EVALUATION OF ABANDONED COMMERCIAL SAND AND GRAVEL DREDGE SITES AS FRESHWATER MUSSEL HABITAT ON THE LOWER TENNESSEE RIVER. **Don Hubbs, Susan Lanier, David McKinney, David Sims, and Pat Black. Tennessee Wildlife Resources Agency, Nashville, Tennessee 37204.**

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ABSTRACT

The Tennessee River supports a diverse freshwater mussel community including federally listed endangered species. Resource extraction operations have been conducted on the lower Tennessee River since at least the 1920's. The condition of abandoned dredge sites as aquatic habitat for benthic organisms, including freshwater mussels, is relatively unknown. This report contains an evaluation of the freshwater mussel resources associated with dredged sites, and is part of a larger study conducted jointly by Tennessee Wildlife Resources Agency, U.S. Army Corps of Engineers, and commercial sand and gravel operators. Elements of the study include evaluation of benthic invertebrate communities, freshwater mussel populations, substrate physical properties characterization at dredge and reference sites, and an inventory of sand and gravel resources available for extraction. Objectives for this report were: 1) determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, 2) compare colonization rates between sites in relation to years post dredging, and 3) provide information pertinent to a greater understanding of the effects of resource extraction in a large regulated river. Data and video from nine abandoned dredge sites and three reference sites were assessed. Dredge sites had not been dredged for periods ranging from one to fifteen years. Variables included river mile, dredge type, on-river materials processing, resulting substrate deposition, and depth related impacts. Statistical analysis of the data indicated significantly lower abundances ($p<0.01$) and poorer diversity ($p<0.01$) at dredge sites than at reference locations. Correlation analysis indicated no significant relationship ($r = 0.2059$, $p>0.10$) between mussel abundance and time (in years) since the last dredging event.

INTRODUCTION

Freshwater mussels are a renewable resource, providing important ecological and economic benefits to the region. They are a food source for many aquatic and terrestrial animals, they improve water quality by filtering contaminants, sediments, and nutrients from rivers, and because they are sensitive to toxic chemicals, they serve as indicators of water quality. During peak harvest years, the commercial mussel shell industry in Tennessee generates revenues approaching $50 million (Hubbs 2003). They are an important component of the aquatic fauna of the Tennessee River and Kentucky Reservoir.

Riverine ecosystems account for the highest diversity of freshwater mollusks among various habitat types because they are more permanent in regards to evolutionary time scale (Neves et al. 1997). These bivalve mollusks evolved in rivers where clean water flowed over shoals composed of sand and gravel suited to their life history needs, and supported a species diversity of unparalleled proportion. In large river systems, they typically occur in dense aggregations known as “mussel beds”. They are intolerant to adverse changes in water and habitat quality, and cannot survive excessive exposure to fine sediment, which clogs the gills and interferes with respiration, feeding and reproduction (Parmalee and Bogan 1998). Except for their brief parasitic larval stage, freshwater mussels spend their entire lives partially or completely buried in the river bottom. Sedentary by nature, freshwater mussels require a stable bottom environment with good current to bring food and disperse reproductive elements and metabolic waste products. Thus, an abundant and diverse mussel bed provides an excellent indication of good habitat quality for freshwater mussels.

Kentucky Reservoir flows 184 miles northward from Pickwick Dam (completed in 1938) at Tennessee River Mile (TRM) 206.7 in Hardin County, TN to Kentucky Dam (completed in 1944) at TRM 22.4 near Gilbertsville, Kentucky. The Tennessee portion contains 1,971 shoreline kilometers and approximately 110,990 surface acres, ending at TRM 49.2 in Stewart County, TN. The main channel and over-bank widths vary from 0.25 to two miles and offer diverse and abundant habitats for freshwater mussels. The study reach is located south of the confluence with the Duck River at TRM 111.1. Commercial sand and gravel dredging, conducted on the Lower Tennessee River since at least the 1920’s, is currently permitted on approximately 48 miles of this 95 mile river segment (Table 1). Lotic habitats dominate this section.

