APPENDIX F

CORPS RPM4 AND RPM5 SUBMITTAL

30 AUGUST 2007

DEPARTMENT OF THE ARMY
MOBILE DISTRICT, CORPS OF ENGINEERS
P.O. BOX 2288
MOBILE, ALABAMA 36628-0001

August 30, 2007

REPLY TO
ATTENTION OF:

Inland Environment Team
Planning and Environmental Division

Ms. Gail Carmody
Field Supervisor
U.S. Fish and Wildlife Service
1601 Balboa Avenue
Panama City, Florida 32405-3721

Dear Ms. Carmody:

On September 5, 2006 the U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BO) and Conference Report for the Jim Woodruff Dam Interim Operations Plan (IOP), pursuant to Section 7 of the Endangered Species Act (ESA). This letter transmits our sediment transport and channel stability evaluation and listed mussel monitoring plan in accordance with Reasonable and Prudent Measure No. 4 (RPM4) and Reasonable and Prudent Measure No. 5 (RPM5) of the BO. RPM4 is intended to improve our understanding of the channel morphology and the dynamic nature of the Apalachicola River as it relates to potential for impacts to listed mussel habitat. RPM5 includes a requirement to evaluate ways to minimize take of listed mussels by studying the distribution and abundance of the listed mussels in the action area. The specific terms and conditions for the two RPMs are included in Enclosure 1.

The BO specifies March 30, 2007 as the date for completion of both the RPM4 and RPM5 actions. By letter dated March 30, 2007 (Enclosure 2), your office agreed to extend the completion date to August 30, 2007 and requested a work schedule for completing the two RPMs. In addition, you requested that we initiate mussel sampling this summer as part of and in support of the mussel monitoring plan. In our letter dated May 11, 2007 (Enclosure 3) we provided the requested information and agreed to initiate a mussel sampling effort this summer. The following describes our actions with regards to RPM4 and RPM5.

Reasonable and Prudent Measure No. 4

RPM4 requires an evaluation of the sediment dynamics and channel morphology trends on the Apalachicola River in order to improve our understanding of dynamic conditions and monitor the zone at which take may occur, and to identify possible alternatives to minimize effects to listed mussels in vulnerable locations. The Terms and Conditions of the BO specify that Mobile District and USFWS will consult with experts, jointly identified by both agencies, to assist in identifying the current status of sediment transport and channel stability in the Apalachicola River as it relates to the distribution of listed mussels and their vulnerability to low-flow conditions. The goals of the evaluation are to identify: 1) feasible water and/or habitat management actions that would minimize listed mussel mortality; 2) current patterns and trends in morphological changes; and, 3) additional information needed, if any, to predict morphological changes that may affect the listed mussels. This evaluation is to be based on available information and tools and best professional judgment.

As a result of previous discussions at our October 2006 and March 2007 semi-annual meetings, we mutually identified three specialists with specific river sediment transport and morphology expertise (Mr. Kirk Vincent, geomorphologist from Department of Interior; Dr. David Biedenharn, sediment transport specialist formerly from the U.S. Army Corps of Engineers Engineering Research Development Center (ERDC), and Dr. Michael Harvey, geomorphologist from the private sector). Additionally, Dr. Andrew Miller, a malacologist formerly from ERDC, with extensive experience regarding freshwater mussels in the Apalachicola River and other large river systems was also identified for participation in this effort. On April 9, 2007, Mobile District and USFWS conducted a teleconference with the potential specialists to determine their availability and willingness to assist in this effort, and to outline the evaluation goals and expectations. Mr. Vincent indicated that he would not be available to participate, but that he could provide comment and review as time allowed. A copy of this letter will be provided to Mr. Vincent for review. All the other specialists were available for the evaluation and their services were procured by Mobile District. Following the teleconference, specific background information was provided to the river specialists to familiarize them with the Apalachicola River and the data available.

We held an initial meeting with Mr. Jerry Ziewitz of your staff and the river and mussel specialists in June 2007, which included a two-day reconnaissance field visit to the Apalachicola River. The field trip consisted of a visual inspection of the entire river from the dam down to the mouth and included numerous stops to more closely investigate sediment sources, potential mussel habitat, and known mortality sites from 2006. During the trip Dr. Miller and Mr. Ziewitz described mussel life history and habitat requirements to the river specialists, and led tours of sites known to provide relatively high, moderate, and low mussel densities. A considerable amount of time was spent discussing the "preferred habitat" at various scales (macro, meso, micro, as well as temporal). A follow-on workshop was held in August 2007, and the individual river specialists shared with both our agencies their observations regarding changes in the river sedimentation and morphology, and opinions regarding any patterns or trends in these processes. Dr. Miller and additional mussel experts from ERDC (Mr. Mark Farr and Mr. Mark Antwine), also provided insight into mussel habitat requirement and mussel responses to predicted or observed riverine sediment or morphological changes. The Memorandum for Record (MFR) for this workshop is provided in Enclosure 4.

Based on review of existing information, the reconnaissance field trip, presentations and discussions at the August workshop, and the summary of findings reports prepared by the river specialists and malacologist, we believe the current version of the IOP adequately meets the intended goal of minimizing or avoiding adverse impacts or providing support to listed species occurring in the Apalachicola River. As documented in the BO, the flow regime in the Apalachicola River has not been changed significantly between the pre- and post- dam periods. The river appears to be in a relatively stable dynamic equilibrium. The morphology of the river could have been impacted over time by land use changes, upstream impoundments and consumptive use of water, and tectonic movement, as well as channel alterations, meander cutoffs, and channel dredging and snagging operations. Obvious channel degradation impacts are noted below Jim Woodruff Lock and Dam immediately after construction. However, these impacts appear to be reduced through time. Data from the Blountstown and Wewahitchka gages downstream of the dam indicate that there was a small change in low flow water surface elevations at those sites in response to Jim Woodruff construction, but the changes appear to have stabilized. Field observations and data analysis by the river specialists suggests that the river is not continuing to degrade and that it may have attained a state of relative equilibrium. This is consistent with the findings of Light et al. (2006) who concluded that channel conditions had been relatively stable for the past ten year period (1995-2004). Although a large portion of the middle river (River Mile (RM) 78 to RM 35) is very sinuous and actively meandering, maximum erosion rates on the outside of the bends in this reach are low compared to other large alluvial rivers and appear to be part of the natural down-valley meander migration which is common to most meandering streams. This does not appear to be the result of continuing post-dam system-wide adjustment such as degradation, aggradation, or channel widening. It appears unlikely that erosion rates will increase over time unless there are significant changes of the flow regime or reduction in sediment supply. Additional studies that further investigate the river widening phenomenon reported by the USGS based on comparative treeline analysis and sediment budget for the river could provide additional insight into whether or not the river has achieved a somewhat dynamic equilibrium. These studies might include development of a one-dimensional sediment continuity model for the river. Perhaps more importantly, additional studies could also be conducted to better understand the spatial and temporal relationships between the meander dynamics of the river and the formation and maintenance of high quality mussel habitat. A two-dimensional hydrodynamic model could be developed for specific sites. A recommendation for this type of study has been incorporated (Phase III) into the proposed mussel monitoring plan described below.

Reasonable and Prudent Measure No. 5

RPM5 requires monitoring of the level of take associated with the IOP and an evaluation of ways to minimize take by studying the distribution and abundance of the listed mussels in the action area. Information from the monitoring of mussel distribution and degree of vulnerability over time will be used to prepare biological assessments for future consultations related to water management operations. The goals of the mussel monitoring plan are to 1) periodically estimate total abundance of listed mussels in the action area; and 2) determine the fraction of the population that is located in habitats that are vulnerable to low-flow impacts. Mobile District collaborated with Dr. Miller and mussel specialists at ERDC in the development of a long-term mussel monitoring plan. As mutually agreed in our March 1, 2007 semi-annual meeting, we integrated the efforts for development of this plan with the observations and evaluations presented by the above sediment/morphology river specialists. Therefore, the mussel specialists were included in the river field inspection and follow-on workshop. Your letter extending the due date for development of the mussel monitoring plan also requested that additional mussel sampling of the distribution of mussels in potentially vulnerable areas be conducted this spring or summer, and that information from the mussel sampling effort be used to assist in developing a more comprehensive monitoring plan.

On May 31, 2007, representatives from your office, the Corps, Florida Fish and Wildlife Conservation Commission (FWCC), and Dr. Drew Miller conducted a field investigation to develop a survey methodology that would support improving our understanding of *Amblema neislerii* densities in areas potentially vulnerable to stranding during low flow conditions similar to those experienced in the summer of 2006. The field trip included inspections of areas of known mussel populations, areas where mussel stranding occurred in 2006, and previously unknown areas that supported the following identified mussel habitat conditions: moderately depositional, low to moderate slope towards thalweg (10 – 20 degrees), silty-sand substrate, and relatively new willow growth. All the areas visited that supported this habitat characteristic were observed to also support *A. neislerii*. During the trip it was agreed that the sampling data to be collected should support an estimate of the density of *A. neislerii* at the sites and that the methods should be repeatable at different flows and locations.

The mussel sampling survey took place on July 7-11, 2007 and focused on habitats occurring between RM 40 and RM 50 on the main channel of the Apalachicola River. The USFWS identified 25 study areas along the river which either supported, or appeared likely to support *A. neislerii*. Ten sites were randomly selected by the USFWS for detailed quantitative study and additional qualitative studies were conducted at the remaining sites. The purpose of the study 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 for the river. A detailed description of the sampling methodology, results, and proposed monitoring plan are provided in Enclosure 5. Based upon qualitative sampling, *A. neislerii* were found at 23 of the 25 areas between RM 40 and RM 50. *A. neislerii* were observed at all 10 of the sites where detailed studies occurred and this species comprised nearly 37 percent of the total mussel fauna. Furthermore, approximately 30 percent of the quadrats (n=180) had at least one individual *A. neislerii* present. There was also evidence of strong recent recruitment.

The results of this and previous surveys suggest that high density, recruiting populations of *A. neislerii* exist in the Apalachicola River and probably always have. Although a few specimens can generally be found in most any aquatic habitat, this species reaches its greatest numerical abundance in habitats with similar meso- and micro-scale hydraulic characteristics. On the Apalachicola River these characteristics include flow separation zones (eddies) at higher flows. These eddy zones result in moderately depositional sites generally occurring on the inside of river bends immediately downstream of point bars. These areas further concentrate fine-grained sediments, organic matter, and if present, glochidia larvae of the mussels. The locations of these types of habitat are likely to change through time and space as the river bends migrate laterally and downriver through the floodplain.

Because of recent low water in 2006, mussel mortality was observed at the mouths of sloughs and in associated swales along the margins of the main channel. Based on the analysis provided by the river specialists and the investigations of these areas during 2007 it appears that most of these "vulnerable" sites are becoming terrestrial habitat due to natural river meandering processes such as erosion and sedimentation. Although mussel habitat is lost during this process, new habitat is generally being created simultaneously, resulting in no net loss of habitat. Mussel mortality has likely always occurred due to this phenomenon and it appears that this species is adapted quite well to recovering from these events as they occur in the Apalachicola River. These mussels represent a dynamic population in a dynamic system and it is important to manage for the whole population and not just individuals. We acknowledge that isolated areas of mortality can and do occur, but based on the channel morphology evaluation and mussel density data it appears that these may not be adverse to the population as a whole. However, additional surveys and studies are needed to more confidently understand the effects of these mortality events on the overall mussel populations. Additional information on channel sedimentation and river morphological changes can also assist in determining whether these trends are increasing or decreasing from historical patterns.

A three-phase monitoring plan has been developed in accordance with the requirements of RPM5 based on the results of mussel surveys and the sediment dynamics and channel morphology evaluations. The purpose of the monitoring plan is to provide a reliable estimate of the total abundance of listed mussels in the action area and determine the fraction of the population that is located in habitats that are vulnerable to low flow. Although numerous mussel studies have been conducted on the Apalachicola River by various groups, this proposed monitoring plan would be the first comprehensive study designed to document overall numbers of federally-protected species (within specified confidence limits); and intensively study biotic and physical processes at selected locations. The three proposed study phases include: 1) Describe the location and areal extent of mussel habitats that are particularly vulnerable to low flow and/or channel migration; 2) Estimate the total abundance of federally-protected mussels in the action area utilizing a stratified random sampling technique, and 3) Investigate the relationship between 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 represents a substantial portion of aquatic habitats that support *A. neislerii*. This information can then be combined with the data collected during the second phase in order to estimate the portion of the population located in vulnerable habitats. The purpose of the second phase is to provide an overall estimate of the total number and distribution of federally-protected mussels in the action area. This study will also demonstrate which meso- and micro-scale habitats support the highest abundances of listed mussels and might therefore warrant additional protection. 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 study will be used to understand the effects of dynamic riverine processes (sedimentation, benthic scour, channel migration) on the long-term survival of mussel populations. All of these studies will ultimately assist planners in determining feasible water and/or habitat actions that minimize listed mussel mortality. A general description of the three phases of this plan is also provided in Enclosure 5. Upon approval of the general plan and the availability of funds, a detailed study plan for these three phases would be developed in late 2007- early 2008 that will specify the number and location of study sites and number of samples to be collected at each site (based on desired precision). The final plan would be coordinated with the USFWS and FWCC to maximize the conservation value of our collective efforts, and avoid unnecessary duplication of effort where possible. The first and second phase studies would begin in 2008 dependent on availability of funds.

The enclosed MFR of the workshop, associated summary of finding documents and presentations, and the mussel survey report and proposed mussel monitoring plan are submitted pursuant to the requirements of Section 7 of the ESA and in accordance with the terms and conditions of the BO. We believe that this sediment dynamics and channel morphology evaluation meets the requirements of RPM4 by: 1) demonstrating that the current IOP minimizes listed mussel mortality to the extent practicable and that additional water and/or habitat management actions are not required at this time based on our current knowledge; 2) describing the current patterns and trends in morphological changes; and, 3) identifying additional studies that could be conducted in order to predict how and to what degree morphological changes affect listed mussels in the action area. We believe the mussel survey report and proposed mussel monitoring plan meet the requirements of RPM5 by providing a feasible plan to monitor listed mussels in the action area and specifically provide a reliable estimate of total abundance of listed mussels and the fraction of the population that occurs in habitats vulnerable to low-flow impacts. Your approval of the general mussel monitoring plan described is hereby requested. As you are aware, the BO recognizes that certain studies and other outreach programs in the RPMs and conservation measures are subject to the availability of funds from the Congress. We will continue to exercise our best efforts to secure funds for these activities. We look forward to discussing these studies and possible implementation schedules with you at the upcoming semi-annual meeting.

A significant amount of time and resources was dedicated by both of our agencies to conduct the sediment dynamics and channel morphology evaluation and to develop the mussel monitoring plan. We especially appreciate the efforts of Mr. Ziewitz, Ms. Karen Herrington, and Ms. Sandra Pursifull to assist our biologists and mussel specialists during development and execution of this summer's mussel sampling effort. I am forwarding a copy of this letter to the following, Mr. Mike Harvey, Mr. David Biedenharn, Mr. Drew Miller, Mr. Jerry Ziewitz, Mr. Kirk Vincent, Mr. Barry Payne and Mr. Mark Farr.

If you have any further questions or comments regarding our operations under the Jim Woodruff Dam IOP and our efforts to minimize or avoid impacts to the listed species on the Apalachicola River, please feel free to contact Ms. Joanne Brandt, (251) 690-3260, Email: joanne.u.brandt@sam.usace.army.mil; or Mr. Brian Zettle, (251) 690-2115, Email: brian.a.zettle@sam.usace.army.mil.

Sincerely,

Curtis M. Flakes
Chief, Planning and Environmental
Division

Enclosures

7.3 REASONABLE AND PRUDENT MEASURES

The Service believes the following reasonable and prudent measures are necessary and appropriate to minimize the impacts of incidental take of fat threeridge and purple bankclimber on the Apalachicola River.

RPM1. Adaptive management. Identify ways to minimize harm as new information is collected.

Rationale. Additional information will be collected about the listed species and their habitats in the action area, water use upstream, and climatic conditions. This information needs to be evaluated to determine if actions to avoid and minimize take associated with the Corps' water management operations are effective or could be improved.

RPM2. Adjust June to February Lower Threshold to 10,000 cfs. Replace the proposed 8,000 cfs threshold in the IOP with a threshold of 10,000 cfs.

Rationale. Mussels may be in vulnerable areas where take may occur when flows are less than 10,000 cfs. Not increasing reservoir storage when basin inflow is 10,000 cfs or less from June to February will avoid and minimize the potential for take in the zone of 8,000 to 10,000 cfs.

RPM3. Drought provisions. Develop modifications to the IOP that provide a higher minimum flow to the Apalachicola River when reservoir storage and hydrologic conditions permit.

Rationale. Take of listed species due to the IOP may occur when the Corps is using a portion of basin inflow to increase ACF reservoir storage. The Corps can minimize mussel mortality due to low-flow conditions by supporting a higher minimum flow when total reservoir storage and/or hydrologic conditions permit. As proposed, the IOP uses reservoir storage to support a 5,000 cfs minimum flow. The available data indicates that higher minimum flows are supportable during normal and wet hydrologic periods, and during dry periods when the reservoirs are relatively full. Conversely, during extended drier than normal conditions, it may be prudent to store more water than allowed under the IOP during certain times of the year to insure minimum water availability later. Possible components and triggers of the drought plan could be, but are not limited to: Corps reservoir action zones, cumulative reservoir storage remaining, total basin inflows, indictors of fish spawn, climatic condition indices, and flow levels at gages downstream of the Chattahoochee gage, such as the gage at Wewahitchka.

RPM4. Sediment dynamics and channel morphology evaluation. Improve our understanding of the channel morphology and the dynamic nature of the Apalachicola River.

Rationale. The dynamic conditions of the Apalachicola need to be evaluated to monitor the zone at which take may occur and to identify alternatives to minimize effects to listed mussels in vulnerable locations. Both sediment transport and channel morphology need to be considered to provide a basis for predicting changes in morphology that may affect the relative vulnerability of mussels to take due to the IOP. The amount of mussel habitat and thus IOP-related take depends on channel morphology. This evaluation will inform alternatives that may be considered under RPM1 and RPM3.

RPM5. Monitoring. Monitor the level of take associated with the IOP and evaluate ways to minimize take by studying the distribution and abundance of the listed mussels in the action area.

Rationale. Take needs to be monitored monthly to insure that the level of take identified in the biological opinion is not exceeded. As natural conditions change, the populations of the species need to be assessed and the amount of take evaluated relative to any new information. Since this is an interim plan and there will be additional consultations on the overall operations of the ACF project for flood control, water supply contracts, hydropower, and navigation, the monitoring information is needed to prepare the biological assessments for these future consultations.

7.4 TERMS AND CONDITIONS

In order to be exempt from the prohibitions of section 9 of the Act, the Corps must comply with the following terms and conditions, which implement the reasonable and prudent measures described above. These terms and conditions are mandatory. Studies and other outreach programs in the RPMs and conservation measures are subject to the availability of funds by Congress. The Corps will exercise its best efforts to secure funding for those activities. In the event the necessary funding is not obtained to accomplish the RPM activities by the dates established, the Corps will reinitate consultation with USFWS.

7.4.1 Adaptive management (RPM1)

a. The Corps shall organize semi-annual meetings with the Service to review implementation of the IOP and new data, identify information needs, scope methods to address those needs, including, but not limited to, evaluations and monitoring specified in this Incidental Take Statement, review results, formulate actions that minimize take of listed species, and monitor the effectiveness of those actions.

b. The Corps shall assume responsibility for the studies and actions that both agencies agree are reasonable and necessary to minimize take resulting from the Corps' water management actions.

c. The Corps shall evaluate refinements to predictive tools.

d. The Corps shall provide an annual report to the Service on or before January 31 each year documenting compliance with the terms and conditions of this Incidental Take Statement during the previous federal fiscal year, any conservation measures implemented for listed species in the action area; and recommendations for actions in the coming year to minimize take of listed species.

7.4.2 Adjust June to February Lower Threshold to 10,000 cfs. (RPM2)

a. The Corps shall immediately release the 7-day moving average basin inflow, but not less than 5,000 cfs, when the 7-day moving average basin inflow is less than 10,000 cfs for the months of June to February, and shall incorporate this revision into the IOP table of minimum discharges.

7.4.3 Drought provisions (RPM3).

a. The Corps, with Service concurrence, shall initiate by January 30, 2007, IOP drought provisions that identify the reservoir, climatic, hydrologic, and/or listed species conditions that would allow supporting a higher minimum flow in the Apalachicola River, and that identify recommended water management measures to be implemented when conditions reach the identified drought trigger point(s).

b. If modifications to the IOP parameters for the months of March through May are adopted as part of the drought provisions, the Corps shall assess potential affects to Gulf sturgeon spawning and floodplain inundation. The Corps shall provide the models and a biological assessment of the effects of the drought provisions on listed species at least 135 days in advance of implementing the drought provisions in order to reinitiate this consultation relative to any proposed changes in the IOP.

7.4.4 Sediment dynamics and channel morphology evaluation (RPM4).

a. In coordination with the Service, and other experts jointly identified, the Corps shall evaluate before March 30, 2007, the current status of sediment transport and channel stability in the Apalachicola River as it relates to the distribution of listed mussels and their vulnerability to low-flow conditions. The goals of the evaluation are to identify: 1) feasible water and/or habitat management actions that would minimize listed mussel mortality; 2) current patterns and trends in morphological changes; and 3) additional information needed, if any, to predict morphological changes that may affect the listed mussels. This evaluation shall be based on available information and tools and best professional judgement.

7.4.5 Monitoring (RPM5).

a. The Corps shall monitor the number of days that releases from Woodruff Dam (daily average discharge at the Chattahoochee gage) are less than the daily basin inflow when daily basin inflow is less than 10,000 cfs but greater or equal to 8,000 cfs. If the total number of days of releases in this range in a calendar year is projected to exceed the total number of days of daily basin inflow in this range by more than 39, the Corps shall reinitiate consultation immediately.

b. In coordination with the Service, the Corps shall develop on or before March 30, 2007, a feasible plan to monitor listed mussels in the action area. The goals are to:
1) periodically estimate total abundance of listed mussels in the action area; and
2) determine the fraction of the population that is located in habitats that are vulnerable to low-flow impacts.

c. The Corps shall implement the studies outlined above as soon as is practicable.

d. The Corps shall include monitoring results in the annual report provided to the Service under Condition 1.c.

The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize the impact of incidental take that might otherwise result from the proposed action. The Service believes that the action will result in no more than 39 days per year when project operations reduce basin inflow when it is in the range of 8,000-10,000 cfs. If, during the course of the action, this level of incidental take is exceeded, such incidental take represents new information requiring the reinitiation of consultation and review of the reasonable and prudent measures provided. The Corps must immediately provide an explanation of the causes of the taking, and review with the Service the need for possible modification of the reasonable and prudent measures.

8 CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the Act directs Federal agencies to use their authorities to further the purposes of the Act by conducting conservation programs for the benefit of endangered and threatened species. Towards this end, conservation recommendations are discretionary activities that an action agency may undertake to minimize or avoid the adverse effects of a proposed action, help implement recovery plans, or develop information useful for the conservation of listed species.

The Service recommends that the Mobile District of the U.S. Army Corps of Engineers:

1. Identify watershed-planning opportunities that would assist in identifying alternatives to reduce overall depletions in the ACF basin, particularly the Flint River, thereby increasing baseline flow to the Apalachicola River.

2. Improve the public understanding of water management of the ACF system, the related conservation needs of listed species, and the management of the multiple purposes of the federal reservoirs.

3. Consider alternatives that would increase flexibility in the management of reservoir storage including the feasibility of flood control alternatives (e.g. moving structures from the floodplain, land acquisition) and providing for recreational access at a variety of pool elevations.

4. Provide additional data and hydrodynamic models that would assist in determining areas of bed stability that should be surveyed for listed mussels.

5. Implement freshwater mussel recovery actions including developing habitat suitability indices, conducting a population assessment of the listed mussels of the Apalachicola River, restoring reaches to provide stable habitat, and validating aging techniques for these species.

6. Use the models developed for the Tri-State Comprehensive Study to determine if changes in flow compared to pre-Lanier flows are significant relative to Gulf sturgeon juvenile growth and if changes in the operation of the reservoirs will benefit Gulf sturgeon recovery.

7. Implement Gulf sturgeon recovery actions such as studies of Gulf sturgeon ecology in Apalachicola Bay and possible effects of reduced basin inflow on the ability of the bay to support sturgeon and providing for fish passage at Jim Woodruff Dam.

8. Establish a clearinghouse for biological and water resource information about the ACF system and make such information readily available in several key locations in the basin.

9. Participate in stakeholder discussions to develop a long-term biological monitoring program for the ACF system and support, as feasible, implementation of a long-term program.

10. Update, as soon as practicable, tools for assessing the effects of ongoing and future system operations, including estimates of basin inflow and consumptive demands. The tools should assist in identifying flows that provide sufficient magnitude, duration, frequency, and rate of change to support the survival and recovery of the listed species in the ACF.

In order for the Service to be kept informed of actions minimizing or avoiding adverse effects or benefiting listed species or their habitats, the Service requests notification of the implementation of any conservation recommendations.

United States Department of the Interior

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IN REPLY REFER TO:

March 30, 2007

Curtis Flakes
Inland Environment Team
Planning Environmental Division
Mobile District, Corps of Engineers
P.O. Box 2288
Mobile, Alabama 36628-0001

Dear Mr. Flakes:

Your letter dated January 31, 2007, which transmitted the "Jim Woodruff Dam Interim Operations (IOP) Plan Biological Opinion (BO) Annual Report" for 2006, requested delaying the completion date for actions required under reasonable and prudent measures 4 and 5 (RPM4 and RPM5) of our September 5, 2006, BO. RPM4 calls for evaluating the current status of sediment transport and channel stability in the Apalachicola River as it relates to the distribution of listed mussels and their vulnerability to low-flow conditions. RPM5 calls for, among other things, developing a plan to monitor listed mussels in the area affected by the IOP. The BO specifies March 30, 2007, as the date for completion of both the RPM4 and RPM5 actions. The BO also includes a provision that the conduct of studies in the RPMs are subject to the availability of funds by Congress; that the Corps will exercise its best efforts to secure funding. You have informed the Fish and Wildlife Service (Service) that the Corps has been operating this entire fiscal year under Continuing Resolution Authority (CRA), which has limited your ability to initiate new work and contracts and delayed the ability of the Corps to initiate these actions. However, you state that you anticipate receiving sufficient funds in the next few weeks to initiate and complete the efforts related to the RPM4 and RPM5 activities this fiscal year. Therefore, your letter requests extending the completion date to August 30, 2007. This letter is our response to your request.

The purpose of an RPM is to minimize the impacts of incidental take. As we explained in the BO, we believe that take of listed mussels associated with the IOP is most likely limited to certain areas of channel instability. The overlapping purpose of RPM4 and RPM5 is to compile information about the threat of continuing channel instability to listed mussel populations that may lead to additional ways to minimize take. This information would be available to assist in developing possible future adaptive modifications to the IOP in accordance with the terms and conditions of RPM1, Adaptive Management. When we completed the BO last fall, the date March 30, 2007, was our agencies' mutual best estimate of a feasible completion date for evaluating channel stability with existing information and for developing a mussels monitoring plan, assuming funds to initiate these efforts would be immediately available. Failing to complete these actions by March 30 does not alter the conclusions of the BO or our estimate of incidental take associated with the IOP. We acknowledge that an RPM cannot require actions inconsistent with an agency's authority and that the CRA has constrained your spending authority. Nevertheless, last year's unusual exposure of mussel beds in the vicinity of Wewahitchka was a clear sign of habitat conditions in transition. RPM4 and RPM5 are intended to assist us in understanding and dealing with these changing conditions. Therefore, we believe the Corps should demonstrate progress on meeting the terms of RPM4 and RPM5 as soon as practicable.

We agree to delay the completion date under RPM4 and RMP5 to August 30, 2007, as you have requested; however, we ask that you coordinate with us on a work schedule that could accelerate the completion of these tasks. Please include in this schedule the steps that you have already taken and can take in the next 30 days to ensure that the scientists you have selected for this work hit the ground running. If you have not already done so, please compile all appropriate information to give to them as soon as possible and organize conference calls to begin the detailed work scoping process in advance of any meetings or site visits. We are available to assist with prioritizing such information and to participate in calls with your scientists.

We had expected to begin implementing a comprehensive mussels monitoring plan in the spring of 2007, and now recognize that is not possible based on funding constraints. However, we ask you to consider providing for some mussel sampling surveys in the scope of work for developing the mussels monitoring plan. Should basin inflow levels fall below 10,000 cfs this summer, it will be useful to know the potential risk of exposure to listed mussels located in vulnerable microhabitats, and this information could be used to assist in developing a more comprehensive monitoring plan.

We note that the BO states that "[i]n the event the necessary funding is not obtained to accomplish the RPM activities by the dates established, the Corps will reinitiate consultation with USFWS." As discussed above, our review of your proposal to extend these deadlines indicates that this extension does not alter the conclusions of the BO or increase the estimate of incidental take associated with the operations described in the IOP. As such, this exchange of letters fulfills the Corps' obligation to reinitiate consultation, and a new formal consultation is not required.

Please contact Jerry Ziewitz at extension 223 for coordinating with us on a schedule for completing the channel stability evaluation and the mussels monitoring plan. We look forward to working with you on these actions.

Sincerely yours,

Gail A. Carmody

Gail A. Carmody
Field Supervisor

DEPARTMENT OF THE ARMY
MOBILE DISTRICT, CORPS OF ENGINEERS
P.O. BOX 2288
MOBILE, ALABAMA 36628-0001

May 11, 2007

REPLY TO
ATTENTION OF

Inland Environment Team
Planning and Environmental Division

Ms. Gail Carmody
Field Supervisor
U.S. Fish and Wildlife Service
1601 Balboa Avenue
Panama City, Florida 32405-3721

Dear Ms. Carmody:

Your letter dated March 30, 2007 extended the due date until August 30, 2007 for implementation of certain activities required by the Biological Opinion (BO) issued by the U.S. Fish and Wildlife Service (USFWS) for the Jim Woodruff Dam Interim Operation Plan; in particular those activities required under reasonable and prudent measure (RPM) 4 and RPM5. The extension was requested due to a delay in receiving fiscal year 2007 funds in U.S. Army Corps of Engineers (Corps), Mobile District, which are necessary to allow the award of the contractual agreements to perform the necessary work. Sufficient funding has now been received by Mobile District to allow us to proceed with the required activities. By this letter, I want to inform you of progress made to date toward implementation of the required RPM4 and RPM5 activities and our schedule for complying with remaining requirements of these RPMs.

RPM4 requires an evaluation of the sediment dynamics and channel morphology trends on the Apalachicola River in order to improve our understanding of dynamic conditions and monitor the zone at which take may occur, and to identify possible alternatives to minimize effects to listed mussels in vulnerable locations. The terms and conditions of the BO specify that Mobile District and USFWS will consult with experts, jointly identified by both agencies, to assist in identifying the current status of sediment transport and channel stability in the Apalachicola River as it relates to the distribution of listed mussels and their vulnerability to low-flow conditions. The goals of the evaluation are to identify: 1) feasible water and/or habitat management actions that would minimize listed mussel mortality; 2) current patterns and trends in morphological changes; and 3) additional information needed, if any, to predict morphological changes that may affect the listed mussels. This evaluation is to be based on available information and tools and best professional judgment. As a result of previous discussions at our October 2006 and March 2007 semi-annual meetings, we have identified three possible specialists with specific river sediment transport and morphology expertise (one river geomorphologist from Department of Interior (DOI), one sediment transport specialist formerly from the U.S. Army Corps of Engineers Research Development Center (ERDC), and one renowned geomorphologist from the private sector). On April 9, Mobile District and USFWS conducted a teleconference with the potential specialists to determine their availability and willingness to assist in this effort, and to outline the evaluation goals and expectations. Following the teleconference, specific background information was provided to the river specialists to familiarize them with the Apalachicola River. We are currently drafting a scope of work for award of a task order to fund efforts by two of the specialists. It is our understanding that USFWS will fund participation of the DOI specialist. We anticipate holding an initial meeting with the river specialists this June, to include a field visit to the Apalachicola River, with mussel specialists to assist in identifying mussel requirements and potentially vulnerable areas. A follow-on workshop is planned for July, at which time the individual river specialists will share with both our agencies their observations regarding changes in the river sedimentation and morphology, and opinions regarding any patterns or trends in these processes. The Corps will prepare a report, in coordination with the USFWS, summarizing our conclusions and recommendations. This summary report is scheduled to be completed by the end of August 2007.

RPM5 requires monitoring of the level of take associated with the IOP and the evaluation of ways to minimize take by studying the distribution and abundance of the listed mussels in the action area. Information from the monitoring of mussel distribution and degree of vulnerability over time will be used to prepare biological assessments for future consultations related to water management operations. The goals of the mussel monitoring plan are to 1) periodically estimate total abundance of listed mussels in the action area; and 2) determine the fraction of the population that is located in habitats that are vulnerable to low-flow impacts. Mobile District has initiated discussions with mussel specialists in our ERDC to assist in development of a long-term mussel monitoring plan. As discussed in our March 1, 2007 semi-annual meeting, we intend to integrate the efforts for development of this plan with the observations and evaluations presented by the above sediment/morphology river specialists. Therefore, the mussel specialists will be included in the river specialists field inspection and follow-on workshop. Your letter extending the due date for development of the mussel monitoring plan requested that additional mussel sampling of the distribution of mussels in potentially vulnerable areas be conducted this spring or summer, and that information be used to assist in developing a more comprehensive monitoring plan. We have incorporated the requested sampling into a draft Scope of Work which was coordinated with Mr. Jerry Ziewitz of your staff and approved in mid-April. We intend to initiate the mussel sampling field work before the end of May and plan to submit a long-term mussel monitoring plan in August 2007.

We believe the above accomplishments and schedule of activities demonstrates that we are working toward implementation of the required activities under RPM4 and RPM5 as expeditiously as practicable, given the funding constraints we have experienced this fiscal year. We plan to continue to work closely with your staff as we develop the additional information that will assist in improving our water management operations and minimizing impact to the listed species.

If you have any additional questions or comments regarding our scope of effort or schedule of activities, please feel free to contact Ms. Joanne Brandt, Senior Environmental Specialist, Inland Environment Team, (251) 690-3260, or email at joanne.u.brandt@sam.usace.army.mil.

Sincerely,

Curtis M. Flakes
Chief, Planning and Environmental
Division

CESAM-PD-EI 27 August 2007

MEMORANDUM FOR RECORD

SUBJECT: Jim Woodruff Interim Operations Plan Biological Opinion –
RPM 4 and 5 Workshop

1. Representatives of the US Army Corps of Engineers, Mobile District (CESAM) met with Jerry Ziewitz of the US Fish and Wildlife Service (USFWS), Panama City Field Office, and specialists in the fields of fluvial geomorphology, riverine hydraulics, and malacology on 14-15 August 2007, to participate in a two-day sediment dynamics and channel morphology workshop. This workshop was a follow-up to a previous two day field reconnaissance inspection by the river specialist and malacologist to the Apalachicola River on 19-20 June 2007, to familiarize the participants with the river process and mussel habitat features. The purpose of the workshop was for the various experts to present the findings of their individual analyses of river sediment and geomorphological trends with respect to mussel habitat requirements; discuss the individual findings with the attendees of the workshop; and present their recommendations regarding the issues identified in Reasonable and Prudent Measures (RPM)4 and RPM5 of the Biological Opinion (BO), issued by USFWS on 5 September 2006. The following representatives participated in the workshop.

Jerry Ziewitz, USFWS	850-769-0552, Ext. 223
Joanne Brandt, CESAM-PD-EI	251-690-3260
Brian Zettle, CESAM-PD-EI	251-690-2115
Mike Eubanks, CESAM-PD-EI	251-694-3861
Doug Otto, CESAM-EN-H	251-690-2718
Cheryl Hrabovsky, CESAM-EN-HW	251-694-4018
Bill Stubblefield, CESAM-EN-HH	251-690-3116
Mark Farr, ERDC-EL-MS	601-634-3049
Mark Antwine, ERDC-EL-MS	601-634-3224
Dr. Andrew Miller, Ecological Applications	850-878-7653
Dr. David Biedenharn, Biedenharn Group	601-636-3492
Dr. Michael Harvey, Mussetter Engineering, Inc.	970-224-4612, Ext. 103

2. The participants provided a brief introduction of themselves and then Mr. Zettle discussed the workshop agenda and provided a review of the workshop goals, the Jim Woodruff Dam Interim Operations Plan Section 7 consultation, and the requirements of the RPM's. The following summarizes the RPM4 and RPM5 issues addressed during the workshop:

RPM4. Sediment dynamics and channel morphology evaluation. Improve our understanding of the channel morphology and the dynamic nature of the Apalachicola River.

Rationale. The dynamic conditions of the Apalachicola need to be evaluated to monitor the zone at which take may occur and to identify alternatives to minimize effects to listed mussels in vulnerable locations. Both sediment transport and channel morphology need to be considered to provide a basis for predicting changes in morphology that may affect the relative vulnerability of mussels to take due to the IOP. The amount of mussel habitat and thus IOP-related take depends on channel morphology. This evaluation will inform alternatives that may be considered under RPM1 and RPM3.

a. In coordination with the Service, and other experts jointly identified, the Corps shall evaluate before March 30, 2007, (**extended to August 30, 2007**) the current status of sediment transport and channel stability in the Apalachicola River as it relates to the distribution of listed mussels and their vulnerability to low-flow conditions. The goals of the evaluation are to identify: 1) feasible water and/or habitat management actions that would minimize listed mussel mortality; 2) current patterns and trends in morphological changes; and 3) additional information needed, if any, to predict morphological changes that may affect the listed mussels. This evaluation shall be based on available information and tools and best professional judgment.

RPM5. Monitoring. Monitor the level of take associated with the IOP and evaluate ways to minimize take by studying the distribution and abundance of the listed mussels in the action area.

Rationale. Take needs to be monitored monthly to insure that the level of take identified in the biological opinion is not exceeded. As natural conditions change, the populations of the species need to be assessed and the amount of take evaluated relative to any new information. Since this is an interim plan and there will be additional consultations on the overall operations of the ACF project for flood control, water supply contracts, hydropower, and navigation, the monitoring information is needed to prepare the biological assessments for these future consultations.

b. In coordination with the Service, the Corps shall develop on or before March 30, 2007, (**extended to August 30, 2007**) a feasible plan to monitor listed mussels in the action area. The goals are to: 1) periodically estimate total abundance of listed mussels in the action area; and 2) determine the fraction of the population that is located in habitats that are vulnerable to low-flow impacts.

3. Dr. Biedenharn (riverine hydraulic engineer) provided a presentation outlining his observations and recommendations regarding a) current patterns and trends in morphological changes; b) possibly feasible water and/or habitat management actions that might minimize listed mussel mortality; and c) additional information needed, if any, to identify trends and/or predict future morphological changes that may affect listed mussels. Dr. Biedenharn's evaluation was based on the reconnaissance field trip conducted on the river in June and his review of the existing data provided by the Corps. Dr. Biedenharn's evaluation is provided in the Summary of Findings report he drafted (see enclosure). However, a brief summary of his observations and resultant discussions is provided below. For the purpose of discussion, the river was divided into three reaches similar to those adopted by USGS in their reports regarding river level decline and floodplain connectivity: Reach 1 (Upper reach) extends from the dam at RM 106 down to RM 78; Reach 2 (Middle reach) extends from RM 78 to RM 35; Reach 3 (Lower reach) extends from RM 35 to the mouth of the Apalachicola River.

- The flow regime has not changed significantly since the upstream dams were constructed. This is somewhat atypical since reservoirs generally reduce downstream flood flows and increase low flows. If the dam does not alter the flow regime significantly, then the effects of bed material retention may be more pronounced (i.e., bed degradation and channel widening).
- It appears that the primary impact of the construction of the upstream dams is trapping bed material sized sediments. However, it is unknown how much sediment is moving through the dam. The upper reach of the river provides evidence that a sediment deficit is occurring, but we don't know how large the deficit is. Bed degradation of 4-5 ft has occurred throughout the reach, but appears to have stabilized now. This reach is relatively straight with little sediment storage and appears to be locally controlled both vertically and laterally by limestone outcrops (natural toe protection). A sediment budget could be calculated for the river in order to assess the magnitude of the sediment deficit.
- It's interesting to note that the river slope remains fairly constant between the three reaches. The middle reach is a much more active meandering channel with a high sinuosity. Coincidentally, this reach has the largest erosion rates of the three. However, based on visual observations and cursory data review, this erosion appears to be part of the natural down-valley meander migration which is common to most meandering streams, and does not appear to be the result of some post dam system-wide adjustments such as degradation, aggradation, or channel widening.
- The middle reach has also degraded approximately 1-2 feet, but there is considerable sediment storage in this reach as evidenced by the large point bars. It appears that most of the dam induced channel degradation is limited to Reach 1.
- The processes responsible for the apparent increase in the percent of flow (25% to 34%) diverted at the Chipola Cutoff warrants further study. Dr. Harvey noted that a paper written by Odom in 1966 stated that approximately 35% of the flow was diverted down the Chipola Cutoff at that time. This flow of relatively "clean" water down the Chipola River may be contributing to sediment aggradation and past dredging efforts in the Apalachicola River between the cutoff and RM 35.
- Comparison of the USGS calculated 1941 and 2004 channel widths (based on treeline) indicate that channel widening is occurring throughout the river down to RM 20, and is especially prevalent in portions of the middle reach. Further analysis is needed to determine if these width increases are real, and if so, what the factors responsible for them are. It was also noted by Mrs. Brandt that some of the areas demonstrating the greatest increase in width appear to be associated with anthropomorphic impacts such as meander cutoffs or other navigation activities. Dr. Harvey noted that the relatively low erosion rates observed on the river do not support the theory of rapid widening. Perhaps some of the widening is a long-term result of snagging and removal of woody debris dams that were prevalent in the past.
- The lower reach is less sinuous and has been less impacted by bed degradation. Bed degradation in this reach is likely attributable to local meander cutoffs.
- It appears there is a correlation between good mussel habitat and the highly sinuous reach in the middle river. However, we must recognize that scale (macro, meso, micro, temporal, spatial) plays an important role in interpreting the impacts of river processes on mussels and their habitat. Mr. Farr noted that mussels represent a dynamic population in

a dynamic system and we must manage for the whole population and not just individuals. Isolated areas of mortality can and does occur, but may not be adverse to the population as a whole.

- Preferred mussel habitat appears to occur in the lower energy environments associated with the flow separation zones (eddies) in the transition between meander bends. However, the size and location of the eddy zones change with flow and through time as the meanders migrate though the floodplain. Eddies, and consequently mussel habitat, are constantly being destroyed and created through the natural process of meander migration. Based on the erosion rates and the movement of the bank lines, it appears that there is no net change in the amount of suitable mussel habitat over time.
- The mussel mortality sites at RM 44.3 and RM 43.6 appear to be the result of the natural migration of the channel and not some systematic channel changes. A discussion of whether or not the rate of change in the spatial extent of these habitats has been altered by water management decisions followed. The similarities in the pre- and post-dam construction period flow regimes suggest that this is not likely the case, but additional studies need to be conducted to verify.
- The mussel stranding in Swift Slough appears to be the result of deposition of sands from the river. It appears that a sand bar has moved to the entrance of Swift Slough and may be the source of the sediment. However, a more detailed analysis of this area is needed to establish the exact processes responsible for this situation.
- Dr. Biedenharn made the following recommendations regarding additional study efforts:
    - Perform eco-geomorphic assessment of the system to fully develop how the system has responded in the past and where it is today with emphasis on the connection between the morphology and mussel habitat;
    - Build a relatively simple 1D sediment continuity model (possibly SIAM) of the river. This would provide the big picture assessment of the entire river system below Jim Woodruff dam with respect to sediment continuity, channel stability, impacts of flow diversions, etc.; and
    - Build a 2D hydrodynamic model for selected reaches. This model could be used to link detailed hydrodynamic processes to the mussel assemblages.

