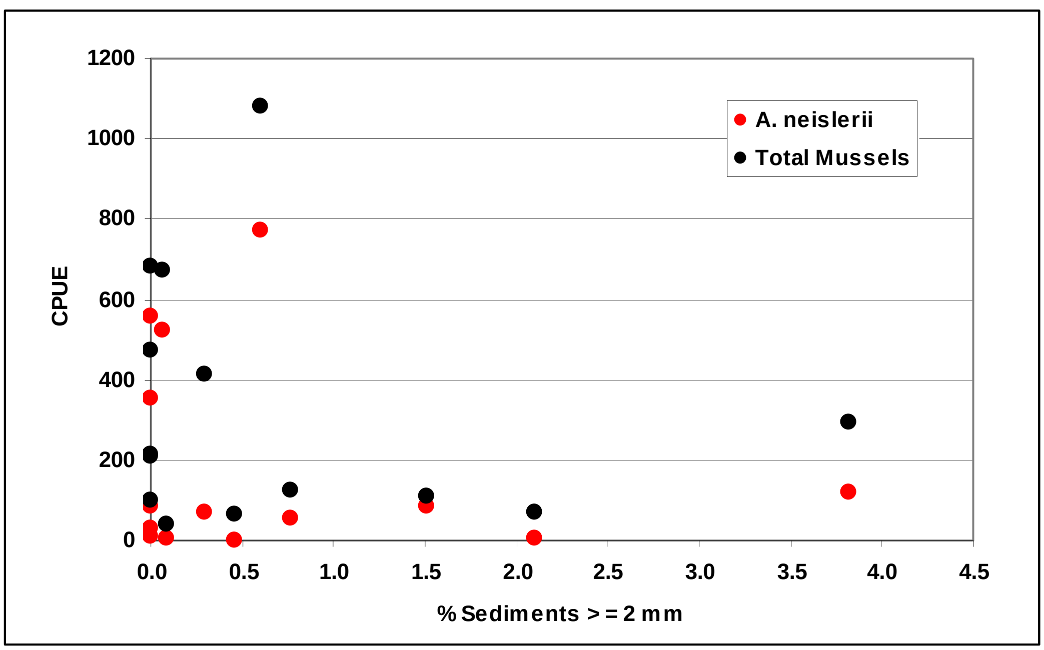

Figure 10b. CPUE for *A. neislerii* and total mussels versus percentage of particles >= 2 mm in diameter.

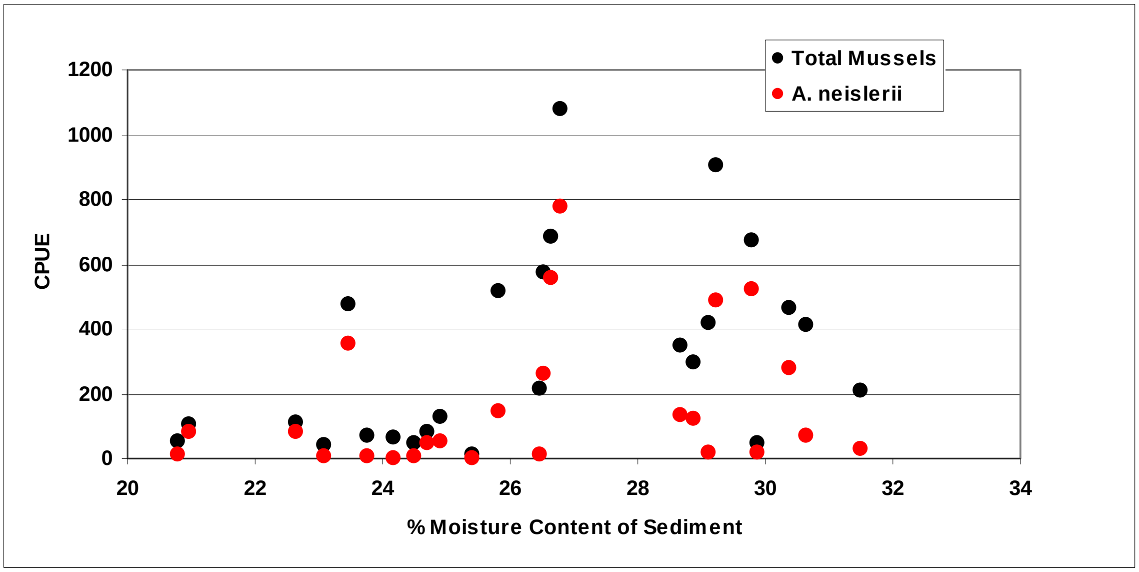

Figure 11a. CPUE for total mussels and *A. neislerii* versus percentage moisture content of sediments.