Many recent records for several endangered mussel species exist for this reservoir reach (Hubbs 2002). Population densities can exceed 100 mussels per square meter, and are normally found in shallow gravel deposits around the inside river bends and at the head and tail areas of mainstream islands. Mussel recruitment associated with these habitats is generally high, and they have served as an important area for harvest of freshwater mussel shell for many years, historically for pearl buttons, and today for the nuclei used in the production of cultured pearls. According to Hubbs (2003), wholesale shell dealer records indicate greater than 90% of Tennessee's commercial mussel shell harvest is from Kentucky Reservoir, and this area produces more commercial shell products than anywhere else does in the world (Neves 1999).

Habitat alteration resulting from in/stream activities has been identified as a contributing factor in the precipitous decline of North American freshwater mussel resources. Watters (2000) concluded that hydraulic impacts to freshwater mussel habitats are often catastrophic, both immediately and over time. He further noted that impacts resulting in mussel declines involve complicated interrelated actions rarely having a single causative agent. Yokley and Gooch (1976) observed decreased mussel shell growth rates at sites located downstream of commercial dredging operations. Dennis (1984) demonstrated that high concentrations of suspended silt interfere with food uptake of freshwater mussels. Nelson (1993) noted that instream mining increases bedload materials and turbidity, changes substrate type and stability, and alters stream morphology. Further, substrate type is directly tied to benthic production, more diverse invertebrate assemblages are associated with complex gravel substrates. Loss of productive substrates resulting from altered stream morphology may result in long term declines in aquatic invertebrate abundance and corresponding declines in the higher organisms that depend on them as food.

This report is part of a larger study conducted jointly by Tennessee Wildlife Resources Agency (TWRA), U.S. Army Corps of Engineers (USACE) and commercial sand and gravel operators. Elements of the study include evaluation of benthic invertebrate communities and substrate physical properties characterization at dredge and reference sites (Pennington and

Associates 2001), freshwater mussel populations, and an inventory of sand and gravel resources available for extraction. Objectives for this portion of the study were: 1) to determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, 2) to compare colonization rates between sites in relation to years post dredging, and 3) to provide information pertinent to a greater understanding of the effects of resource extraction in a large regulated river.

METHODS

Site Selection – TWRA and USACE personnel selected sites during September 2000. Potential dredged sites were located by referencing USACE file data followed by field verification. During two days of field reconnaissance, a boat equipped with a differentially corrected Global Positioning System (DGPS) and liquid crystal display (LCD) depth sounder traversed each site. Nine dredged sites were selected based on clearly defined, sudden changes in bottom contours (Figure 1). Once a dredged area was located, the DGPS coordinates for the site were recorded along with references to physical structures (navigation lights, buoys or other permanent structures) and approximate river mile location from USACE navigation charts. After the sites had been delineated, a USACE survey boat mapped the bottom contours from bank to bank at 50-foot intervals, within a 500-foot length of river (except site 4, at mile marker 126, was mapped a length of 1,500 feet to establish bottom contours extending upstream of a mainstream island).

Three reference sites were chosen based on relative proximity to the previously selected dredge sites, habitat characteristics, and an extant mussel population. Each site was selected based on presumed similar physical characteristics to the dredge sites prior to resource extraction, and their representation of the mussel fauna inhabiting the immediate vicinity. Reference sites were dispersed throughout the study reach to allow comparisons relative to the changing hydrology of the river as it flows downstream.

Site Locations - Where a structure was not available, a tree was flagged to identify the lower limits of the site, except as noted below. During freshwater mussel sampling trips, five anchor points (sample stations) within each site were established using GPS and a hand held laser range finder to determine distance to the nearest shore.

Site 1. Figure 2. (N36° 56.08, W87° 55. 53) Located at TRM 111.2 along the right descending bank just upstream from the confluence with the Duck River. The site limits begin at the navigation buoy and continues upstream for a distance of 500 feet.
This site was last dredged in 1995.