4. Dr. Harvey (Geomorphologist) followed Dr. Biedenharn with a presentation sharing many of the same conclusions. A brief summary of further explanations or differences in opinion is provided below. A detailed description of Dr. Harvey's evaluation is available in the Summary of Findings report he drafted (see enclosure). Dr. Harvey utilized slightly different reach delineation as Dr. Biedenharn. Reach 1 (Upper reach) extends from the dam down to RM 78; Reach 2 (Middle reach) extends from RM 78 to RM 42; Reach 3 (Non-tidal Lower reach) extends from RM 42 to RM 20.

- In the upper reach, the bed has degraded about by about 5 feet near the dam and by about 2 feet at Blountstown and the bed material has coarsened, both of which are river responses that are consistent with upstream dam construction.
- It is unclear, based on field observations and the uncertainty associated with measuring treeline width of the main channel, if river widening reported by USGS has actually occurred in this reach (and others) or to the extent which has been reported. Analysis of the comparative bank lines does not indicate much lateral adjustment of the channel in

this reach. This is likely due to the presence of numerous limestone outcrops throughout the upper reach.

- Very little sediment storage occurs within this reach, except between RM 77.2 and RM 78.8 where annual dredging occurred in the past. The observed bed degradation and the limited amount of sediment stored in the numerous dike fields in the reach indicate that the reach was supply limited following construction of the dam.
- The middle reach of the river is very sinuous and the banks are composed of a mixture of cohesive and non-cohesive sediments that exhibit widespread erosion on the outside of bends. The very high sinuosity of the river in the middle reach appears to be the result of the river responding to active tectonics. The axis of the northeast –southwest trending Gulf Trough geologic structure crosses the Apalachicola River near the confluence with the Chipola River at about RM 27. The steeper valley floor (0.00018) on the down-dip side of the trough between about RM 78 and RM 35 requires the river sinuosity to be higher (1.92) to balance the river slope (0.000094) and thus the sediment continuity.
- The bed has degraded approximately 1 to 2 feet within the reach, but there is no evidence that the bed material has coarsened.
- The degree of channel widening reported by USGS for this reach was also questioned. Field observations indicate that bank erosion is limited to the outside of bends as expected for sand bed rivers. Comparative bank lines (1941, 1963, 1993, 1999, 2002) clearly indicate that the bends within the middle reach are migrating laterally and down-valley as a result of cutbank erosion and point bar deposition. The USACE previously reported that erosion rates were highest where the radii of curvature of the bends were smaller, and accordingly, the highest erosion rates were located in the most sinuous portion of the river (between RM 40 and RM 60). The findings of the USACE study are totally consistent with the literature on erosion rates on meandering rivers. Further analysis including the addition of the channel widths to the USACE radii of curvature and erosion rate data for the studied bends permits the Apalachicola River data to be compared with data from other rivers. The maximum erosion rates are associated with radius of curvature to channel width ratios (R/W) of between 1.5 and 2.5, which is consistent with the literature. Dr. Harvey noted that these maximum erosion rates (about 10 ft/yr) are consistent with those calculated for the Alabama River, but are very low in comparison with those reported for other large alluvial rivers. Erosion rates in this range do not suggest that bank erosion on the middle reaches of the Apalachicola River is in response to an upstream sediment deficit. Bank erosion appears to be consistent with what is to be expected for sand bed meandering rivers.
- The upper portion of the lower reach (RM 42 – RM35) is very sinuous and the banks exhibit widespread erosion on the outside bends leading to active channel migration. As stated previously this appears to be the result of the river responding to active tectonics. This high sinuosity could also be due to the diversion of about 35% of the flow (and very little of the bed material load) into the Chipola Cutoff (RM 41.5). This diversion effectively increases the sediment supply to the upper portion of the lower reach which in turn accelerates the meander processes. Below RM 35 the sinuosity is much lower and there is little evidence of channel migration.
- Stage data at the Sumatra gauge do not indicate that the bed of the river has degraded or the channel has widened in the post-dam period and there is no evidence that the bed material has coarsened.

- There is concern regarding the USGS reports that significant widening has occurred in throughout the Apalachicola River. Given the uncertainty associated with these measurements (Smith and Vincent, 2004) and the extensive presence of dredge material disposal sites, especially within the reach between RM 35 and RM 42 that limit vegetation recovery, it is unclear whether the river has actually widened in this reach in the post-dam period. Field observations do not indicate that both channel banks are eroding along the reach, rather the bank erosion is limited to the outside of bends, which is to be expected.
- Fat threeridge mussel habitat appears to be associated with eddy deposits (downstream end of bends, backwater bars, dike fields). Qualitative sampling data for the fat threeridge mussel in the Apalachicola River appear to support the hypothesis that the fat threeridge habitat is formed and maintained by meander processes. These types of habitat are ephemeral and change with time and space. Rates of change are a function of the frequency and magnitude of flood events. Distributary channels (e.g. Swift Slough) which can support mussels are also ephemeral features and are expected to become disconnected or fill in with sediment as the channel migrates through the floodplain. However, these active meander processes are likely to create new channels as the older distributary channels are eliminated. Dr. Harvey noted that based on the qualitative sampling data from the dike field at RM 47.4, it appears that suitable habitat can be created if amount of habitat available is deemed a limiting factor.
- The mortality occurring at sites located along the mainstem of the river and Swift Slough in 2006 appear to be related to deposition of sandy bed material and can be explained by the dynamics of the river.
- Dr. Harvey noted that the erosion rates within the highly sinuous reach are low in comparison to other alluvial rivers and are unlikely to increase over time under the current operations of the system. Bends with low radii of curvature (RM 62, RM 50, RM 43, RM 40, and RM 38) could cutoff in the not too distant future (dependent on hydrology). This would result in reduced sinuosity and increased hydraulic slope.
- Available data do not indicate that the river is continuing to degrade, and in fact the uniformity of the average channel slopes in all three reaches (0.000093 – 0.000095) suggests that the river may have attained a measure of equilibrium. This hypothesis should be further tested by development of a sediment budget for the river.
- Additional studies are needed to speculate on future trends in channel width as there is some uncertainty in the comparative channel width measurements utilized to date. If the channel is indeed widening, then the river processes or anthropomorphic means responsible need to be determined.
- Dr. Harvey made the following recommendations regarding additional study efforts:
    - Conduct an in-depth quantitative geomorphic assessment of the river between the dam and RM 20;
    - Develop a one-dimensional sediment continuity analysis using the SIAM computer code;
    - Develop two-dimensional hydrodynamic models of selected listed mussel habitat sites located: 1) downstream of a bend, 2) in association with a backwater-induced bar complex, and 3) in the upper reach of a distributary channel; and
    - In conjunction with the mussel experts use the results of the above to develop a biological process-physical response model that can be used to predict the

impacts of water management operations at Jim Woodruff Dam on fat threeridge mussel habitat.

5. Dr. Miller concluded the first day of the workshop with a presentation on the sampling efforts he conducted this summer and a recommendations for long-term studies.

- Dr. Miller provided a brief review of fresh water mussels and the fat threeridge in particular. He followed this with a discussion on the methodology and results of this summer's sampling.
- Based on the May 2007 reconnaissance field trip conducted by representatives of the Mobile District, USFWS, and FWCC, personnel of the USFWS identified 25 study areas between RM 40 and 50 along the Apalachicola River which either supported, or appeared likely to support *A. neislerii*. Detailed field studies were conducted at the 10 randomly selected sites and partial (qualitative) studies were conducted at most remaining sites (23 total). In addition, one new site (DS01) was added at a disposal area of interest at the downstream extent of the reach. 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, or 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.
- *A. neislerii* was found at 23 of the 25 areas between NM 40 and 50. This species comprised nearly 37% of the mussel fauna and at least one individual was present in approximately 30% of the 180 quadrats sampled. Dr. Miller noted that it is unusual to have an endangered species dominate the mussel assemblage.
- Total mean density of *A. neislerii* ranged from 0.2 to 12.7/m^2. 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.
- 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. 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 estimated at 19,000 individuals. It is likely that this strip is wider than 1 meter and extends into deeper water. 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*.
- There was evidence of strong recent *A. neislerii* recruitment at the sample sites. *Amblema neislerii* is most abundant close to shore and becomes less common moving offshore.
- Dr. Miller agreed that the 2006 mortalities observed during low water conditions appear to be the product of natural river processes. He also noted that Swift Slough supported substantial mussel populations prior to 2006. 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 off channel habitat contributed substantially to *A. neislerii* populations in the river (since this species is more prolific in main stem large river

channels). 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.

- 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. Long-term monitoring should be conducted, including sediment and velocity modeling, in order to provide a better understanding of the distribution and abundance of *A. neislerii* in the Apalachicola River.
- Dr. Miller recommended the following types of long-term study:
    - Knowledge of riverine geomorphic processes is needed to understand effects of reduced flow on the density and distribution of important mussel resources. Three sites that support dense and species rich mussel assemblages would be selected for intensive long-term study and sediment and hydrodynamic models could be used to identify site specific habitat conditions relative to the mussel distribution. The models could also be used to demonstrate how biologically important parameters change in response to various flows and river processes.
    - Conduct stratified random sampling across the various types of mussel habitat in the river in order to estimate mussel population distribution and abundance.

6. The second day (half day) of the workshop consisted of open discussion of the previous day presentations. Specific discussions included:

- Large sample sizes are sometimes required to reach acceptable confidence margins for population estimates.
- Current data suggests that *Amblema* population in Apalachicola River is relatively robust.
- A stratified random design is appropriate for estimating mussel abundance in the river.
- The stratified random design could be accomplished by 1) mapping potential mussel habitat areas (eddies etc.); 2) sorting the habitat by specific type; 3) randomly sampling subgroups from each habitat type; and 4) apply density estimates from samples to amount of habitat available for each type.
- Additional studies could include looking at habitat change over time and mussel response, as well as, using 2D models that measure velocity, vector, and bed sheer stress to understand site specific mussel "hot spots".
- Mark Antwine mentioned that recent satellite imagery could be purchased and utilized to determine the amount of vulnerable habitat compared to relatively stable habitat. This would help verify the theory that the 2006 mortality sites represent only a small portion of the suitable mussel habitat.

- Jerry Ziewitz suggested that we should coordinate our mussel sampling strategy with Florida's plan in order to avoid duplication of effort and perhaps be able to produce more refined population estimates. He will facilitate these discussions.
- Dr. Harvey and Dr. Biedenharn agreed to edit their Summary of Findings reports and provide final copies the following week.
- Dr. Miller agreed to edit and incorporate the sediment sampling data and new study recommendations into his long-term monitoring proposal and provide a draft copy the following week.

Encl
Agenda
Presentations
Reports

BRIAN ZETTLE
Biologist
Inland Environment Team

Jim Woodruff Dam Water Management Operations
Section 7 Consultation
RPM4 - Sediment Dynamics and Channel Morphology Evaluation
5 Rivers - Alabama's Delta Resource Center
Spanish Fort, Alabama
14-15 August 2007
9:00 a.m.

Workshop Objectives:

- Provide written and oral Summary of Findings documenting geomorphology/sediment transport specialist's individual assessments of the stability of the river, shoaling trends, sediment transport characteristics, and possible reasons for anomalous features (e.g.; shoaling on the outside of some bends) as they relate to the distribution of listed mussels and their vulnerability to low-flow conditions.

- Provide assessment of:
  1) current patterns and trends in morphological changes;
  2) feasible water and/or habitat management actions that might minimize listed mussel mortality; and
  3) additional information needed, if any, to identify trends and/or predict future morphological changes that may affect listed mussels.

- Provide opportunity for mussel specialist and geomorphology/sediment transport specialists to interact with the Corps, USFWS, and each other regarding questions specific to their field of knowledge.

- Provide an opportunity for clarification and understanding of the Summary of Findings.

- Provide an opportunity for the USFWS to evaluate and draw independent conclusions regarding the Summary of Findings as well as verify that the study efforts meet the intent of RPM4.

<u>August 14</u>

Brian Zettle	**Welcome, Introductions, Opening Comments**
Brian Zettle	**Review Workshop Goals, Agenda, and Ground Rules**
Brian Zettle/Jerry Ziewitz	**Section 7 Consultation / RPM4**
Dr. David Biedenharn	**Summary of Findings, Questions and Answers**
Dr. Michael Harvey	**Summary of Findings, Questions and Answers**
Dr. Andrew Miller	**Summary of 2007 Mussel Study, Questions and Answers**

<u>August 15</u>

ALL	**Open Discussion On All Presentations And How They May Relate To Recommendations For Future Actions; and Elements To Be Included In The Final Report Of Findings To USFWS**

[This workshop is scheduled for 2 days. Discussions will be open-ended, but the intention is to cover all material by the end of the second day. There will be a lunch break and two other brief breaks scheduled during each day.]

Directions: 5 Rivers is located across from Meaher State Park on the Mobile Bay Causeway (US Highway 90/98) in Spanish Fort, about five miles from downtown Mobile.

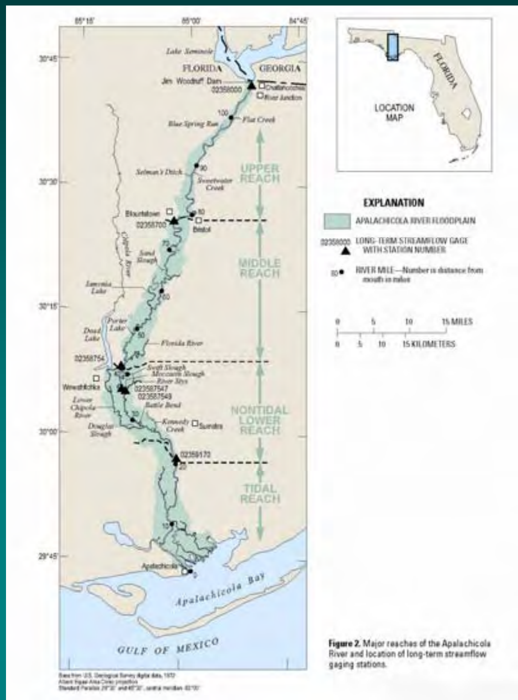
FROM PENSACOLA:
I10 West, take Exit 35 (Daphne-Fairhope)
Cross by the overlook on Hwy 98, go to top of hill to red light
Go straight across, and merge into Hwy 90/98, also called Battleship Parkway
Cross over Blakeley River
Turn right onto 5 Rivers Blvd, directly across from Maeher State Park.
Follow the road and signs into the property.

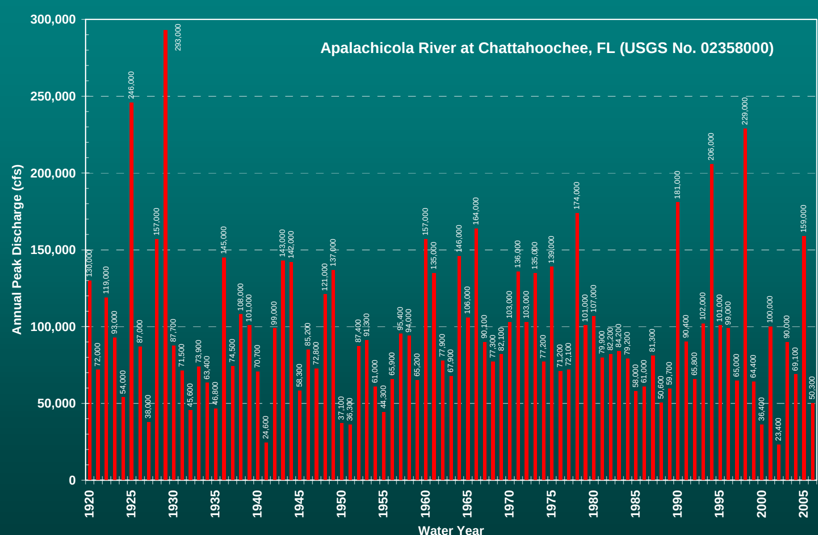
FROM MOBILE/MISSISSIPPI
I10 East through the George Wallace Tunnel.
Take the immediate exit after the Tunnel, Exit 27 onto Battleship Parkway (US 90E).
Go past the Blue Gill Restaurant and turn left onto Five Rivers Blvd, which is directly across the road from Meaher State Park.
Follow the road and signs into the property.


Cursory Geomorphologic Evaluation of the Apalachicola River

David S. Biedenharn


Observations





- The flow regime (based on pre-and post-dam flow duration curves) downstream of Jim Woodruff Dam has not been changed significantly between the pre- and post-dam periods.
- The primary impact of Jim Woodruff Dam on the downstream channel appears to be the trapping of bed material sized sediments.
- The amount of bed material that is transported through Jim Woodruff Dam is not known.
- Other alterations impacting the Apalachicola River include localized meander cutoffs, distributary flows, channel training structures, maintenance dredging, and the cessation of maintenance dredging in the 2000 timeframe.

Observations

- The degradational response due to the dam appears to extend downstream to about RM 77 near Blountstown. About 4 to 5 feet of lowering has occurred in this reach.
- Reach 1 (Dam to RM 78) is a relatively straight reach with little sediment stored in the channel, and is controlled in places by local geologic outcrops of limestone.
- The streambanks in Reach 1 are predominately composed of cohesive material and bank erosion and channel widening is minimal.
- The dike fields in Reach 1 do not contain significant amounts of sediment.

Observations

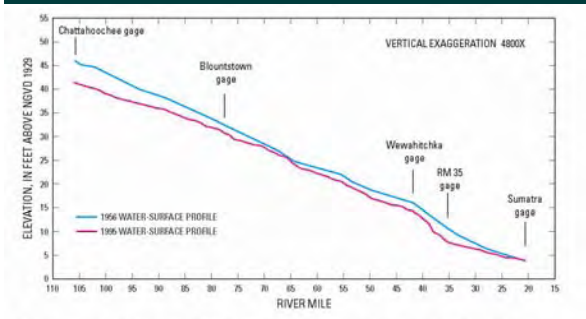
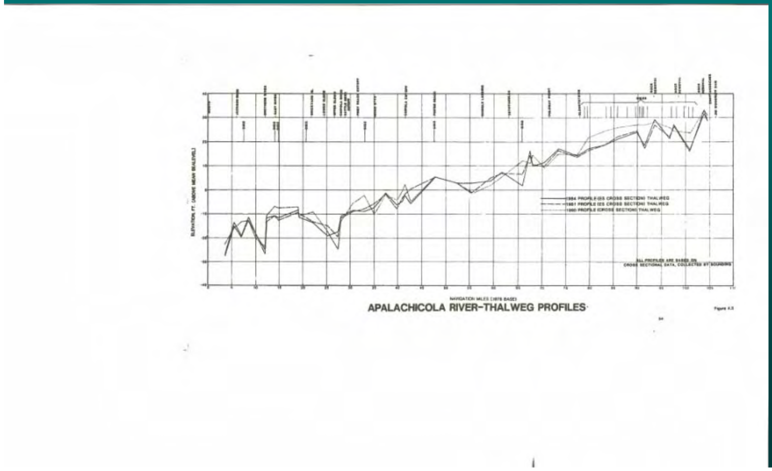


Figure 4. Water-surface profiles developed in 1956 and 1995 for the nontidal reach of the Apalachicola River, Florida, for a discharge of 9,300 ft^3/s at Chattahoochee streamgage. The 1956 water-surface profile is from Plate 43A of Design Memorandum No. 1 (U.S. Army Corps of Engineers, 1955). Design Memorandum No. 1 is dated December 15, 1955 (with transmittal to the Division Engineer December 23, 1955); however, Plate No. 43A is dated March 1956 with the notation: "This Plate is a supplement to Plate No. 43". Apparently computations for this water-surface profile were completed after the report was transmitted and were made an official supplement to the report after-the-fact. The 1995 water-surface profile is provisional (USACE, Mobile District, unpublished data, 2005).



- The river in Reach 2 (RM 78 to RM 35) downstream of Blountstown is a much more active meandering channel with a high sinuosity (sinuosity =1.9).
- Low water gage records and water surface profiles indicate that the channel between Blountstown and RM 20 has experienced about 1 to 2 feet of lowering. However, comparative thalweg plots between 1960 and the early 1980s indicate that the channel has experienced localized areas of scour and fill.
- Reach 2 has the largest erosion rates on the river. This erosion appears to be part of the natural down-valley meander migration which is common to most meandering streams, and does not appear to be the result of some system-wide adjustments such as degradation, aggradation, or channel widening.

Observations

- The channel between the Chipola Cutoff and RM 35 has been one of the most frequently dredged areas on the river. It appears that little sediment is diverted into the Chipola Cutoff, which might be a partial explanation for the frequent dredging just downstream.
- The processes responsible for the apparent increase in the percent of flow (25% to 34%) diverted at the Chipola Cutoff warrants further study.
- There is considerable sediment storage in Reach 2 as evidenced by the large point bars.
- The effects of the cessation of dredging in the 2000 timeframe on the morphology of the channel warrants further study
- Comparison of the 1941 and 2004 channel widths indicated that channel widening throughout the river down to RM 20. Further analysis is needed to determine if these width increases are real, and if so, what are the factors responsible for them.

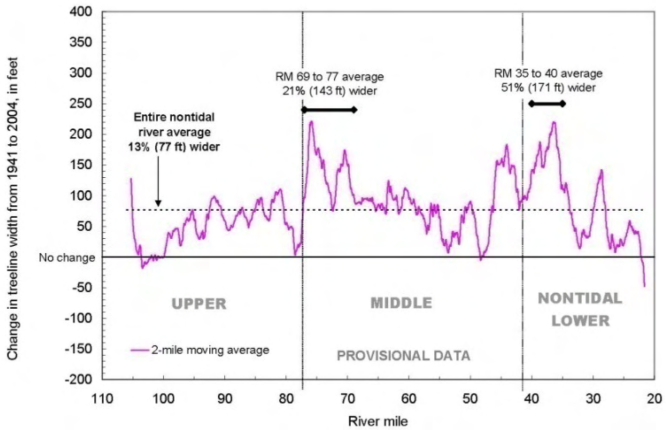


Figure 2. Change in treeline width of main channel of nontidal reach of Apalachicola River, Florida, from 1941 to 2004. Widths were measured at approximately 2,800 points at 164-foot intervals along channel centerline in aerial photographs. Data shows a 2-mile (64-point) moving average. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005.

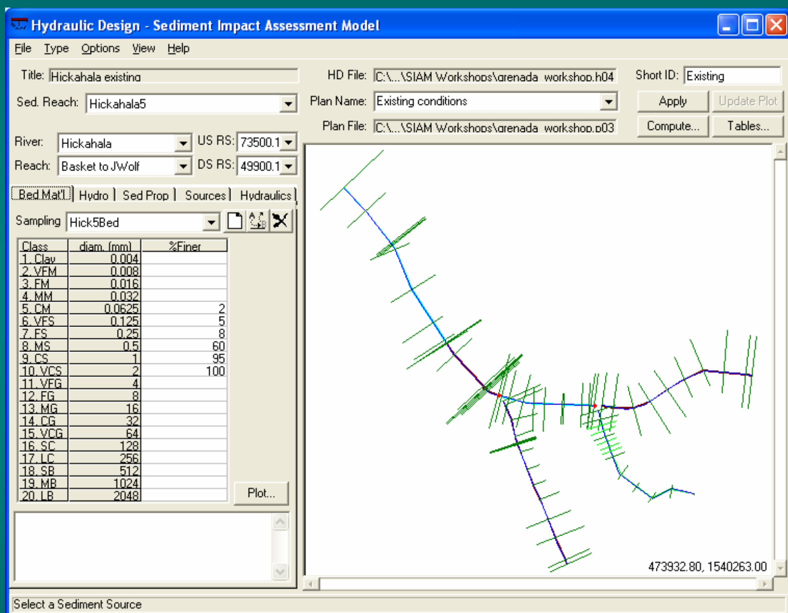
Observations

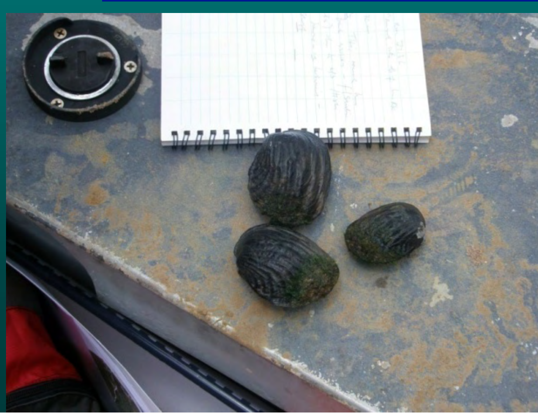
- **The river downstream of the River Styx (RM 35) has a lower sinuosity (1.3) and less bank erosion.**
- **Local meander cutoffs downstream of the River Styx may be responsible for some of the bed lowering in this area.**
- **Preferred mussel habitat appears to occur in the lower energy environments associated with the flow separation zones (eddies) in the transition between meander bends**
- **The size and location of the eddie zones change with flow and through time as the meanders migrate though the floodplain**

Observations

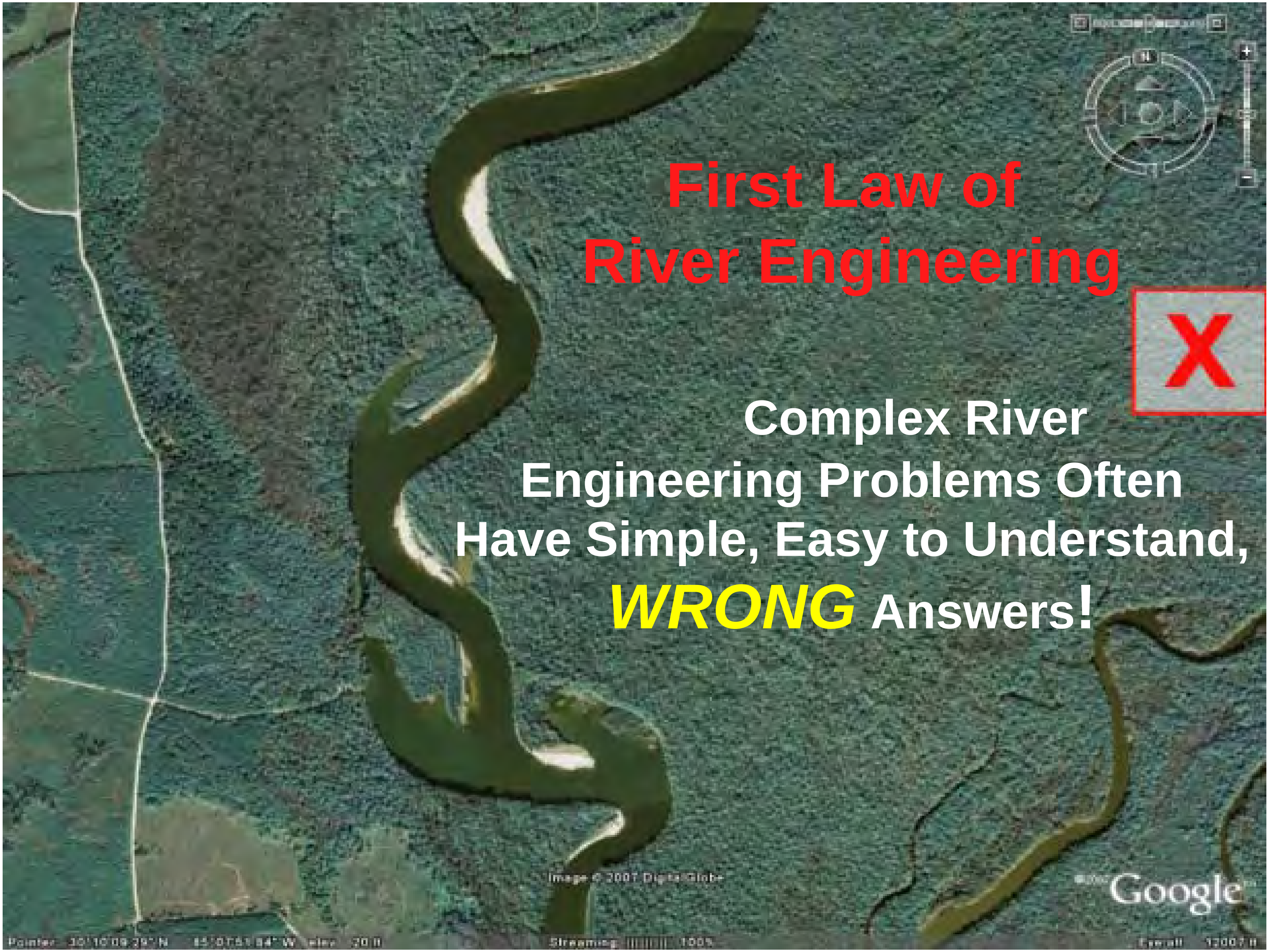
- Reach 2 contains some of the highest mussels counts on the river
- Eddies, and consequently mussel habitat, are constantly being destroyed and created through the natural process of meander migration
- The mussel mortality sites at RM 44.3 and RM 43.6 appear to be the result of the natural migration of the channel and not some systematic channel changes.
- The mussel stranding in Swift Slough appears to be the result of deposition of sands from the river. It appears that a sand bar has moved to the entrance to the Swift Slough and may be the source of the sediment. However, a more detailed analysis of this area is needed to establish the exact processes responsible for this situation.

Recommendations





- Eco-geomorphic assessment of the system to fully develop how the system has responded in the past and where it is today with emphasis on the connection between the morphology and mussel habitat.
- Relatively simple 1D sediment continuity model (possibly SIAM) of the river. This would provide the big picture assessment of the entire river system below Jim Woodruff dam with respect to sediment continuity, channel stability, impacts of flow diversions, etc.
- 2D hydrodynamic model for selected reaches. Once again the key would be linking these detailed hydrodynamic processes to the mussel assemblages



First Law of River Engineering

Complex River Engineering Problems Often Have Simple, Easy to Understand, *WRONG* Answers!

SUMMARY OF FINDINGS: APALACHICOLA RIVER

Mike Harvey

Mussetter Engineering, Inc.

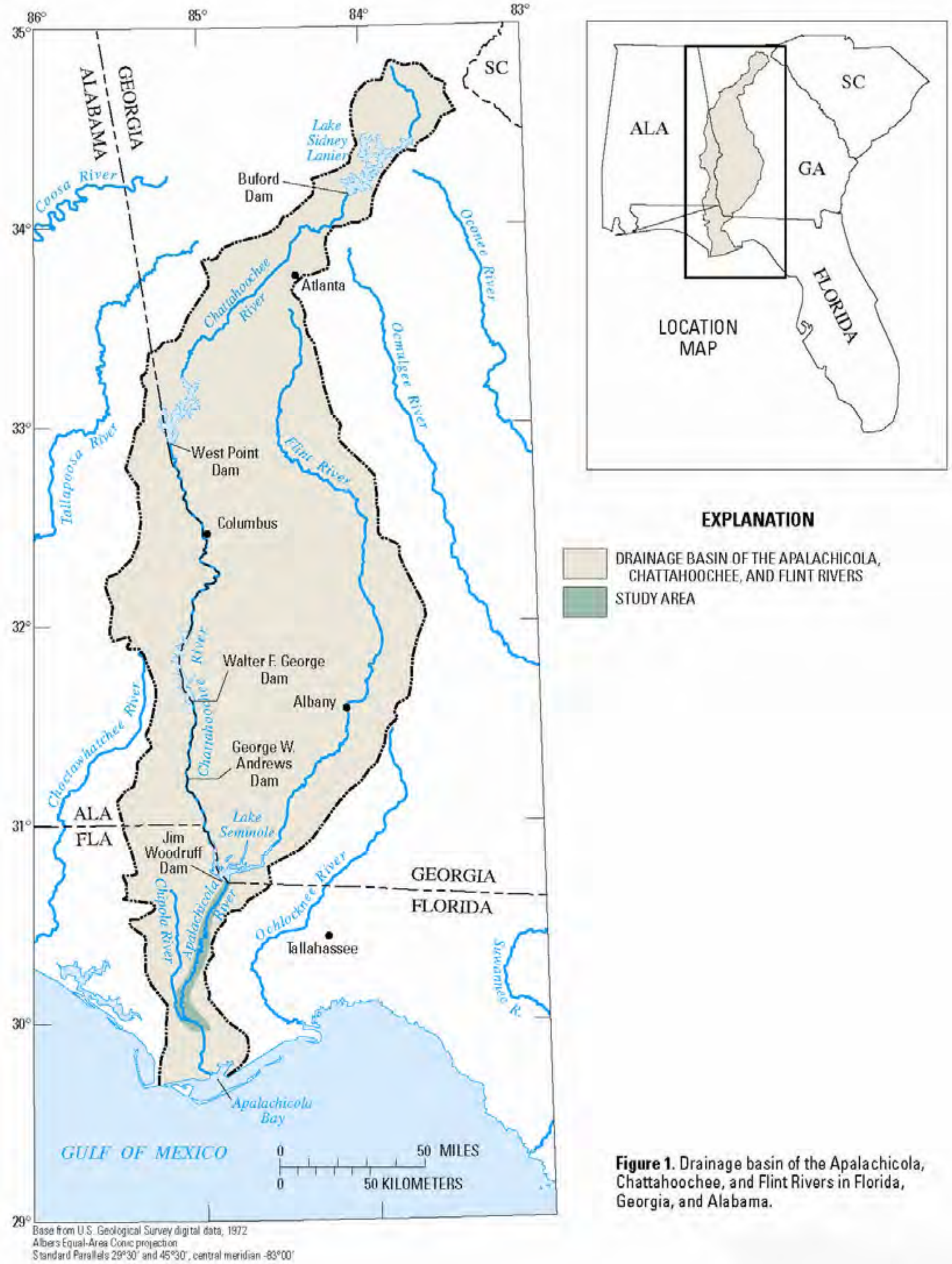


Figure 1. Drainage basin of the Apalachicola, Chattahoochee, and Flint Rivers in Florida, Georgia, and Alabama.

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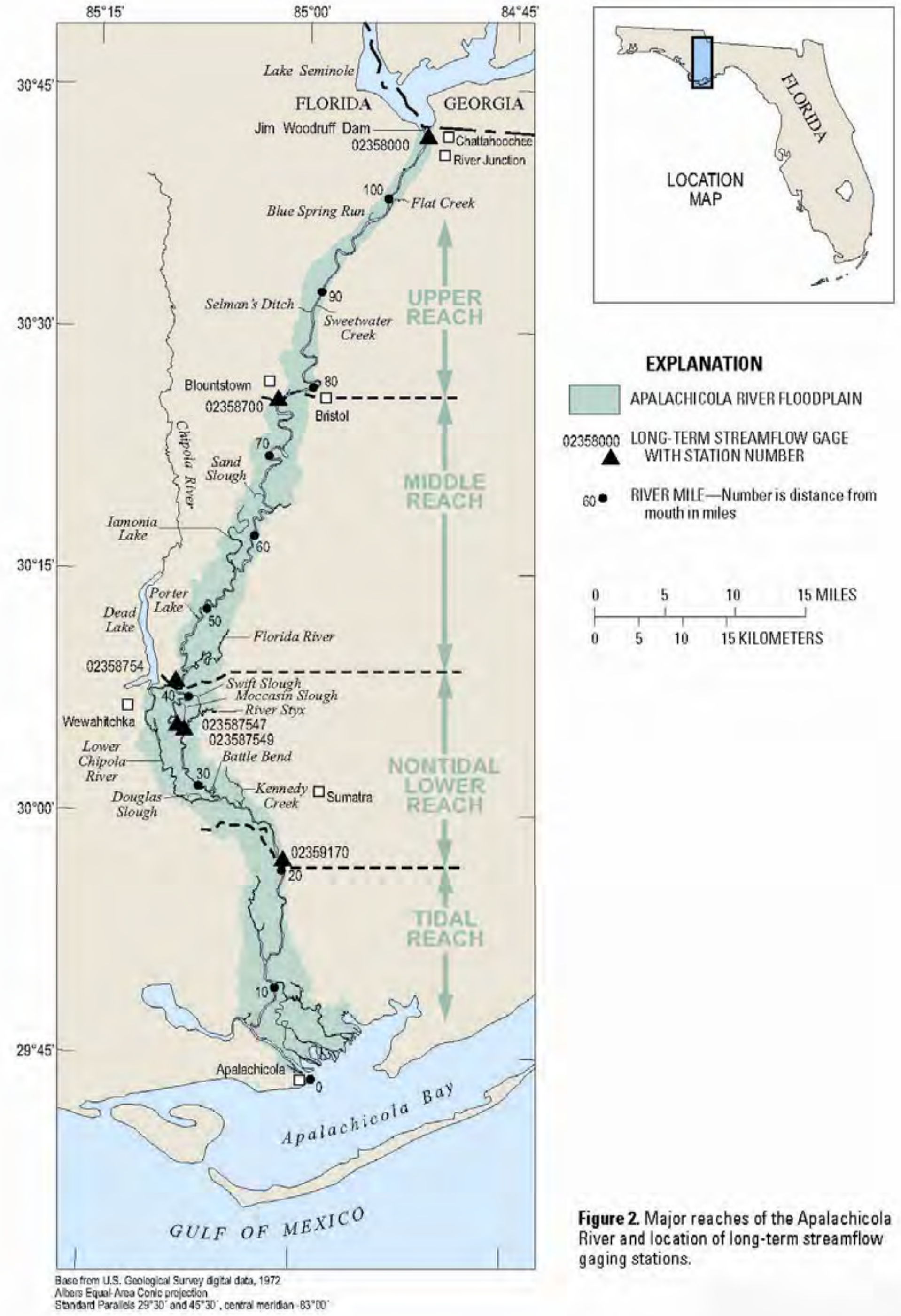

Figure 2. Major reaches of the Apalachicola River and location of long-term streamflow gaging stations.

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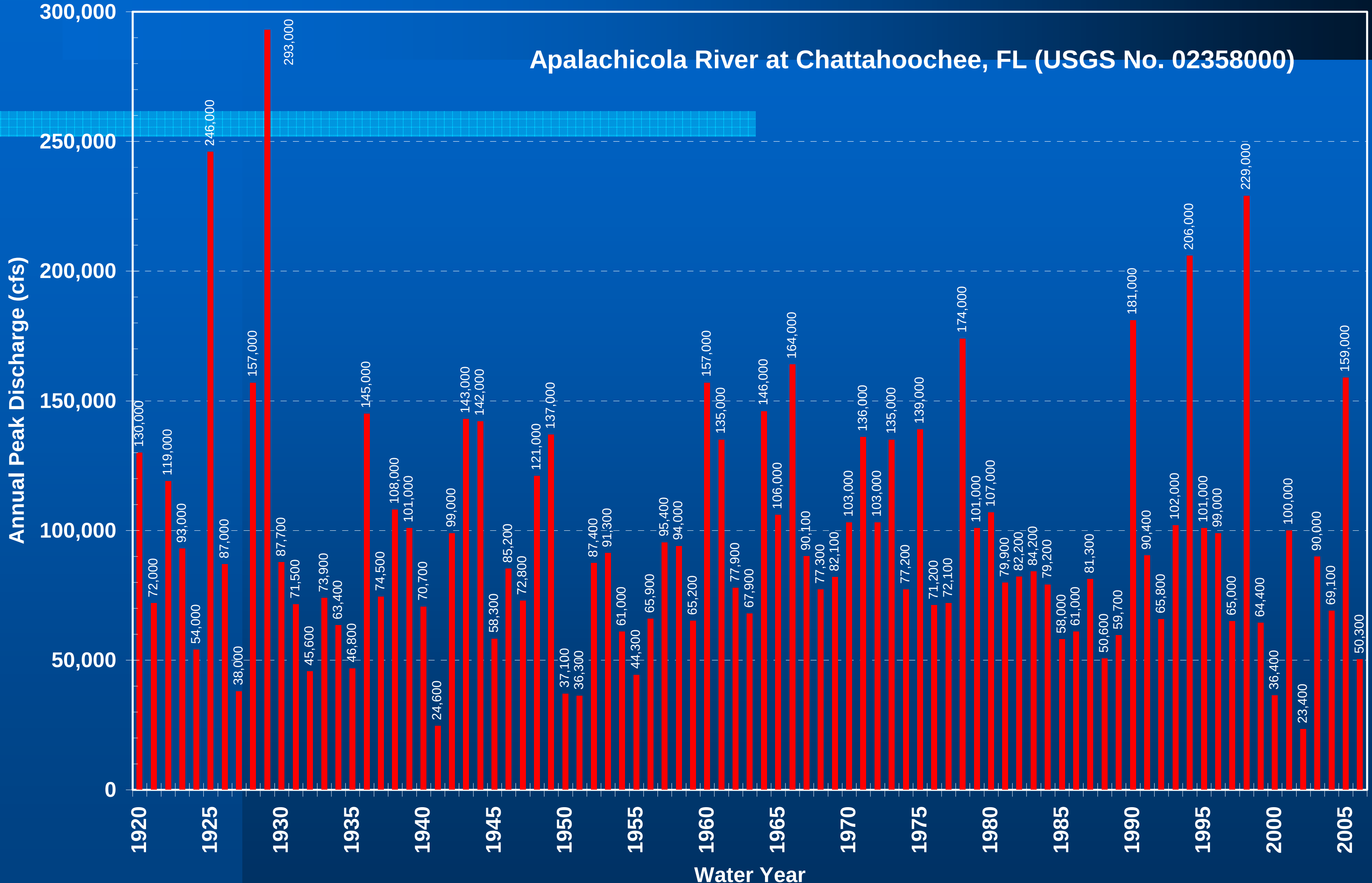

Apalachicola River at Chattahoochee, FL (USGS No. 02358000)
Annual Peak Discharge (cfs)
0
50,000
100,000
150,000
200,000
250,000
300,000
Water Year
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
130,000
72,000
119,000
93,000
54,000
246,000
87,000
38,000
157,000
293,000
87,700
71,500
45,600
73,900
63,400
46,800
145,000
74,500
108,000
101,000
70,700
24,600
99,000
143,000
142,000
58,300
85,200
72,800
121,000
137,000
37,100
36,300
87,400
91,300
61,000
44,300
65,900
95,400
94,000
65,200
157,000
135,000
77,900
67,900
146,000
106,000
164,000
90,100
77,300
82,100
103,000
136,000
103,000
135,000
77,200
139,000
71,200
72,100
174,000
101,000
107,000
79,900
82,200
84,200
79,200
58,000
61,000
81,300
50,600
59,700
181,000
90,400
65,800
102,000
206,000
101,000
99,000
65,000
229,000
64,400
36,400
100,000
23,400
90,000
69,100
159,000
50,300

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ALABAMA
GEORGIA
FLORIDA
GULF OF MEXICO
CHATTAHOOCHEE ANTICLINE
GULF TROUGH
SOUTHEAST GEORGIA EMBAYMENT
NASSAU NOSE
JACKSONVILLE BASIN
ST. JOHNS PLATFORM
SANFORD HIGH
BREVARD PLATFORM
OSCEOLA LOW
OKEECHOBEE BASIN
OCALA PLATFORM
APALACHICOLA EMBAYMENT
N
0 50 100 150 MILES
0 80 160 240 KILOMETERS
SCALE
31°
29°
27°
25°
88°
86°
84°
82°
80°

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Reach	Sv	Sc	P
Upper RM 106-78	0.00012	0.000094	1.3
Middle RM 78 - 35	0.00018	0.000093	1.9
Lower RM 35 - 6	0.00012	0.000095	1.3

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Jim Woodruff Dam


Tributary sediment supply


Low sediment storage in dikes

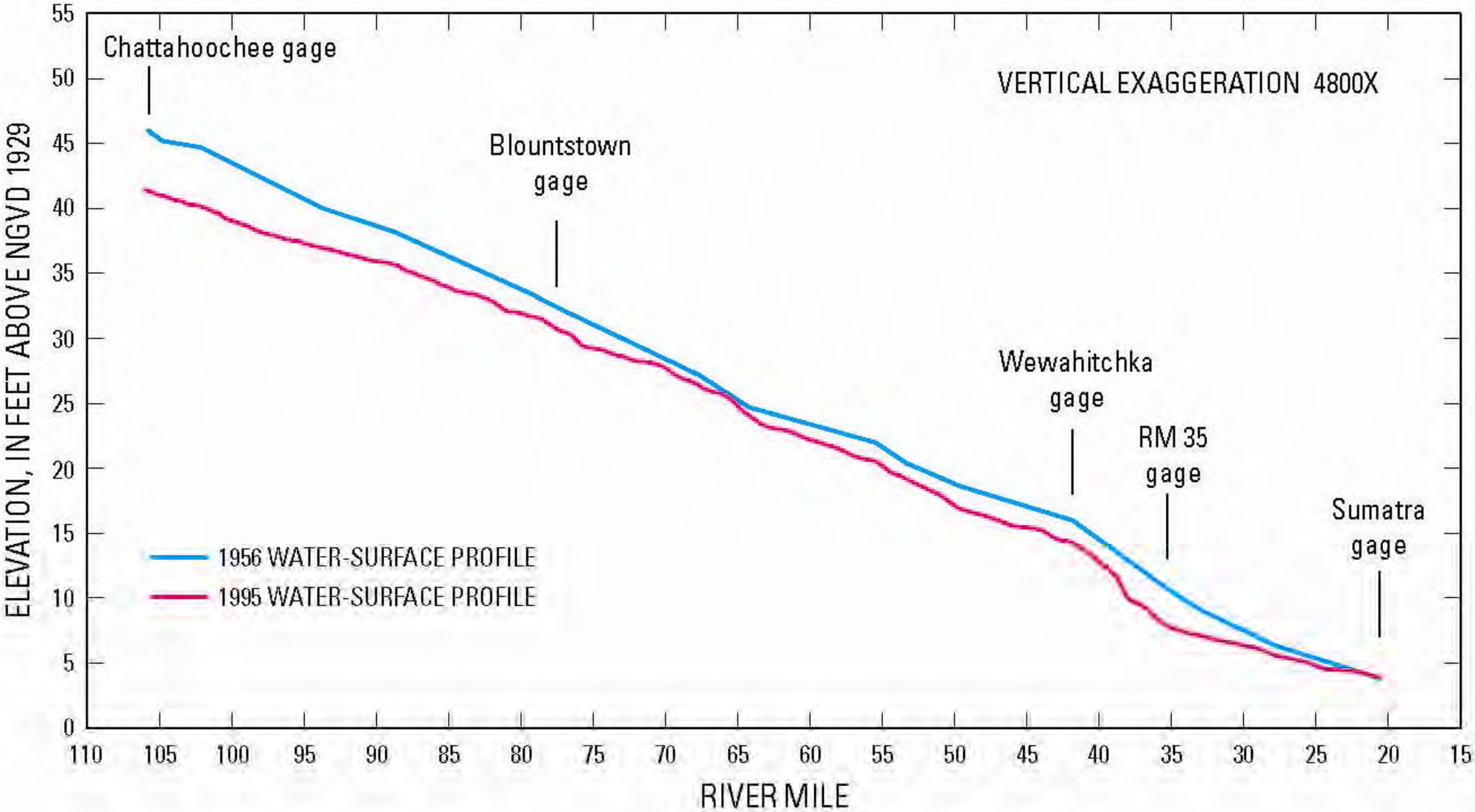

Limestone outcrop


Cohesive banks


Alum Bluff Fm.