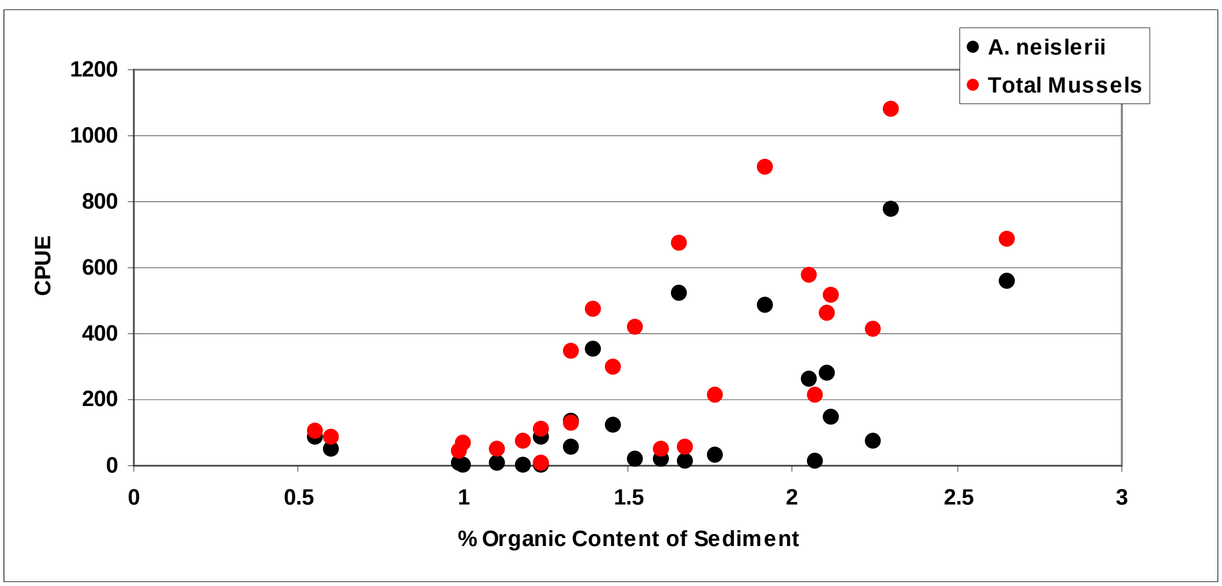

Figure 11b. CPUE for total mussels and *A. neislerii* versus percent organic content of sediments.

Technical Appendices

Appendix A. A Three-Phased Mussel Monitoring Program for the Apalachicola and Chipola Rivers, Florida

Appendix B. List of Waypoints

Appendix C. Maps of the Project Area

Appendix A

A Three-Phased Mussel Monitoring Program for the Apalachicola and Chipola Rivers, Florida

Background. A meeting was held on 14 - 15 August 2007 with personnel of the Panama City Office of the US Fish and Wildlife Service (USFWS), US Army Engineer District, Mobile, US Army Engineer Research and Development Center (ERDC), as well as Dr. Mike Harvey (Mussetter Engineering, Inc.), Dr. David Biedenharn (Biedenharn Group, LLC), and Dr. Andrew Miller (Ecological Applications). The purpose was to discuss a strategy to address Reasonable and Prudent Measures (RPMs), recommended by the USFWS in their Biological Opinion (BO) for the Mobile District water management operations at Jim Woodruff Dam and associated releases to the Apalachicola River. The intent of an Interim Operations Plan (IOP) is to minimize impacts to and provide support for the federally-protected Gulf sturgeon and mussel species (specifically, *Amblema neislerii*, *Elliptoideus sloatinanus*, and *Elliptio chipolaensis*) in the Apalachicola and Chipola rivers, FL. The two RPMs of concern, taken from the BO, are:

RPM4 – Sediment dynamics and channel morphology evaluation. The goals are to identify 1) feasible water and/or habitat management actions that would minimize listed mussel mortality; 2) current patterns and trends in (river) morphological changes; and 3) additional information needed, if any, to predict morphological changes that could affect federally-protected mussels.

RPM5. Monitoring – Monitor the level of take associated with the IOP and evaluate ways to minimize take by studying the distribution and abundance of federally-protected mussels in the action area. The goals are to 1) periodically estimate total abundance of federally-protected mussels in the action area; 2) determine the fraction of the population that is located in habitats that are vulnerable to low-flow impacts.

Long-Term Mussel Monitoring. At the meeting it was decided that a three phased, long-term monitoring study would be required to meet these RPMs. Although many mussel studies have been conducted on the Apalachicola River by the USACE, state of Florida, and USFWS, this proposed monitoring plan would be the first comprehensive study designed to 1) document overall numbers of federally-protected species (within specified confidence limits); and, 2) intensively study biotic and physical processes at selected locations.

The three study phases are: 1) Describe the location and aerial extent of mussel habitats that are particularly vulnerable to low flow; 2) Estimate the total abundance of federally-protected mussels in the Apalachicola and Chipola Rivers, Florida, and 3) Relate mussel abundance and distribution to geomorphic processes at specific sites in the Apalachicola River. The purpose of the first phase will be to determine if the surface area of vulnerable habitats are a substantial proportion of aquatic habitats that support *A. neislerii*. The purpose of the second phase is to provide an overall estimate of the total number of federally-protected mussels in the Apalachicola and Chipola rivers. This information will assist planners determine the best strategies for protecting these organisms during low water. The purpose of the final phase is to more thoroughly understand biotic and physical processes at three or more high-quality mussel beds in the Apalachicola River. This will be used to understand the effects of dynamic riverine processes (sedimentation, benthic scour, channel migration) on the long-term survival of mussel populations. This final phase will explore relationships reported in related studies by Benda et al. (2004), Graf and Qu (2004), Morales et al. (2006), and Gangloff and Feminella (2007).

The following is a brief description of the three phases of this plan. A detailed study plan for these three phases will be developed in 2007-08 that will specify number and location of study sites and number of samples to be collected. The final plan will be sent to the biologists and planners in the USFWS and State of Florida for their comment and possible cooperation. Studies will begin in 2008. All study efforts are dependent upon the availability of funds by Congress.

Phase I: Describe Location and Aerial Extent of Mussel Habitats that are Particularly Vulnerable to Low Water

Background. In 2005 - 2007 resource personnel identified sites along the Apalachicola River where large numbers of native mussels had been killed by aerial exposure due to low water caused by reduced rainfall. Most sites were in low areas (swales) immediately adjacent to the main channel. Evidently, when water level dropped, resident mussels were trapped and died. Water levels also declined in the main channel, however it is believed that those mussels were able to move into deeper water and survive. Resource personnel felt that these swales were particularly vulnerable to low water. They also felt that the USACE might be able to develop management strategies that could alleviate this problem.