Anchor point 1. N35° 56.11, W87° 55.54, 525 feet off RDB, Depth 55-65 ft, gravel, cobble substrate, sampled 6/26/01.
Anchor point 2. N35° 56.08, W87° 55.53, 558 feet off RDB, Depth 55-65 ft, gravel, cobble, silt substrate, sampled 6/26/01.
Anchor point 3. N35° 56.06, W87° 55.52, 525 feet off RDB, Depth 45-65 ft, gravel, cobble, silt substrate, sampled 6/26/01.
Anchor point 4. N35° 56.05, W87° 55.54, 577 feet off RDB, Depth 50-65 ft, gravel, cobble, silt substrate, sampled 6/26/01.
Anchor point 5. N35° 56.03, W87° 55.50, 564 feet off RDB, Depth 50-65 ft, gravel, cobble, silt substrate, sampled 6/26/01.

Site 2. Figure 3. (N35° 53.47, W87° 55.93) Located at TRM 114.0 along the right descending bank. The site begins at the flagging and continues upstream for 500 feet. Dredging operations ended in 1989.

Anchor point 1. N35° 53.47, W87° 55.93, 262 feet off RDB, Depth 55 ft, gravel, silt, mud substrate, sampled 6/6/01.
Anchor point 2. N35° 53.45, W87° 55.94, 315 feet off RDB, Depth 50-55 ft, gravel, silt, mud substrate, sampled 6/6/01
Anchor point 3. N35° 53.43, W87° 55.94, 272 feet off RDB, Depth 55 ft, gravel, silt, mud substrate, sampled 6/6/01
Anchor point 4. N35° 53.42, W87° 55.95, 295 feet off RDB, Depth 45 ft, gravel, silt, mud substrate, sampled 6/6/01.
Anchor point 5. N35° 53.41, W87° 55.98, 417 feet off RDB, Depth 55 ft, gravel, silt substrate, sampled 6/6/01.

Site 3. Figure 4. (N35° 48.92 & W87° 58.22) Located at TRM 120.1 along the right descending bank. No identifying structures were present at this site, so flagging was placed near a prominent bald cypress tree. The site begins at the flagging and continues upstream 500 feet. Last dredged in 1986.

Anchor point 1. N35° 48.88, W87° 58.20, 295 feet off RDB, Depth 45-55 ft, cobble, gravel, silt substrate, sampled 7/18/01
Anchor point 2. N35° 48.85, W87° 58.18, 197 feet off RDB, Depth 36 ft, gravel, silt substrate, sampled 7/18/01.
Anchor point 3. N35° 48.82, W87° 58.21, 295 feet off RDB, Depth 42 ft, gravel, silt, sampled 7/18/01.
Anchor point 4. N35° 48.78, W87° 58.20, 302 feet off RDB, Depth 42 ft, gravel, silt, mud substrate, sampled 7/18/01.
Anchor point 5. N35° 48.75,W87° 58.21, 302 feet off RDB, Depth 52 ft, gravel, silt, mud substrate, sampled 7/18/01.

Site 4. Figure 5. (N35° 42.43, W88° 00.87) Located at TRM 126.0 along the left descending bank (LDB). This is a sensitive area where in 1999 a dredge was required to move away from the head of Denson=s Island upstream about 0.1 mile to the permitted area. The site was set from the head of Denson=s Island and extends 1,500 feet upstream.

Anchor point 1. N35° 44.73, W88° 00.82, 427 feet off LDB, Depth 47 ft, cobble, gravel, silt substrate, sampled 7/17/01

Anchor point 2. N35° 44.71, W88° 00.85, 558 feet off LDB, Depth 45-50 ft, sand, gravel, silt substrate, sampled 7/17/01

Anchor point 3. N35° 44.69, W88° 00.85, 541 feet off LDB, Depth 30-65 ft, mud, loose gravel, silt substrate, sampled 7/17/01.

Anchor point 4. N35° 44.54, W88° 01.02, 525 feet off LDB, Depth 55-70 ft, cobble, loose gravel, silt substrate, sampled 7/18/01

Anchor point 5. N35° 44.53, W88° 01.07, 302 feet off LDB, Depth 55 ft, loose gravel, silt substrate, sampled 7/18/01.