Alum Bluff Fm. sands


Bluff sediment supply



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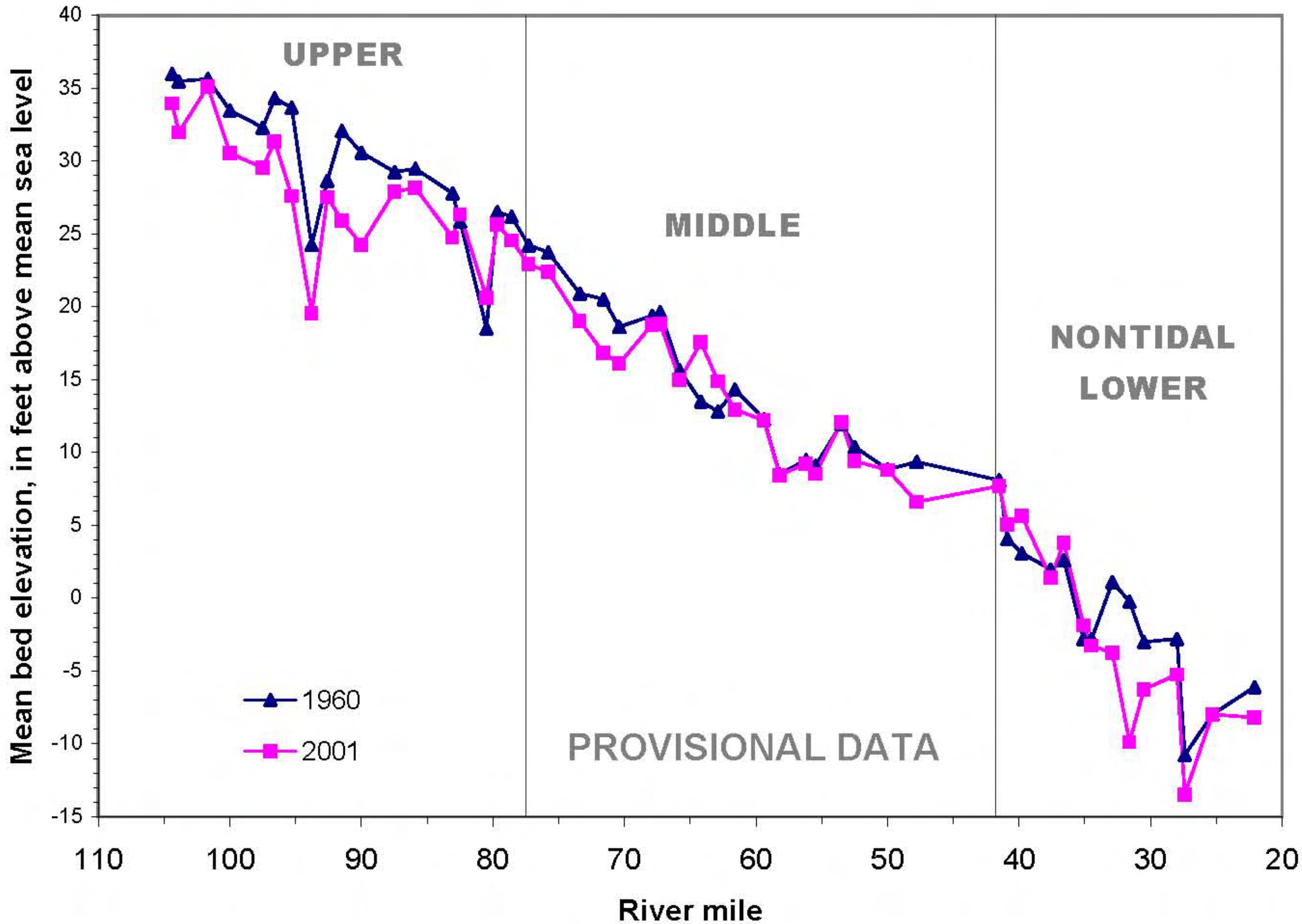

Figure 4. Mean bed elevation of low-flow channel of the nontidal Apalachicola River, Florida, in 1960 and 2001. Data was derived from U.S. Army Corps of Engineers cross-sections surveys. At each cross-section, the water-surface elevation at a lagged discharge of 10,000 cubic feet per second at the Apalachicola River gage at Chattahoochee, Florida, was used to calculate mean bed elevation. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005.

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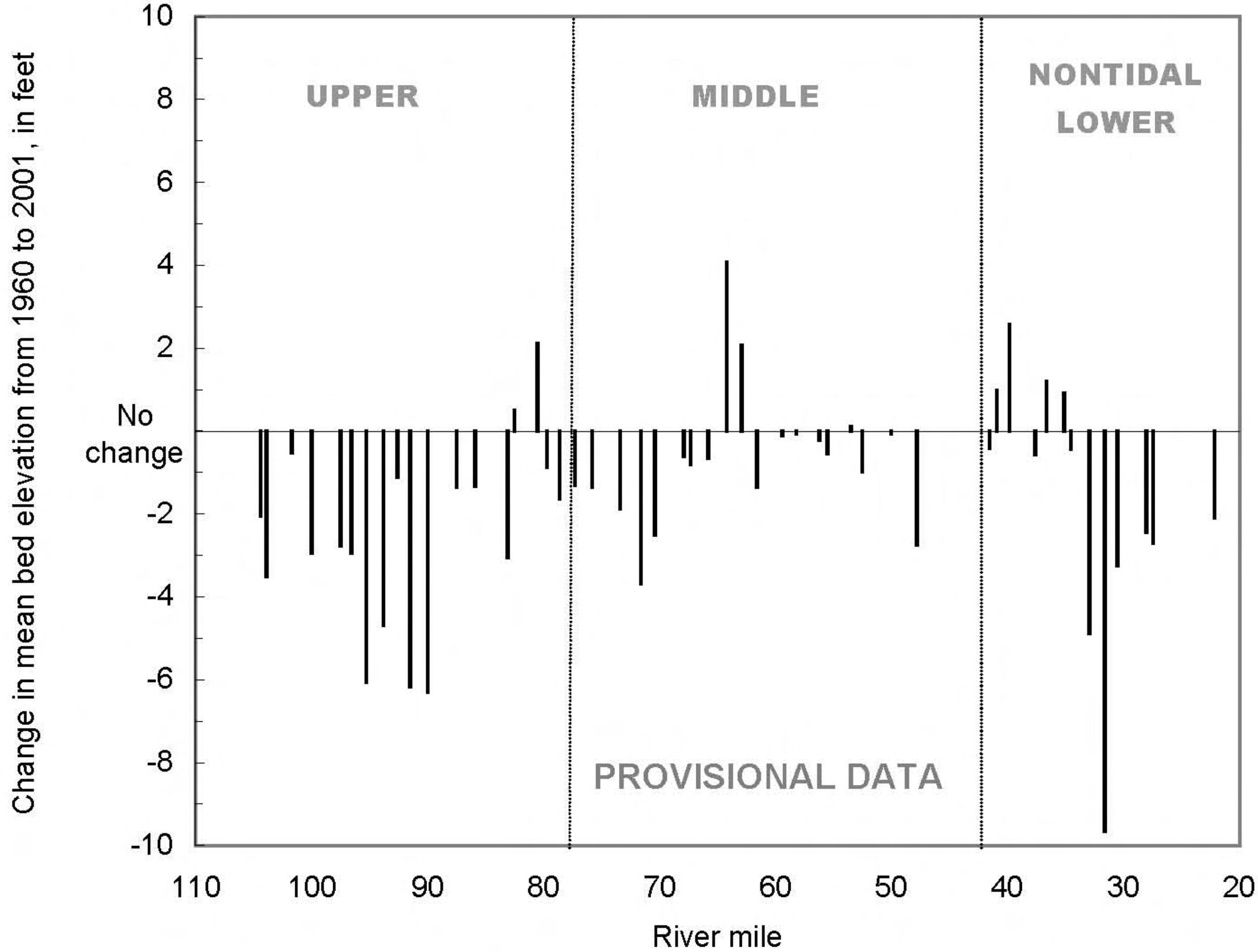

Figure 5.--Change in mean bed elevation of low-flow channel of the non-tidal Apalachicola River, Florida, from 1960 to 2001. Data was derived from U.S. Army Corps of Engineers cross-sections surveys. At each cross-section, the water-surface elevation at a lagged flow of 10,000 cubic feet per second at the Apalachicola River gage at Chattahoochee, Florida, was used to calculate mean bed elevation. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005.

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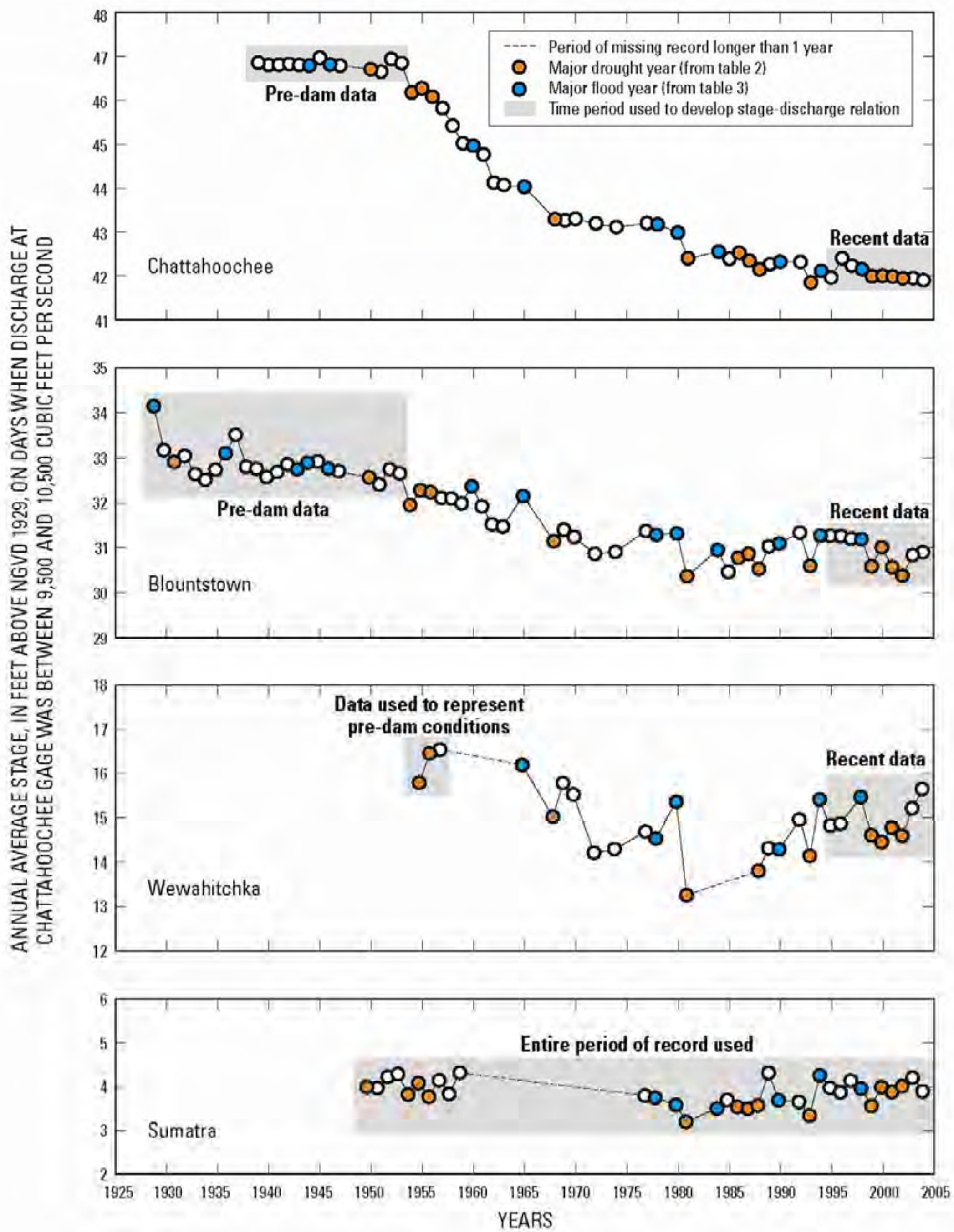
Period of missing record longer than 1 year
Major drought year (from table 2)
Major flood year (from table 3)
Time period used to develop stage-discharge relation
Pre-dam data
Recent data
Chattahoochee
Blountstown
Data used to represent pre-dam conditions
Wewahitchka
Entire period of record used
Sumatra
ANNUAL AVERAGE STAGE, IN FEET ABOVE NGVD 1929, ON DAYS WHEN DISCHARGE AT CHATTAHOOCHEE GAGE WAS BETWEEN 9,500 AND 10,500 CUBIC FEET PER SECOND
YEARS

MEI

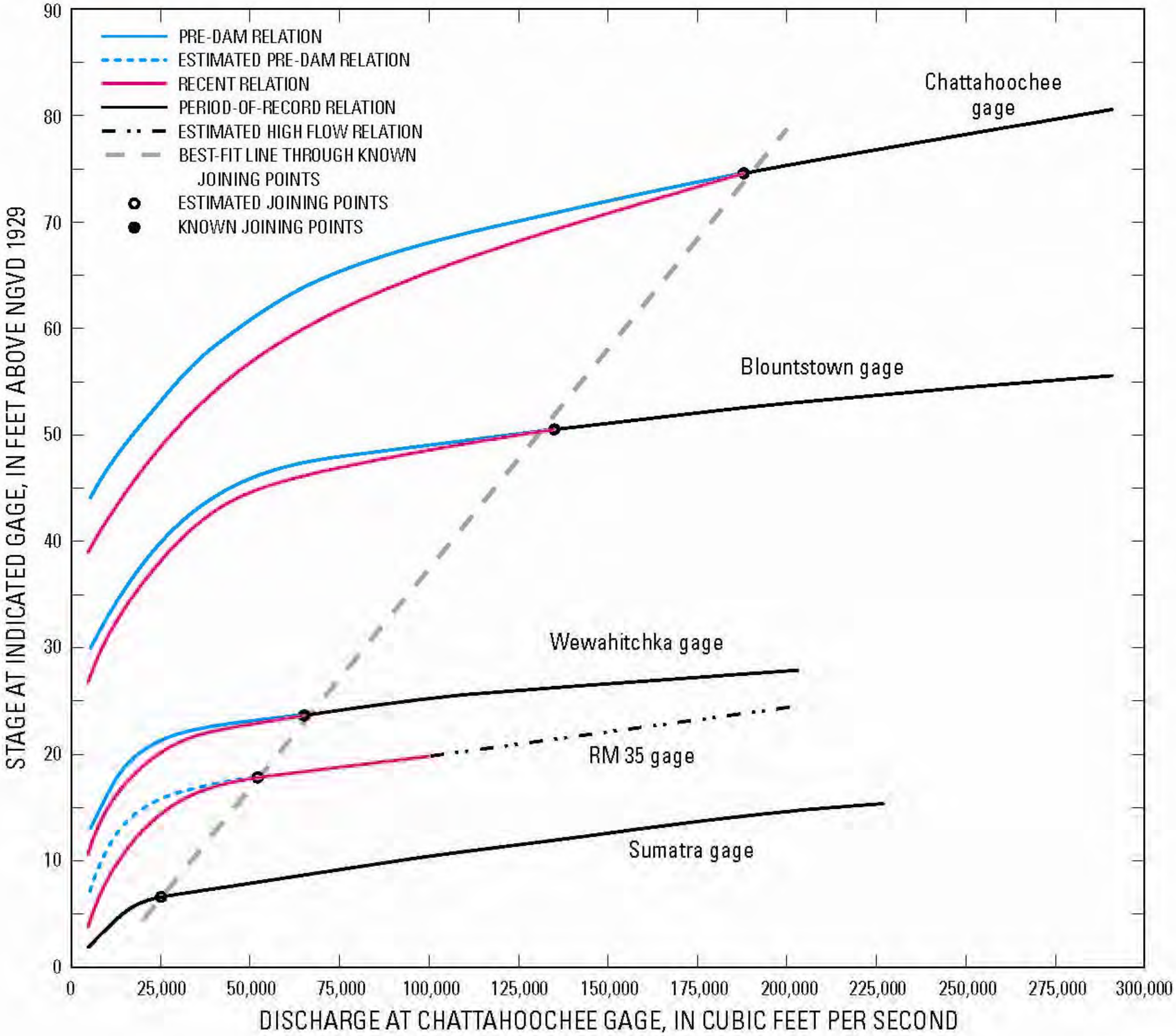

Figure 6. Stage at five streamgages on the Apalachicola River in relation to discharge at Chattahoochee, Florida, with known and estimated joining points for pre-dam and recent relations. Relations at streamgages downstream from Chattahoochee were developed using lag times as defined in glossary. An estimated joining point was needed for Sumatra, even though there is only one curve at that site, so that interpolated pre-dam and recent relations could be developed between RM 35 and Sumatra.

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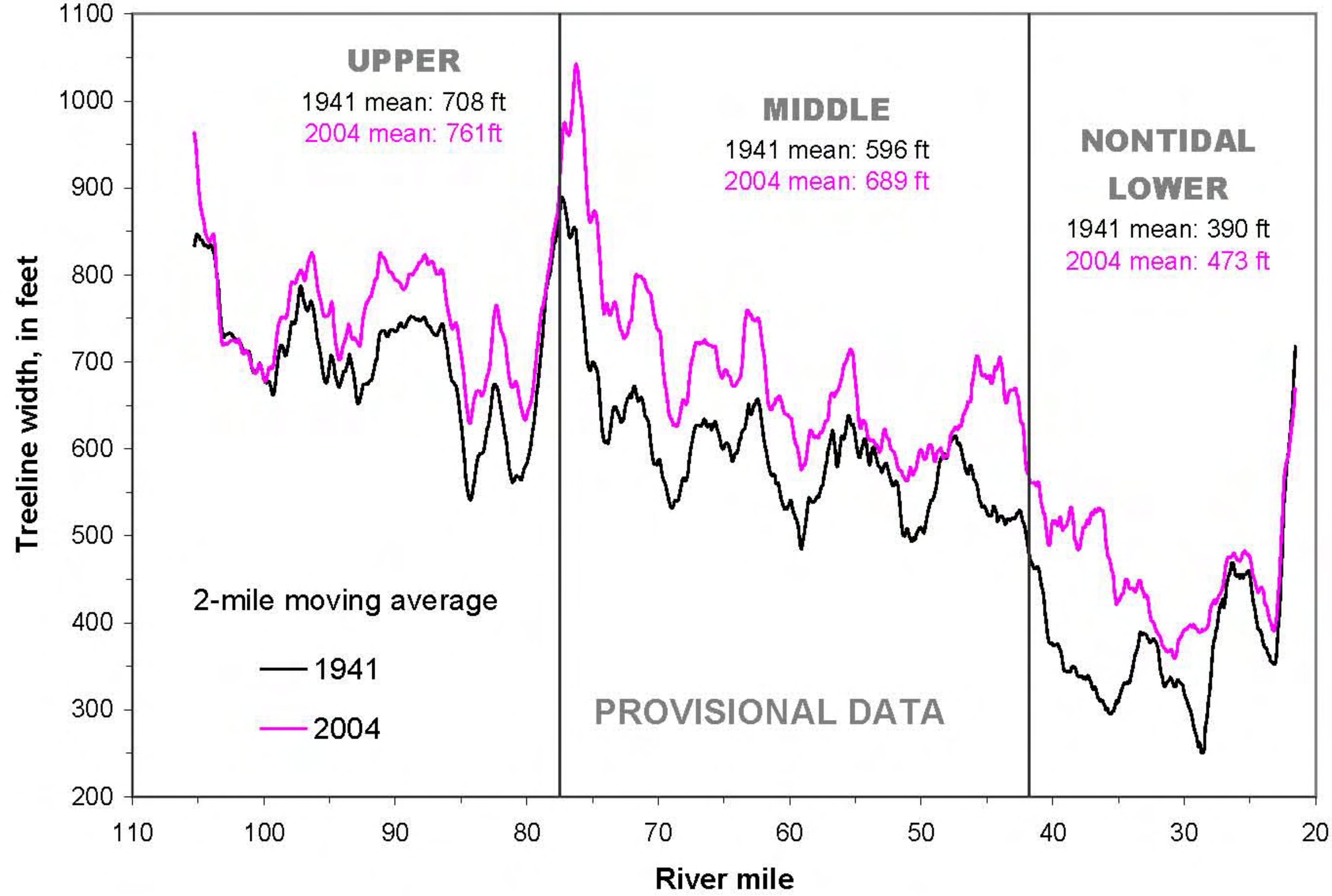

Figure 1. Treeline width of main channel of nontidal reach of Apalachicola River, Florida, in 1941 and 2004. Widths were measured at approximately 2,800 points at 164-foot intervals along the channel centerline in aerial photographs. Data shows a 2-mile (64-point) moving average. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005.

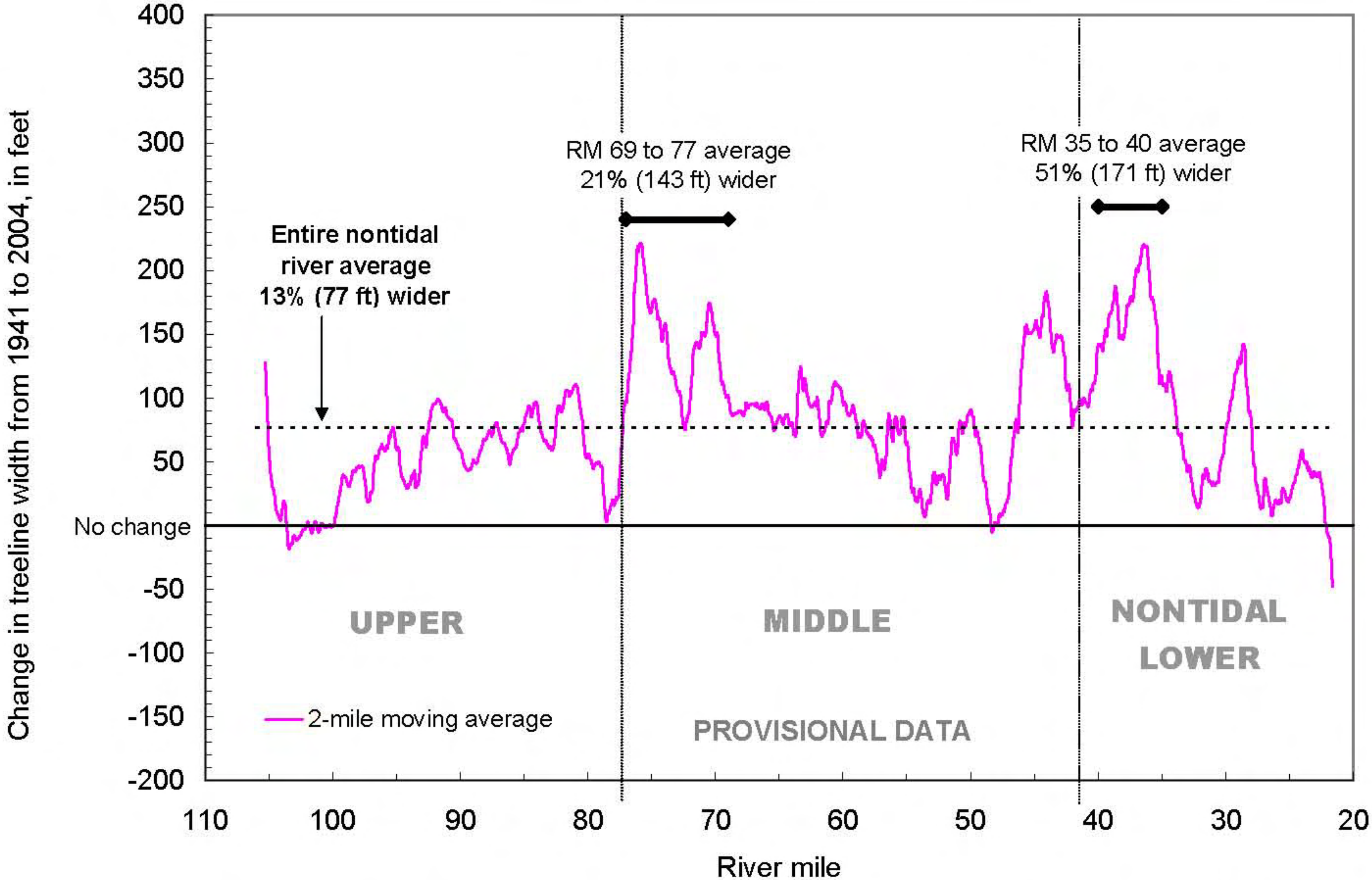

Figure 2. Change in treeline width of main channel of nontidal reach of Apalachicola River, Florida, from 1941 to 2004. Widths were measured at approximately 2,800 points at 164-foot intervals along channel centerline in aerial photographs. Data shows a 2-mile (64-point) moving average. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005.

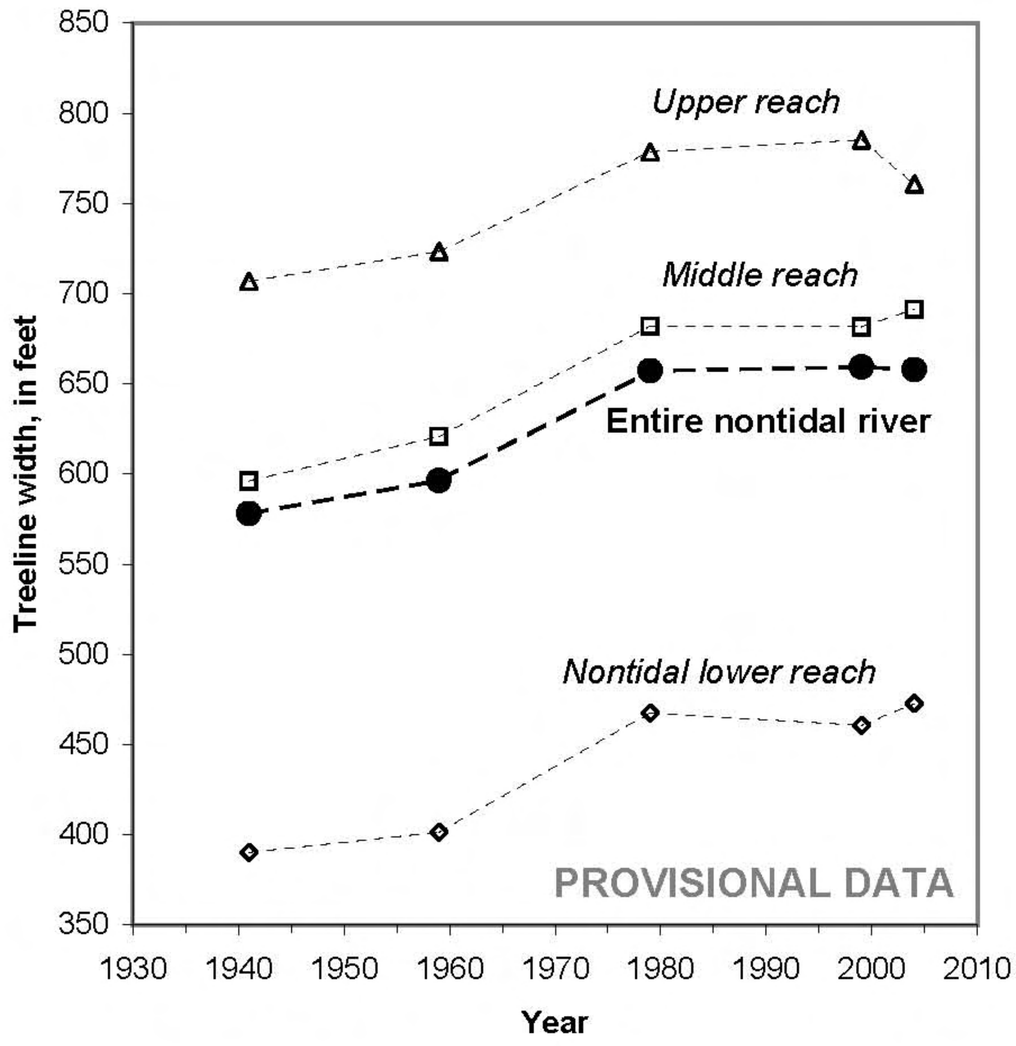

Figure 3.--Mean treeline width of main channel of nontidal reach of Apalachicola River, Florida, in relation to time. Measurements were made on aerial photographs along the river centerline at approximately 2,800 points equally spaced at 164-foot intervals.

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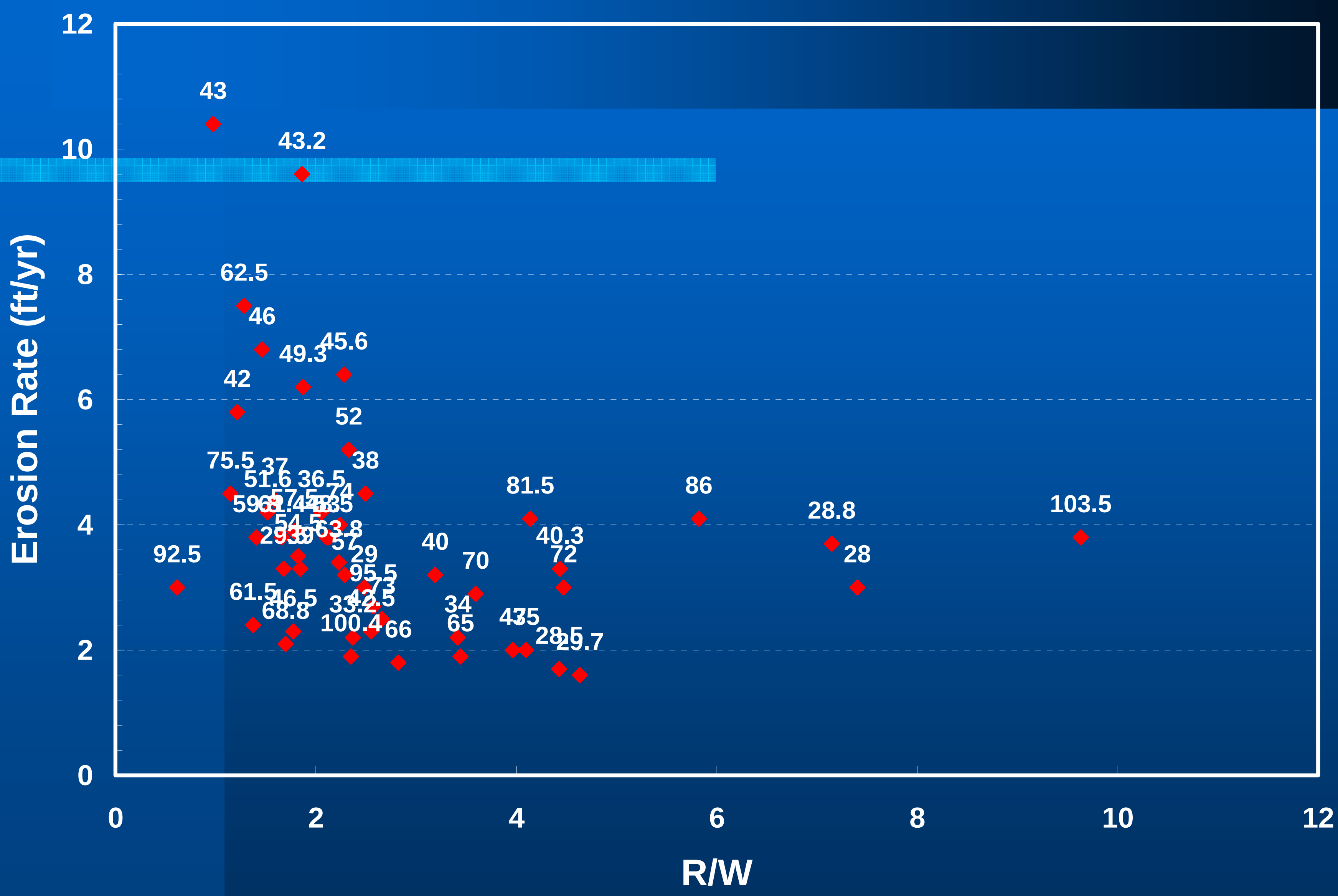
Erosion Rate (ft/yr)
R/W
0
2
4
6
8
10
12
43
43.2
62.5
46
49.3
45.6
42
52
75.5
38
81.5
86
28.8
103.5
92.5
40
40.3
72
70
28
61.5
68.8
34
65
66
29.7

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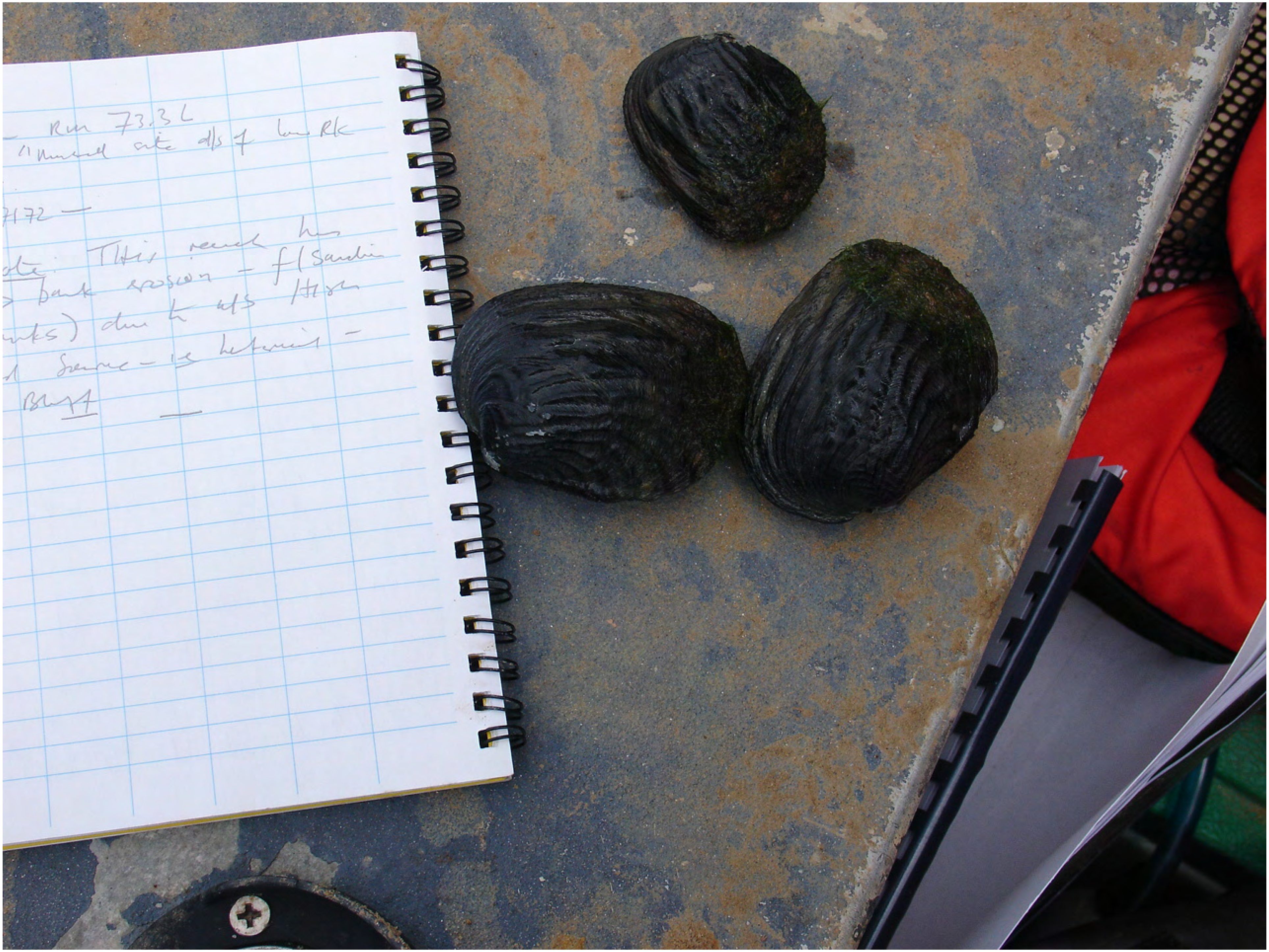


Equiloxic Creek


RM47.2R


RM 44L


Kentucky Ldg.


Swift Slough


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post-consumer recycled material.

CONCLUSIONS - 1

- **JW Dam and upstream dams have reduced sediment supply to AR, but have not changed hydrology significantly.**
- **AR has degraded: 5 ft us – 2 ft ds**
- **Not clear if AR has widened**
- **Bed slope is uniform through the reaches (0.000093-95)**
- **Very high sinuosity from RM 78 – RM 35 probably due to active tectonics**

CONCLUSIONS - 2

- Maximum erosion rates (~ 10 ft/yr) are low in comparison to other rivers
- FTM habitat is associated with eddy deposits; ds end of bends, backwater bars, dikes.
- FTM habitat is ephemeral and changes with time and space.
- Rates of change are a function of the frequency and magnitude of flood events.
- Distributary channels (e.g. Swift Slough) are also ephemeral features.

IDENTIFIED ISSUES

- Is the AR widening and what are the processes
- Has the AR attained a level of equilibrium or will instability move ds.
- Quantification of the relationships between meander dynamics and FTM habitat
- How much eddy habitat is available in the meandering reach (RM 78 – RM 35).

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RECOMMENDATIONS

- Thorough integrated geomorphic evaluation
- Development of a sediment mass balance with SIAM
- 2-D models of different habitat types
- Develop process-response model for prediction of impacts of water ops. on FTM habitat.