Purpose: The purpose is to locate vulnerable areas along the Apalachicola River, measure their surface area, and estimate the nature and extent of native mortality in each. Work will be accomplished by the completion of the following tasks:

Task 1: Identify vulnerable habitats. Recent aerial photography taken during low water will be analyzed to determine the location and approximate size of vulnerable habitats. Each area will be visited, and an assessment of mussel mortality will be made by counting and measuring total shell length of each individual in 6 randomly placed 0.25 m^2 quadrats. (It must be recognized that density estimates under these conditions could not be representative due to 1) losses due to predation, 2) counting shells that were carried in by high water, and 3) losses due to organisms that were transported away by high water.

Task 2: Estimate the relative percentage of vulnerable habitats. The total area of vulnerable mussel habitat along the river will be estimated. This value will then be compared with the total amount (linear extent) of existing mussel habitat based on surveys conducted in 2007, as well as 1996, 1997, 1999, 2001, 2002, and 2003 by personnel from ERDC as well as other studies conducted by EnviroScience, the USFWS, the USGS, and others.

The overall purpose of Phase I will be to identify habitats vulnerable to low water and to determine if reported mortality in these areas is substantial and likely to jeopardize federally-protected mussels. This phase of the work will provide information needed for RPM5.

Phase II: Estimate the Total Abundance of Federally-Protected Mussels in the Apalachicola and Chipola Rivers, Florida

Background. Low water in the Apalachicola River in 2005 - 2007 caused considerable mortality of *A. neislerii*, and likely two other species of federally protected mussels, *E. sloatianus*, and *E. chipolaensis*. Regardless, since the total number of these federally-protected species is not known, it is difficult to determine if mortality due to low water will have a substantial negative effect on survival of the population. For example, if stranded *A. neislerii* comprised a very small percentage of the total, then such mortality would have little effect on population survival. Conversely, if a substantial percentage of the population died as a result of low flow, then *A. neislerii* could be in jeopardy.

Purpose: The purpose is to estimate the population size of three federally-protected mussel species (*A. neislerii*, *E. sloatianus*, and *E. chipolaensis*) in the Apalachicola and Chipola rivers, Florida (action area). This information will be used to determine if observed mortality, due to recent strandings, is likely to have a substantial negative affect. This will be accomplished by completion of the following tasks:

Task 1: Identify mussel habitat types. Topographic maps and recent aerial photographs will be analyzed to identify and delineate the various types of aquatic habitats along the Apalachicola and Chipola rivers. Results of previously conducted mussel surveys by the ERDC, EnviroScience, USFWS, and others will also be consulted. It is likely that the following habitat types exist: 1) low-velocity, moderately depositional areas (eddies) downriver of point bars, 2) straight reaches with bank slope less than 45 degrees, 3) sharp bends with steep bank slopes, 4) sandy areas associated with point bars, 5) dike fields and other man made features, 6) tributaries, sloughs, backwaters, and distributaries; and, 7) the main channel or thalweg.

The purpose of this task is to identify all mussel habitats in both rivers. Since every river mile cannot be surveyed, representative habitats will be studied in some detail, and then results will be extrapolated to similar habitats in the project area.

Task 2: Develop a preliminary study plan. Based on constraints of time and budget, needs of resource personnel and the USACE, a preliminary study plan will be developed. The plan will describe the number of each habitat type (straight reaches, eddies downriver of point bars, etc.) that support mussels in the project area. In addition, the approximate number of sample areas within each habitat type will be estimated. This will be developed based upon a description of stratified random sampling in Strayer and Smith (2003), and the number of samples required to achieve a desired precision (Green 1979). For example, a desired precision could be +/- 10% or +/- 20% of the true mean. Results of previous studies by ERDC, EnviroScience, and others will be used for this task. Based on our understanding of conditions in the project area, it is likely that 3-5 habitat types could be chosen for study, and that 5-7 similar areas could be chosen in each habitat type. Therefore, from 15 to 35 areas in the Apalachicola and Chipola River could be identified for detailed study. In addition, it is likely that 2-4 different density strata (see Strayer and Smith 2003) exist in each habitat type. Between 50 and100 replicate (0.25m^2 quadrat) samples could be taken from each study area; as many as 3,500 individual samples could be required in all. Final values would depend on the desired precision, based on needs of resource personnel and availability of funds.

It could be decided that sampling every year in each area is not required. A sampling plan that includes sampling each area every second, third or fifth year could be acceptable. In this scenario, a subset of different areas could be surveyed each year. This would spread the costs and time required more evenly over the length of the project. A temporal sampling plan will be developed as part of this task.

Finally, a quality assurance/ quality control (QA/QC) protocol will be developed to assess completeness of the sampling plan. Results of detailed sampling will be used to determine if the number of samples actually collected will achieve the desired confidence level. In addition, a protocol will be established to analyze a subset of the sites that were not chosen for detailed study. This will be done to test the effectiveness of the site-selection process.

It is important to note that the purpose is not to conduct a general survey of a great number of sites, but to carefully select representative sites. Results from these representative sites will be extrapolated to the remainder of the project area.

Task 4: Conduct sampling. A brief reconnaissance of each study area will be conducted to identify and delineate the various strata within each habitat type. These strata could be delineated based on either biotic or physical conditions (Strayer and Smith 2003). A dive crew equipped with surface supplied air and communications equipment will collect mussels in deep water and a shore crew will collect in shallow water. It is anticipated that collecting and observations will take place along a set of transects (shallow to deep water) evenly placed along each study area. Divers will collect mussels along transects by touch while describing bottom conditions to the surface crew.

Based on results of the reconnaissance, a preliminary map of the strata defined by either physical or biotic conditions will be prepared. A global positioning system (GPS) will be used to mark coordinates and a pneumofathometer or fathometer will be used to measure depth. Sediment samples to assess moisture content, organic content, and grain-size distribution will also be obtained from each stratum.