Site 5. Figure 6. (N35° 42.43, W88° 02.00) Located at TRM 129.0 along the left descending bank. This site had no identifying structures, so its limits begin at the flagging and extend upstream the standard 500 feet. Dredge removed from the site in 1989.

Anchor point 1. N35° 42.43, W88° 01.99, 492 feet off LDB, Depth 48-55 ft, gravel, silt, bedrock substrate, sampled 7/17/01.

Anchor point 2. N35° 42.41, W88° 02.01, 361 feet off LDB, Depth 55-65 ft, cobble, gravel, silt substrate, sampled 7/17/01.

Anchor point 3. N35° 42.40, W88° 02.01, 345 feet off LDB, Depth 50-55 ft, silt, mud substrate, sampled 7/17/01.

Anchor point 4. N35° 42.40, W88° 02.00, 512 feet off LDB, Depth 50 ft, gravel, silt substrate, sampled 7/17/01.

Anchor point 5. N35° 42.36, W88° 01.97, 450 feet off LDB, Depth 52 ft, gravel, silt, bedrock substrate, sampled 7/17/01.

Site 6. Figure 7. (N35° 29.43, W87° 58.95) located at TRM 145.7 along the left descending bank near Southeastern Forest Products Dock. Last dredged in 1991. The site extends from the mouth of Short Creek upstream 500 feet.

Anchor point 1. N35° 29.75, W87° 58.82, 141feet off LDB, Depth 39 ft, mud, sand, silt, bedrock substrate, sampled 9/18/01.

Anchor point 2. N35° 29.72, W87° 58.83, 171 feet off LDB, Depth 39 ft, sand, silt substrate, sampled 9/18/01.

Anchor point 3. N35° 29.83, W87° 58.79, 253 feet off LDB, Depth 45 ft, sand, silt substrate, sampled 9/18/01.

Anchor point 4. N35° 30.02, W87° 58.74, 246 feet off LDB, Depth 53 ft, sand, silt, mud substrate, sampled 9/18/01.

Anchor point 5. N35° 29.55, W87° 58.89, 253 feet off LDB, Depth 40 ft, rock outcrop, sand, silt substrate, sampled 9/18/01.

Site 7. **Figure 8.** (N35° 28.73, W88° 00.13) Located at TRM 147.1 along the left descending bank. Last dredged in 1992. No distinguishing structures were available for site location; therefore, flagging identified the lower limit of the site, which extends 500 feet upstream.

Anchor point 1. N35° 28.76, W88° 00.06, 295 feet off LDB, Depth 38 ft, rock, gravel, sand substrate, sampled 9/19/01.

Anchor point 2. N35° 28.79, W87° 59.99, 161 feet off LDB, Depth 38 ft, silt, gravel substrate, sampled 9/19/01.

Anchor point 3. N35° 28.78, W87° 59.98, 233 feet off LDB, Depth 45 ft, large gravel, rock substrate, sampled 9/19/01.

Anchor point 4. N35° 28.79, W87° 59.95, 177 feet off LDB, Depth 48 ft, sand, gravel substrate, sampled 9/19/01.

Anchor point 5. N35° 28.80, W87° 59.90, 226 feet off LDB, Depth 43 ft, rock, cobble, gravel substrate, sampled 9/19/01.

Site 8. Figure 9. (N35° 18.08, W88° 13.20) Located at TRM 180.0 along the right descending bank. Last dredged in 1992. Two shed type buildings adjacent to the site provide a good reference point for the lower limit of this site, which extends 500 feet upstream.

Anchor point 1. N35° 18.10, W88° 13.15, 410 feet off RDB, Depth 30-40 ft, sand, cobble substrate, sampled 5/01/01.

Anchor point 2. N35° 18.10, W88° 13.18, 394 feet off RDB, Depth 38-50 ft, sand, gravel, cobble substrate, sampled 5/01/01.

Anchor point 3. N35° 18.10, W88° 13.20, 394 feet off RDB, Depth 35-45 ft, sand, gravel, cobble substrate, sampled 5/01/01.