NO
SWIMMING
ALLIGATORS
FREQUENT
THIS AREA !
BE SAFE
SAVE YOUR LIFE

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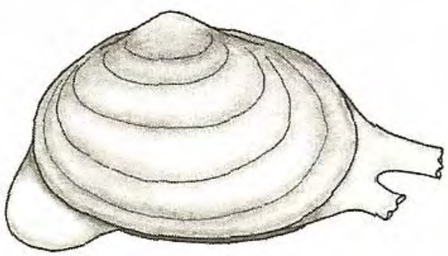
Density and distribution of *Amblema neislerii*, Apalachicola River, Florida

- **Mussel biology and ecology**
- **Sampling for mussels**
- **Background on *A. neislerii***
- **Abundance & distribution (2007 Survey)**
- **Mussel monitoring plan**

Unionidae: Freshwater Mussels

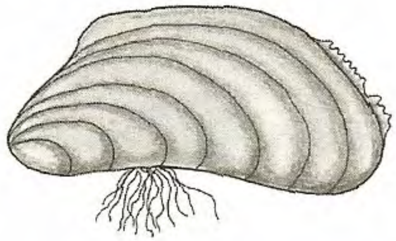
'Clam'



Burrows, no byssal threads

Asian clam, *Corbicula fluminea*

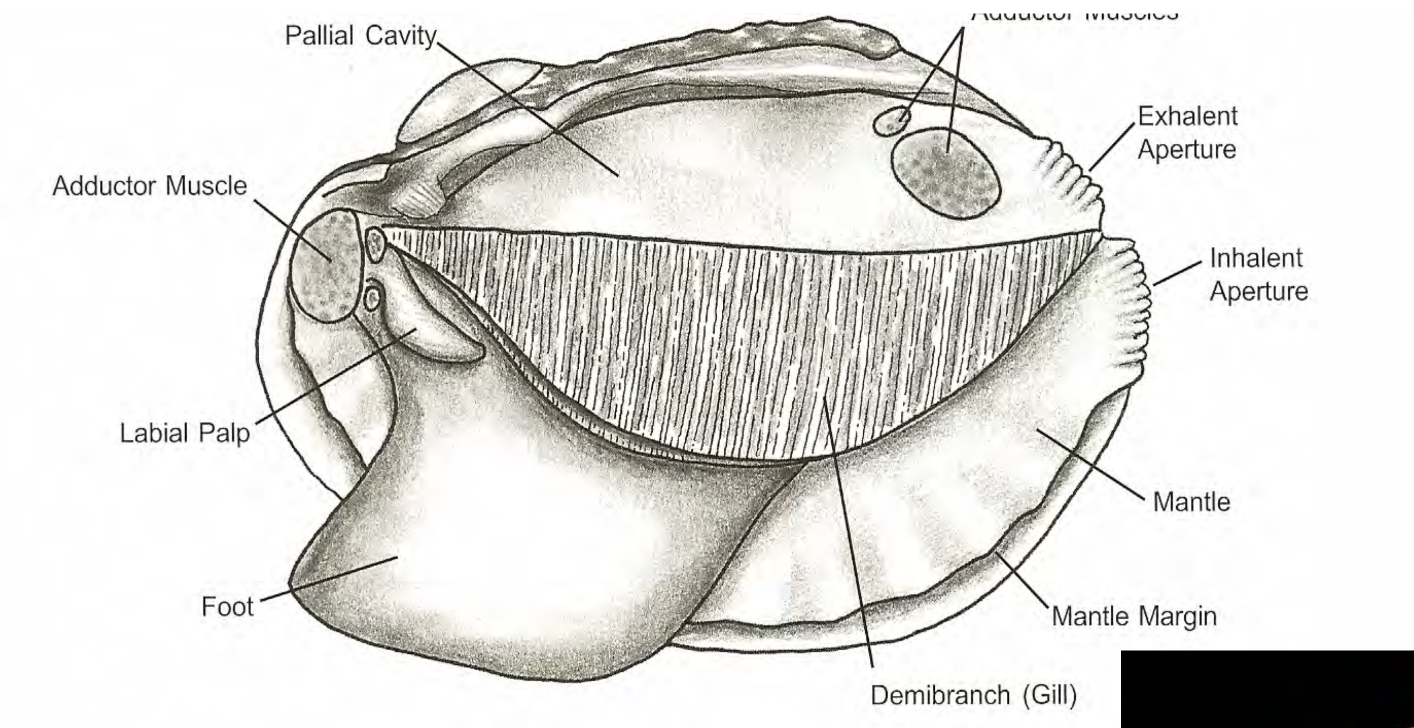
'Mussel'

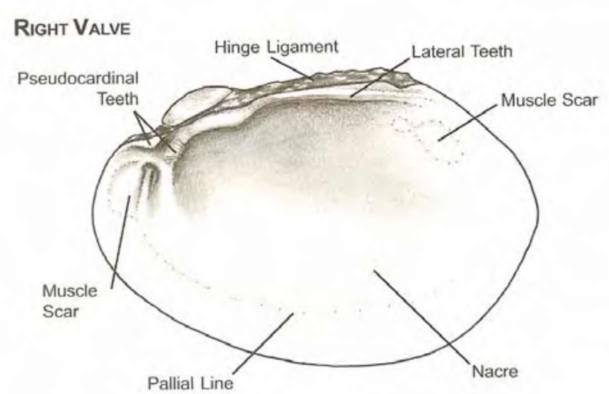


Attached, one or More byssal threads

***Amblema neislerii*, the fat Threeridge mussel (Endangered)**

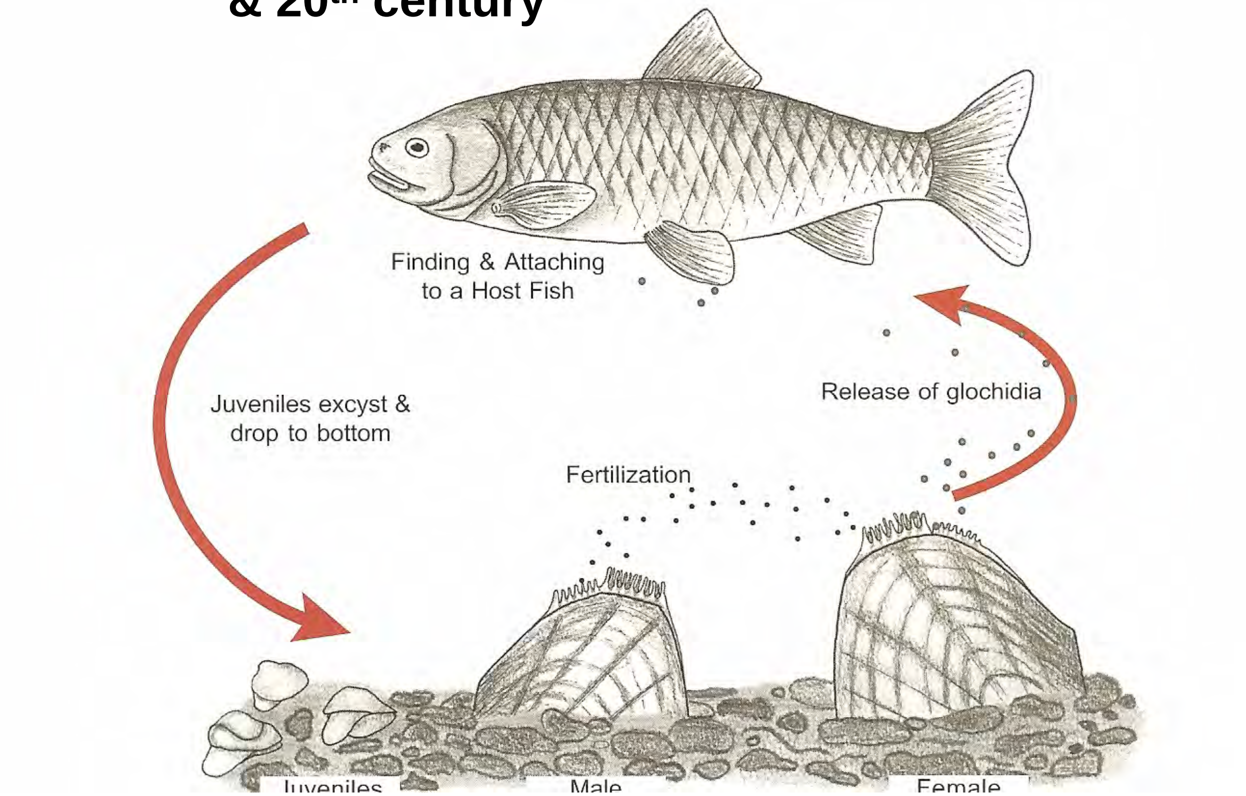
Unionidae: Freshwater Mussels





Unionidae: Freshwater Mussels

- Need for specific fish host
- Requirement for moderately depositional area
- Chance that juveniles can be dropped in unsuitable habitat
- Mussel beds can be self-sustaining
- Large rivers support diverse, dense assemblages
- Permanent water & stable substratum are important
- Tolerant of short periods of desiccation, poor water quality
- Mussels were affected by large-scale habitat changes in 19th & 20th century

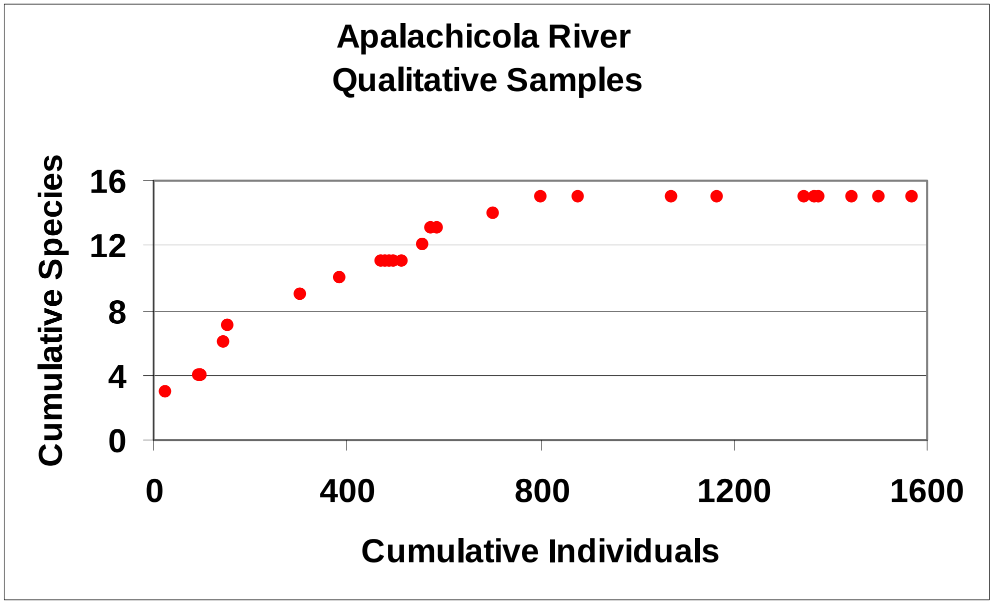


Swift Slough

Mussel Sampling Methods

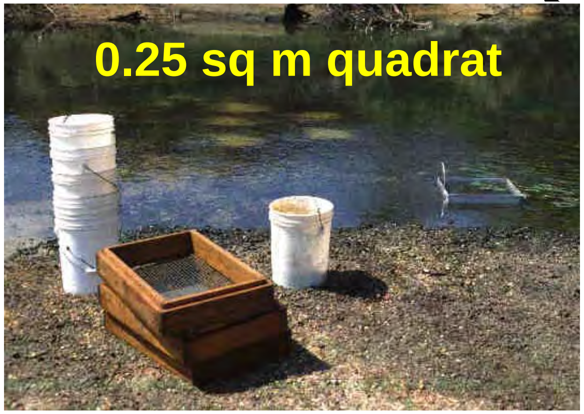
- Prior to 1980s – hand collecting or commercial brail
- After 1980s virtually everyone used divers equipped with scuba or surface supplied air

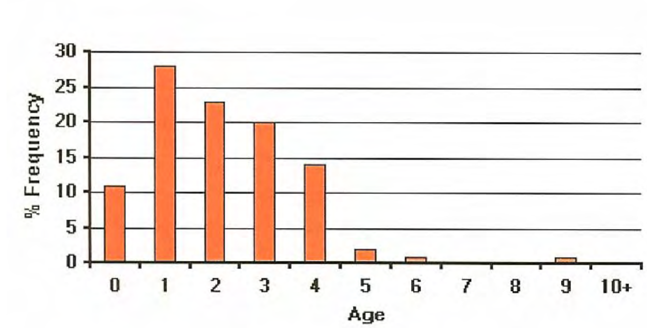
Sampling Strategies



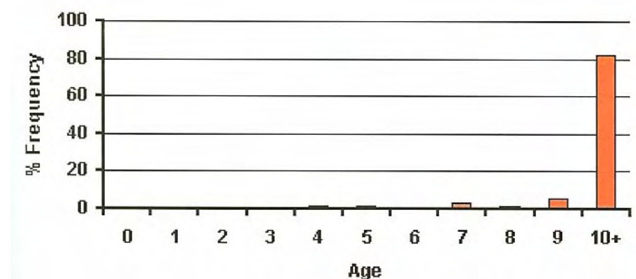
- **Reconnaissance**
- **Qualitative – timed search**
  - **Species list, relative species abundance**
  - **Catch per unit effort (CPUE)**
  - **<u>Spatially extensive</u>**
- **Quantitative - 0.25 m^2 samples, sieve & pick**
  - **Density**
  - **Size demography**
  - **<u>Spatially intensive</u>**

Quantitative Sampling

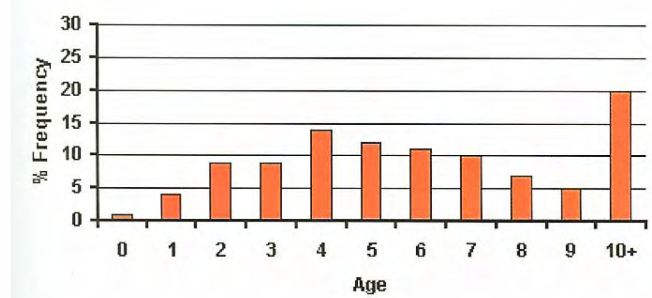




Juveniles



Adults



Even distribution

Amblema neislerii in the Apalachicola River

- "Rare" – Hyning (1925)
- "Rare…but locally abundant" (Clench & Turner 1956)
- *A. neislerii* found at one site (Heard 1975)
- 32 live A. neislerii at 7 sites (Brim Box & Williams 2000)

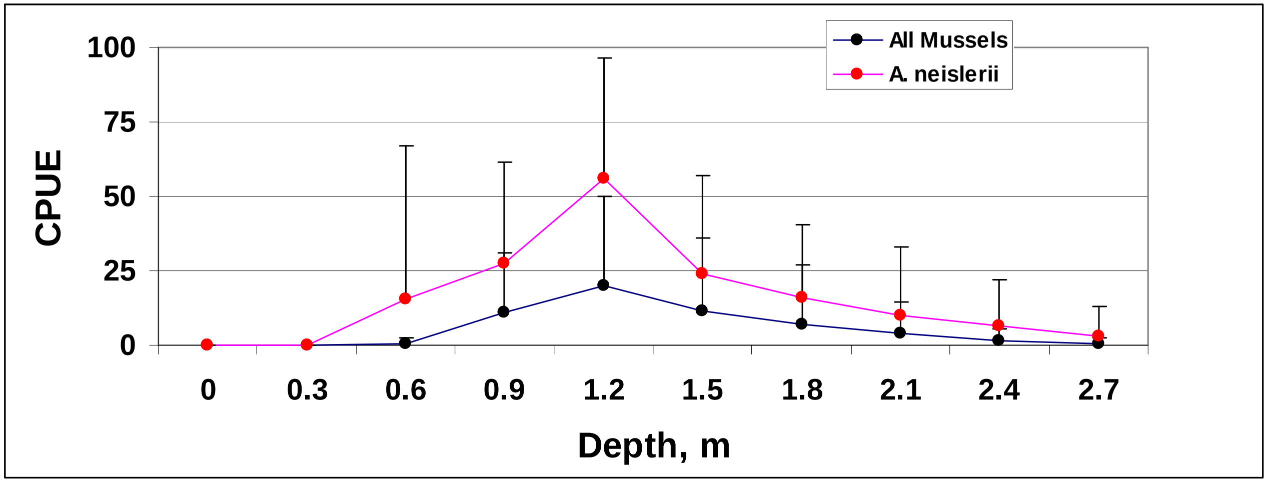
Mussels in the Apalachicola River have been misunderstood and misrepresented……

Previous Studies

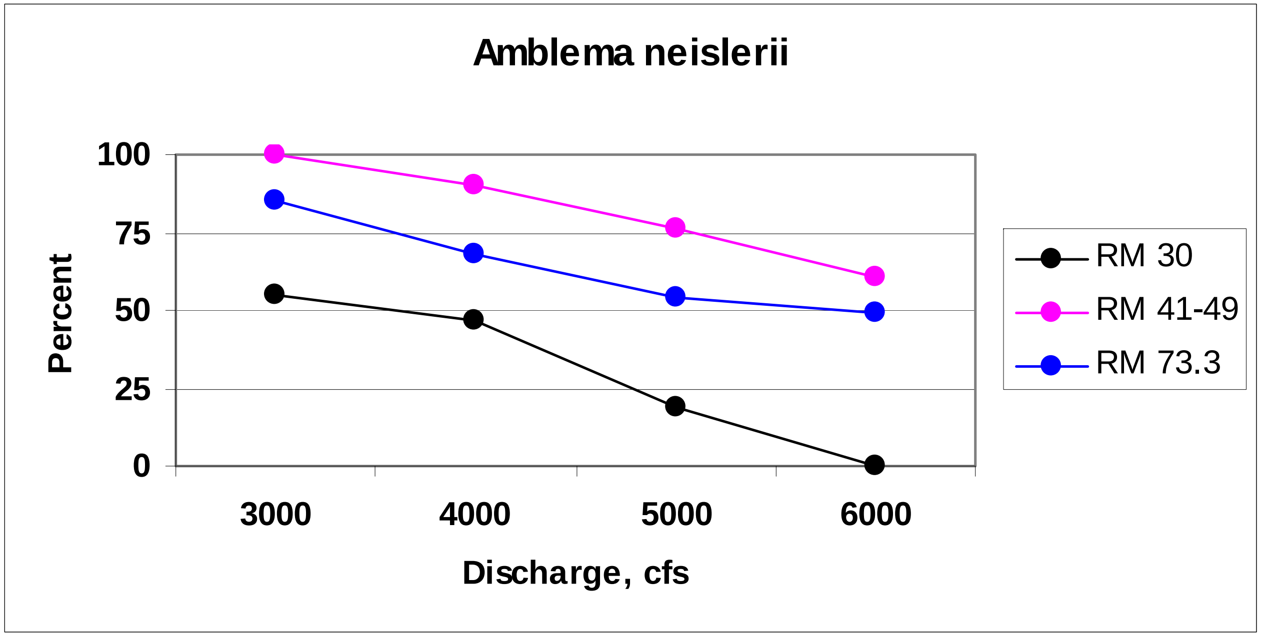
- **Phase I – Dredging impacts**
  - **96 sites likely affected by dredging**
  - **Timed searches above & below disposal areas**
  - **Studies conducted 96, 97, 99, 01, 02**
- **Phase II – Low water impacts**
  - **11 sites where A. neislerii was abundant**
  - **Transects from shallow to deep water**
  - **CPUE for *A. neislerii* versus water depth**
  - **Studies conducted in 2003**

Much data on mussels in the river…..
but how much understanding and wisdom?

Predicting Low Water Impacts-2003 Study



Depth vs. distribution

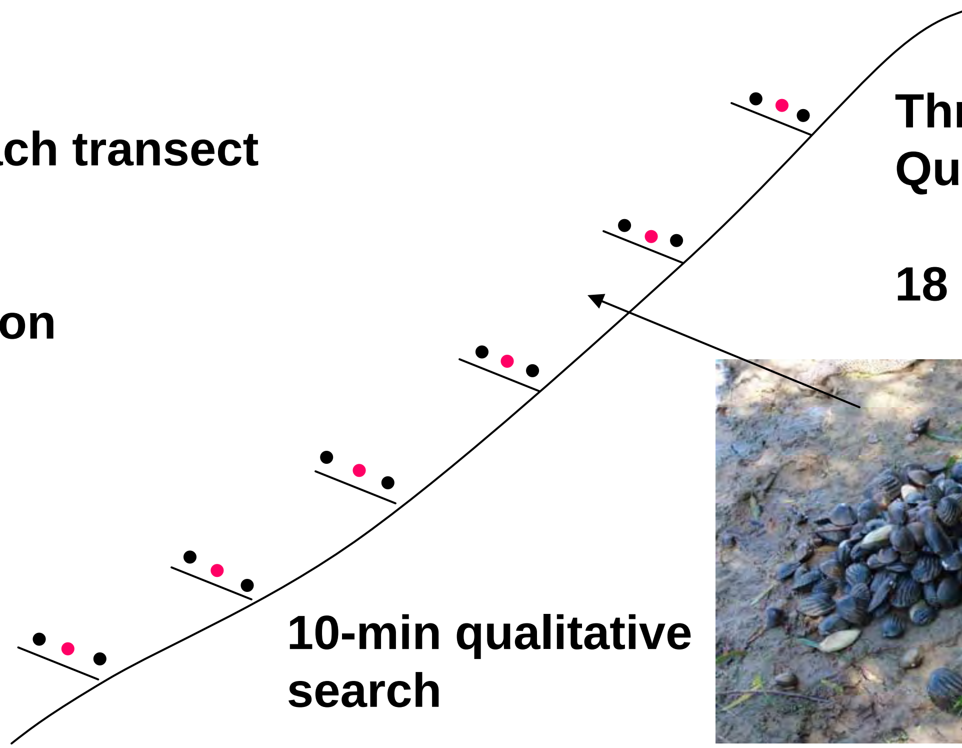


Percent exposed at low water

Based on decisions at a multi-agency meeting, USFWS chose ~25 sites between NM 40 & 50

Ten were randomly chosen for detailed studies

Depth & Distance at each transect
- **~ 1 m deep**
- **Shoreline**
- **Beginning of vegetation**



Three 0.25 m^2 Quadrats/transect

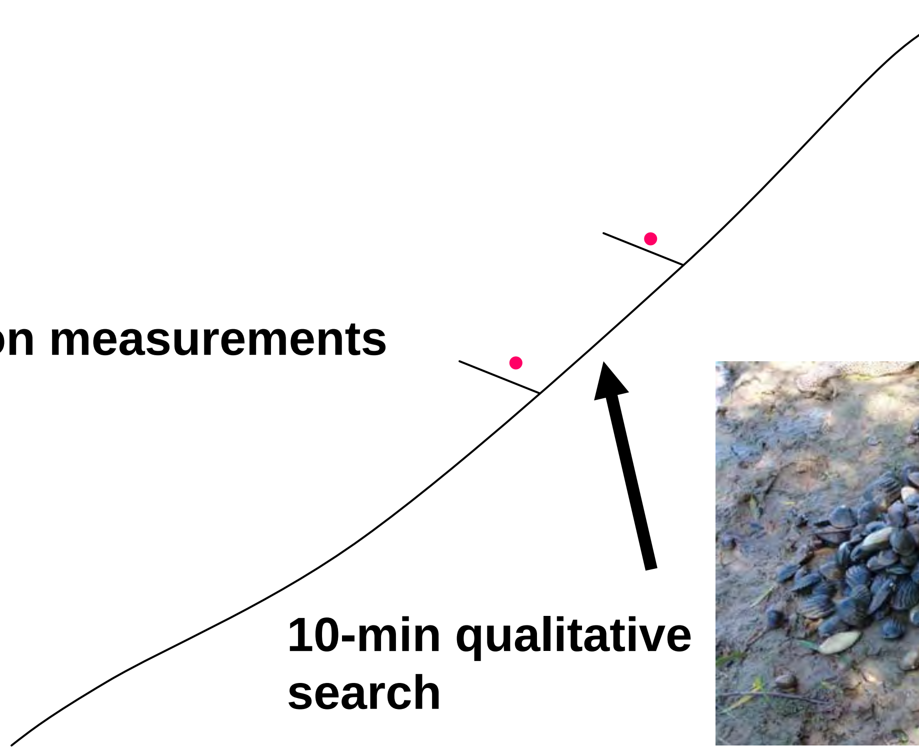
18 quadrats/site

Sediment samples •
- **Moisture content (60^{o}C)**
- **Organic content (550^{o}C**
- **Grain size distribution**

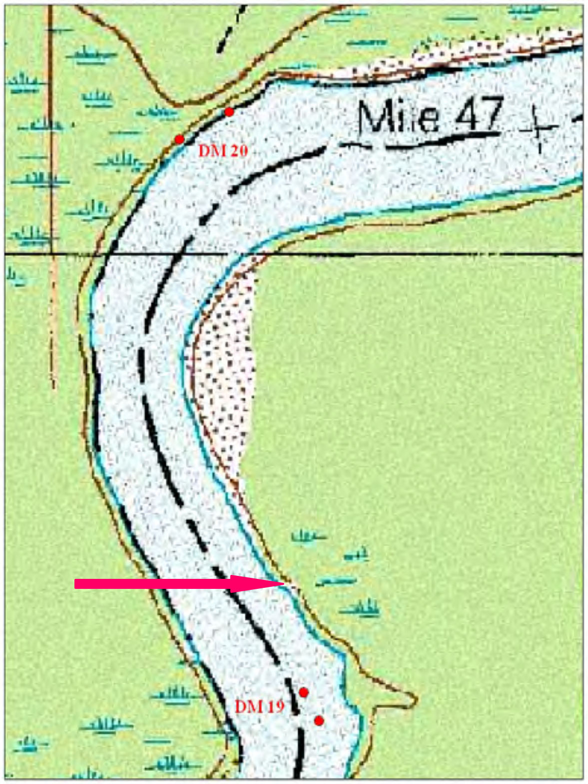
10-min qualitative search

Reduced studies were conducted
At the remaining 15 sites

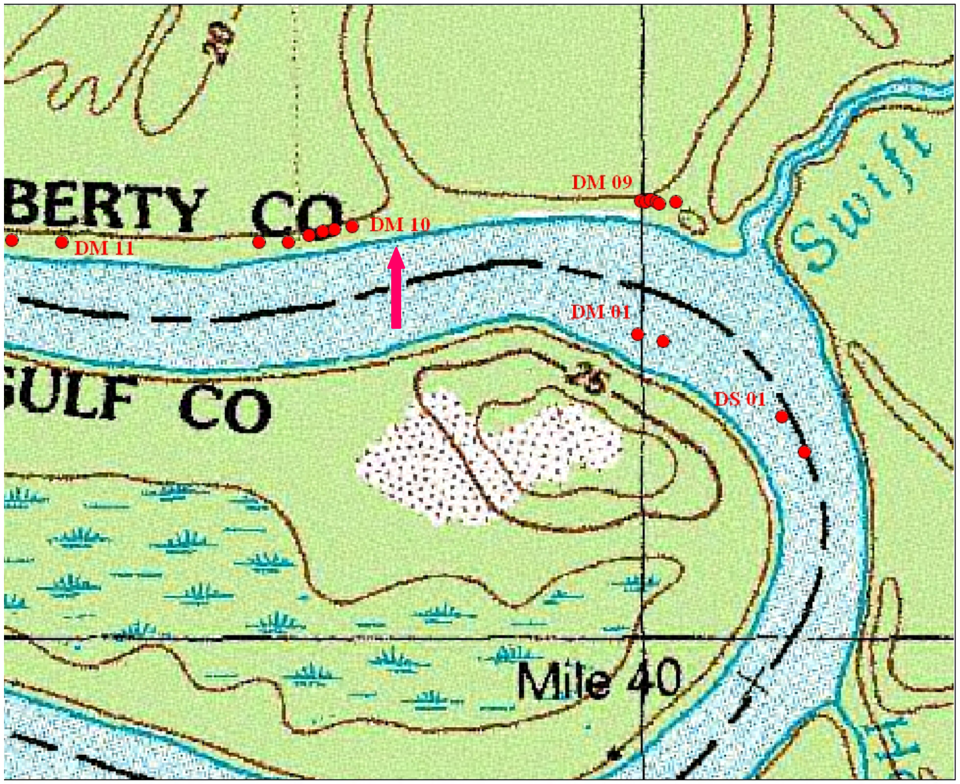
Sediment samples
Distance and elevation measurements
Along two transects



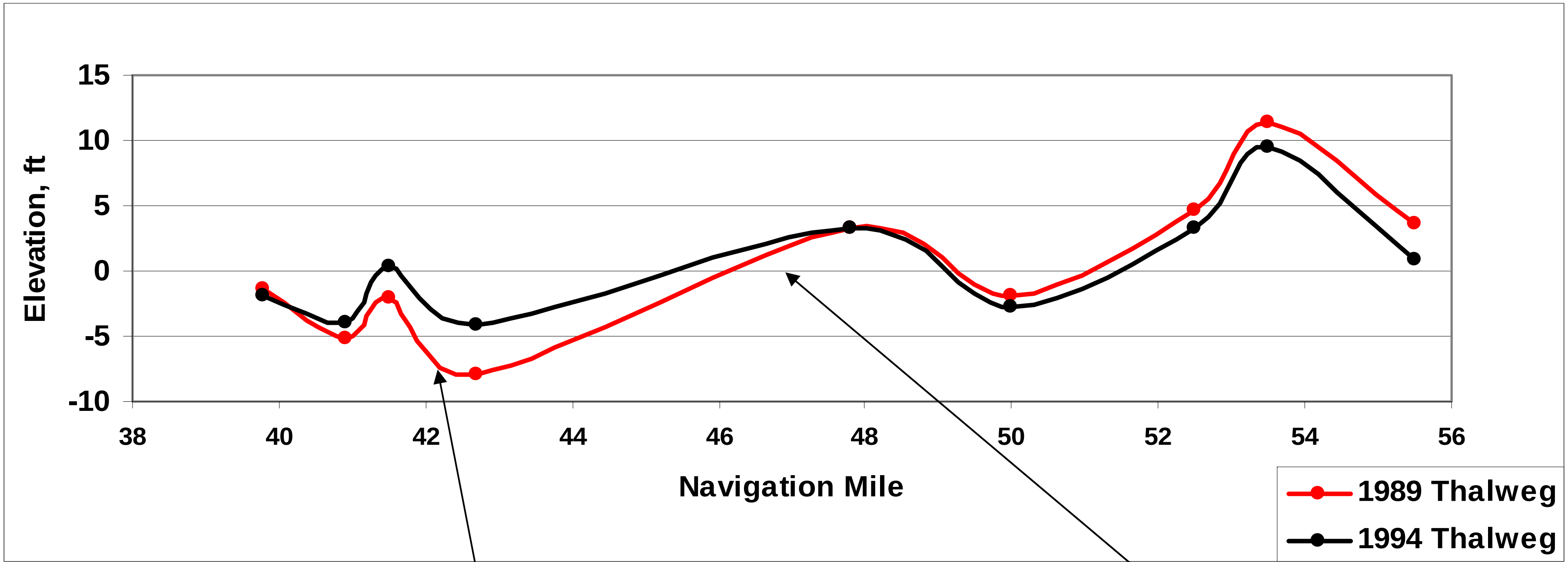
10-min qualitative search



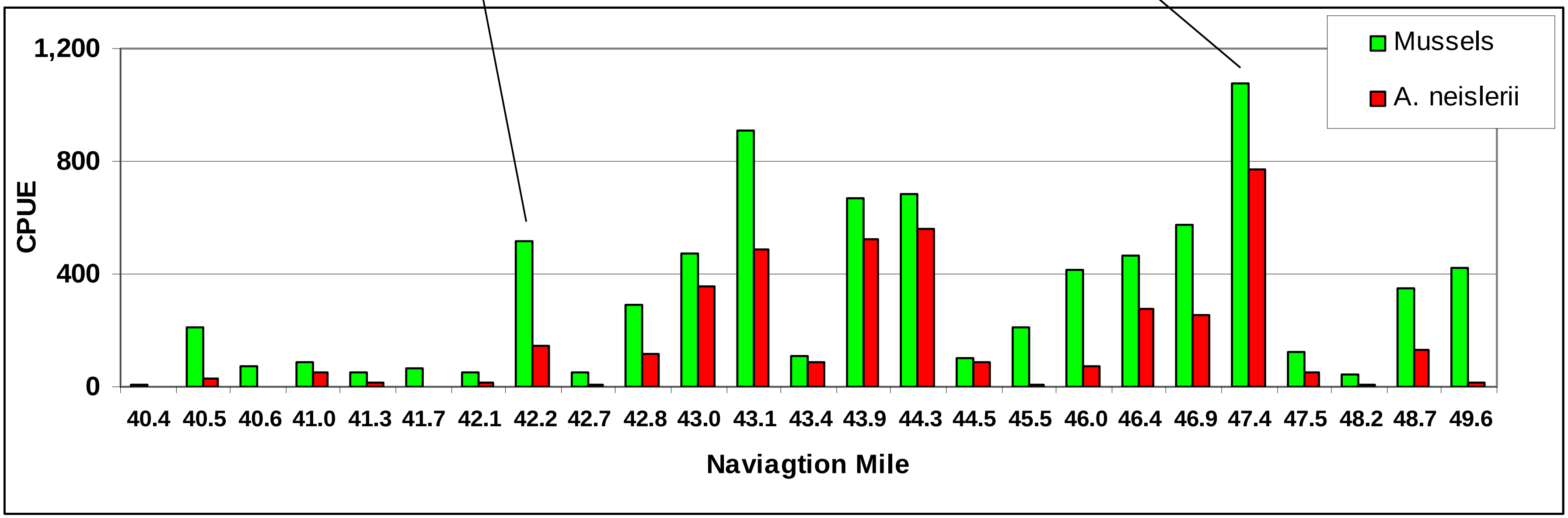
DM19
NM 46.4
CPUE
***A. neislerii* – 276**
All Mussels - 462



DM 10
NM 40.6, LDB
CPUE
***A. neislerii* – 3**
All mussels - 72

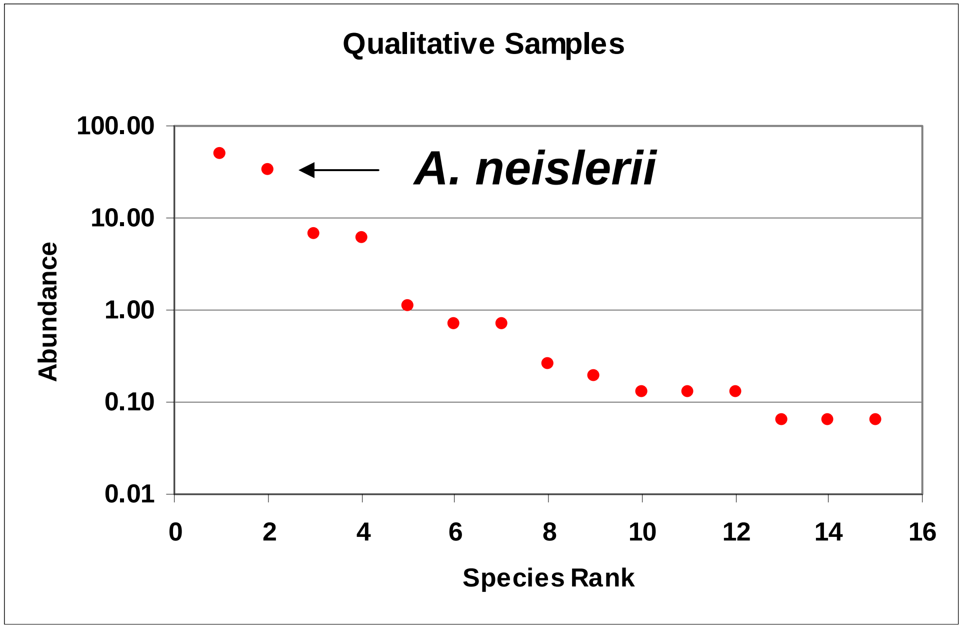


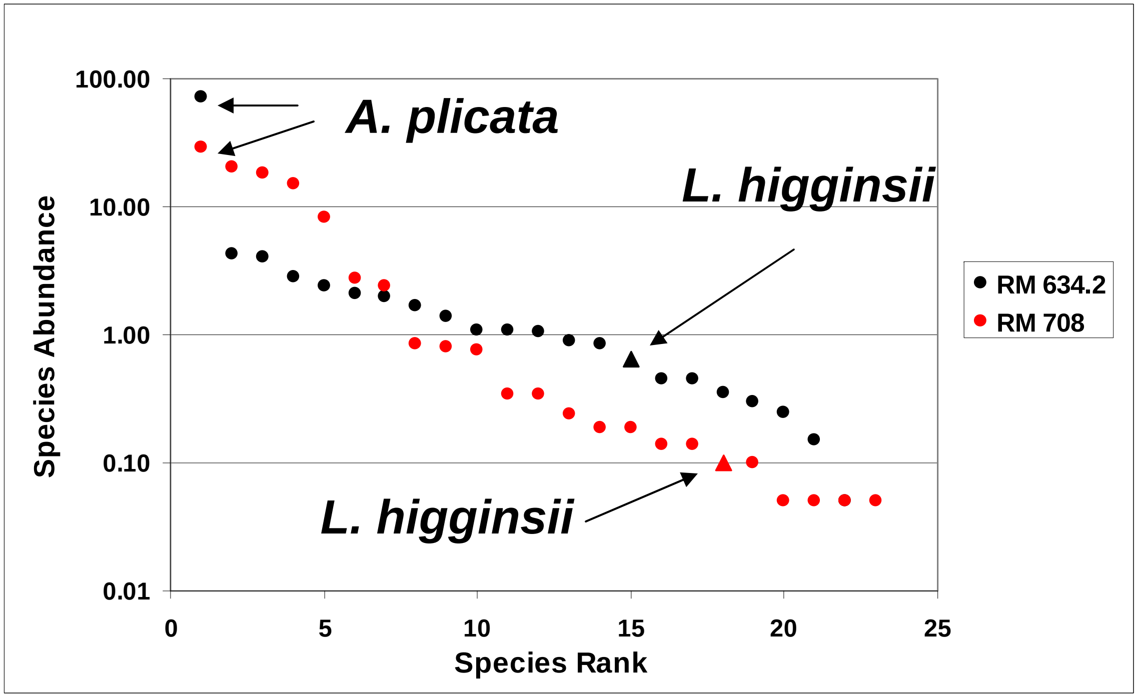
Elevation, ft
15
10
5
0
-5
-10
38
40
42
44
46
48
50
52
54
56
Navigation Mile
1989 Thalweg
1994 Thalweg



CPUE
1,200
800
400
0
Mussels
A. neislerii
40.4
40.5
40.6
41.0
41.3
41.7
42.1
42.2
42.7
42.8
43.0
43.1
43.4
43.9
44.3
44.5
45.5
46.0
46.4
46.9
47.4
47.5
48.2
48.7
49.6
Naviagtion Mile

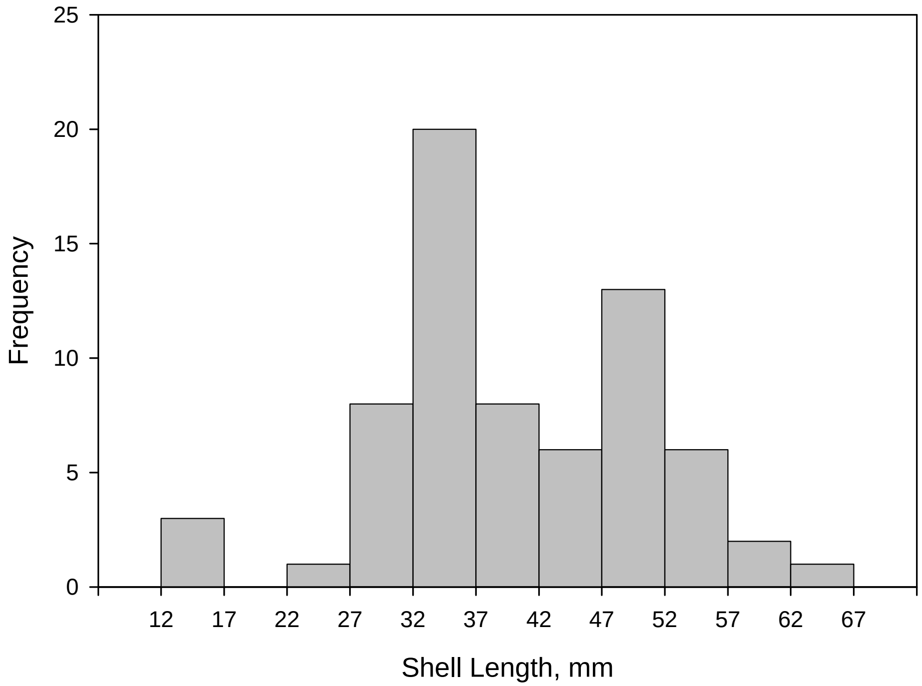
Relative Species Abundance



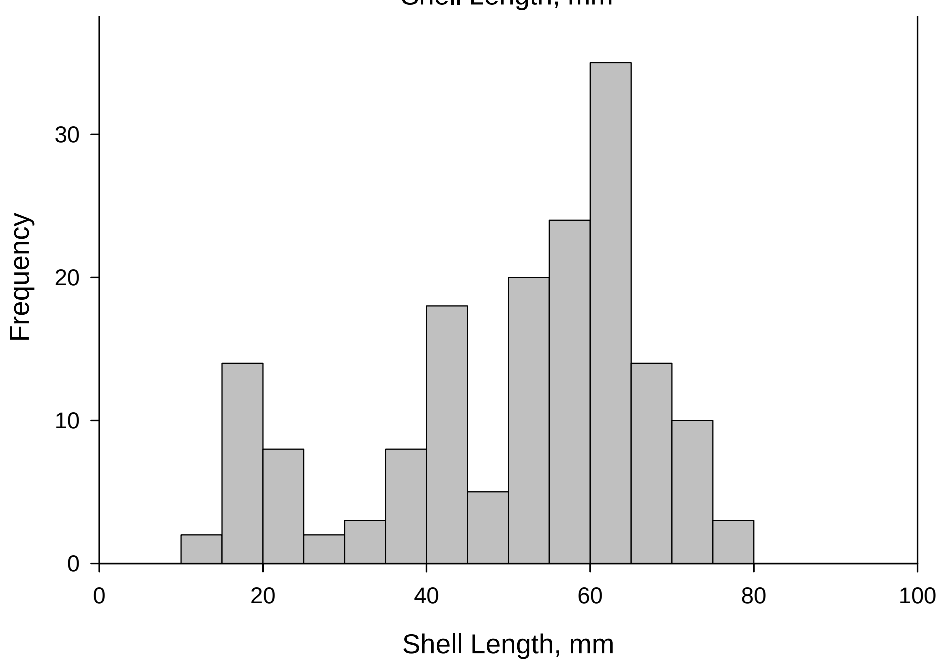


RM 635 near Prairie du Chien, WI

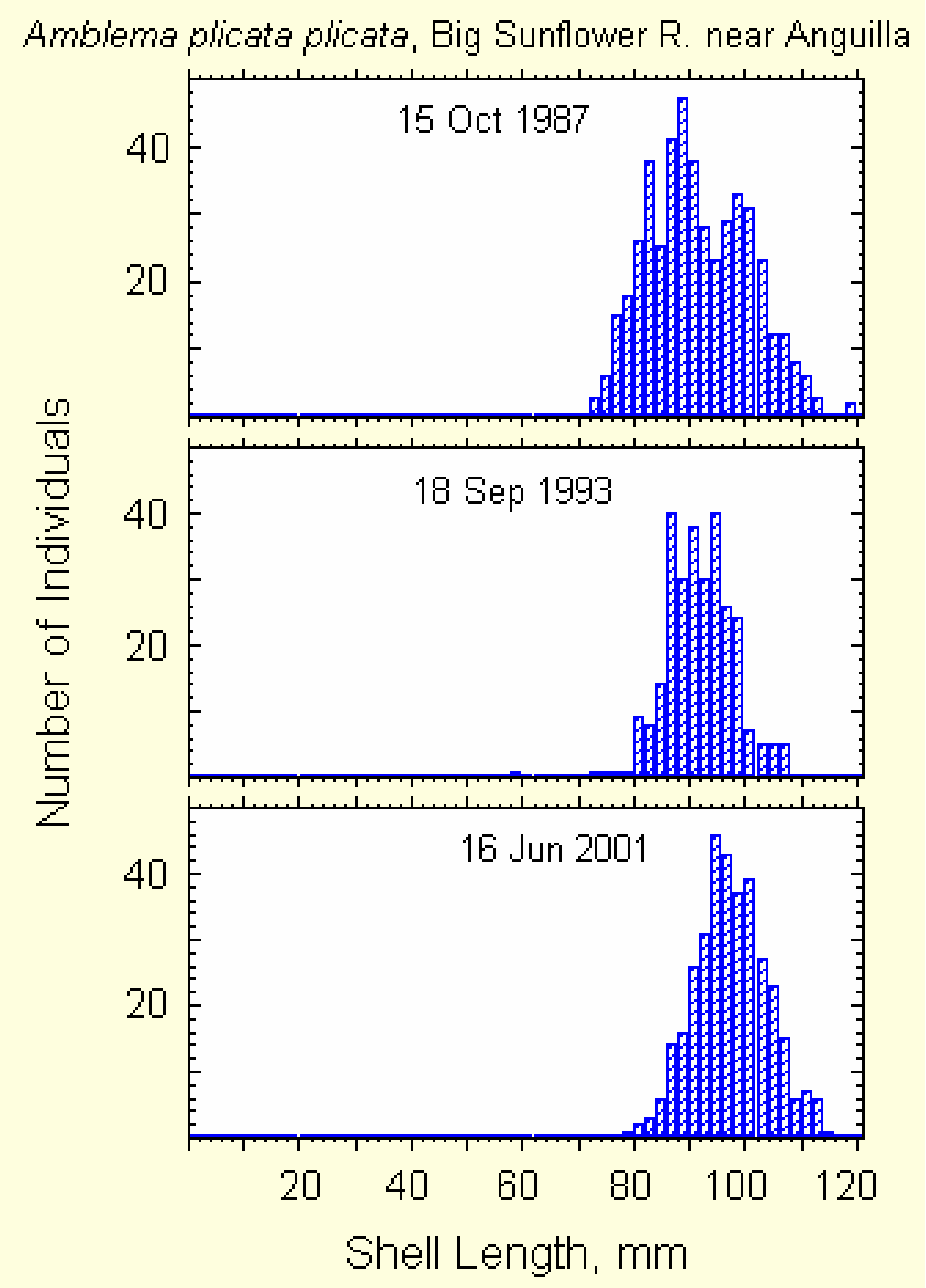
Amblema neislerii, Evidence of Recent Recruitment