Variance to mean ratios from previous sampling on the river will be used to estimate the total number of samples required in each strata to assess density within certain confidence limits (Green 1979). If necessary, a pilot study will be conducted to collect this information. Density will be characterized within each stratum with replicated, $0.25m^2$ total substratum samples. Collectors will excavate each quadrat to a depth of 10 – 20 cm and all substratum, to include shells and live mussels, will be taken to shore and sieved through a nested screen series (minimum mesh size approximately 6.4 mm). Live mussels will be identified, total shell length measured, then returned to the river unharmed. Quantitative sampling will provide density estimates by stratum and an unbiased assessment of size demography for common to abundant species.

After the quantitative sampling is completed, qualitative (timed searches) will be conducted within each stratum at each study area. The purpose is to obtain an estimate of Catch per Unit Effort (CPUE) and a more complete species list than can be obtained through the quantitative sampling.

Based on results of this task, a map of each area will be made that describes local conditions of habitat and mussel density. The estimated density in each stratum will be multiplied by the total area of habitat to obtain an estimate of the total number of mussels present (Strayer and Smith 2003). Results from all strata in each study area will be extrapolated to areas that have not been sampled. Ultimately, a reliable estimate (within desired confidence limits) of the total population density of the three species of interest in the project area will be obtained.

In summary, this phase of study will obtain the following:

1. A reliable estimate (within specified confidence limits) of the total population size of three federally-protected species (*A. neislerii*, *E. sloatianus*, and *E. chipolaensis)* in the project area. This information will be used to determine if low water in the project area is likely to negatively affect threatened species of mussels.

2. An assessment of mussel distribution, habitat preference, relative species abundance, species richness and diversity, total mean density, density of major taxa, and size demography of major taxa by stratum within each habitat type. This phase will provide information required for RPM5.

Phase III: Relate Mussel Abundance and Distribution to Geomorphic Processes in the Apalachicola River

Background. Dense and diverse mussel assemblages are usually found in moderately depositional zones in medium-sized rivers that are not negatively affected by erosion during high discharge or sediment deposition during low flow. Often these areas are found downriver of point bars or along straight reaches where flow is moderate. Since mussels can live 30 or more years, habitat must be suitable during high and low discharge.

One and two-dimensional models can be used to better understand geomorphic processes in flowing water systems. Knowledge of these geomorphic processes is important in understanding density and distribution of riverine mussel populations. For example, Sediment Impact Analysis Methods (SIAM) provides a framework for combining morphological, hydrologic, and hydraulic information that can be used to assess sediment movement through a watershed. In addition, hydrological transport models can be used to simulate river flow under various discharge conditions and ultimately can be used to estimate water quality parameters.

Purpose. The purpose is to apply sediment and hydrodynamic models to reaches of the Apalachicola River that support dense and species rich mussel assemblages. Knowledge of riverine geomorphic processes is needed to understand effects of reduced flow on the density and distribution of important mussel resources.

Task 1: Choose sites for detailed study. Based on results of the Phase I and Phase II of this research, plus requirements for successful application of water velocity and sediment models, three sites for detailed study will be chosen. Sites will be relatively similar with respect to mussel density and species composition, but dissimilar with respect to physical characteristics such as sinuosity, water depth, velocity, etc.

Task 2: Apply hydrodynamic and sedimentation models. The hydrodynamic model will be used to prepare a map of water velocity and direction for each study area. Maps will be prepared for low, moderate, and high discharge.

Task 3: Conduct mussel surveys. Maps developed in Task 2 will be used to identify collection sites. Sites will include the range of physical conditions (low, medium, and high quality) to meet physical requirements for mussels. Based on results of Task 2, Phase II, the number of samples needed to estimate density within specified confidence limits will be determined. Samples will be collected using quantitative methods as in Phase II, and all mussels will be identified, measured, then returned to the river unharmed.

Task 4. Growth Studies. A demographically complete collection (all sizes present) of *A. neislerii* will be obtained, measured, aged, marked, and then replaced in the sediment. Shells from a subset of collected specimens will be sectioned to obtain more reliable estimates of age. Marked specimens will be re-collected each year to assess growth. Data from mark-recapture studies will be used to develop relationships between shell length and ring counts, and to develop population models, for example the RAMAS model described by Akcakaya and Regan (2002) in *Ecological Modeling and Risk Assessment*.

Task 5: Relating physical and biological processes. This phase will provide quantitative data on *A. neislerii* density, population structure and recruitment strength, and relative species abundance with respect to important physical variables (water depth, velocity, and direction), and how these variables affect sediment accretion and erosion.

Studies will be conducted for multiple years to assess large-scale (e.g., river gradient and discharge) as well as small-scale (e.g., local sediment deposition and accretion) effects on *A. neislerii* density, relative species abundance, and recent recruitment. The physical models can be used to simulate geomorphic processes (sedimentation) which were noted during recent low water events.

In summary, Phase III will obtain the following:

1. Tools and techniques for relating information on water velocity, direction of flow, and ultimately shear stress and sedimentation patterns on density, distribution, recent recruitment, and relative abundance of common to abundant mussels including *A. neislerii.*

2. Detailed growth and density information on common to abundant mussel species, including the endangered *A. neislerii*, which can be used for detailed population modeling using software such as RAMAS.

3. Tools and techniques for simulating various geomorphic processes on this river, such as sedimentation and channel movement, on distribution and abundance of common mussels including *A. neislerii*.

Phase III of this monitoring plan will obtain information for RPM4.