Mouth of Chipola Cutoff,
NM 41.6, 1999

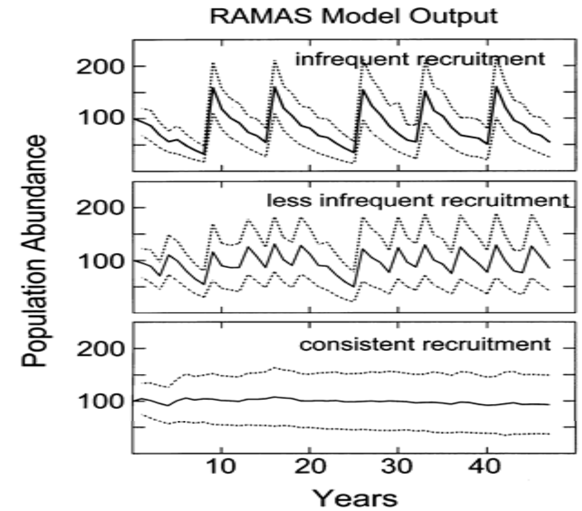


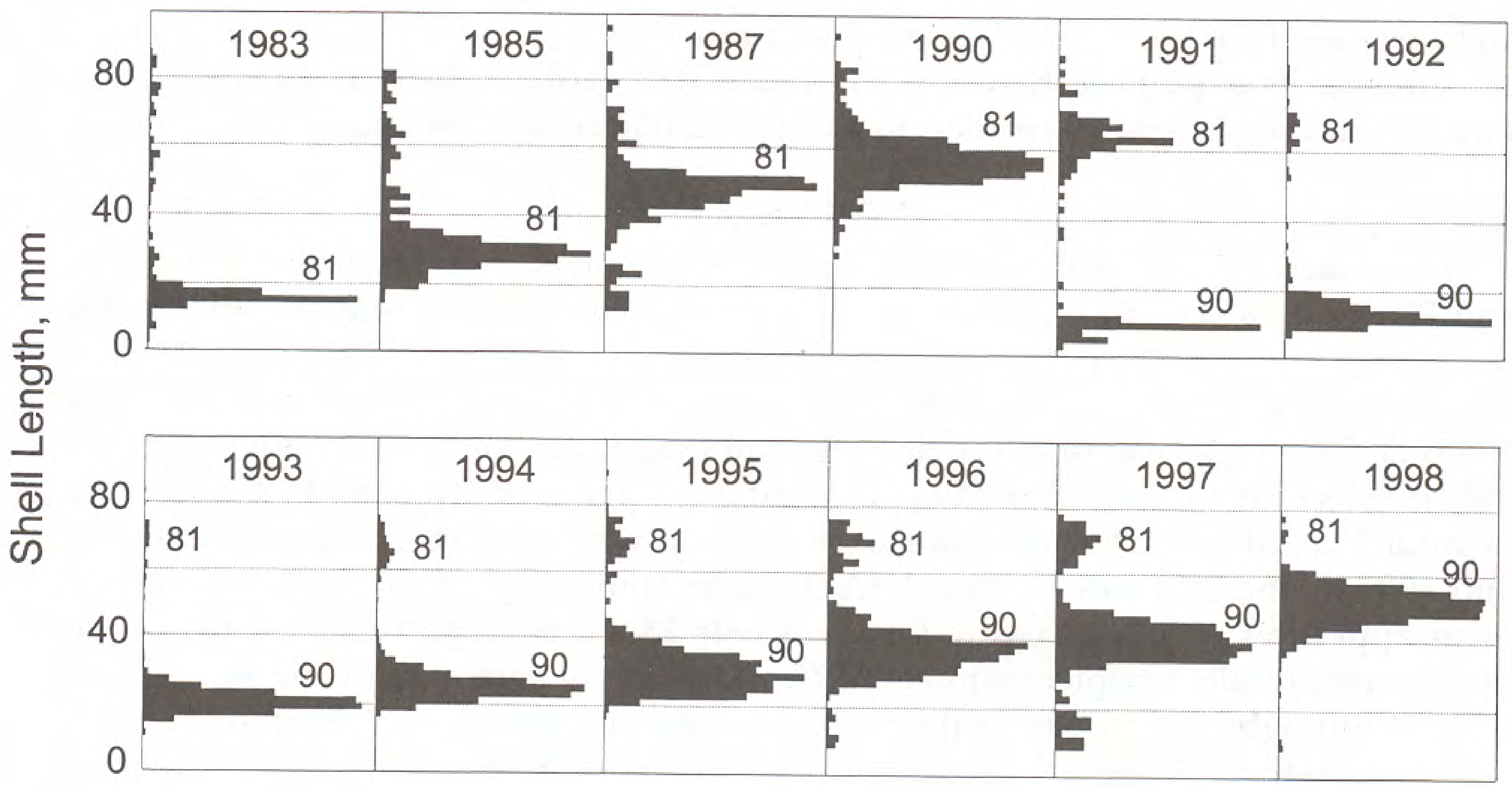
10 Sites between NM 40 & 50
2007



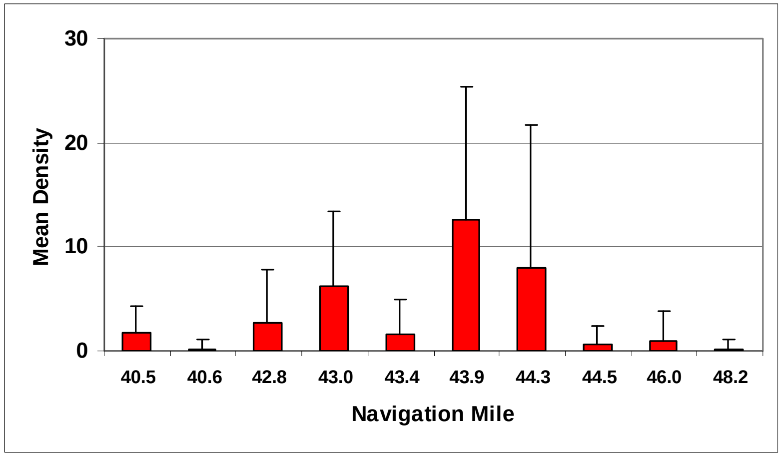
We have never found much evidence of recent mussel recruitment in the Big Sunflower River

Fusconaia ebena, Lower Ohio River, KY

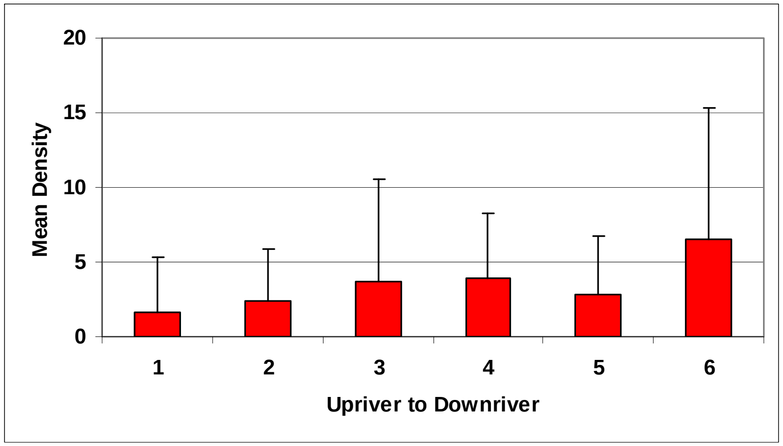




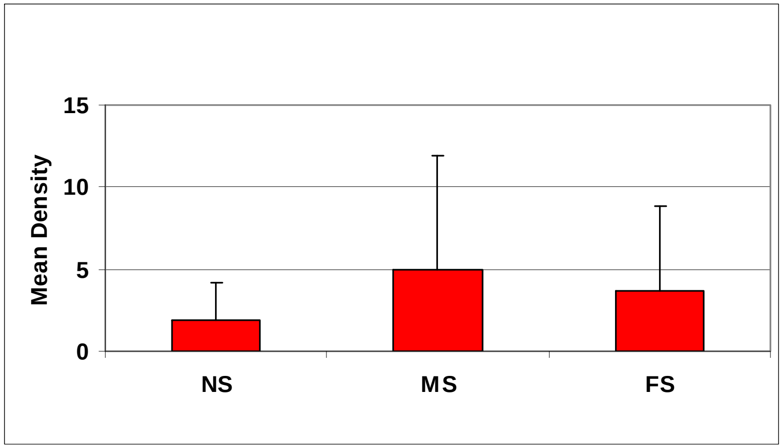
Total Mussel Density



By river mile

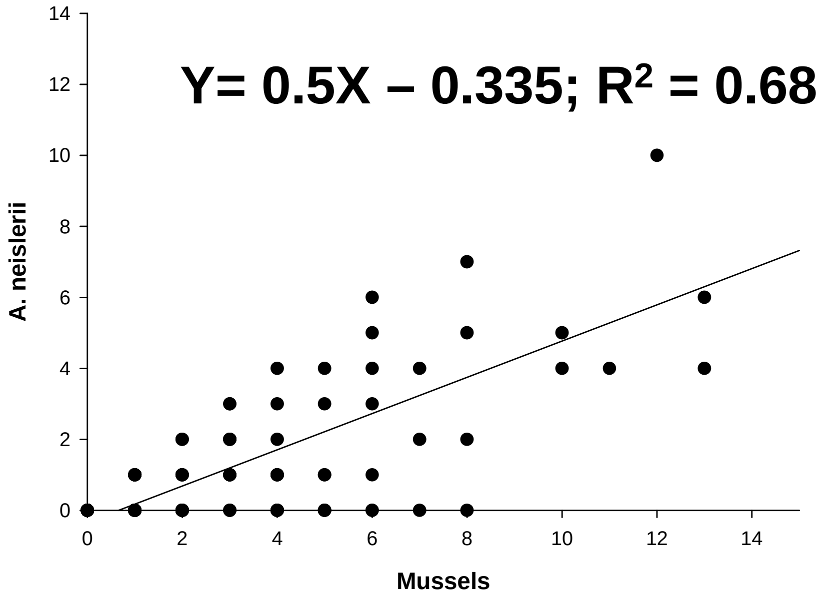


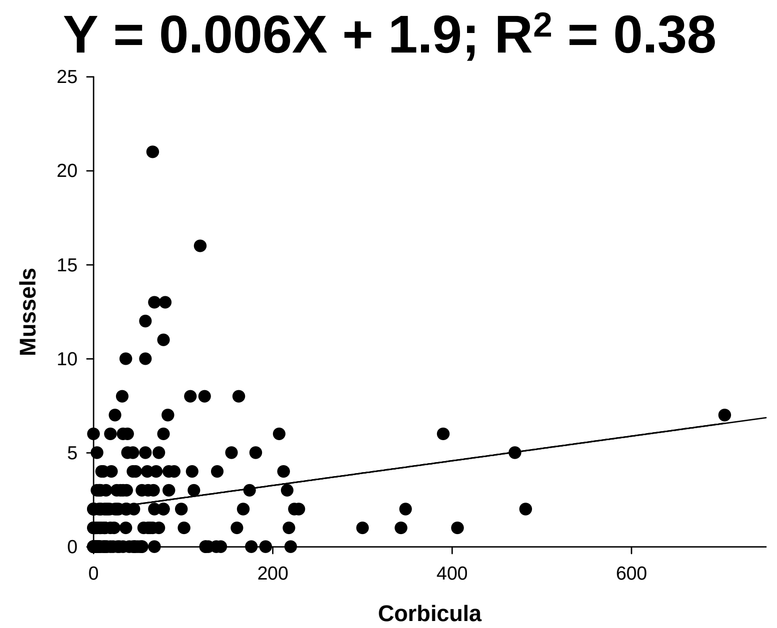
Within site variation – up to downriver

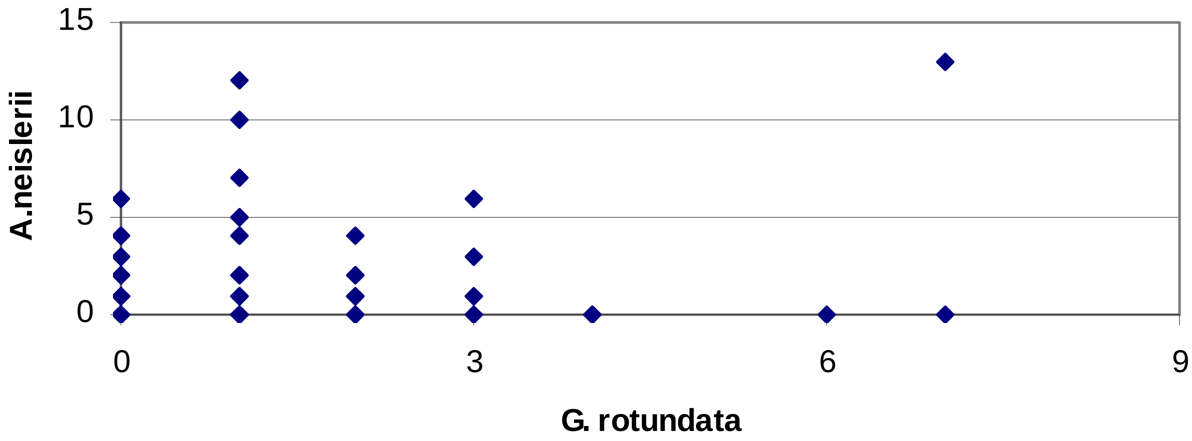


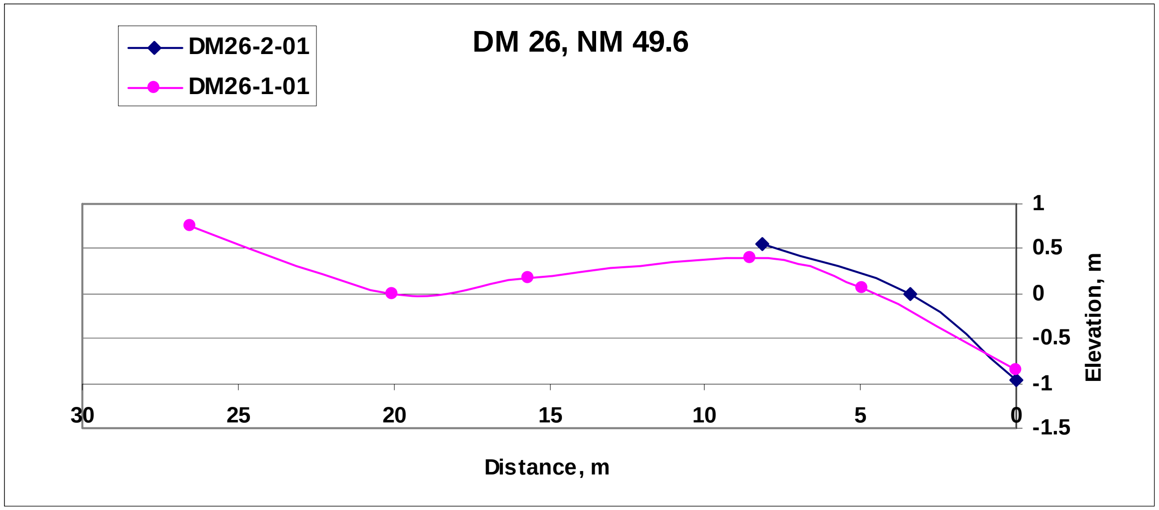
Within site variation – near to farshore

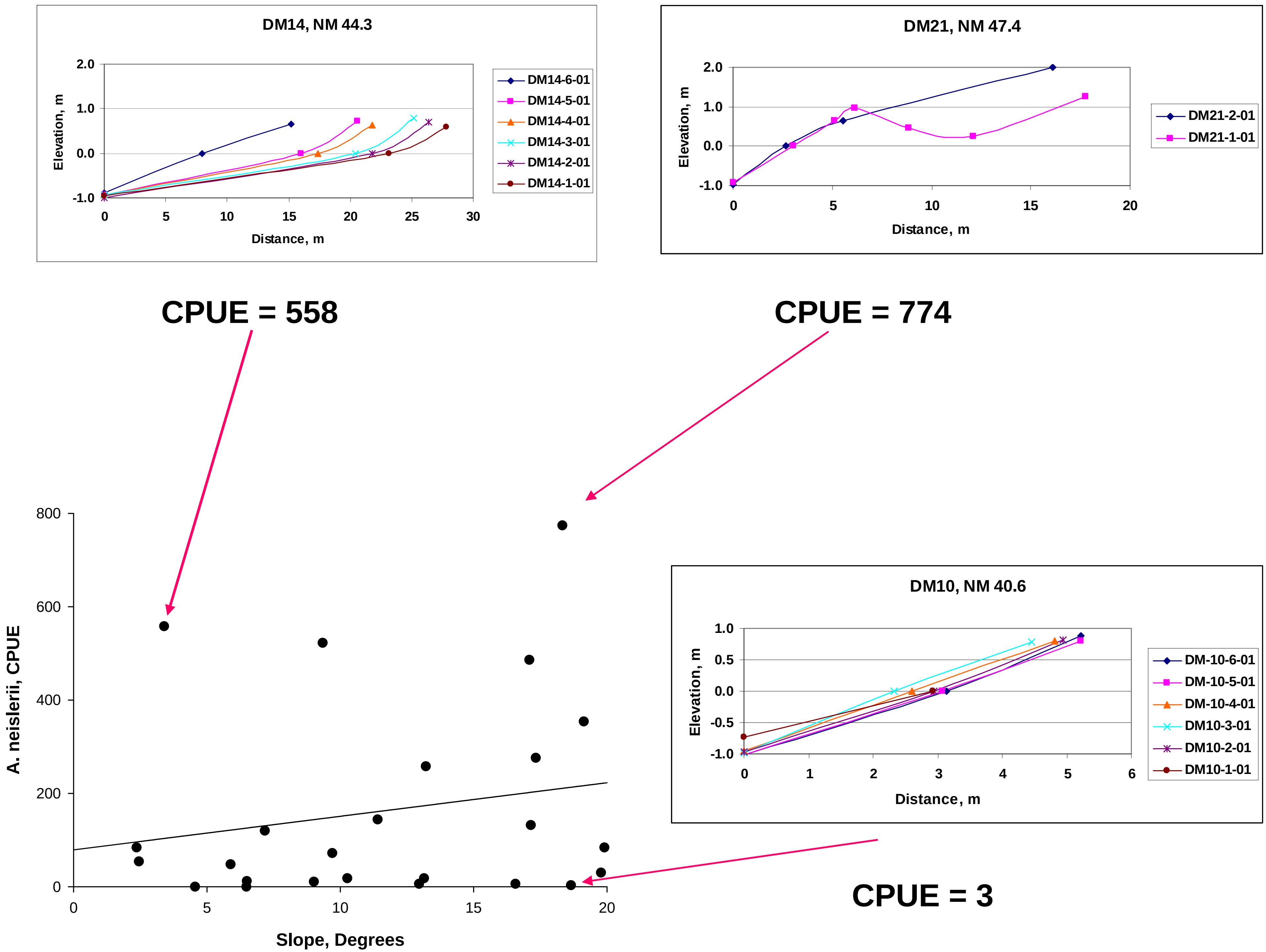
Year	River	State	Density
1998	Upper Mississippi	IA	333.2
1993	**Big Sunflower, Lock & Dam**	**MS**	**235.0**
1990	Lower Tennessee	KY	128.0
1997	Lower Ohio	IL	40.4
1993	Upper Ohio	WV	13.4
1993	**Big Sunflower, RM 71.4**	**MS**	**8.0**
2001	Upper Mississippi	IA	4.2
1992	Green	KY	3.3
1993	**Big Sunflower, RM 68.4**	**MS**	**1.3**


Y= 0.5X – 0.335; R2 = 0.68
A. neislerii
Mussels
0
2
4
6
8
10
12
14


Y = 0.006X + 1.9; R2 = 0.38
Mussels
Corbicula
0
5
10
15
20
25
200
400
600


A.neislerii
G. rotundata
0
5
10
15
3
6
9


DM 26, NM 49.6
DM26-2-01
DM26-1-01
Distance, m
Elevation, m
30
25
20
15
10
5
0
1
0.5
0
-0.5
-1
-1.5



DM14, NM 44.3
Elevation, m
Distance, m
DM14-6-01
DM14-5-01
DM14-4-01
DM14-3-01
DM14-2-01
DM14-1-01
DM21, NM 47.4
Elevation, m
Distance, m
DM21-2-01
DM21-1-01
CPUE = 558
CPUE = 774
A. neislerii, CPUE
Slope, Degrees
DM10, NM 40.6
Elevation, m
Distance, m
DM-10-6-01
DM-10-5-01
DM-10-4-01
DM10-3-01
DM10-2-01
DM10-1-01
CPUE = 3

Amblema neislerii in the Apalachicola River

- ***A. neislerii*** **is much more common in Apalachicola River than previously thought**
- **Most abundant in moderately depositional areas**
- **Ample evidence of recent recruitment**
- **Considerable mortality in 2006 and 2007; however, dense populations still survive— Sedimentation and low water are natural phenomena**
- **Swift Slough should not be considered a source or sink for** ***A. neislerii*** **– A moot point since there are no mussels in Swift Slough**

Major Findings

- **Swift Slough**
  - **Maximum CPUE: 228**
  - **Density: 0.0 – 4.4/m^2**
  - **19.8% abundance**

- **Apalachicola River,**

  NM 40 - 50
  - **CPUE: 0.0 -774**
  - **Density: 0.2 – 12.7/m^2**
  - **37 % abundance**

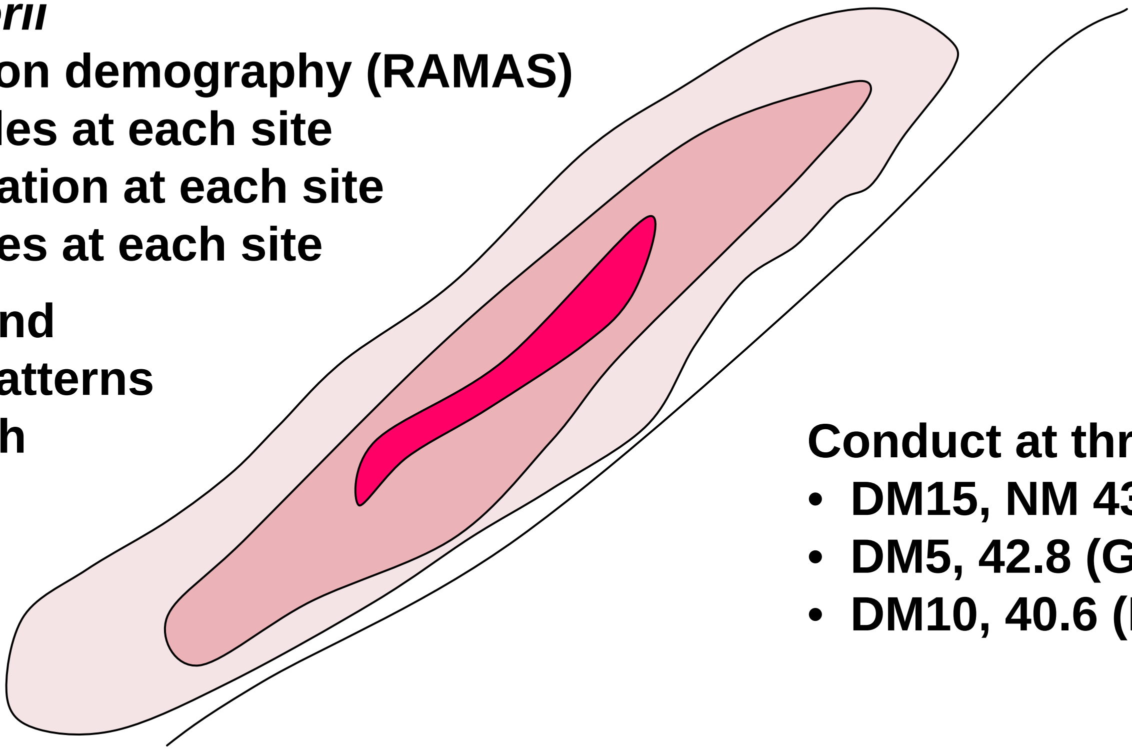
I – Detailed monitoring at <u>three</u> locations

Relate sedimentation and velocity patterns at a Site to A. neislerii distribution and abundance

- **Reconnaissance to map bed**
- **Identify 6 – 10 permanent sites**
- **~ 10 quantitative samples/site**
- **30 min search/site**
- **Measure & mark demographically complete set of *A. neislerii***
- **Model population demography (RAMAS)**

  Sediment samples at each site
- **Depth and elevation at each site**
- **GPS Coordinates at each site**

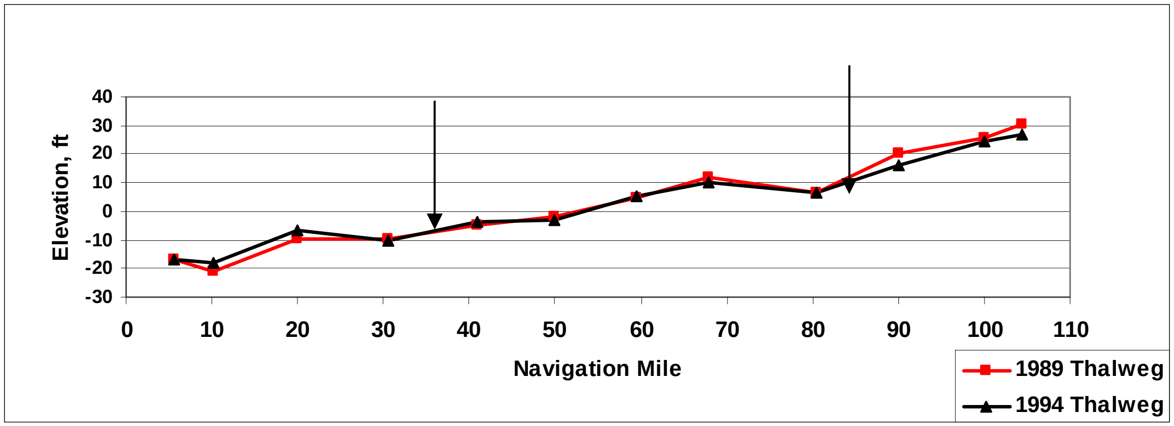
Model velocity and sedimentation patterns in this river reach



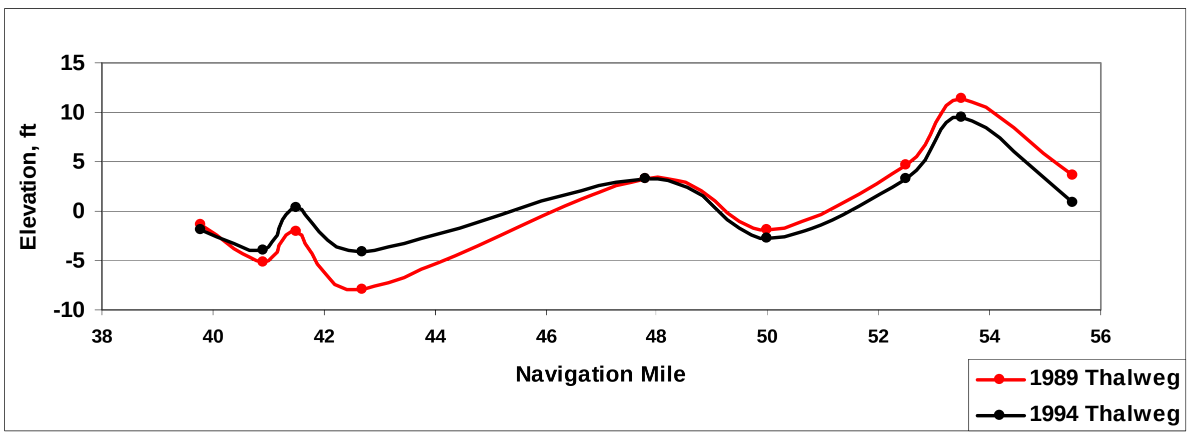
Conduct at three locations

- **DM15, NM 43.9 (Very good)**
- **DM5, 42.8 (Good)**
- **DM10, 40.6 (Poor**

II – Assess effects of scale by biotic and modeling physical studies in selected river reaches



Also—
Good quality mussel aggregations at NM 30 & 73.3



Understand importance of large and small scale physical effects on density & distribution of mussels…..

Summary of Findings

Cursory Geomorphologic Evaluation of the Apalachicola River in Support of the Jim Woodruff Dam Interim Operations Plan

David S. Biedenharn, Ph.D, PE
Biedenharn Group, LLC
August 14, 2007

1. Purpose of Study

A final Biological Opinion (BO) for the Jim Woodruff Dam Interim Operations Plan (IOP) was issued by the U.S. Fish and Wildlife Service (USFWS), Panama City Field Office on 5 September 2006. The BO included five reasonable and prudent measures (RPMs) for further limiting the amount of incidental take associated with water management operations at Jim Woodruff Dam. This current study was undertaken under RPM4, sediment dynamics and channel morphology evaluation. RPM4 was intended to improve the understanding of the channel morphology and the dynamic nature of the Apalachicola River. The objectives of the current study was to provide a cursory fluvial geomorphologic evaluation of the Apalachicola River below Jim Woodruff Dam for the purposes of providing professional opinions regarding trends (especially trends that could impact listed mussels) and potential remedial actions to reduce impacts to mussels. The effort consisted of a two day field trip (June 2007) along the Apalachicola River followed by a limited analysis based on the field observations and review of existing studies and data.

2. Background

The Apalachicola River reflects an integration of natural river processes coupled with various anthropogenic factors. Sorting out the relative contribution of the factors is often a challenge in complex river systems such as the Apalachicola River. A complete listing of alterations to the Apalachicola River is not provided here, but some of the more recent activities are discussed. The modern navigation project began with the construction of the Jim Woodruff Dam (RM) 107) in 1957. Between 1957 and 1971, the U.S. Army Corps of Engineers constructed numerous training structures, and several channel cutoffs. Additional cutoffs were constructed in the 1960's and rock removal in the upper river channel was completed in the 1980's. After about 1971, the major operations on the river consisted of maintenance dredging to maintain the navigation channel. Dredge material is generally placed within-banks in depositional areas such as on point bars. Dredging was stopped in the 2000 timeframe.

Channel degradation is the typical response downstream of a dam due to the retention of bed material sized sediment. However, the channel response to dam construction is highly variable and is a function of both the sediment retention and the altered outflows from the dam. Typically, reservoirs reduce downstream flood flows and increase low flows. The magnitude of these changes is site specific and depends on the manner of operation of the dam. Reduced flood peaks and reduced bed material loads may have somewhat of a compensating effect on downstream morphology. If the reduction in flood peaks is large, then the amount of degradation due to the retention of bed material may be lessened. Conversely, if the dam does not alter the flow regime significantly, then the effects of the bed material retention may be more pronounced.

3. Channel Characteristics

In a detailed geomorphic study, the river system is typically divided into a series of geomorphically similar reaches based on changes in slope, tributary location, geologic outcrops, sediment sources, planform changes, etc. For this cursory geomorphic study, the river was only divided into three broad areas. Reach 1 extends from the dam to about RM 78 near Blountstown. Reach 2 extends from RM 78 to RM 35 near the confluence with the Styx River. Reach 3 extends from RM 35 to RM 0. A brief discussion of these reaches follows.

Reach 1. Reach 1 is a fairly straight reach with an average sinuosity of about 1.3. The limestone outcrops of the Chatahoochee Formation occur frequently in this reach and were observed on the boat trip as far downstream as about RM 92. In fact, rock outcrops between RM 95 and 101.8 were removed in the 1960s and 1980s to provide more satisfactory navigation depths (Odom, 1966; Joanne Brandt pers. Comm.). The reach is also bounded by the Alum Bluffs and the Citronelle Formation. Based on the June 2007 field investigation, there does not appear to be a significant amount of sediment stored within the channel boundaries in this reach, which may reflect the impacts of the dam. Near the lower end of the reach the river encounters the Alum Bluffs at two locations (RM 84.5 and 81). These are very high (greater than 30 feet) bluffs consisting of a mix of sands and cohesive materials. These two locations represent the first major sand source observed downstream of the dam.

Valley slope was measured for all three reaches from topo maps. The sinuosity was calculated as the length of the reach measured along the channel divided by the straight line length of the reach. The channel slope was calculated by dividing the valley slope by the sinuosity. The results are shown in Table 1. As shown in Table 1, Reach 1 is fairly straight with a sinuosity of about 1.3 and a valley slope and channel slope of about 0.00012 and 0.000093, respectively.

Table 1. Valley slope, channel slope and sinuosity for the three reaches of the Apalachicola River.

REACH	Valley Slope	Channel Slope	Sinuosity
Reach 1 (RM 106 – 78)	0.00012	0.000093	1.3
Reach 2 (RM 78 – 35)	0.00018	0.000094	1.9
Reach 3 (RM 35 – 0)	0.00012	0.000095	1.3

A comparison of the pre and post dam flow duration curves indicates that there has not been a significant impact on the flow regime downstream of the dam. Since the hydrology is not significantly impacted by the dam, the primary impact of the dam would be the trapping of bed material. Following the construction of Jim Woodruff Dam in 1957, the channel immediately downstream began to degrade. It is possible that the amount of degradation immediately downstream of the dam may have been limited by the limestone outcrops in this area. Based on low water gage records from Light et al, (2006), stages at the Chattahoochee gage had dropped about 3.6 feet by the mid 1960s (Figure 1). Stages then stabilized until about 1980 when another foot of lowering occurred. According to Mobile District personnel, there was a series of rock removal in the early to mid 1980's that may be responsible for this additional lowering. Since that time, stages have remained fairly stable with maybe a very slight downward trend. At the downstream end of the reach near Blountstown, the gage records indicate that that low water stages had dropped about 1.9 feet by about 1970. Since the early 1970s, the low water stage levels have remained fairly constant. A comparative thalweg plot from Lidstone and Anderson (1989) also indicates about 3 to 4 feet of lowering in this reach between 1960 and the early 1980s (Figure 2). The plot of mean bed elevation of the low flow channel for 1961 and 2001 also illustrates the bed lowering in this reach (Figure 3).

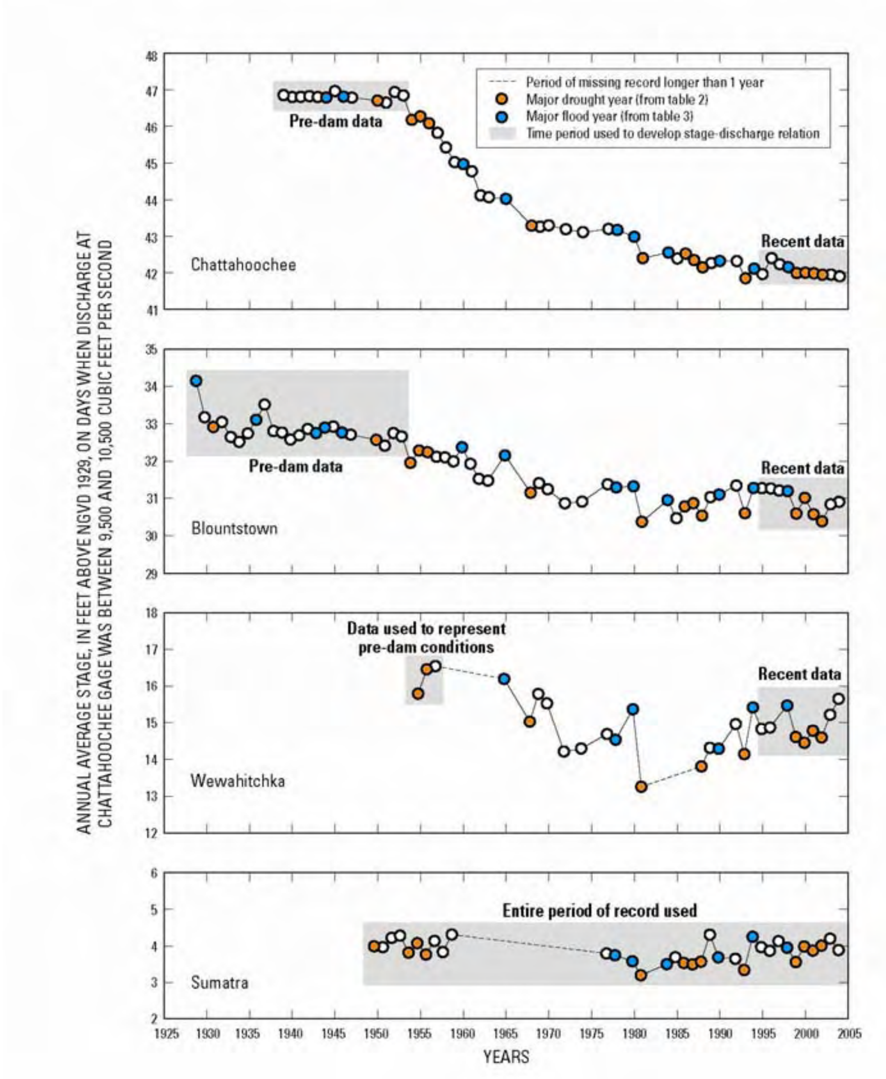


Figure 1. Gage changes at low water along the Apalachicola River downstream of Jim Woodruff Dam (from Light et al, 2006).

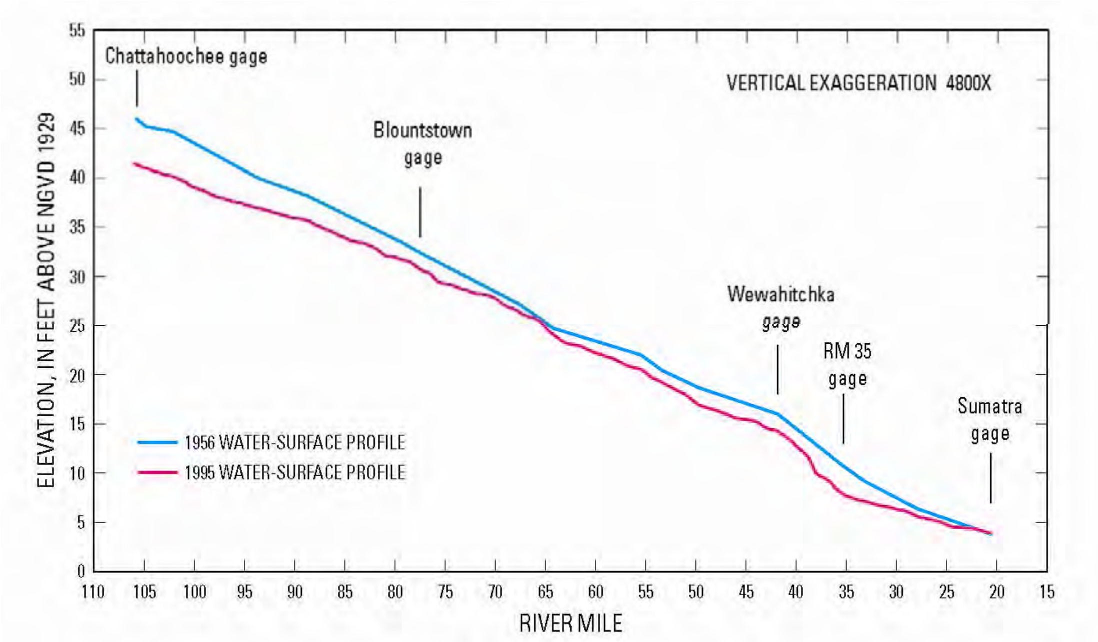


Figure 2. Water surface profiles along the Apalachicola River for the 1956 and 1995 time periods (from Light et al, 2006).

The streambanks in this reach are composed primarily of cohesive materials and bank erosion appears to be minimal throughout most of this reach based on the June 2007 field trip. A cursory examination of the bankline overlays for the periods 1941, 1963, 1993, 1999, and 2002 seems to confirm that there has not been any significant systematic channel widening throughout this reach. One factor that may contribute to the bank stability, particularly in the upper portions of this reach is the present of limestone. In many locations the limestone was observed to extend several feet up the banks, thus, providing protection of the bank toe. In contrast to these observations of stability, is the comparison of channel widths between 1941 and 2004 that was provided by the Mobile District. These data were developed from a USGS GIS system and were based on treeline measurements. According to these measurements, the channel in this reach has widened from an average of about 708 feet in 1941 to about 761 feet in 2004, or about 7%.

Reach 2. The character of the stream changes dramatically in Reach 2. Below Blountstown, the channel becomes much more sinuous with an average sinuosity of about 1.9 (Table 1). The streambanks in this reach are typically a mix of sands and cohesive materials, and active bank erosion was observed throughout this reach along the outside of the meander bends. Erosion of these streambanks is a source of sediment for the river system. The point bars in this reach are much larger than in the reach upstream. The exception to this is the sub-reach between about RM 70 and 64, where the point bars do not appear to be as large as upstream or downstream. These lower point bars may reflect the lower sinuosity, longer radius bends, more cohesive bank material, and reduced sediment supply in this reach. At about RM 64 the channel encounters a high bluff which is a significant sediment source. The reach downstream of this bluff is one of the most sinuous in the river. This high sinuosity may reflect the steeper valley slope (0.00018) in this reach. The average channel slope is about 0.000094 which is almost identical to the slopes in Reaches 1 and 3 (Table 1).

Comparison of water surface profiles between 1956 and 1995 (Figure 2) suggest that there has been some minor lowering down to about RM 20. The gage at Wewahitchka indicates that the low water stages may have dropped by about 2 feet by the mid 1970s, but have since rebounded about a foot or more. The comparison of thalweg plots for 1960, 1981, and 1984 (Lidstone and Anderson 1989) shows localized areas of scour and fill but no systematic lowering (Figure 3). The mean bed elevation comparison between 1961 and 2001 indicates that there may have been some slight lowering in the upper part of this reach, but overall, it appears that the reach has experienced localized areas of scour and fill (Figure 4). Thus, it appears that most of the dam induced degradation may have been limited to Reach 1.