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Appendix B. List of Waypoints

Table B1. Location of sites sampled for mussels along the Apalachicola River, Florida, 7-11 June 2007				
Location	**Bank**	**NM**	**Waypoint**	**Position**
DSDM01	RDB	40.3	143	N30 07.125 W85 07.779
			144	N30 07.148 W85 07.795
DM01	RDB	40.4	141	N30 07.201 W85 07.899
			142	N30 07.197 W85 07.880
DM'09	LDB	40.5	135	N30 07.286 W85 07.895
			136	N30 07.285 W85 07.891
			137	N30 07.286 W85 07.888
			138	N30 07.285 W85 07.883
			139	N30 07.284 W85 07.881
			134	N30 07.285 W85 07.869
DM10	LDB	40.6	128	N30 07.263 W85 08.173
			129	N30 07.263 W85 08.151
			130	N30 07.267 W85 08.137
			131	N30 07.270 W85 08.126
			132	N30 07.271 W85 08.118
			133	N30 07.272 W85 08.105
DM11	LDB	41.0	186	N30 07.267 W85 08.353
			187	N30 07.266 W85 08.317
DM12	LDB	41.3	169	N30 07.407 W85 08.655
			168	N30 07.385 W85 08.647
DM13	LDB	41.7	167	N30 07.801 W85 08.597
			166	N30 07.790 W85 08.611
DM'03	RDB	42.1	165	N30 08.008 W85 08.296
			164	N30 07.985 W85 08.304
DM'02	LDB	42.2	162	N30 08.032 W85 08.207
			163	N30 08.004 W85 08.201
DM'04	LDB	42.7	153	N30 08.412 W85 08.168
			152	N30 08.406 W85 08.189
DM'05	RDB	42.8	145	N30 08.437 W85 08.042
			146	N30 08.447 W85 08.061
			147	N30 08.460 W85 08.092
			148	N30 08.468 W85 08.090
			149	N30 08.476 W85 08.099
			151	N30 08.482 W85 08.114
DM'06	LDB	43.0	161	N30 08.568 W85 07.816
			160	N30 08.560 W85 07.808
			159	N30 08.554 W85 07.803
			158	N30 08.547 W85 07.797
			157	N30 08.539 W85 07.793
			156	N30 08.531 W85 07.789
DM'07	LDB	43.1	155	N30 08.614 W85 07.902
			154	N30 08.608 W85 07.886
DM'08	RDB	43.4	180	N30 08.853 W85 08.350

			181	N30 08.847 W85 08.354
			182	N30 08.841 W85 08.357
			183	N30 08.834 W85 08.362
			184	N30 08.818 W85 08.371
			185	N30 08.798 W85 08.381
DM15	RDB	43.9	201	N30 09.104 W85 08.159
			202	N30 09.079 W85 08.170
			203	N30 09.048 W85 08.185
			204	N30 09.036 W85 08.194
			205	N30 09.018 W85 08.207
			206	N30 08.995 W85 08.225
DM14	LDB	44.3	188	N30 09.199 W85 08.056
			189	N30 09.191 W85 08.055
			190	N30 09.182 W85 08.055
			191	N30 09.175 W85 08.055
			192	N30 09.161 W85 08.055
			193	N30 09.148 W85 08.054
DM16	RDB	44.5	170	N30 09.444 W85 08.032
			171	N30 09.439 W85 08.041
			172	N30 09.436 W85 08.049
			173	N30 09.429 W85 08.058
			174	N30 09.423 W85 08.069
			175	N30 09.417 W85 08.077
DM17	LDB	45.5	176	N30 09.934 W85 08.206
			177	N30 09.911 W85 08.184
DM18	RDB	46.0	222	N30 10.284 W85 08.306
			223	N30 10.277 W85 08.323
			224	N30 10.281 W85 08.338
			225	N30 10.276 W85 08.348
			226	N30 10.270 W85 08.358
			227	N30 10.267 W85 08.367
DM19	LDB	46.4	196	N30 10.498 W85 08.060
			197	N30 10.478 W85 08.048
DM20	RDB	46.9	207	N30 10.898 W85 08.113
			208	N30 10.880 W85 08.154
DM21	RDB	47.4	209	N30 11.160 W85 07.553
			210	N30 11.135 W85 07.566
DM22	LDB	47.5	214	N30 11.413 W85 07.403
			215	N30 11.396 W85 07.408
DM23	LDB	48.2	216	N30 11.777 W85 07.229
			217	N30 11.772 W85 07.238
			218	N30 11.767 W85 07.246
			219	N30 11.749 W85 07.270
			220	N30 11.749 W85 07.272
			221	N30 11.735 W85 07.285
DM24	RDB	48.7	228	N30 12.200 W85 06.999
			229	N30 12.173 W85 06.979
DM26	RDB	49.6	230	N30 12.689 W85 07.019

			231	N30 12.693 W85 07.060

Appendix C: Detailed Maps of the Project Area

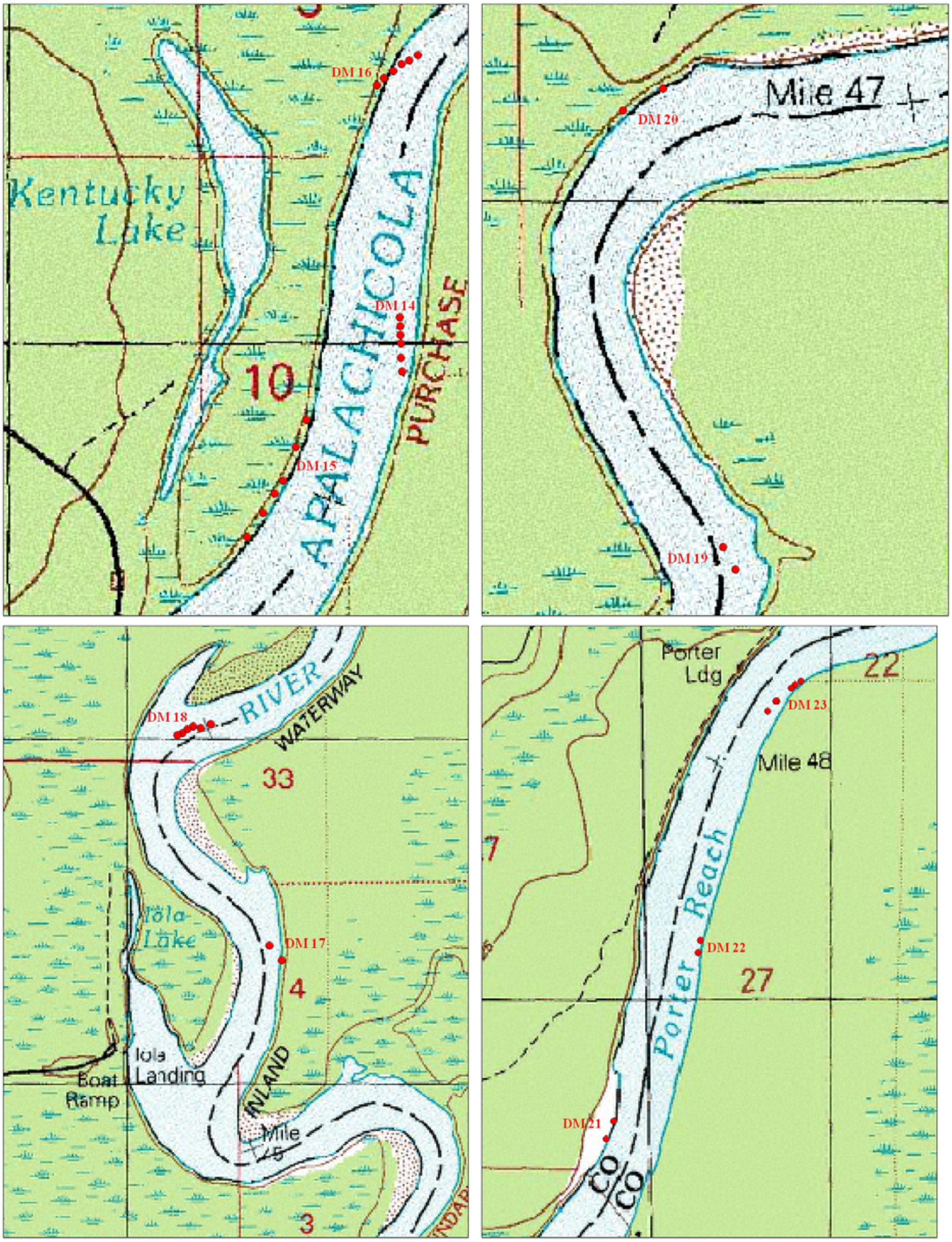


Figure C1. DM15, DM14, and DM16 (top left); DM19 and DM20 (top right), DM17 and DM18 (bottom left), and DM21, DM22, and DM23 (bottom right).