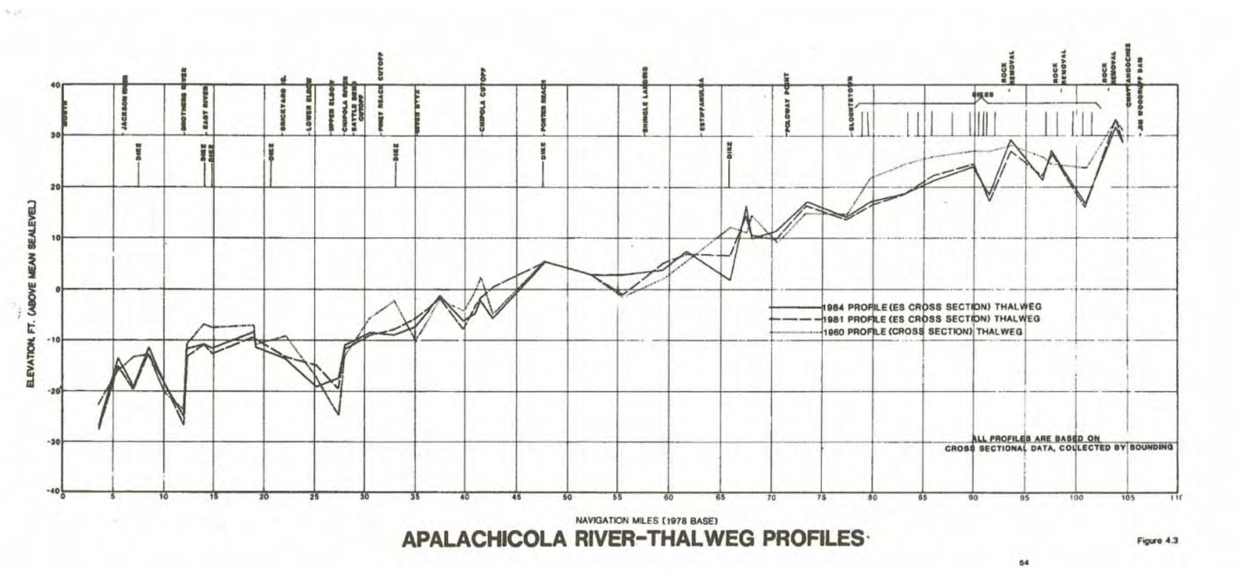


Figure 3. Thalweg comparisons for 1960, 1981 and 1984 (from Lidestone and Anderson (1989)

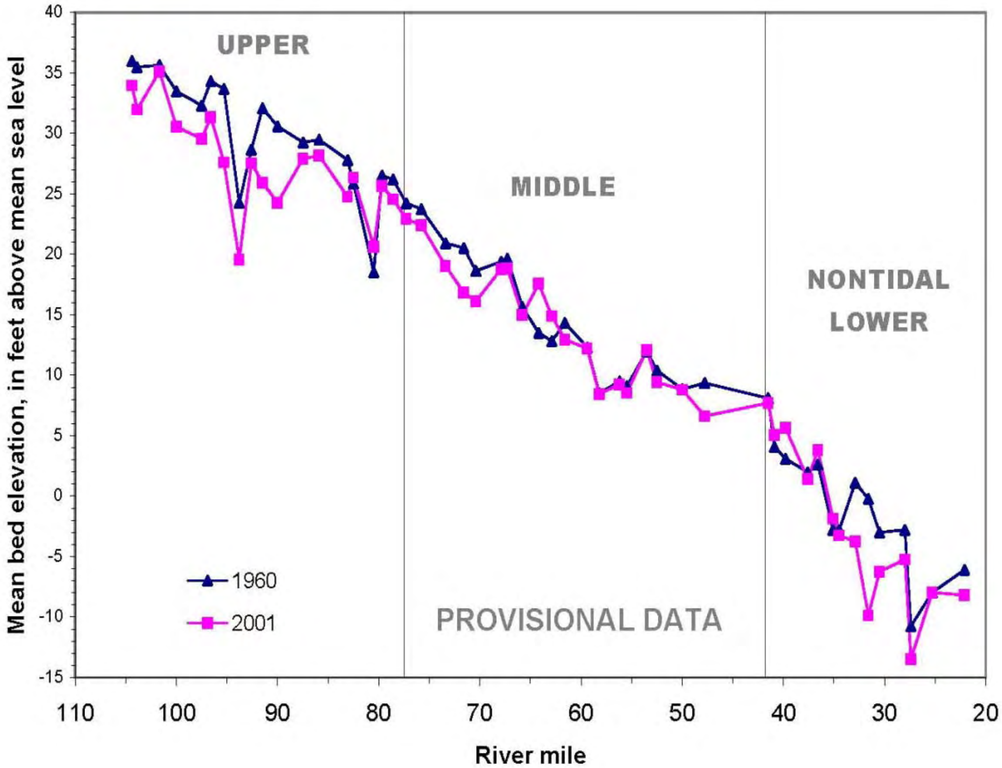


Figure 4. Mean bed elevation for low flows (USGS data provided by U.S. Army Corps of Engineers, Mobile District.

The Chipola Cutoff occurs in this reach at about RM 41.6. According to Mobile District records, the percent of flow entering the Chipola Cutoff has increased from about 25% to 34% over the past 20 years or so. The explanation for this increasing diversion percentage is not clear at this time. A cursory examination of aerial photography suggest that there is very little sediment in the Chipola channel, which would suggest that there is very little sediment being diverted into this system. This lack of sediment being diverted coupled with a 34% reduction in discharge may partially explain why the reach between the Chipola Cutoff and RM 35 has been one of the most frequently dredged areas on the river.

A plot of erosion rate versus the radius of curvature to width ratio (R/W) was developed and examined. The relationship between erosion rate and R/W was similar to most other meandering rivers. However, the erosion rates were quite low, generally less than about 4 feet per year, which is low compared to many large river systems. For instances, average erosion rates on the Red River in Louisiana and Arkansas range from about 25 ft/year to over 150 ft/year (Biedenharn et al, 1989). As expected the maximum erosion rates (between about 6 and 10 feet per year) occurred in the meander bends where the R/W was between about 1 and 3. The maximum erosion rate bends were all located in Reach 2. The field investigation confirmed that this is a very active reach with bank erosion being observed at most all meander bends. This erosion appears to be part of the natural down-valley meander migration which is common to most meandering streams, and does not appear to be the result of some system-wide adjustments such as degradation, aggradation, or channel widening. However, the comparison of the 1941 and 2004 channel widths in this reach indicate that the channel is much wider today than prior to the dam (Figure 4). In fact, the reach between RM 69 and 77 was reported to have increased on average by 143 feet, or 21%. The reach between RM 35 and 40 apparently increased about 171 feet, or a 51% increase. These are significant width increases when one considers that this reach has experienced only minimal bed lowering (less than 2 feet) and that the hydrology has not been significantly altered. Consequently, these width increases should be investigated in more detail to determine if these increases are real, and if so, what are the driving factors responsible for them.

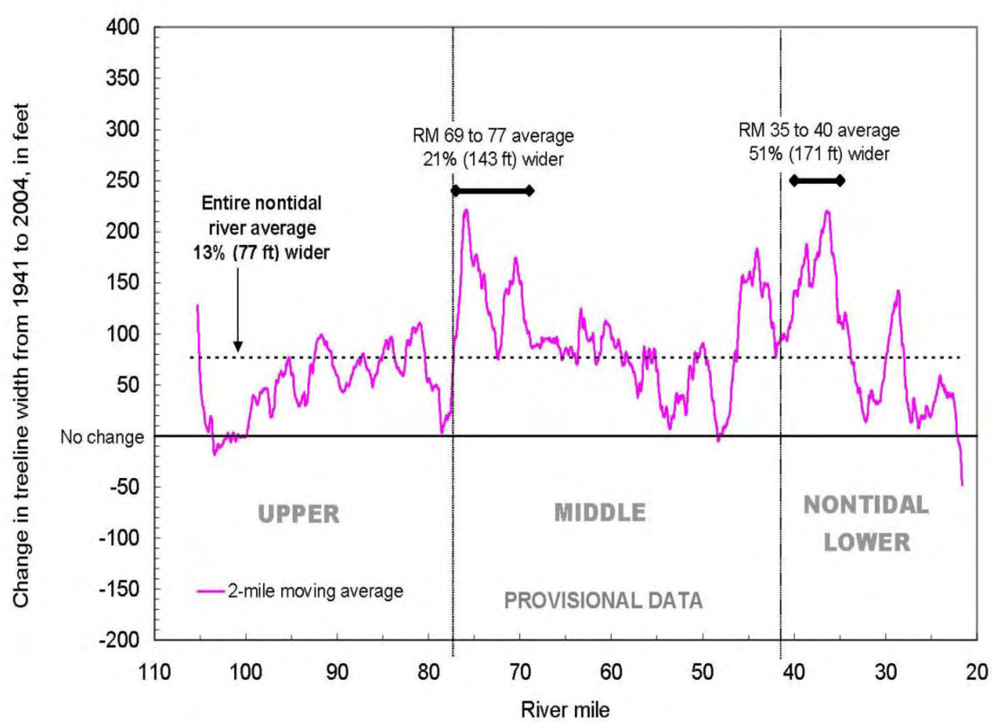


Figure 4. Changes in treeline width of main channel of the non-tidal portion of the Apalachicola River.

Based on data from Dr. Drew Miller, the highest mussel counts occur in the reach between about RM 43 (Florida River confluence) and 47.5. The highest mortality sites from 2006 also occur in this reach at RM 44, and 43.6, and in Swift Slough at RM 40.2.

Reach 3.   Although Reach 3 encompasses the entire river below RM 35, the study focused primarily on the non-tidal zone down to about RM 20. The channel morphology changes dramatically downstream of the Styx River confluence (RM 35). The valley slope flattens to about 0.00012, and the channel becomes much less sinuous (sinuosity about 1.3). The channel slope through this reach is about 0.000095 (Table 1). The field investigation indicated that there was much less bank instability in this reach than in Reach 2.

The comparison of water surface profiles between 1956 and 1995 (Figure 2) indicate that there may have been a couple of feet of bed lowering in this reach. The mean bed elevation comparison (Figure 4) also shows that there was some local bed lowering between about RM 28 and 34, with localized scour and fill occurring throughout the other parts of the reach. The comparative thalweg plots from Lidstone and Anderson (Figure 3) also showed similar patterns. The exact cause of this localized lowering between RM 28 and 34 is not known, but it may be in response to some of the local meander cutoffs that were constructed in this reach.

The lowest known mussel site is in this reach at about RM 21.5 in the vicinity of the Brickyard Island.

4. Mussel Habitat.

A significant component of the June field investigation was the opportunity to learn about the preferred habitat of the Fat Three Ridge Mussel. It appears that the preferred habitat is in the lower energy environments such as occur in the flow separation zones (eddies) at the upstream and downstream transitions between meander bends. During the boat trip there was considerable discussion about the recent loss of some of these habitat areas and the stranding of mussels. A characteristic of meandering rivers such as the Apalachicola River is that they are continually changing in space and time. The size and location of the eddie zones change with flow and through time as the meanders migrate though the floodplain. This dynamic behavior is illustrated by examining the bankline overlays from 1941, 1963, 1993, 1999, and 2002. It is important to remember is that as the river meanders through the system, eddies may be destroyed at one location, but are being created at another. Consequently, the mussel habitat areas are constantly being destroyed and created and will vary with space and time. The question is whether there is a net increase or decrease in mussel habitat or is it in some sort of dynamic equilibrium. A more detailed analysis would be needed to answer this question.

The mortality site at RM 44.3 is a good example of mussel habitat being impacted by the natural processes in the river. At this location, an area that provided good habitat a year or so ago became depositional this past year, stranding many mussels. One explanation for this might be that the channel is experiencing some sort of systematic change in its morphology. However, upon closer examination, it became clear that this situation occurred as part of the natural meandering process of the river as the channel migrates downvalley. The mortality site at RM 43.6 also appears to be a result of the natural meander process.

Another area of concern was the mussel strandings in Swift Slough. Swift Slough is a distributary stream that diverts off the river at RM 40.2. According to Jerry Ziewitz (personal communication), Swift Slough was a perennial stream that was disconnected for the first time in July 2006. During the field investigation we were able to walk several hundred yards down Swift Slough. The channel is currently clogged with sand. The depth of sand in the channel was determined, by probing, to be over 4 feet in depth. It appears that during high flows there is a considerably amount of sediment that is delivered from the Apalachicola River into Swift Slough. A sand bar located near the entrance to Swift Slough may be a source of the sand that is entering the slough. The location of this bar may have been further upstream a few years ago, and may have only recently moved into the Swift Slough entrance location as this meander bend migrates down-valley. It is also possible that prior to about 2000, this bar may have been routinely removed by maintenance dredging (Terry Jangular, personal communication). At this time, there is insufficient information to develop a complete understanding of these processes. A more detailed investigation of this site is warranted.

5. Conclusions.

A summary of conclusions based on the cursory geomorphologic study is presented. The conclusions are divided into morphological and biological categories.

Morphology

1) The flow regime (based on pre-and post-dam flow duration curves) downstream of Jim Woodruff Dam has not been changed significantly between the pre- and post-dam periods.
2) The primary impact of Jim Woodruff Dam on the downstream channel appears to be the trapping of bed material sized sediments.
3) The amount of bed material that is transported through Jim Woodruff Dam is not known.
4) Other alterations impacting the Apalachicola River include localized meander cutoffs, distributary flows, channel training structures, maintenance dredging, and the cessation of maintenance dredging in the 2000 timeframe.
5) The degradational response due to the dam appears to extend downstream to about RM 77 near Blountstown. About 4 to 5 feet of lowering has occurred in this reach. Some of this lowering (perhaps one foot) may have been the result of rock removal from the bed in the early 1980’s.
6) Reach 1 (Dam to RM 78) is a relatively straight reach with little sediment stored in the channel, and is controlled in places by local geologic outcrops of limestone.
7) The streambanks in Reach 1 are predominately composed of cohesive material and bank erosion and channel widening is minimal.
8) The dike fields in Reach 1 do not contain significant amounts of sediment.
9) The river in Reach 2 (RM 78 to RM 35) downstream of Blountstown is a much more active meandering channel with a high sinuosity (sinuosity =1.9).

10) Low water gage records and water surface profiles indicate that the channel between Blountstown and RM 20 has experienced about 1 to 2 feet of lowering. However, comparative thalweg plots between 1960 and the early 1980s indicate that the channel has experienced localized areas of scour and fill.
11) There is considerable sediment storage in Reach 2 as evidenced by the large point bars.
12) Reach 2 has the largest erosion rates on the river. This erosion appears to be part of the natural down-valley meander migration which is common to most meandering streams, and does not appear to be the result of some system-wide adjustments such as degradation, aggradation, or channel widening.
13) The channel between the Chipola Cutoff and RM 35 has been one of the most frequently dredged areas on the river. It appears that little sediment is diverted into the Chipola Cutoff, which might be a partial explanation for the frequent dredging just downstream.
14) The processes responsible for the apparent increase in the percent of flow (25% to 34%) diverted at the Chipola Cutoff warrants further study.
15) The effects of the cessation of dredging in the 2000 timeframe on the morphology of the channel warrants further study
16) Comparison of the 1941 and 2004 channel widths by USGS indicated that channel widening throughout the river down to RM 20. Further analysis is needed to determine if these width increases are real, and if so, what are the factors responsible for them.
17) The river downstream of the River Styx (RM 35) has a lower sinuosity (1.3) and less bank erosion.
18) Local meander cutoffs downstream of the River Styx may be responsible for some of the bed lowering in this area.

Biological Impacts

1) Preferred mussel habitat appears to occur in the lower energy environments associated with the flow separation zones (eddies) in the transition between meander bends
2) The size and location of the eddie zones change with flow and through time as the meanders migrate though the floodplain
3) Reach 2 contains some of the highest mussels counts on the river
4) Eddies, and consequently mussel habitat, are constantly being destroyed and created through the natural process of meander migration
5) The mussel mortality sites at RM 44.3 and RM 43.6 appear to be the result of the natural migration of the channel and not some systematic channel changes.

6) The mussel stranding in Swift Slough appears to be the result of deposition of sands from the river. It appears that a sand bar has moved to the entrance to the Swift Slough and may be the source of the sediment. However, a more detailed analysis of this area is needed to establish the exact processes responsible for this situation.

6. Recommendations

The conclusions from this cursory geomorphic study should be considered as preliminary due to the limited nature of the study. Although this cursory investigation did provide considerable insight into many of the morphologic processes occurring on the Apalachicola River, there are still many issues that need to be explored in further detail. A key example is the lack of understanding about exactly what processes are responsible for the apparent width increases that have occurred along the river. In order to develop a better understanding of the system, I would recommend a more detailed study be conducted. I could envisage some sort of a three tiered approach. The first tier would be an eco-geomorphic assessment of the system to fully develop how the system has responded in the past and where it is today with emphasis on the connection between the morphology and mussel habitat. I think this would go a long way towards developing a clearer understanding of these complex processes. The next tier would be relatively simple 1D sediment continuity model of the river. This would provide the big picture assessment of the entire river system below Jim Woodruff dam with respect to sediment continuity, channel stability, impacts of flow diversions, etc. I think the SIAM (Sediment Impact Analysis Methods) model might be a good candidate model for this. The third tier might be a 2D hydrodynamic model for selected reaches. Once again the key would be linking these detailed hydrodynamic processes to the mussel assemblages.

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Cursory Fluvial Geomorphic Evaluation of the Apalachicola River in Support of the Jim Woodruff Dam Interim Operations Plan: Summary of Findings

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1. INTRODUCTION

A final Biological Opinion (BO) for the Jim Woodruff Dam Interim Operations Plan (IOP) was issued by the U.S. Fish and Wildlife Service (USFWS) on September 5, 2006. The BO included five reasonable and prudent measures (RPM) for further limiting the amount of incidental take associated with water management operations at Jim Woodruff Dam at the head of the Apalachicola River. RPM4 of the BO, that is the subject of this memorandum, required an evaluation of the sediment dynamics and channel morphology trends in the Apalachicola River in order to improve the understanding of the dynamic channel conditions and how listed mussels (fat threeridge, *Amblema neislerii*; purple bankclimber, *Elliptoidus sloatianus*; Chipola slabshell, *Elipto chipolaensis*) are affected by the IOP. The goals of the evaluation were to:

1. Identify feasible water and/or habitat management actions that would minimize listed mussel mortality

2. Identify current patterns and trends in morphological changes, and

3. Identify additional information needed, if any, to predict morphological changes that may affect the listed mussels.

This evaluation, that was conducted for the Mobile District, U.S. Army Corps of Engineers (Corps), was based on available information, a 2-day boat-based inspection of the river from Jim Woodruff Dam at River Mile (RM) 106.5 to the mouth of the river at the City of Apalachicola (June 19 and 20, 2007) at RM 0 and best professional judgment. The 2-day field inspection was conducted in the company of mussel experts (Mr. Jerry Ziewitz, USFWS, Dr. Drew Miller, Ecological Applications, Inc. and Mr. Brian Zettle, Corps) and engineers from the Corps with extensive knowledge and experience of Corps operations on the river (Mr. Bill Stubblefield, P.E. and Mr. Terry Jangula, P.E.). The field inspection was focused on the non-tidal reach of the river that extended from the dam (RM 106.5) to RM 20 at the Sumatra gage (**Figure 1**).

Documents that were provided by the Corps and that were reviewed for this evaluation included:

- Apalachicola-Chattahoochee-Flint (ACF)1996 Annual Maintenance 5-year Report, Main Report, Mobile District, Corps of Engineers.

- ACF 1996 Annual Maintenance 5-Year Report Appendix, Mobile District, Corps of Engineers.

- ACF 2001 Annual Maintenance 5-Year Report, Mobile District, Corps of Engineers.

- ACF Navigation Maintenance Plan V1, Mobile District, Corps of Engineers.

- ACF Navigation Maintenance Plan V2, Mobile District, Corps of Engineers.

- ACF JWD IOP Biological Opinion Final Corrected prepared by the U.S. Fish and Wildlife Service, Panama City Field Office, September 5, 2006.

- USGS: (Darst and Light, 2007) Drying of Floodplain Forests Associated with Water-Level Decline in the Apalachicola River, Florida – Interim Results, 2006, Open File Report 2007-1019.

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- USGS: Excerpts from an anonymous and un-dated document on Apalachicola River Channel Widening 2006.

- USGS: Smith and Vincent, 2004. Understanding the Physical Processes of the Apalachicola River and Floodplain: Preliminary Comments and Suggested Additional Analyses, February 3, 2004.

Additionally, the Corps provided ArcView files of banklines from 1941, 1963, 1993, 1999 and 2002 as well as other files that identified dredge material disposal sites, and the locations of recent mussel surveys.

Other documents reviewed for this evaluation included the literature on downstream effects of dams on alluvial rivers (Williams and Wolman, 1984; Ligon et al., 1995), the effects of active tectonics on alluvial rivers (Schumm et al., 2000) and the geology of Florida (Florida Geological Survey).

1.1. Background

The Apalachicola River formed by the confluence of the Chattahoochee and Flint Rivers (drainage area of about 17,600 mi^2) (**Figure 2**) has been modified anthropogenically since the 1800's (Light et al., 2006). Jim Woodruff Dam (Lake Seminole) at RM 106.5 was constructed between 1950 and 1954 and filled by 1957 (Odom, 1966). It is operated as a run-of-the river structure, and its primary influence on the downstream river is to limit the downstream sediment supply. Upstream from Jim Woodruff Dam are a further 15 mainstem dams on the Chattahoochee (13) and Flint (2) Rivers that also cause a reduction in the bed material sediment supply to the Apalachicola River. Hydrologic analysis of the streamflows at the Chattahoochee gage (1929-2004) indicate that the average annual discharge appears to be relatively unchanged in the post-dam period, but minimum flows have decreased and the seasonal distribution of flows have changed with higher fall and winter flows and lower spring and summer flows (Light et al., 2006). Hydrologic changes have not been attributed to the operation of Jim Woodruff Dam, and since 2000 a minimum flow of 5,000 cfs has been maintained by reservoir releases (Light et al., 2006). The average annual discharge at the Chattahoochee gage is 21,900 cfs, and the median flow is 15,900 cfs. Review of the peak flow record at the gage indicates that 7 of the 10 largest flows in the period of record (1920-2006) have occurred in the post-dam period (**Figure 3**).

Various navigation improvement projects have been implemented on the Apalachicola River since the 1800's, including construction of the Congressionally Authorized 9-foot by 100-foot navigation channel in 1953. Attempts to maintain the navigation channel by dredging alone were unsuccessful (Odom, 1966), and river training dikes were installed between 1963 and 1970 mainly upstream of RM 78 (USACE, 1968). Dredge material disposal was initially out-of-channel, but subsequently in-channel disposal was utilized. The last time there was significant dredging of the river was in 1999, and no dredging has been conducted since 2001 (Terry Jangula, Corps, personal communication). As part of the dredging operations snagging of woody debris from the channel was also conducted. Meander cutoffs were implemented for navigation purposes at RM 35.5, RM 36.5, RM 31.5 and RM 29 (Battle Bend) and RM 71.5 (Lower Poloway). Limestone outcrop in the bed of the river at RM 99.5 and RM 101.8 was removed in the 1950's to provide more satisfactory navigation depths (Odom, 1966), and it was again removed in the upper river reaches in the 1980s to improve navigation depths (Joanne Brandt, Corps, personal communication).

2. EXISTING CONDITIONS

In general terms, the Apalachicola River is a low gradient (S=0.00009), alluvial, meandering river with an average sinuosity of 1.44 in the non-tidal reach (Light et al., 2006). The river is located within the Gulf Coast Plain Physiographic province. From Chattahoochee to Blountstown (Upper Reach) the river forms the boundary between the rolling topography of the Tallahassee Hills on the east, and the Mariana Lowlands to the west and the width of the meanderbelt is somewhat constrained by the bounding hills (Figure 1). From Blountstown to the Gulf the river flows through the Coastal Lowlands, and has a much wider meanderbelt.

The non-tidal reach of the Apalachicola River (RM 106 to RM 20) has previously been subdivided into 3 subreaches (Light et al., 2006) and these subreach designations are utilized in this report (Figure 1):

1. Upper Reach (RM 106 – RM 78) (Jim Woodruff Dam to Blountstown)
2. Middle Reach (RM 78 –RM 42) (Blountstown to Chipola Cutoff/ Wewahitchka gage)
3. Lower Reach (RM 42 – RM 20 (Chipola Cutoff/Wewahitchka gage to Sumatra gage)

2.1. Upper Reach

The Upper Reach extends from Jim Woodruff Dam (RM 106) to Blountstown (RM 78), a distance of 28 river miles. The valley floor slope in the reach is 0.00012, the channel slope is 0.000093 and the sinuosity is 1.3. In general terms, the river in this subreach is relatively straight, the banks are composed of cohesive, relatively erosion resistant materials, and the bed materials are composed of coarse sands, gravels and limestone outcrop (Chattahoochee Fm). Historically, the bed material in the reach was composed of poorly graded fine to medium sand ranging in size from 0.3 to 0.7 mm (Odom, 1966). As a result of dam construction, and possibly the effects of dredging and installation of the dikes, the river bed has degraded by about 5 feet near the dam and by about 2 feet at Blountstown (Light et al., 2006) (**Figure 4**), and the bed material has coarsened, both of which are river responses that are consistent with dam emplacement (Williams and Wolman, 1984: Ligon et al., 1995). It is conceivable that the amount of bed degradation would have been greater if the limestone outcrop was not present in the bed of the river at a number of locations through the subreach, and this could have led to accelerated mass bank failure of the relatively cohesive bank materials. USGS measurements of tree-line width of the main channel from aerial photography in 1941 and 2004 suggest that the mean width of the channel in this subreach has increased from 708 to 761 feet (53 feet), an increase of about 7.5 percent (**Figure 5**). Given the uncertainty associated with these measurements (Smith and Vincent, 2004) and the extensive presence of dredge material disposal sites within the reach that limit vegetation recovery, it is unclear whether the river has actually widened in this reach in the post-dam period. Field observations do not indicate that both channel banks are eroding along the reach, rather the bank erosion is currently limited to the outside of bends, which is to be expected. Comparative bank lines (1941, 1963, 1993, 1999, 2002) do not indicate much lateral adjustment of the channel in the reach.

Very little sediment appears to be stored within the subreach, except in the reach between RM 77.2 and RM 78.8, where annual dredging has been required downstream of two eroding bluffs located at RM 81 and RM 84 (Terry Jangula, personal communication). The bluffs are composed of the relatively erodible sandy Alum Bluff Group sediments that are overlain by unconsolidated to partly consolidated sands of the Citronelle Fm. Sediment supply to the reach downstream of the dam is limited to delivery by the tributaries that drain the Tallahassee Hills, local bank erosion and erosion of the bluffs. The observed bed degradation and the limited amount of sediment stored in the numerous dike fields in the reach indicate that the reach in general was supply limited following construction of the Jim Woodruff Dam.

2.2. Middle Reach

The Middle Reach extends from Blountstown (RM 78) to the Chipola Cutoff/ Wewahitchka gage area (RM 42), a distance of 36 river miles. The valley floor slope in the reach is 0.00018, the channel slope is 0.000094 and the sinuosity is 1.92. The river in this subreach is very sinuous and the banks are composed of a mixture of cohesive and noncohesive sediments that exhibit widespread erosion on the outside of the bends. The very high sinuosity of the river in the reach between RM 78 and RM 35 may well be the result of the river responding to active tectonics (Schumm et al., 2000). The axis of the northeast-southwest trending Gulf Trough geologic structure crosses the Apalachicola River near the confluence with the Chipola River at about RM 27 (**Figure 6**). The steeper valley floor (0.00018) on the down-dip side of the trough between about RM 78 and RM 35 requires the river sinuosity to be higher (1.92) to balance the river slope (0.000094) and thus the sediment continuity. Historically, the bed material in the reach was composed of relatively uniform sands that averaged 0.4 mm in size (Odom, 1966). As a result of dam construction, and possibly the effects of dredging the river bed has degraded by between 1 and 2 feet within the reach (Light et al., 2006), but there is no evidence that the bed material has coarsened. Sediment sources within the reach are primarily the eroding banks, many of which are composed of sands.

USGS measurements of tree-line width of the main channel from aerial photography in 1941 and 2004 indicate that the mean width of the channel in this subreach has increased from 596 to 689 feet (93 feet), an increase of about 16 percent (Figure 5). Given the uncertainty associated with these measurements (Smith and Vincent, 2004) and the extensive presence of dredge material disposal sites within the reach that limit vegetation recovery, it is unclear whether the river has actually widened in this reach in the post-dam period. Field observations do not indicate that both channel banks are currently eroding along the reach, rather the bank erosion is limited to the outside of bends, which is to be expected. Although channel widening could be a response to the upstream dams, in sand bed rivers the most likely response to the reduced sediment supply is bed degradation and not channel widening (Buchanan, 1985). Clearly, about 2 feet of bed degradation has occurred within the reach, but an increase in bank height of this magnitude (about 6 percent) is highly unlikely to cause bank stability thresholds to be exceeded and initiation of channel widening (Schumm et al., 1984; Harvey and Watson, 1986; Watson et al., 1988). However, the location of greatest channel widening (RM 78) is in an area where dredging has been required on an annual basis, and this aggradation could be the cause of localized channel widening. Additionally, the apparent widening in the reach between RM 43 and RM 46 (the "Hook and Bay" reach) is clearly due to the presence of unfilled portions of the laterally migrated 1941 channel. The lack of in-filling of the former channel locations could be due to a reduced upstream sediment supply in the post-dam period.

Comparative bank lines (1941, 1963, 1993, 1999, 2002) clearly indicate that the bends within the Middle subreach are migrating laterally as well as down-valley as a result of cutbank erosion and point bar deposition (Knighton, 1984). Analysis of bank erosion rates at banks opposite dredge disposal sites and without dredge disposal sites by the USACE did not indicate that the disposal sites were responsible for accelerated bank erosion rates. The analysis showed that the erosion rates were highest where the radii of curvature of the bends were smaller, and that the highest erosion rates were located in the reach between RM 40 and RM 60, which is the most sinuous portion of the river. The findings of the USACE study are totally consistent with the literature on erosion rates on meandering rivers (Nanson and Hickin, 1986; Harvey, 1989). Addition of the channel widths to the USACE radii of curvature and erosion rate data for the studied bends permits the Apalachicola River data to be compared with data from other rivers. The maximum erosion rates are associated with radius of curvature to channel width ratios (R/W) of between 1.5 and 2.5 (**Figure 7**), which is consistent with the trends reported in the geomorphic literature (Nanson and Hickin, 1986; Harvey, 1989). The maximum erosion rates (about 10 ft/yr) are consistent with those of the Alabama River (Harvey and Schumm, 1994), but are very low in comparison with those reported for other large alluvial rivers. The highest normalized erosion rates (erosion rate divided by channel width) on the Apalachicola River (**Figure 8**) are an order of magnitude lower than those reported for the Canadian rivers (0.14;

Nanson and Hickin, 1986) and the Sacramento River (0.26; Harvey, 1989). This does not suggest that the measured bank erosion on the Apalachicola River is in response to an upstream sediment deficit.

2.3. Lower Reach

The Lower reach extends from the Chipola Cutoff/ Wewahitchka gage area (RM 42) to the Sumatra gage at RM 20, a distance of 22 river miles (Figure 1). The valley floor slope in the upper portion of the subreach reach is 0.00018, the channel slope is 0.000086 and the sinuosity is 2.1. The upper portion of this subreach of the river (RM 42- RM 35) is very sinuous and the banks are composed of a mixture of cohesive and noncohesive sediments that exhibit widespread erosion on the outside of the bends that leads to active channel migration. As stated previously, this may well be the result of the river responding to active tectonics (Schumm et al., 2000). The high sinuosity in this part of the subreach could also be due to diversion of about 35 percent of the flow but not very much of the bed-material load into the Chipola Cutoff at RM 41.5 (Odom, 1966) which effectively increases the sediment supply to the subreach, which in turn accelerates the meander processes (Anthony and Harvey, 1991). Between RM 35 and RM 20 the sinuosity is much lower (1.27) and there is little evidence of channel migration. The lower valley floor slope (0.00012) on the up-slope side of the Gulf Trough syncline (downstream of the axis) is consistent with the presence of an active geologic structure (Figure 6). Comparative mean bed elevation data (1960 and 2001) suggest that the bed of the channel may have degraded between RM 29 and RM 35, possibly as a result of the cutting off of two bends in the reach. Stage data at the Sumatra gage do not indicate that the bed of the river has degraded or the channel has widened in the post-dam period (Figure 4; Light et al., 2006). Historically, the bed material in the reach was composed of relatively uniform sands that averaged 0.4 mm in size (Odom, 1966). Sediment sources within the reach are primarily the eroding banks, many of which are composed of sands as well as erosion and reworking of dredge material disposal sites (e.g., Sand Mountain).

USGS measurements of tree-line width of the main channel from aerial photography in 1941 and 2004 indicate that the mean width of the channel in this subreach has increased from 390 to 473 feet (83 feet), an increase of about 21 percent (Figure 5). Given the uncertainty associated with these measurements (Smith and Vincent, 2004) and the extensive presence of dredge material disposal sites, especially within the reach between RM 35 and RM 42 that limit vegetation recovery, it is unclear whether the river has actually widened in this reach in the post-dam period. Field observations do not indicate that both channel banks are eroding along the reach, rather the bank erosion is limited to the outside of bends, which is to be expected. However, channel cutoffs could be responsible for localized channel widening especially in the vicinity of Sand Mountain.

3. TRENDS

There is little doubt that the non-tidal reach of the Apalachicola River has responded to the construction of the upstream dams and the consequent reduction, or possibly elimination, of the bed material supply from upstream by degrading and possibly widening. Light et al. (2006) concluded that channel conditions in the last decade (1995-2004) had been relatively stable.

In the Upper Reach, the channel has degraded, but further degradation potential is limited by the presence of the limestone outcrop and coarser bed materials, as well as local sediment sources downstream of RM 84. The presence of relatively cohesive materials in the banks and the reinforcement of the toes of many of the banks with limestone or other geologically more erosion resistant materials limits the potential for bank erosion, lateral migration and channel widening. Additionally, the presence of extensive dike fields in the reach further limits the potential for lateral channel adjustment. Given the uncertainty in the comparative channel width data, it is not possible to speculate on future trends in channel width.

In the very sinuous Middle Reach, the riverbed has degraded by about 2 foot, but that amount of degradation is very unlikely to be sufficient to cause widespread instability of the channel and general channel widening. The channel is actively migrating as a result of cutbank erosion and point bar accretion, and as a result the hydraulic characteristics and resulting erosional and depositional components of the bends continue to change in time and space. Erosion rates within the highly sinuous reach are low in comparison to other large alluvial rivers, and are unlikely to increase over time. A number of bends have low radii of curvature (RM 62, RM 50, RM 43), and it is conceivable that in the not too distant future these bends could cutoff leading to reduced sinuosity and increased hydraulic slope. In fact, it appears that the cutoff process has already commenced at the bend centered on about RM 50. Given the uncertainty in the comparative channel width data, it is not possible to speculate on future trends in channel width.

The highly sinuous upper portion of the Lower Reach (RM 42 to RM 35) appears to be net aggradational, possibly as a result of diversion of about 35 percent of the flow of the Apalachicola River into the Chipola cutoff without a commensurate proportion of the bed material load. Between RM 35 and RM 29 the bed has degraded most probably as a result of the bend cutoffs, but further degradation is unlikely given the accelerated sediment supply to the river in the vicinity of RM 35. The channel in the sinuous upper portion of the reach is actively meandering and is likely to continue to do so. The low radii of curvature of the bends between RM 40 and RM 38 suggest that natural cutoffs could occur in the future, which would lead to a reduction in channel sinuosity and an increase in hydraulic slope. Given the uncertainty in the comparative channel width data, it is not possible to speculate on future trends in channel width.

4. MUSSEL HABITAT

During the course of the boat inspection of the non-tidal reach of the Apalachicola River, a number of locations where fat threeridge mussels (FTM) were present were identified by the mussel experts and these sites were inspected. Sites inspected that had FTM present included RM 73.2L (downstream end of a point bar) (**Figure 9**), RM 51.8L (downstream end of a point bar & mouth of Equiloxic Creek) (**Figure 10**), RM 48L (downstream of a sharp bend caused by erosion-resistant bank materials) (**Figure 11**), RM 47.2R (dike field) (**Figure 12**) and RM 43.1L (backwater-induced bank-attached bar) (**Figure 13**). While these sites have different macro-scale physical characteristics, they all have common meso- and micro-scale hydraulic characteristics (Harvey et al., 1993). All of the sites are located in flow separation zones (eddies) at higher flows than were present in the river (about 5,000 cfs) at the time of the field inspection. Within the eddy zones finer sediments (fine to medium sand and some silts and clays) are deposited against the bankline and appear to create conditions that provide suitable FTM habitat. In general, the flow separation zones occur on the inside of the bends downstream of the point bar apexes, and therefore, the FTM habitat appears to be related to meander bend dynamics. Consequently, the location of the preferred habitat is likely to change through time and space as the bends migrate laterally and down-valley. This is in contrast to the situation where eddy deposits are formed in fixed locations within canyons (Schmidt and

Rubin, 1995; Cenderelli and Cluer, 1998). Where the local sinuosity is very high and there are a number of very low radii of curvature bends present that cause upstream backwater, mid-channel and bank-attached bars are formed in the upstream limbs of the bend because of the very high energy losses through the bends (Bagnold, 1960; Harvey, 1989). Such conditions are present for example from RM 43 to RM 46. The eddy deposits associated with the backwater-induced bars also appear to create suitable habitat for the FTM.

Qualitative sampling data for the FTM in the Apalachicola River were provided by the Corps and Dr. Miller, and these data appear to support the hypothesis that the FTM habitat is formed and maintained by meander processes (**Table 1**). Within the limits of the ability to identify the FTM sampling sites on the 2002 aerial photography, it appears that the preferred habitat for the FTM is located downstream of the bend apexes within bank-attached eddy deposits and in eddy deposits associated with backwater-bars that have formed in the upstream limbs of the bends. It is of interest to note that the highest number of FTM were collected in the eddy deposits in a dike field at RM 47.4R, which does suggest that if the amount of available habitat is a limiting factor for the FTM it could be created.

Table 1. Locations of FTM habitat (Source of data Dr. D. Miller).

Location (RM)	CPUE/hr	Site Description
49.6R	18	d/s end of bend
48.7R	132	crossing
48.2L	6	d/s end of bend
47.5L	54	d/s end of bend
47.4R	774	dike field
46.9R	258	d/s end of bend
46.4L	276	d/s end of bend
46.0R	72	backwater bar
45.5L	11	d/s end of bend
44.5R	84	d/s end of bend
44.3L	558	d/s end of bend
43.9R	522	point bar near apex
43.4R	84	backwater bar
43.1L	486	backwater bar
43.0L	354	backwater bar
42.7L	120	d/s end of bend
42.2L	144	d/s end of bend
42.1R	12	point bar apex
41.3L	18	d/s end of bend
41.0L	48	d/s end of bend
40.6L	3	d/s end of bend
40.5L	30	d/s end of bend
40.4	0	backwater bar

FTM mortality observed in 2006 following the high sustained flows of 2005 (peak flow of 159,000 cfs at the Chattahoochee gage) is a matter of concern for the Corps and the USFWS. Three sites were inspected where FTM mortality had occurred following the 2005 high flows. These included RM 44L (**Figure 14**) and RM 43.6R (**Figure 15**) on the Apalachicola River and

Swift Slough (RM 40.2L) (**Figure 16**). Mortality of the FTM at each of the sites appears to be related to deposition of sandy bed material, and can be explained by the dynamics of the river. It is axiomatic that most changes in a meandering river occur during periods of high flow, since these are the conditions that cause sediment transport, bank erosion and sediment deposition. At RM 44L, the FTM mortality occurred in an eddy deposit on the downstream end of the bend centered at RM 44.5. Field observations of the conditions at the site (age and size of the willows) indicate that the eddy deposit has moved downstream through time in response to the shift of the bend caused by erosion of the opposing bank (**Figure 17**). Thus, at this site, suitable FTM habitat prior to the 2005 high flows is no longer present at the same location, and FTM present at the site appear to have been killed by excessive sedimentation that is expected as the bendway moves across and downvalley. However, the downstream shift of the eddy appears to be creating suitable FTM habitat downstream of that identified prior to 2005 which indicates that FTM habitat at a given location is likely to be ephemeral, but that new habitat is formed as the bends adjust.

At RM 43.6R, FTM mortality was associated with growth of a bank-attached bar on the outside of the bend. An extremely low radius of curvature bend is located downstream of this site at RM 43. During the high and long duration flows of 2005, the downstream bend created backwater conditions that induced further sedimentation on the bank-attached bar, which was probably responsible for the deaths of the FTM that were present at the site prior to 2005 when the site provided suitable habitat. Whether new suitable FTM habitat will be created in this general location is difficult to predict without a better knowledge of the hydraulic characteristics of the river at a range of higher flows. It is quite possible that the bank-attached bar has a limited lifespan as suitable habitat for FTM.

In the upper reaches of Swift Slough, which is a distributary channel for the Apalachicola River at about RM 40.2L, there is little doubt that relatively recent flows have introduced sandy bed material into the upper reaches of the slough and dead FTM were observed in the channel (**Figure 18**). Prior to 2005, there appears to have been a population of FTM in the upper reaches of Swift Slough, but the large numbers of mussels observed in the channel following the 2005 high flows were probably transported into the slough (Jerry Ziewitz, USFWS, personal communication). During the 2005 high and long duration flows it is quite likely that the cumulative energy losses created by the low radius of curvature bends between RM 38 and RM 40 created sufficient backwater to cause in-channel sedimentation at about RM 40. Additionally, the loss of about 35 percent of the flow without a commensurate amount of the sediment into the Chipola Cutoff was probably also responsible for in-channel sedimentation upstream of RM 40. Annual dredging of the reach between the cutoff and RM 40 was required historically to permit navigation (Terry Jangula, Corps, personal communication), and dredging has not been conducted since 2001, which could have led to a build up of bed material in the reach prior to and subsequent to the 2005 event. The hydraulics of the river at the mouth of Swift Slough are not known with certainty, but it is likely that during the high flows of 2005, sediment deposition was occurring while the bankfull flow was exceeded (about 50,000 cfs) and the overbank areas were submerged. During the recessional flows, it is quite possible that the bed material deposited in the river at the mouth of Swift Slough was re-entrained by flows entering Swift Slough which is a steep distributary with fairly high velocities (Light et al., 1998). Hydraulic modeling of the river and slough will be required to verify or reject this hypothesis. If the hypothesis is correct, it again points to the ephemeral nature of FTM habitat, which will change in response to changes in the meander planform and dynamics of the river.

5. CONCLUSIONS

Based on the review of the information, data and documents provided by the Corps, other information derived from the scientific literature, as well as the field inspection of the non-tidal reach of the Apalachicola River between Jim Woodruff Dam (RM 106.5) and the Sumatra gage (RM 20) the following are concluded:

1. Construction of Jim Woodruff Dam as well as the other federal and non-federal dams on the Chattahoochee and Flint Rivers has significantly reduced the bed material sediment load to the Apalachicola River, but the hydrology of the Apalachicola River has not changed significantly in the post-dam period.