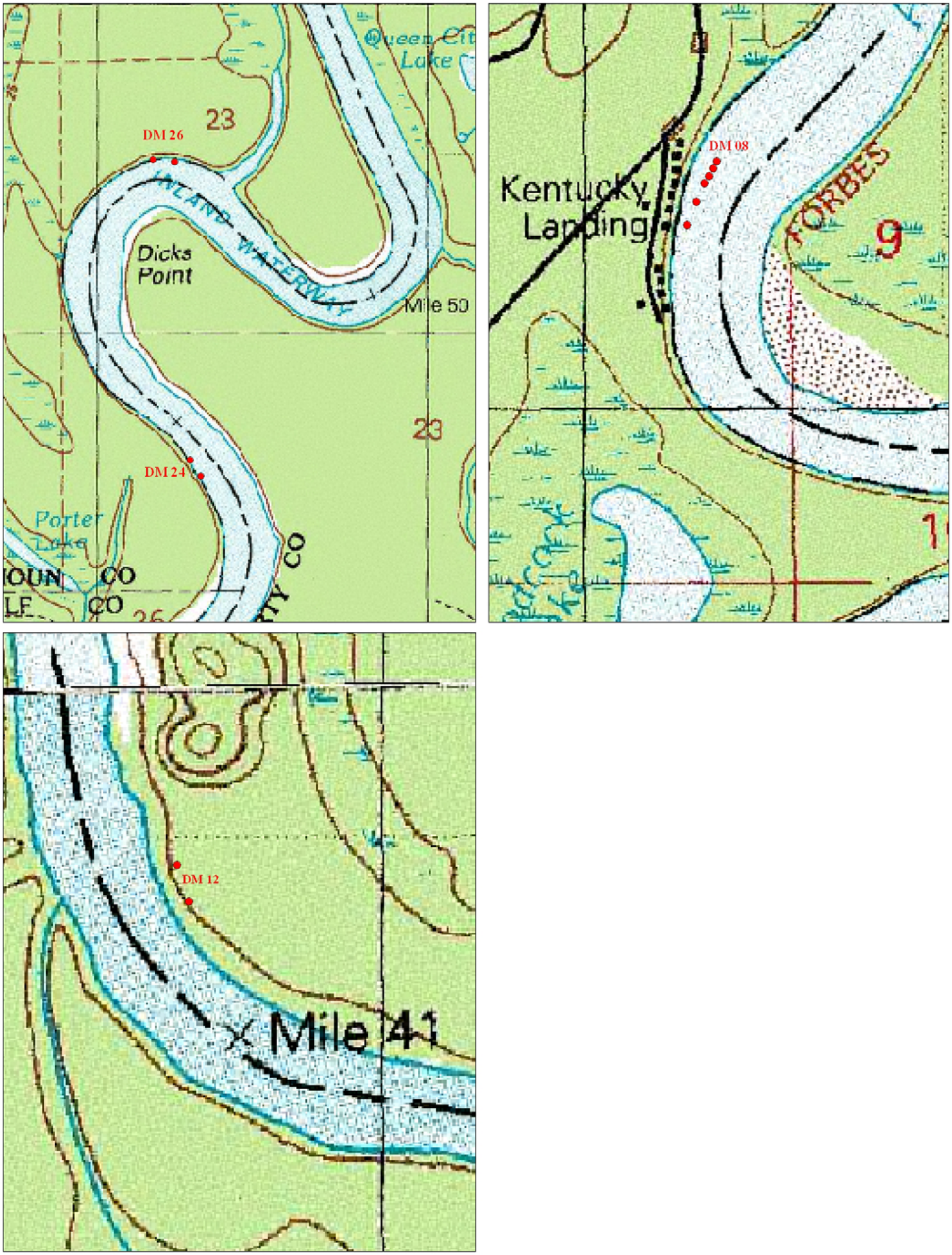
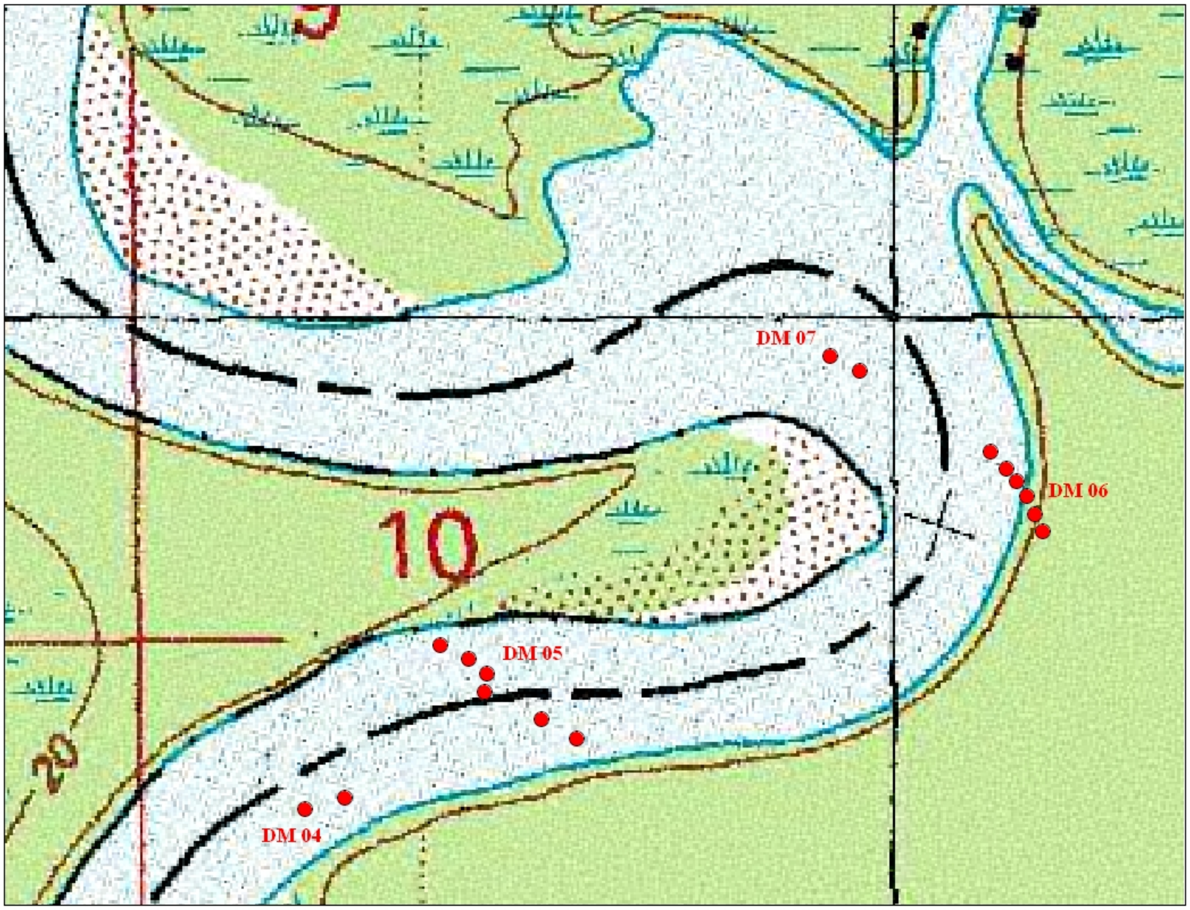


Figure C2. DM24 and DM26 (top left), DM08 (top right), and DM12 (bottom left)