2. The Apalachicola River has responded to the reduced bed material sediment supply from upstream by degrading. In the Upper Reach (RM 106.5 to RM 78) the degradation has ranged from about 5 feet in the upstream part of the reach to about 2 feet in the downstream part of the reach. Further degradation is likely to be prevented by the presence of limestone outcrop and possibly by coarser bed material. About 2 feet of degradation has occurred in the Middle Reach (RM 78 to RM 42). Between RM 35 and RM 29 in the Lower Reach degradation has occurred in response to bend cutoffs. Available data do not indicate that the river is continuing to degrade, and in fact the uniformity of the average channel slopes in all three reaches (0.000093 – 0.000095) suggests that the river may have attained a measure of equilibrium.

3. Because of the limitations of the data, and the extensive presence of un-vegetated dredge disposal sites along the river, it is very unclear whether the Apalachicola River in general has widened in response to the upstream dams. Clearly, local widening has occurred at specific locations where dredging and channel cutoffs have occurred.

4. Between RM 78 and RM 35 the Apalachicola River is a very sinuous (1.92) and actively meandering river which may be due to the presence of a tectonically-active trough (Gulf Trough) whose axis crosses the river just downstream of the mouth of the Chipola River. Maximum erosion rates on the outside of the bends are similar to those measured on the Alabama River, but are very low compared to other large alluvial rivers.

5. FTM habitat in the Apalachicola River appears to be associated with eddy deposits that are located on the inside of bends downstream of the point bar apexes, around bank-attached and mid-channel bars that are located in backwatered reaches upstream of low radii of curvature bends, and in dike fields.

6. FTM habitat is essentially ephemeral and changes location through time as the bends themselves adjust by lateral and downstream migration. Because of the limited mobility of FTM, sites that may have provided suitable habitat prior to a morphogenetically significant event such as the 2005 high flows may end up being unsuitable following the event which leads to mortality. The duration of site suitability for FTM is most probably related to the frequency and magnitude of high flow events. However, as existing habitat is lost as a result of meandering processes, new habitat is also created.

7. Over a longer period of time the hydraulic connections and sediment transport relations between the mainstem river and distributary channels such as Swift Slough will change

in response to changes in the planform and hydraulics of the mainstem. Ultimately, individual distributary channels are ephemeral features, but active meander processes are likely to create new channels as older channels are eliminated.

6. RECOMENDATIONS

This cursory geomorphological investigation of the non-tidal reach of the Apalachicola River has identified a number of issues that require resolution if the dynamics of the river and FTM habitat are to be more fully understood and predictable. Identified issues include:

1. Whether the river has in fact widened in response to the upstream dams, and if so what are the driving processes and mechanisms.

2. Whether the river has fully adjusted to the presence of the upstream dams or if further channel degradation will occur through time in the Middle and Lower Reaches. In other words, will the degradation that was experienced in the Upper Reach move downstream through time, or is the sediment supply within the reaches sufficient to maintain the channel bed at its current elevation.

3. Quantification of the spatial and temporal relationships between the meander dynamics of the river and the formation and maintenance of FTM habitat.

4. Assessment of the amount of habitat that is available for the FTM in the meandering reaches of the Apalachicola and whether the lack of habitat is a limiting factor for the species.

To address the identified issues it is recommended that the following be conducted:

1. An in-depth quantitative geomorphic assessment of the river between the dam and RM 20.

2. Development of a one-dimensional sediment-continuity analysis using the SIAM computer code.

3. Development of two-dimensional hydrodynamic models of selected FTM habitat sites located: (1) downstream of a bend, (2) in association with a backwater-induced bar complex, and (3) in the upper reach of a distributary channel.

4. In conjunction with the mussel experts use the results of the above to develop a physical process-biological response model that can be used to predict the impacts of water management operations at Jim Woodruff Dam on FTM habitat.

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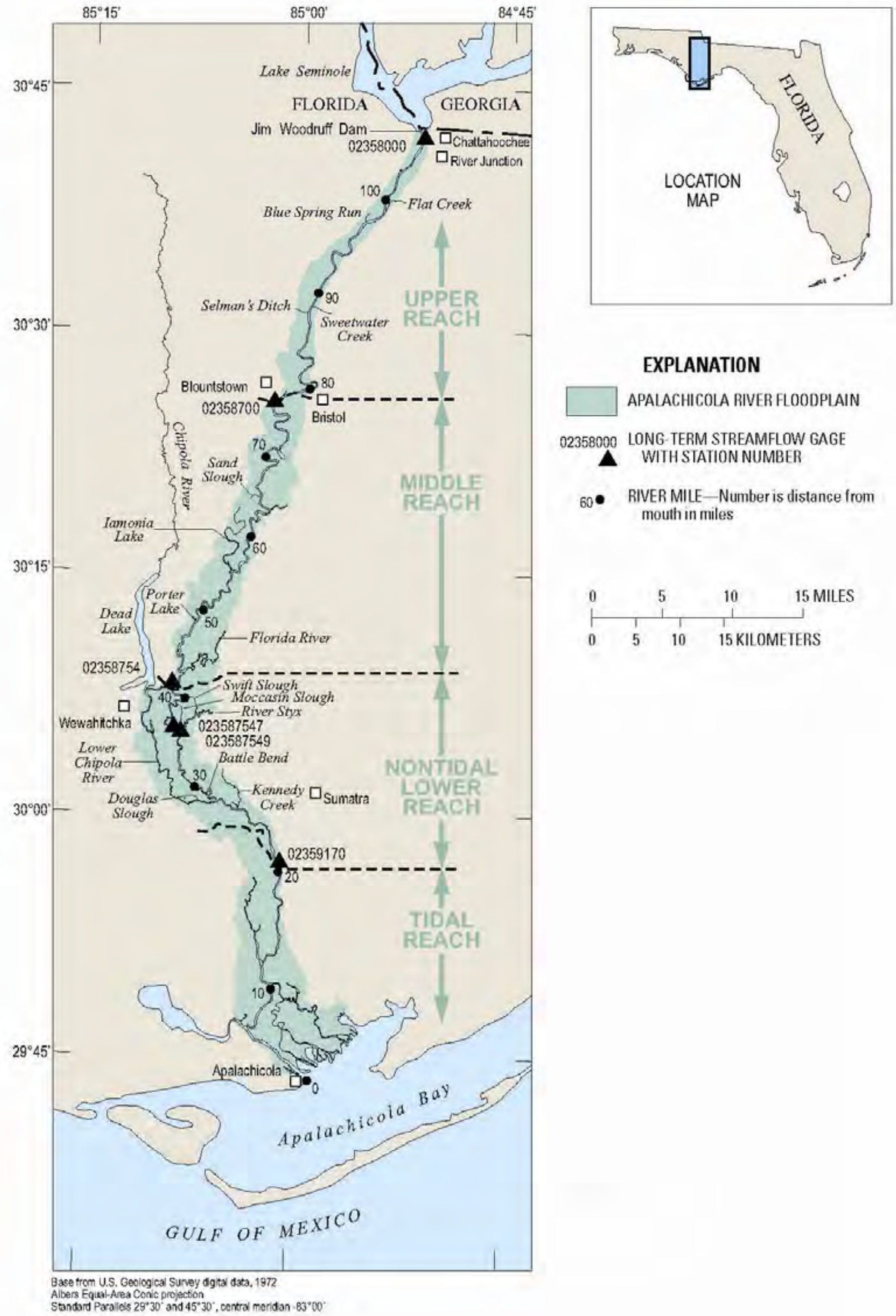

Figure 1. Major reaches of the Apalachicola River and location of long-term streamflow gaging stations (Light et al., 2006).

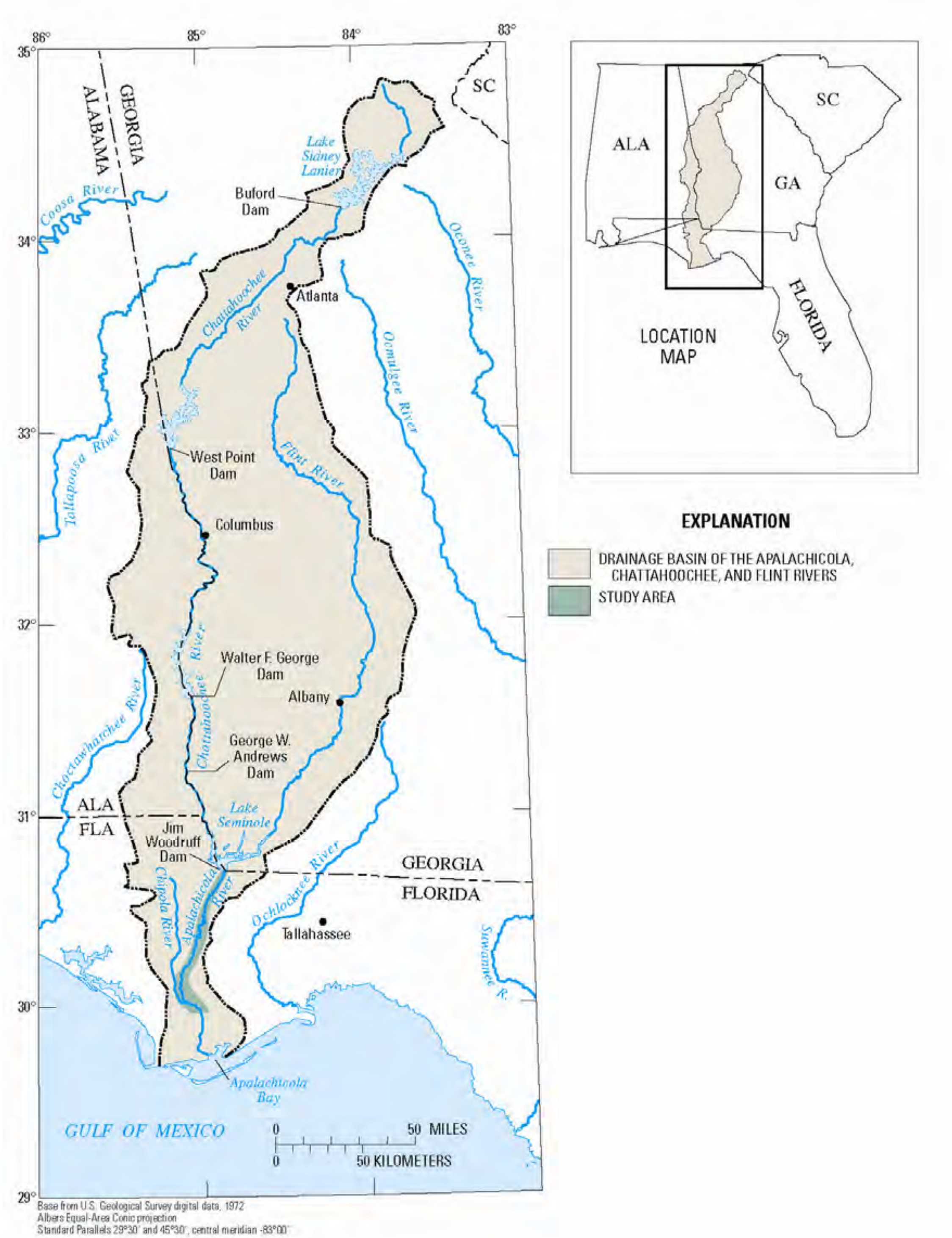

Figure 2. Drainage basin of the Apalachicola, Chattahoochee, and Flint Rivers in Florida, Georgia, and Alabama (Light et al., 2006).

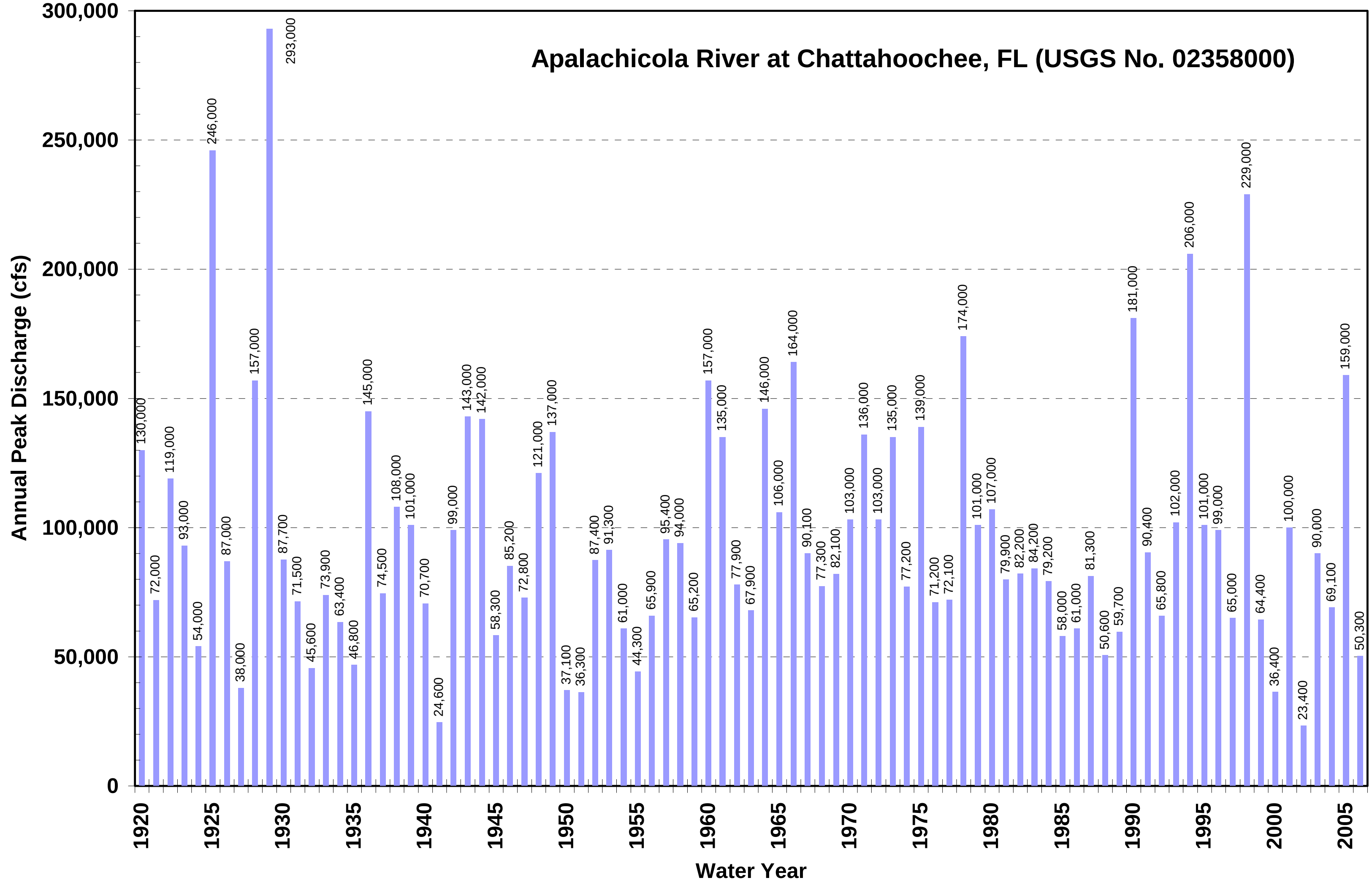

Figure 3. Annual peak flow record (1920-2006) for the Apalachicola River at Chattahoochee, Florida.

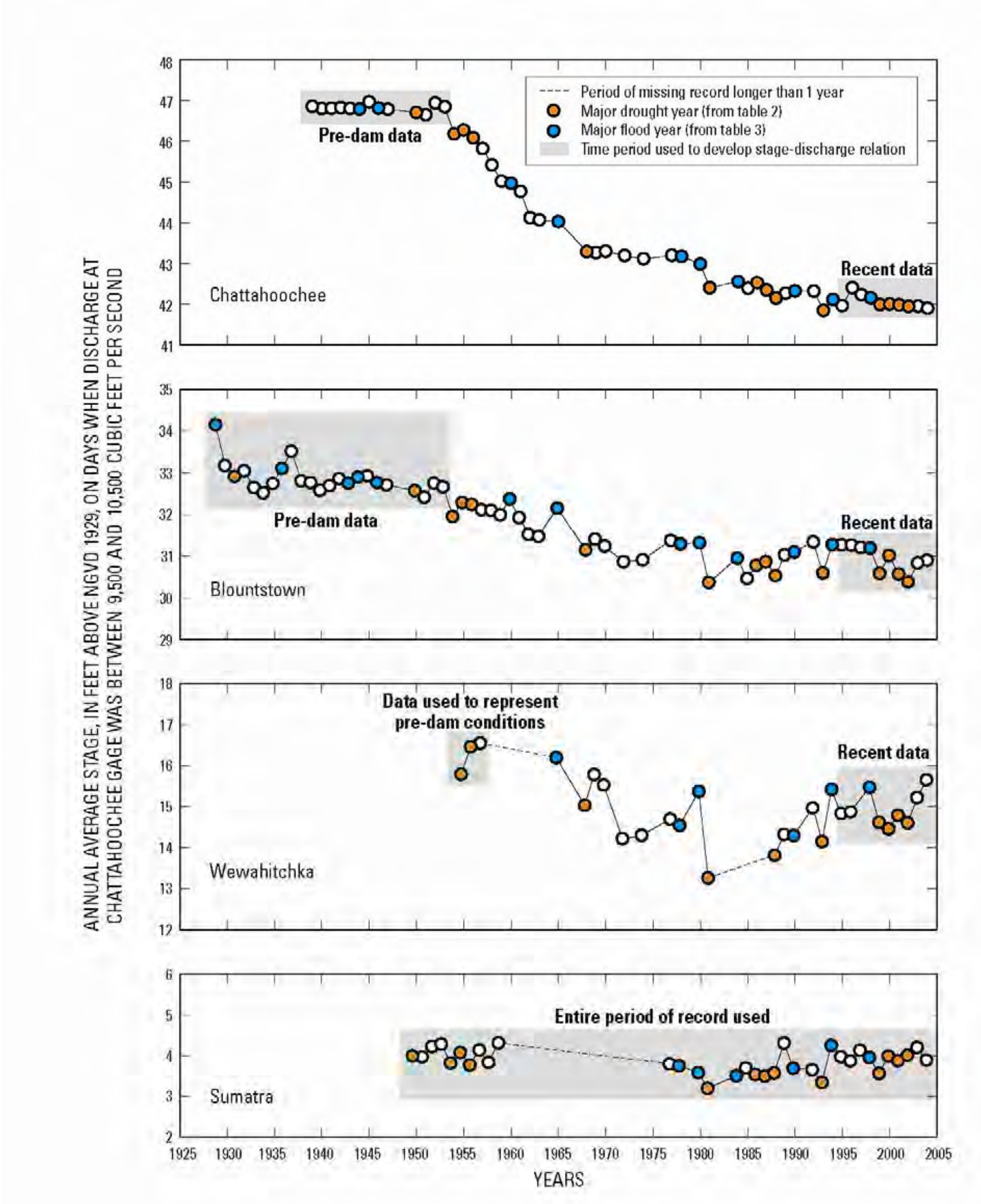

Figure 4. Average annual stages for the four gages on the Apalachicola River for flows at the Chattahoochee gage between 9,500 and 10,500 cfs (Flint et al., 2006).

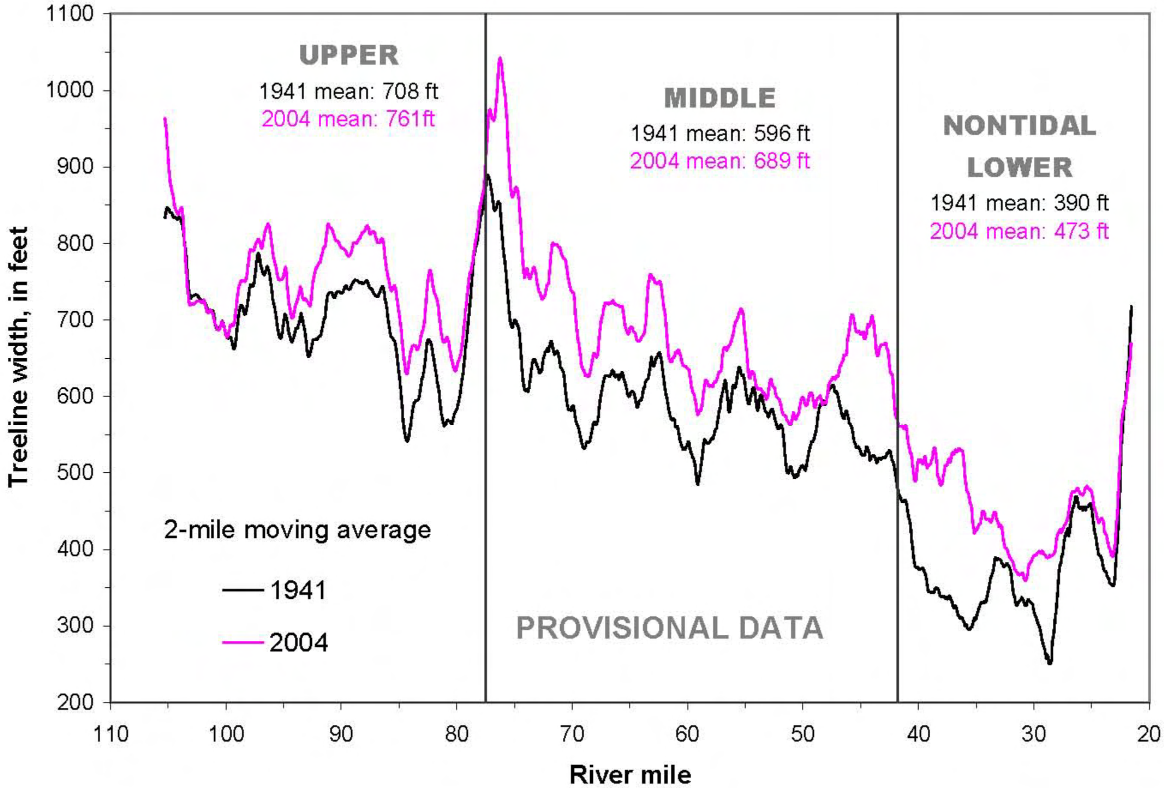

Figure 5. Tree-line width of main channel of nontidal reach of Apalachicola River, Florida, in 1941 and 2004. Widths were measured at approximately 2,800 points at 164-foot intervals along the channel centerline in aerial photographs. Data show a 2-mile (64-point moving average. River miles represent those depicted on the most recent USGS quadrangle maps available in 2005 (undated USGS data provided by Mobile District COE).

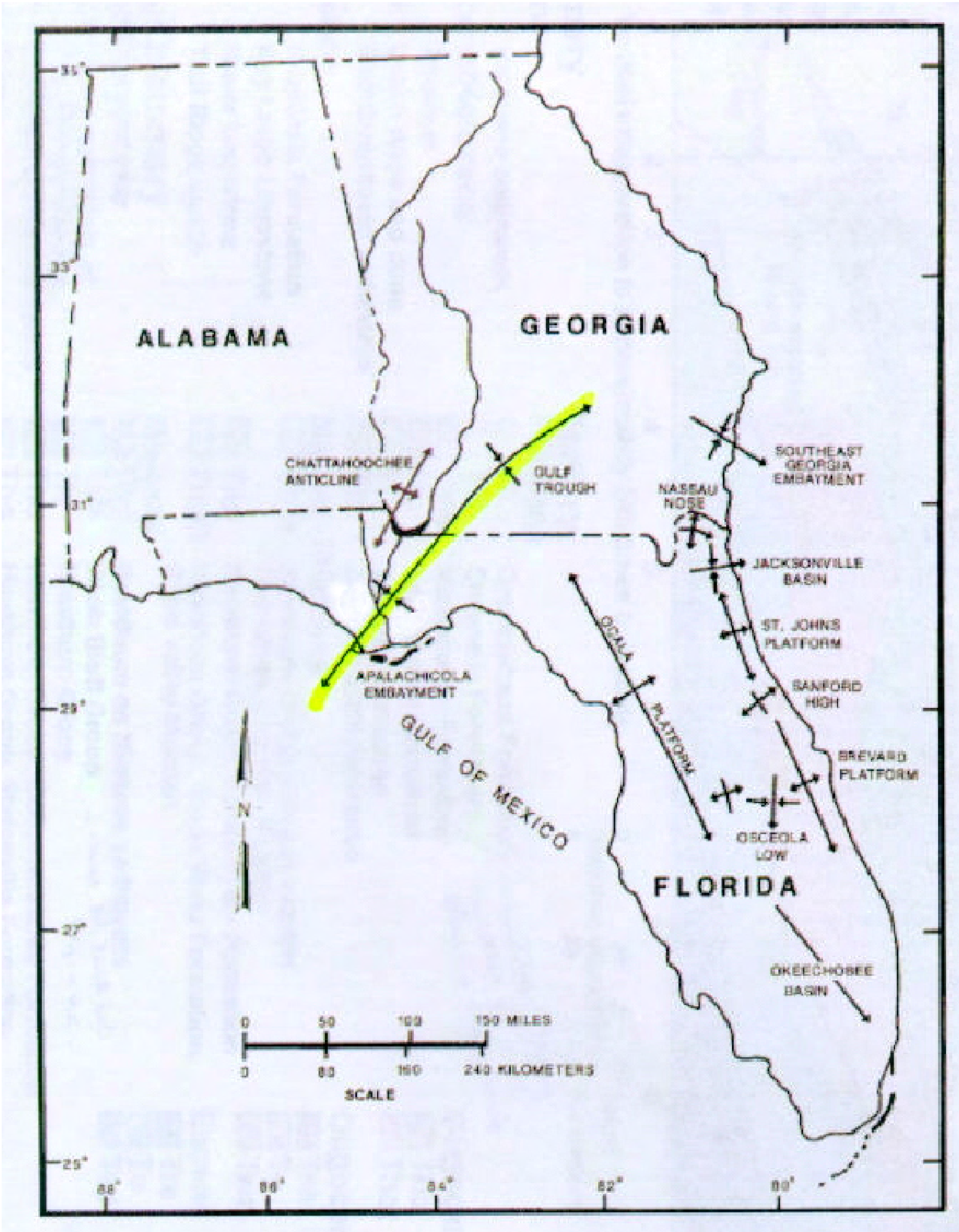

Figure 6. Map showing the location of geologic structures in the State of Florida. Highlighted is the Gulf Trough syncline that crosses the Apalachicola River.

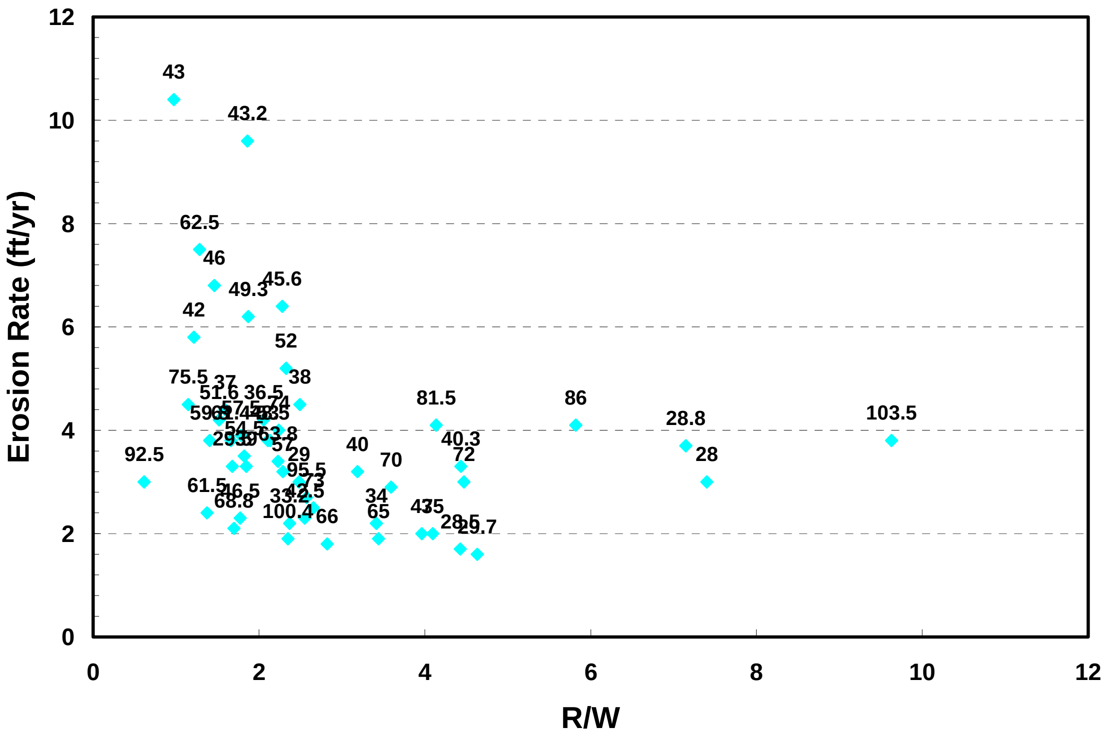

Figure 7. Erosion rates plotted against the radius of curvature to channel width ratio for bends in the Apalachicola River. Numbers shown on the figure are river miles (source of erosion rate and radius of curvature data is USACE).

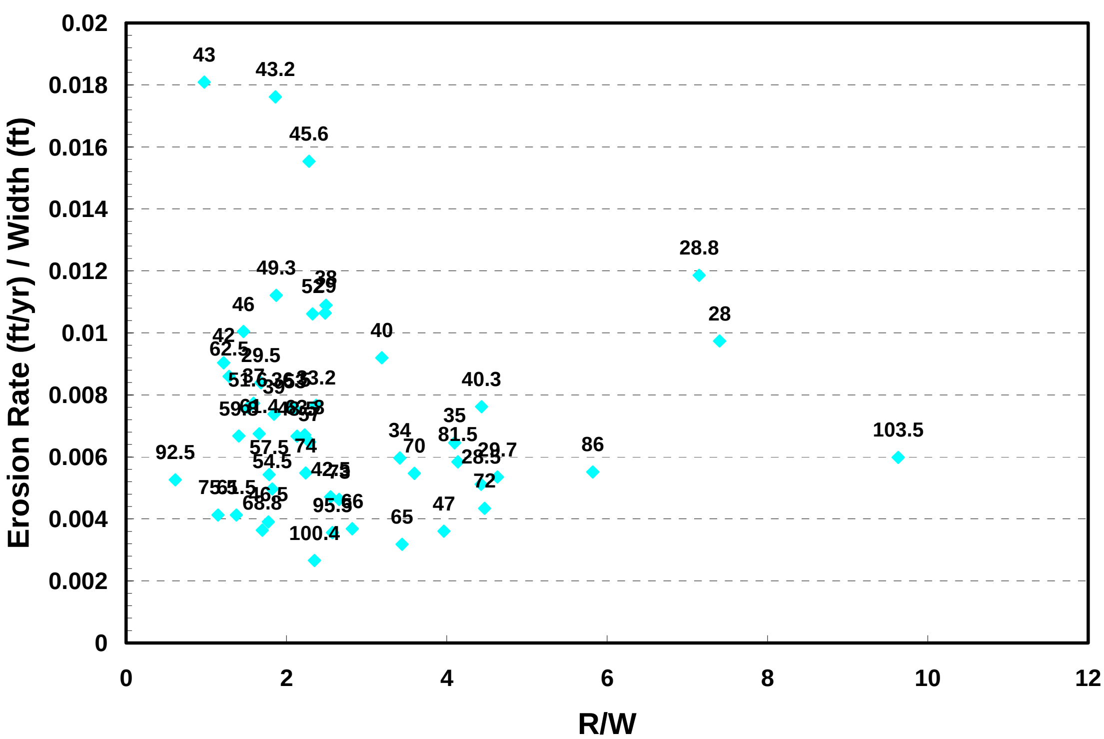

Figure 8. Normalized erosion rates plotted against the radius of curvature to channel width ratio for bends in the Apalachicola River. Numbers shown on the figure are river miles (source of erosion rate and radius of curvature data is USACE).

Figure 9. Upstream view of FTM habitat at RM 73.2L.

Figure 10. Upstream view of FTM habitat at RM 51.8L.

Figure 11. Upstream view of FTM habitat (upstream of house boat) at RM 48L.

Figure 12. View of sediment deposition and FTM habitat in the dike field at RM 47.2R.

Figure 13. FTM habitat associated with a backwater-induced bar at RM 43.1L.

Figure 14. Upstream view of FTM mortality site at RM 44L.

Figure 15. Upstream view of FTM mortality site at RM 43.6R (Kentucky Landing).

Figure 16. Upstream view of the mouth of Swift Slough with the Apalachicola in the background. Note the sand deposits in the bed of the slough.

Figure 17. Downstream view of willow succession at RM 44L.

Figure 18. Downstream view of sand waves on the bed of Swift Slough.

Brian,

Your memo is a very thorough and accurate summary of last week's discussions. I have no suggested edits; however, I will summarize my impressions regarding those ecological issues discussed at the workshop as they affect BO coordination.

1) I am a little concerned because we focused most of our discussions on issues affecting only *Amblema neislerii*, although RPM5 poses the same 2 questions for all 3 species. If RPM5 is to be fully addressed, there must be substantial consideration of population size and effect of low-water events for all three listed species.

2) As with most Coastal Plain streams, the middle section of the Apalachicola River is highly dynamic. Native organisms, at both individual and population levels, typically are well-adapted to dynamic flow and channel migration. Mortality associated with life in this dynamic environment affects all such populations and should not be perceived as particularly unusual or threatening to *A. neislerii*.

3) The mussel populations in the Apalachicola typify those in such dynamic environments. The population depends on many patches of suitable habitat (e.g., eddy habitats) to persist even if portions of the population suffer high mortality from major physical changes at one or a few locations. Habitat suitability probably improves in some locations and declines in others during any particularly forceful hydrologic event. For populations to persist over a long period, habitat losses must be balanced by habitat gains at some biologically significant temporal scale (i.e., "dynamic equilibrium"). Dr. Harvey referred to distributary dynamics as well as the implications of stranding during low water in precisely this sense.

   Aerial photos indicated that the geomorphic phenomenon associated with stranding events has occurred many times in the past. Therefore it is reasonable to assume that stranding events are natural and probably not detrimental to the longterm survival of mussel populations in the Apalachicola.

   Both geomorphic experts were skeptical of the idea that the river is widening. If a detrimental widening process has been occurring since 1940, it is not likely that so many mussels would remain in the middle reach.

4) It seems that the Apalachicola "stranding" or "vulnerable habitat" or "other concern" issues were used to infer that "take" is occurring, thereby requiring actions by the Corps. However, it could be (should be) argued that mortality, stress, harassment, etc…resulting from natural phenomena does not constitute "take." Mortality due to stranding is no different from any other natural selective force on a population. The RPM states that you must estimate population size and estimate effect of stranding on populations. However, the question that most directly addresses to what degree the Corps should be held responsible should be:

> Have actions of the Corps caused natural hydrogeomorphological events to occur at an accelerated or altered rate so that mussel mortality occurs in an unnatural manner?

“Take” is really only justified if the above question is answered in the affirmative.

RPM5, as currently written, seems to concede such and requires **monthly** monitoring of “take.” It implies that the Corps is responsible for “take,” that “take” might be detectable each month, and therefore intense mussel monitoring studies must be conducted. However, preliminary results and discussions at the workshop support the argument that “take” does not occur (i.e., is the result of natural processes, not Corps actions).

I appreciate the opportunity to attend the workshop. Section 7 coordination is difficult enough without pending litigation. We have been assisting the St. Paul and Rock Island Districts with Biological Opinion actions for *Lampsilis higginsii* (Higgin’s eye pearly mussel) for several years and are about to initiate a risk-informed decision analysis project to help them design a conservation management plan for another Endangered species, *Quadrula fragosa* (winged mapleleaf).

Please feel free to contact us if you want to discuss such issues in the future. Take care, and good luck with the Apalachicola project.

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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).

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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**
Site	**CPUE/hr**	**Predicted Density**	**Length, m**	**Density 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.

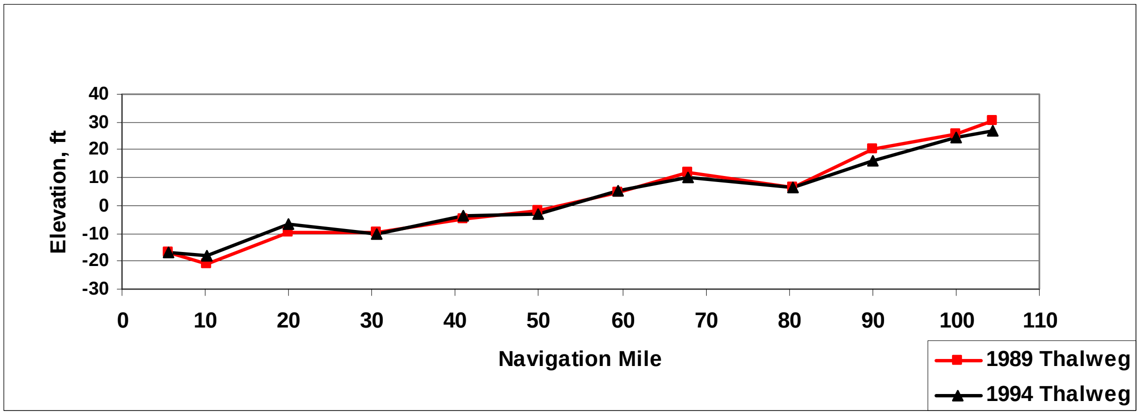

Figure 2a. Elevation profile of the Apalachicola River.

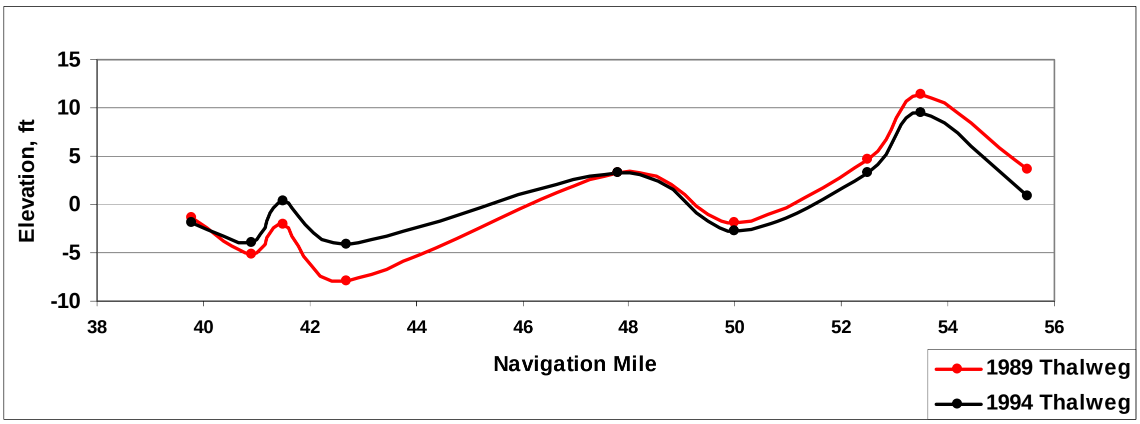

Figure 2b. Elevation profile of the study area, Apalachicola River.

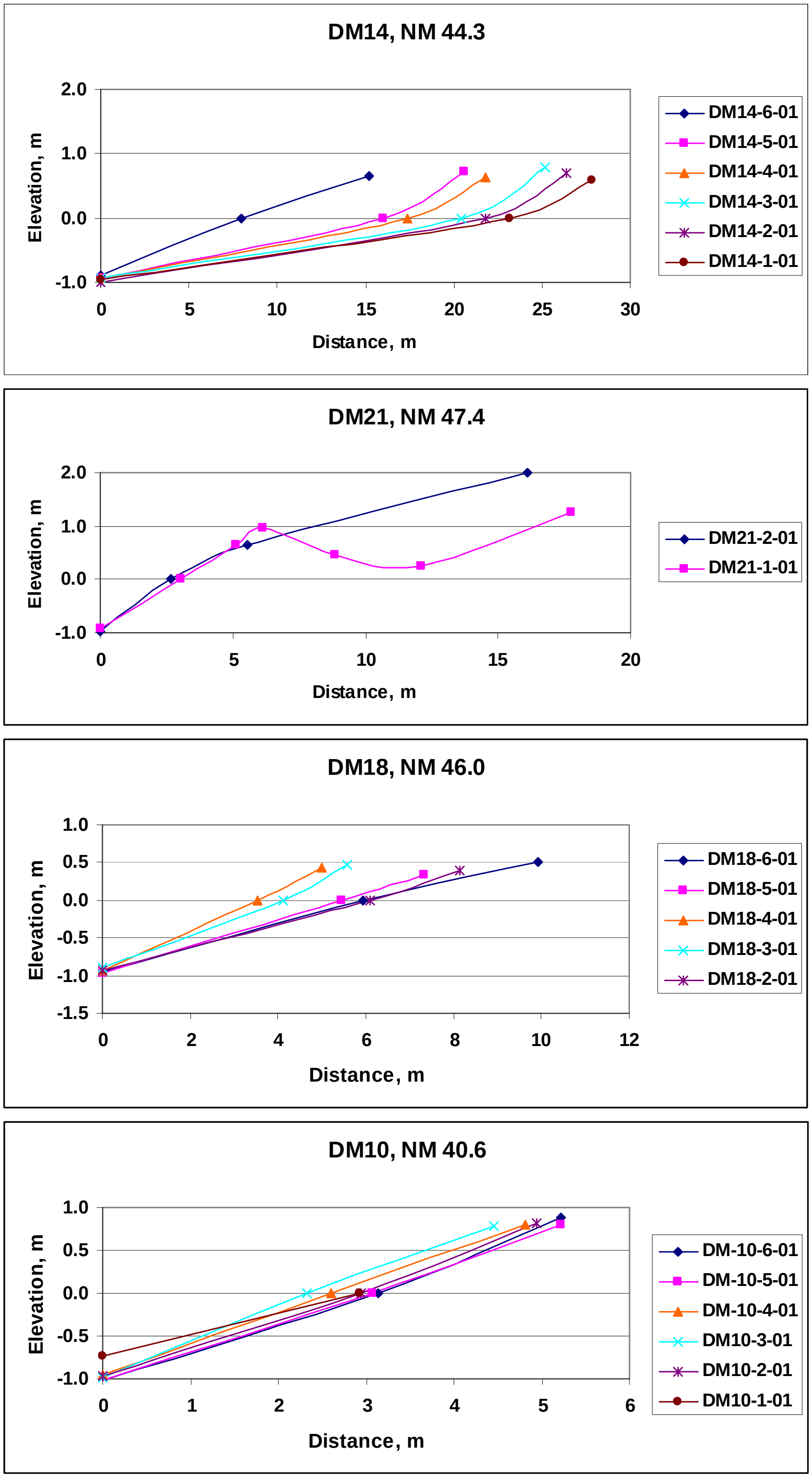

Figure 3. Elevation profiles at DM14 and DM21 (very good habitat), DM18 (good habitat), and DM10 (poor habitat) for *A. neislerii*.

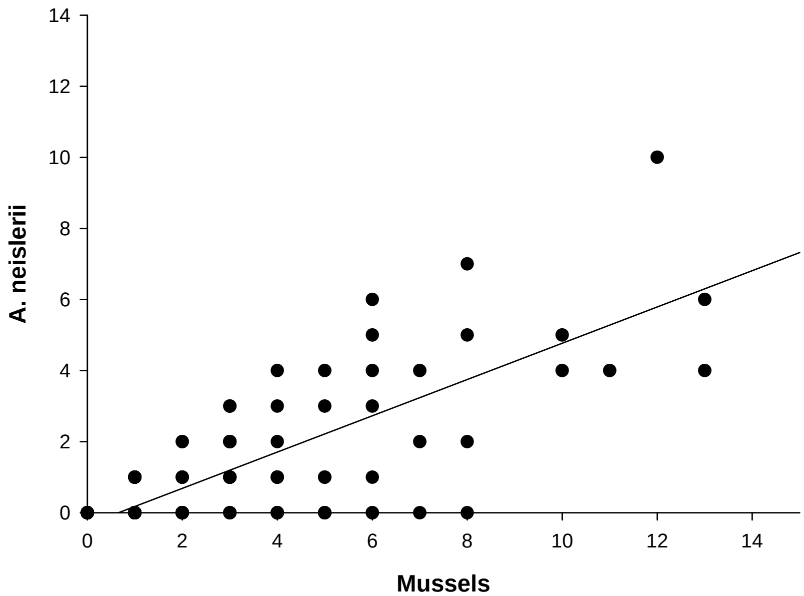

Figure 4a. Relation between total number of mussels and total number of *A. neislerii* (Y= 0.5X – 0.335; R^2 = 0.68).

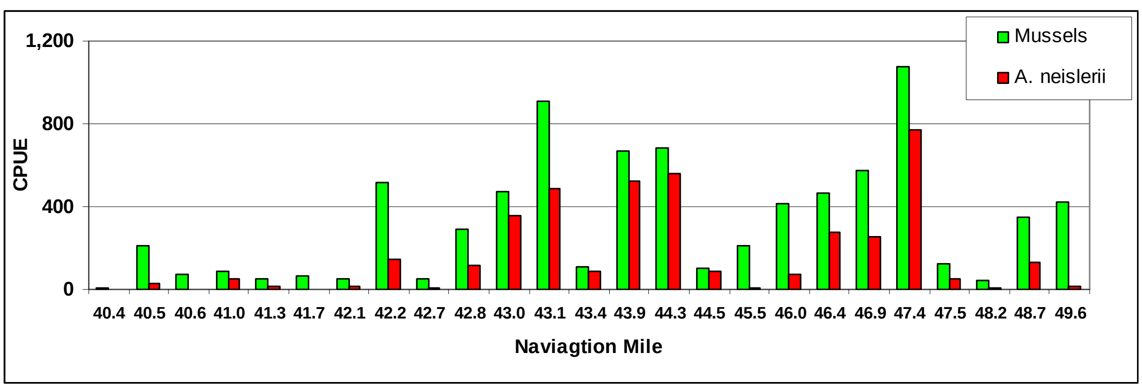

Figure 4b. Catch per unit effort for *A. neislerii* and all mussels at 25 areas, Apalachicola River, 7-11 June 2007.

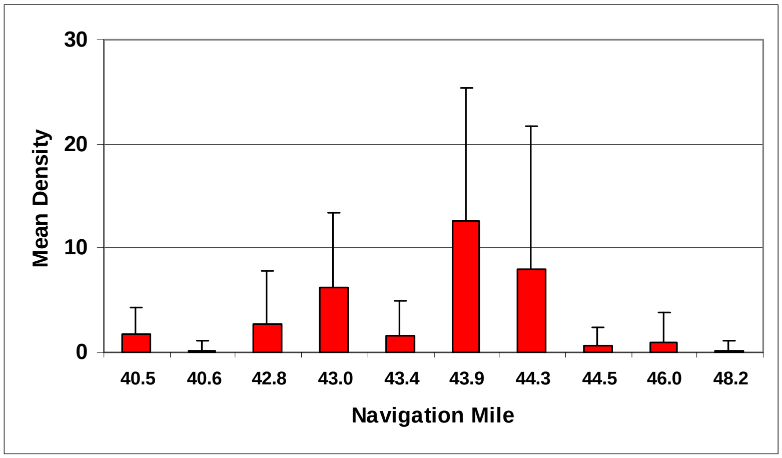

Figure 5a. Mean density of *A. neislerii* at 10 sites in Apalachicola River, 7-11 June 2007.

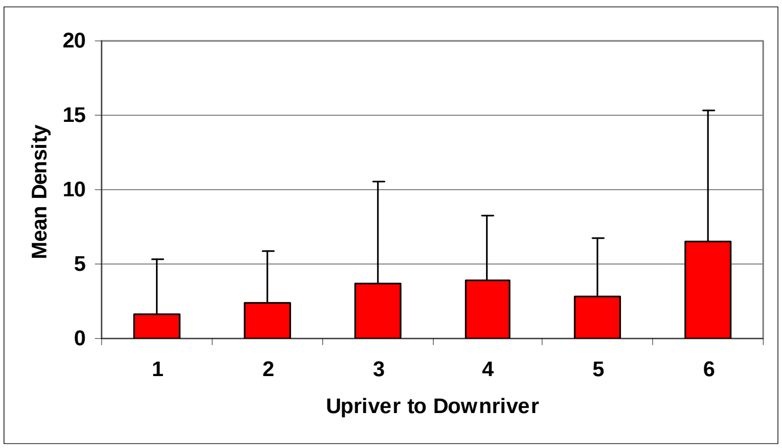

Figure 5b. Pooled within site variation in up-to-downriver density of *A. neislerii,* Apalachicola River, 7-11 June 2007.

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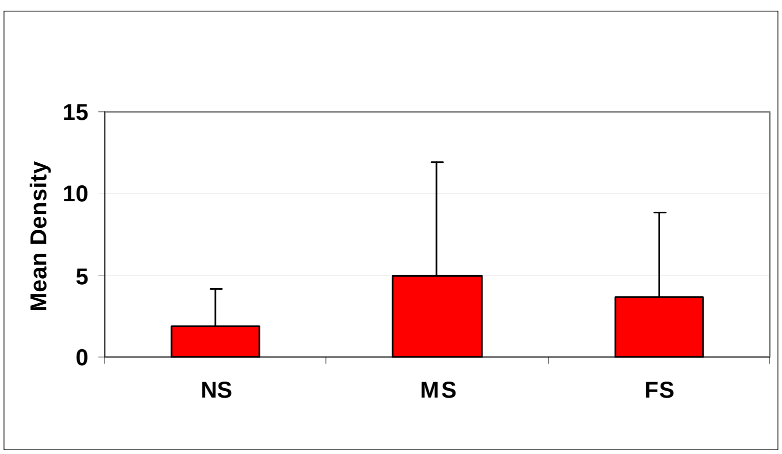

Figure 5c. Pooled within site variation in nearer-to-farshore density of *A. neislerii,* Apalachicola River, 7-11 June 2007.

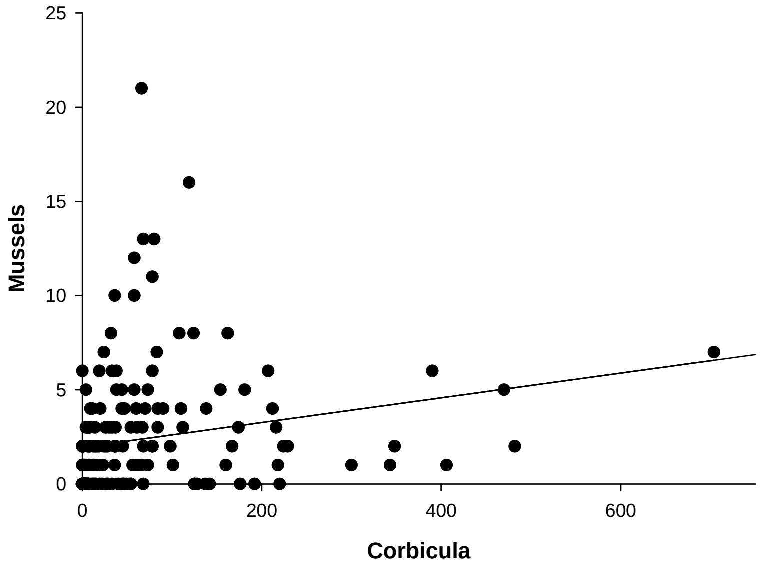

Figure 6. Relation between total number of *C. fluminea* and total number of mussels, Apalachicola River, Florida, 7-11 June 2007 ($Y = 0.006X + 1.9$; $R^2 = 0.38$).

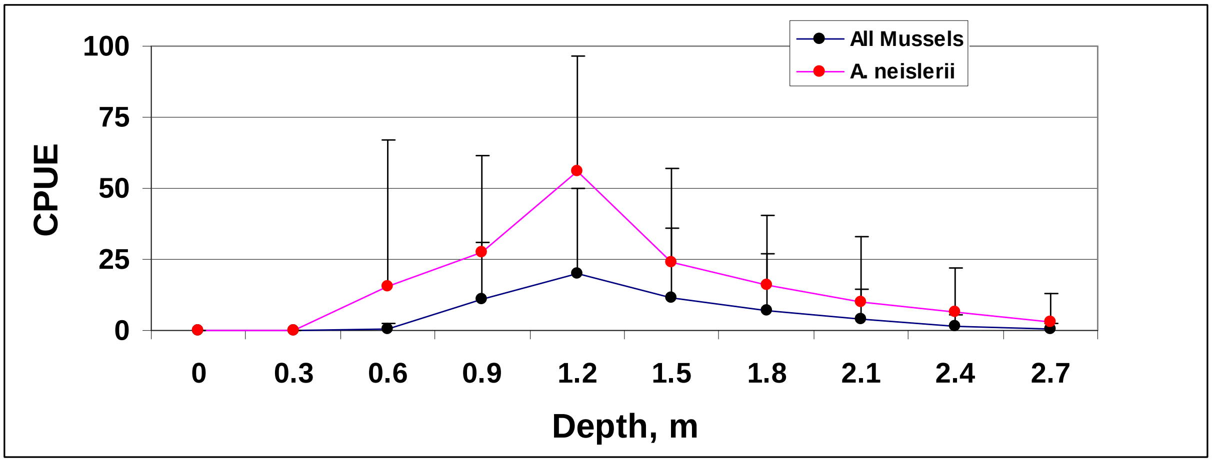

Figure 7. Relationship between abundance of all mussels and *A. neislerii* at multiple locations in the Apalachicola River, FL, 2003. During the survey period gage height and discharge at Blountstown (NM 78) was 3.63 ft, 9,420 cfs (18 Nov 03), 4.17 ft, 10,300 cfs (19 Nov 03), and 4.94 ft 11,500 cfs (20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

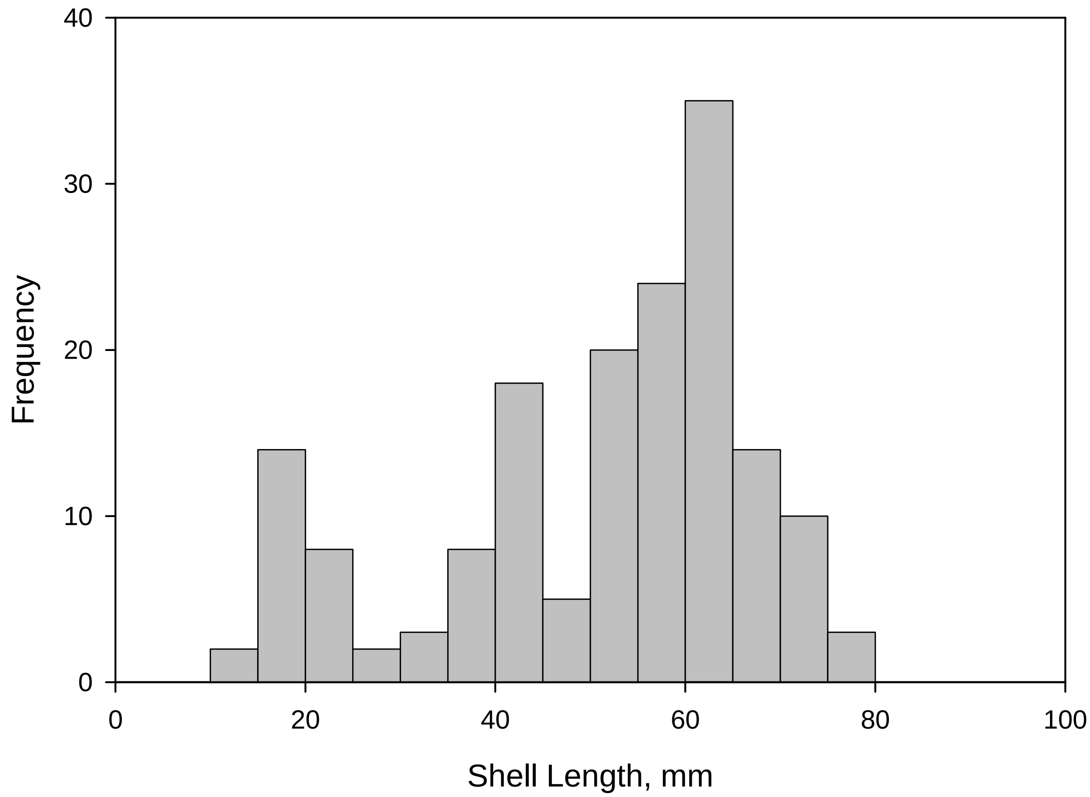

Figure 8. Length-frequency histogram for *A. neislerii*, Apalachicola River, FL, 5-7 June 2007.

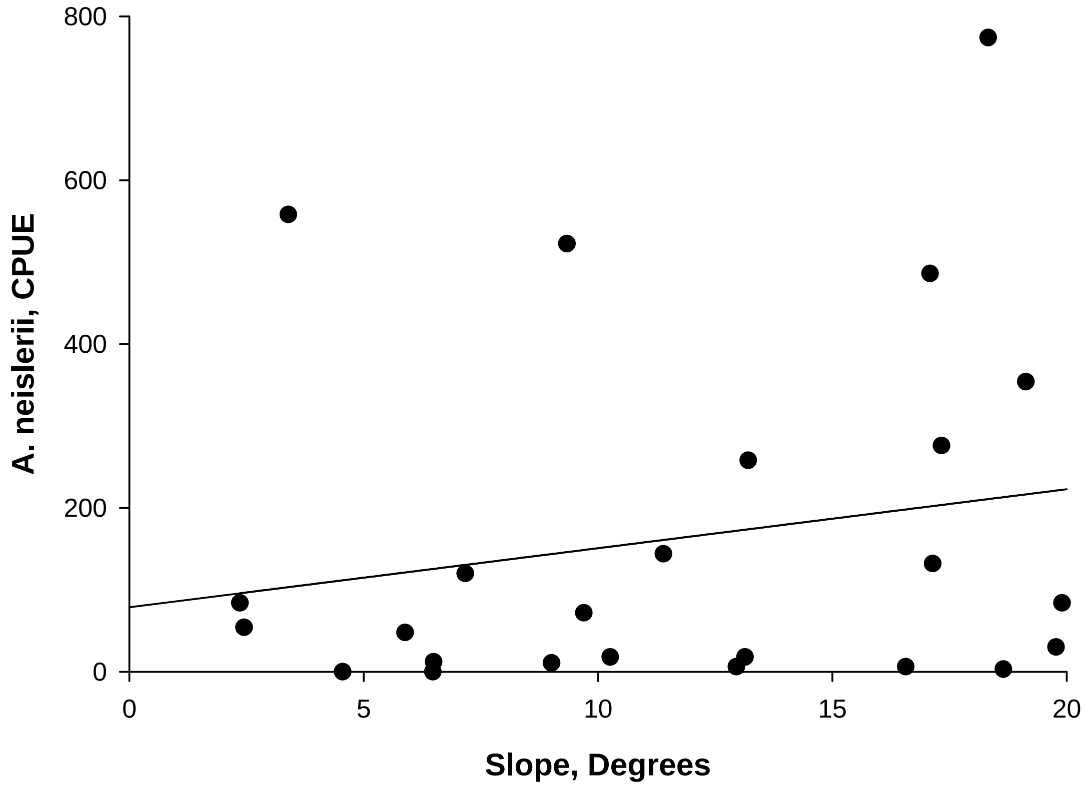

Figure 9. Relationship between bank slope and CPUE for *A. neislerii,* Apalachicola River, FL, 7-11 June 2007 (Y = 7.19X + 78.9; R^2 = 0.038).

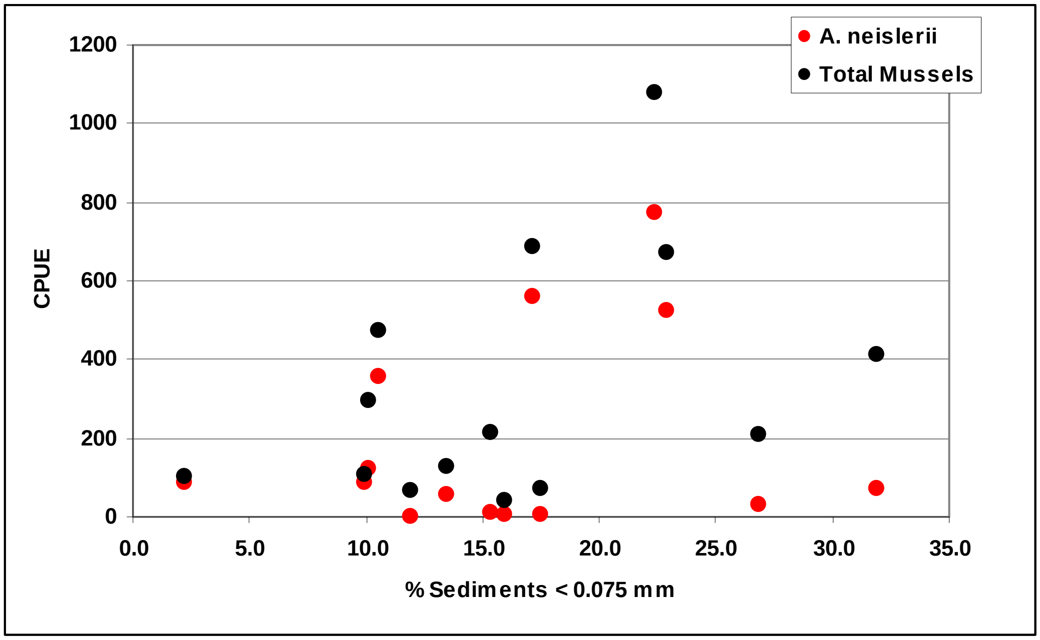

Figure 10a. CPUE for *A. neislerii* and total mussels versus percentage of particles < 0.075 mm.

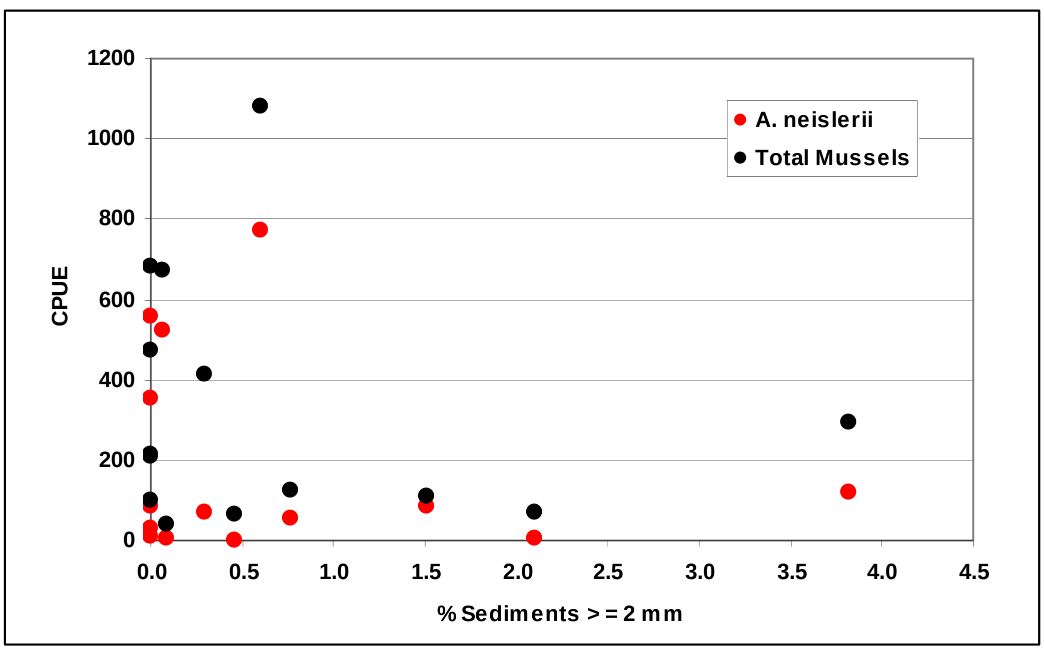

Figure 10b. CPUE for *A. neislerii* and total mussels versus percentage of particles >= 2 mm in diameter.

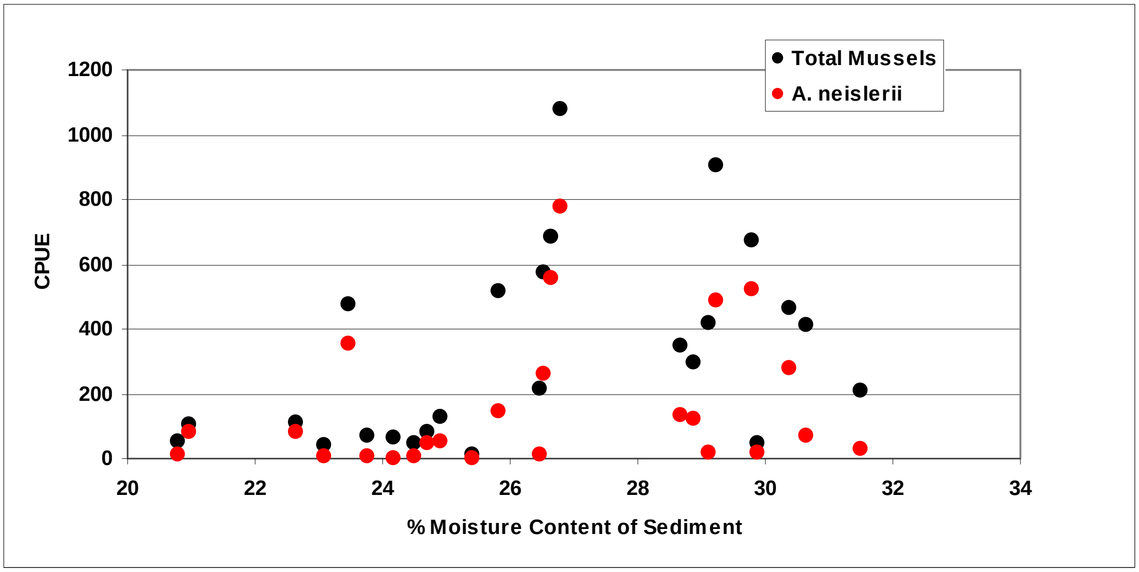

Figure 11a. CPUE for total mussels and *A. neislerii* versus percentage moisture content of sediments.

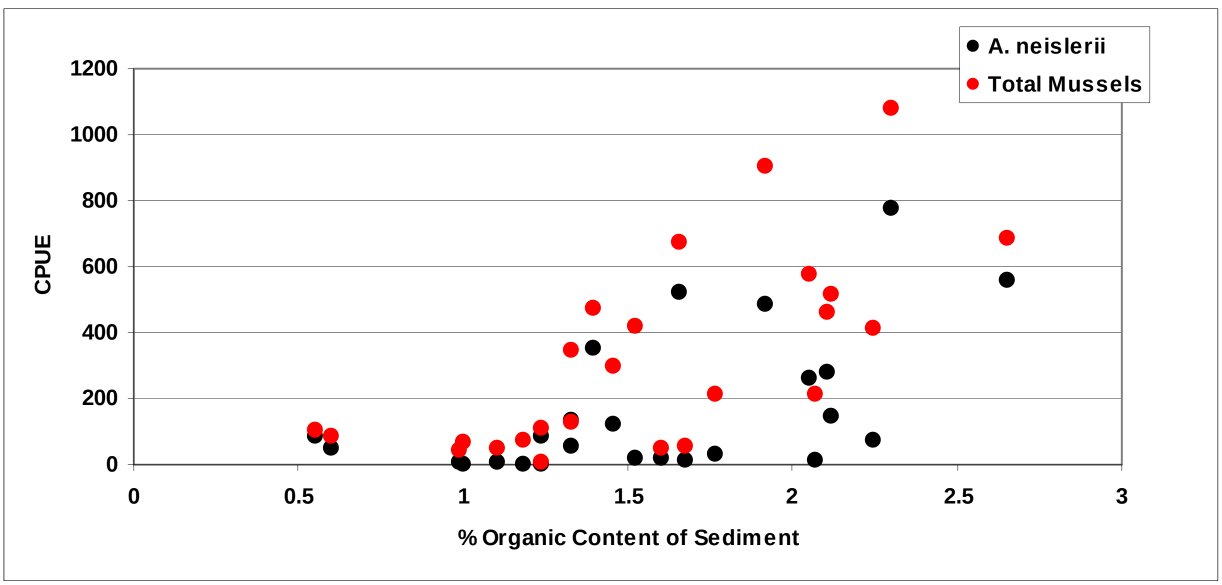

Figure 11b. CPUE for total mussels and *A. neislerii* versus percent organic content of sediments.

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

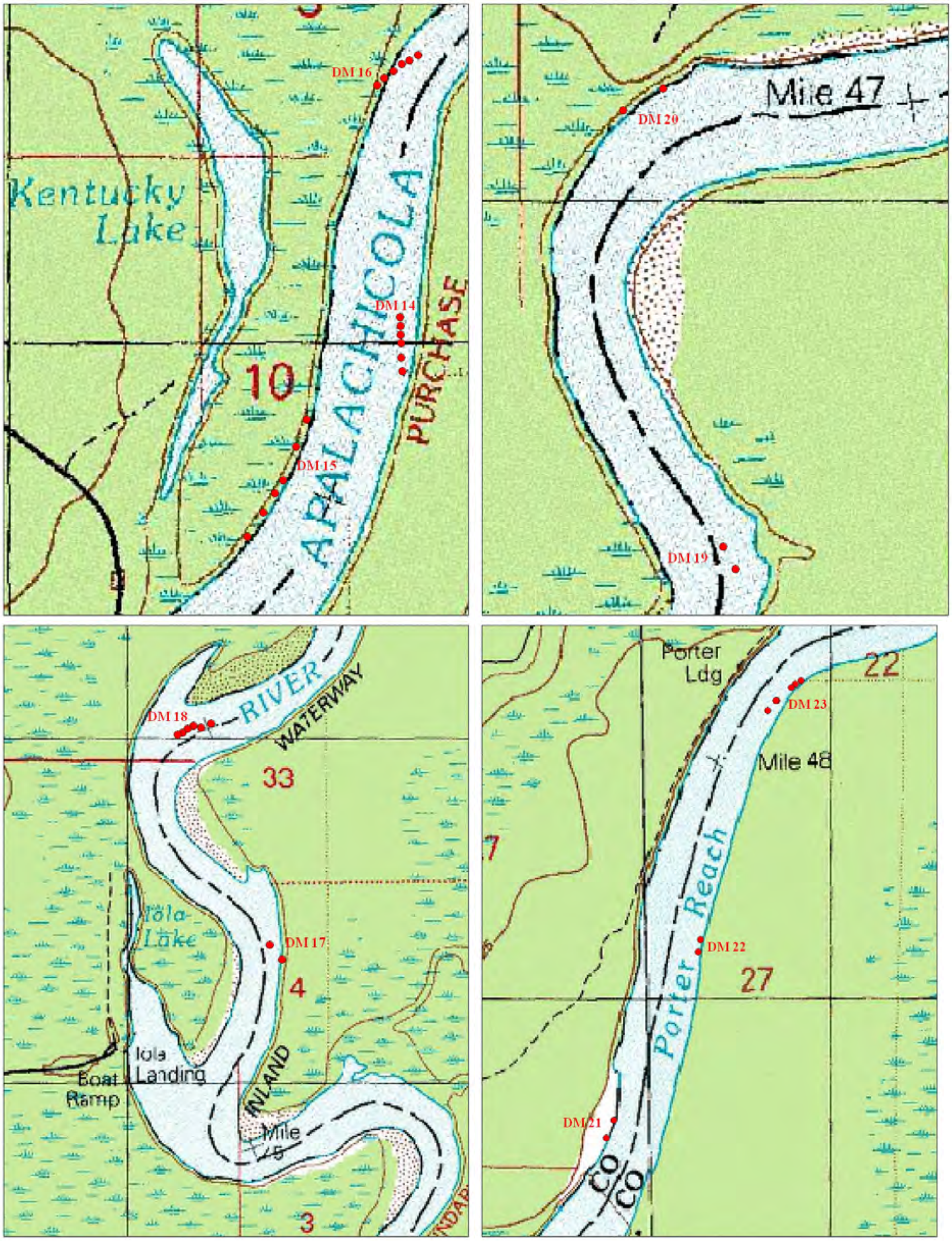


Figure C1. DM15, DM14, and DM16 (top left); DM19 and DM20 (top right), DM17 and DM18 (bottom left), and DM21, DM22, and DM23 (bottom right).

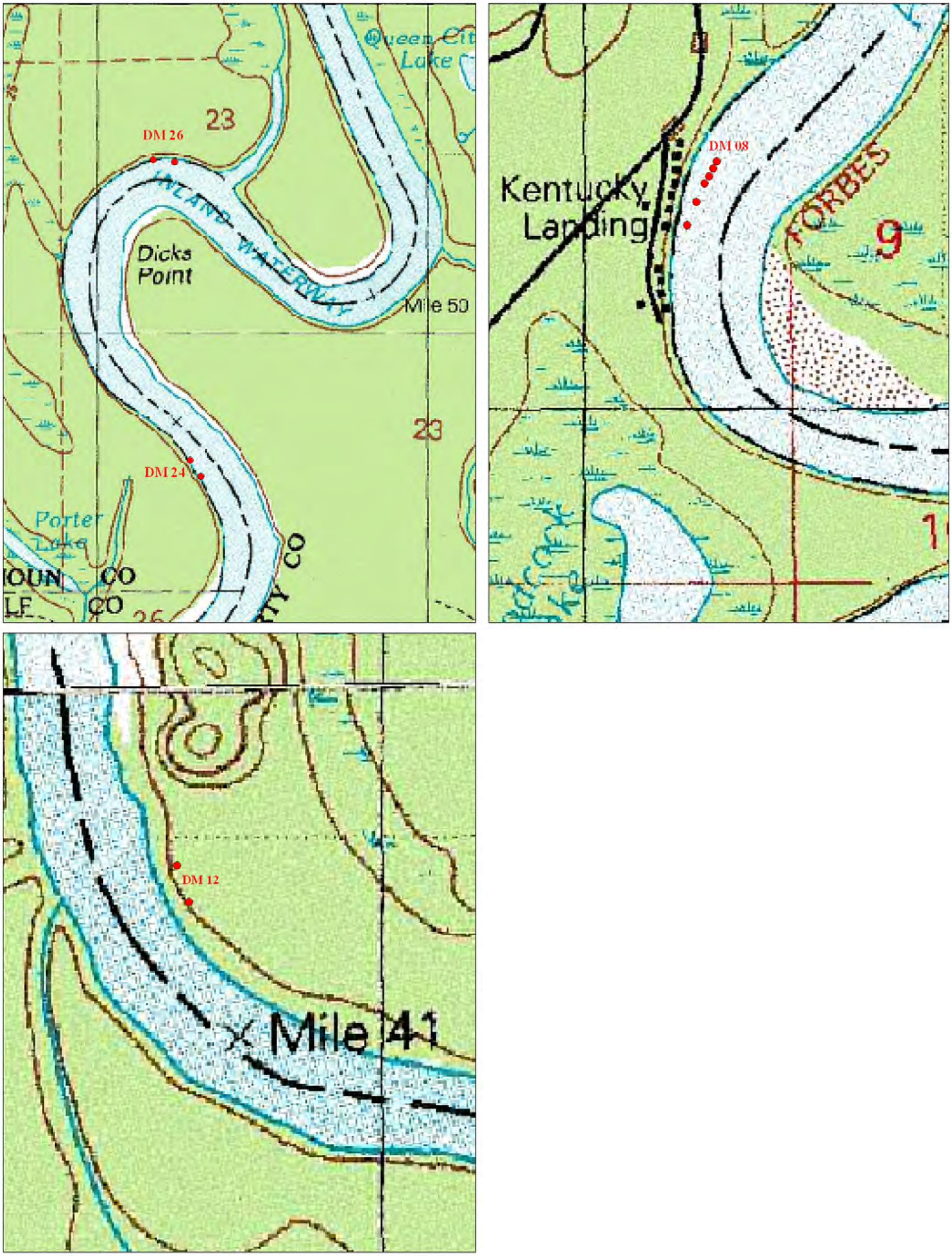
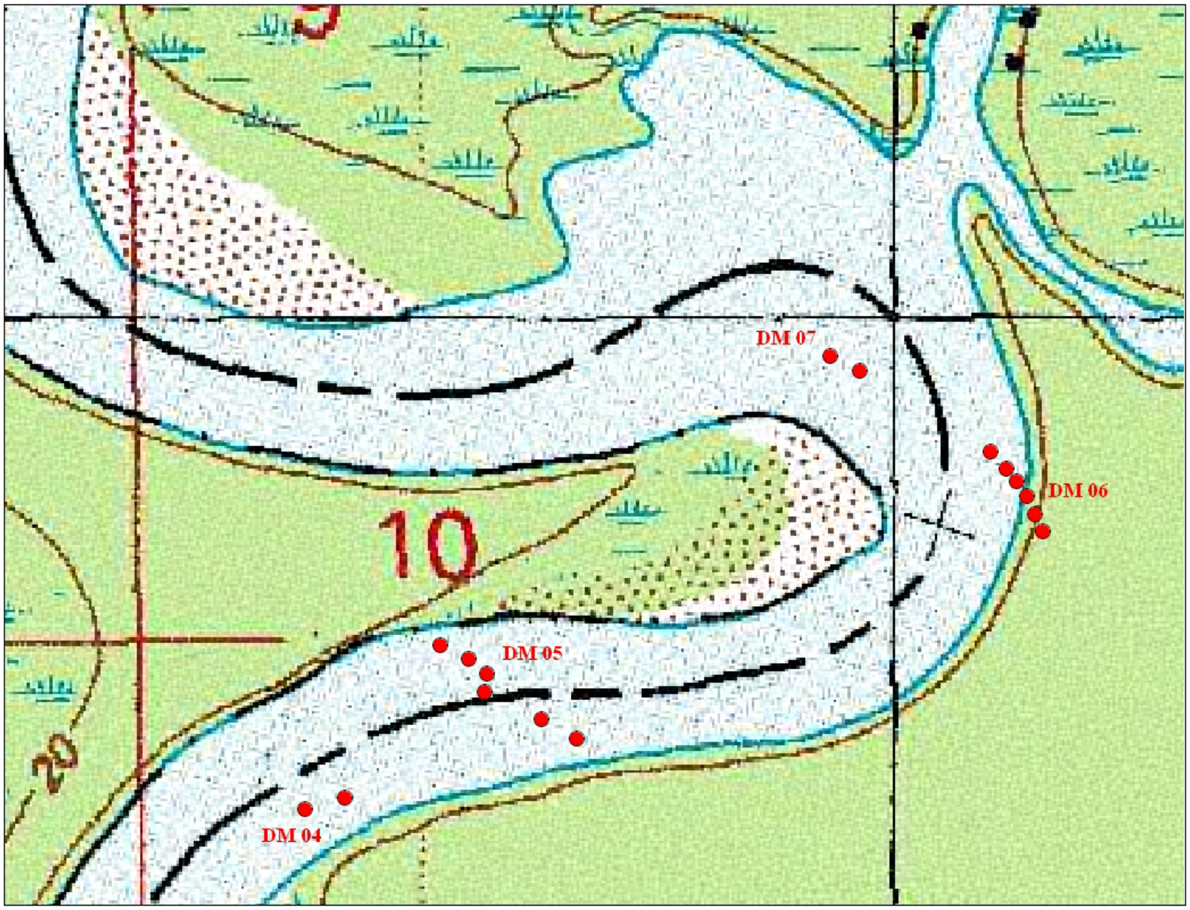


Figure C2. DM24 and DM26 (top left), DM08 (top right), and DM12 (bottom left)



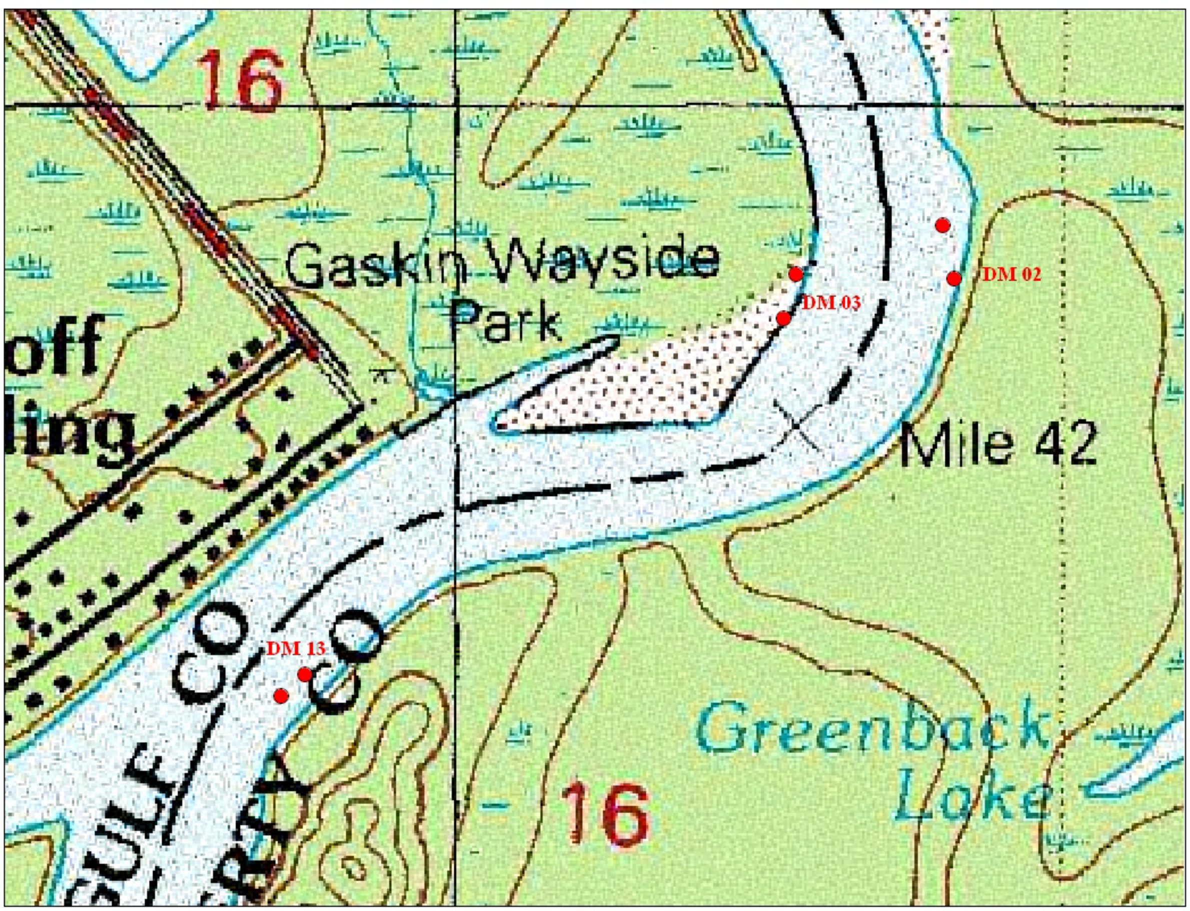


Figure C3. DM04, DM05, DM06 and DM07 (top), and DM13, DM03, and DM02 (bottom)

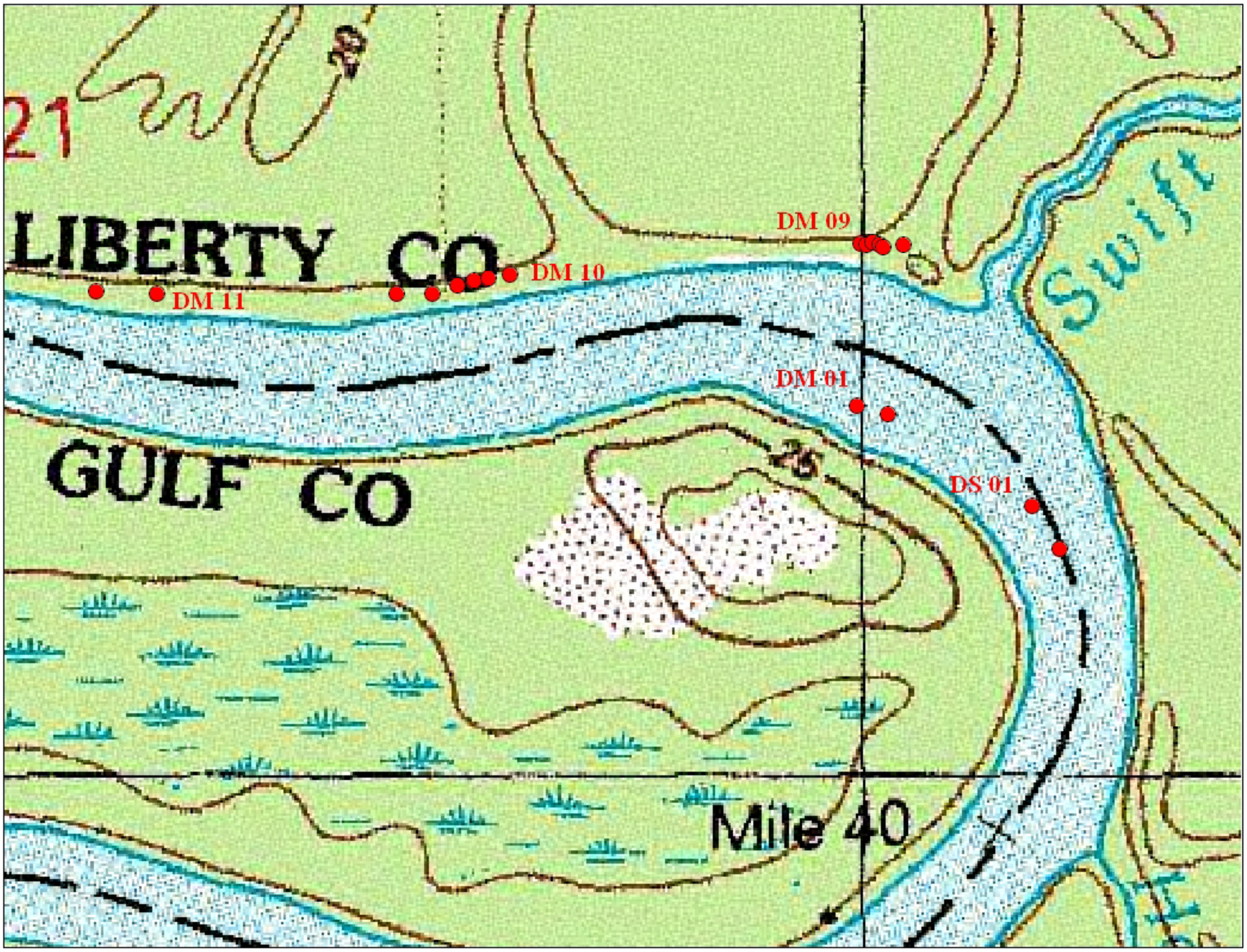


Figure C4. DS01, DM01, DM09, DM10, and DM11.