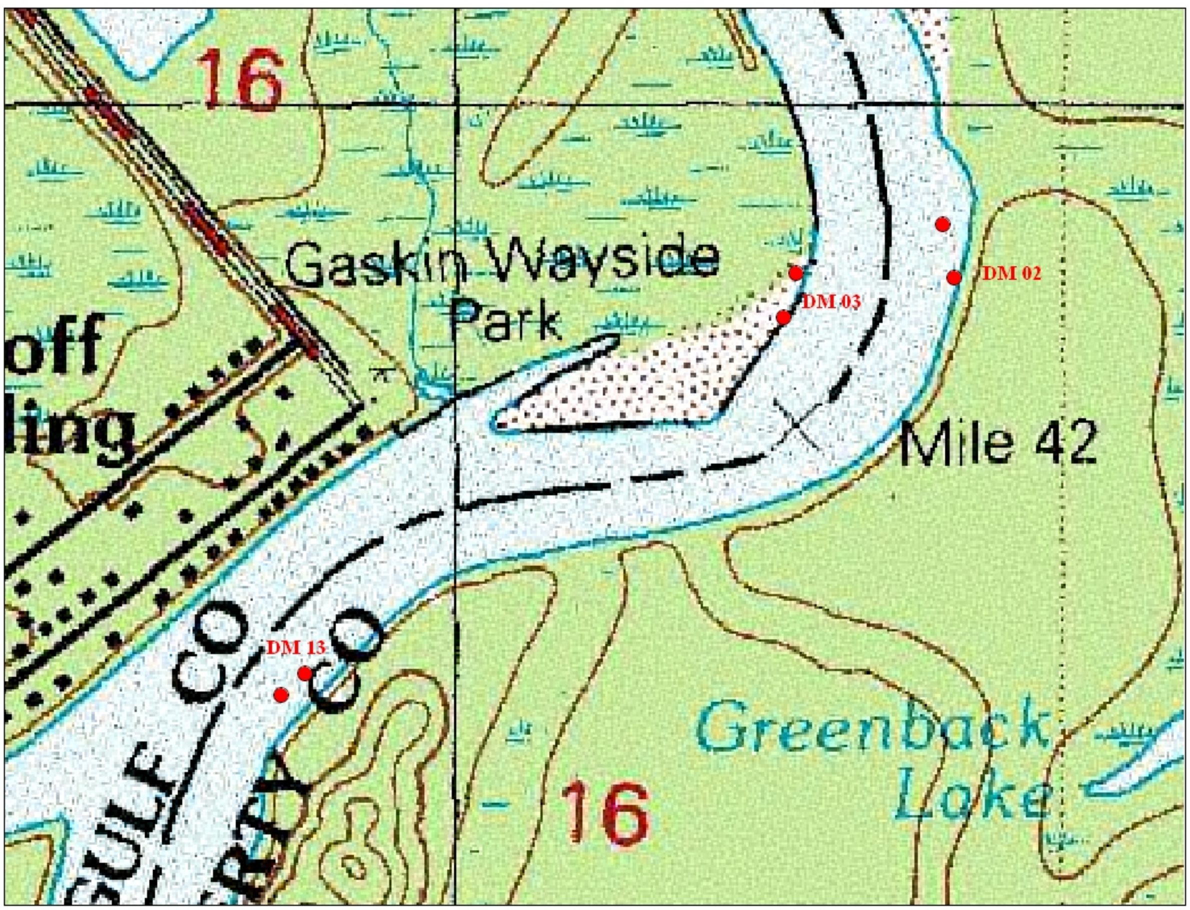


Figure C3. DM04, DM05, DM06 and DM07 (top), and DM13, DM03, and DM02 (bottom)

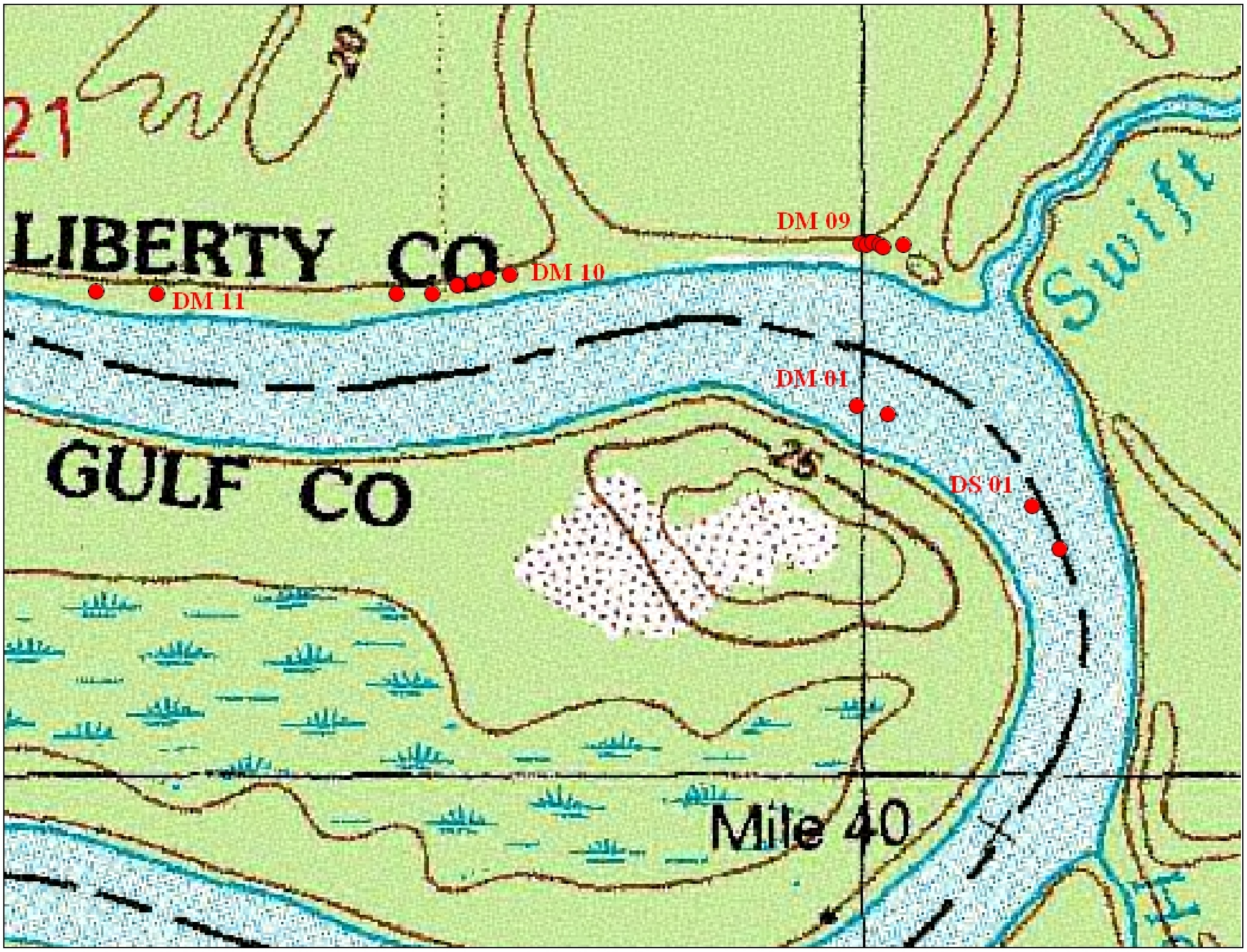


Figure C4. DS01, DM01, DM09, DM10, and DM11.