Anchor point 4. N35° 18.01, W88° 13.26, 161 feet off RDB, Depth 20-40 ft, sand, cobble substrate, sampled 7/31/01.

Anchor point 5. N35° 17.97, W88° 13.31, 184 feet off RDB, Depth 40 ft, clay, silt, sand, cobble substrate, sampled 7/31/01.

Site 9. Figure 10. (N35° 14.32, W88°15.47) Located at TRM 189.0 along the left descending bank. The site begins at the flagging at mile marker 189.0 and extends downstream 500 feet. A dredge was working this site during the 9/19/00 site selection trip.

Anchor point 1. N35° 14.35, W88° 15.50, 220 feet off LDB, Depth 33 ft, sand, loose gravel substrate, sampled 8/1/01.

Anchor point 2. N35° 14.37, W88° 15.50, 259 feet off LDB, Depth 33 ft, sand, loose gravel substrate, sampled 8/1/01.

Anchor point 3. N35° 14.38, W88° 15.49, 305 feet off LDB, Depth 30 ft, consolidated sand substrate, sampled 8/1/01.

Anchor point 4. N35° 14.41, W88° 15.50, 279 feet off LDB, Depth 25 ft, gravel substrate, sampled 8/1/01.
Anchor point 5. N35° 14.45, W88° 15.49, 315 feet off LDB, Depth 30 ft, consolidated sand substrate, sampled 8/1/01.

Reference Site 1. Figure 5. Located at TRM 125.5 along a shelf on the right descending side adjacent to the dredged site.

Anchor point 1. N35° 44.877, W88° 00.253, 171 feet off RDB, Depth 36 ft, silt and sand substrate, sampled 8/27/02.
Anchor point 2. N35° 44.040, W88° 00.375, 459 feet off RDB, Depth 26 ft, silt and sand substrate, sampled 8/27/02.
Anchor point 3. N35° 44.932, W88° 00.219, 266 feet off RDB, Depth 43 ft, sand, gravel, bedrock substrate, sampled 8/27/02.
Anchor point 4. N35° 44.935, W88° 00.189, 148 feet off RDB, Depth 33 ft, sand, gravel, bedrock substrate, sampled 8/28/02.
Anchor point 5. N35° 44.962, W88° 00.163, 233 feet off RDB, Depth 36 ft, sand, gravel, bedrock substrate, sampled 8/28/02.

Reference Site 2. Figure 7. Located at TRM 143.9 along the right descending side.

Anchor point 1. N35° 30.726, W87° 58.399, 177 feet off RDB, Depth 39 ft, silt, sand and gravel substrate, sampled 9/10/02.
Anchor point 2. N35° 30.766, W87° 58.387, 157 feet off RDB, Depth 39 ft, silt, sand and gravel substrate, sampled 9/10/02.
Anchor point 3. N35° 30.851, W87° 58.366, 148 feet off RDB, Depth 36 ft, silt, sand and gravel substrate, sampled 9/10/02.
Anchor point 4. N35° 30.816, W87° 58.373, 112 feet off RDB, Depth 36 ft, sand and gravel substrate, sampled 9/11/02.
Anchor point 5. N35° 30.876, W87° 58.360, 190 feet off RDB, Depth 26 ft, sand and gravel substrate, sampled 9/11/02.

Reference Site 3. Figure 9. Located at TRM 189.0 along the right descending side.

Anchor point 1. N35° 13.85, W88° 15.54, 292 feet off RDB, Depth 32 ft, sand substrate, sampled 5/23/02.
Anchor point 2. N35° 13.84, W88° 15.55, 207 feet off RDB, Depth 32 ft, sand, gravel substrate, sampled 5/23/02.
Anchor point 3. N35° 14.10, W88° 15.49, 276 feet off RDB, Depth 32 ft, sand, gravel substrate, sampled 6/4/02.
Anchor point 4. N35° 14.15, W88° 15.47, 282 feet off RDB, Depth 26 ft, sand, gravel substrate, sampled 6/5/02.
Anchor point 5. N35° 14.15, W88° 15.47, 282 feet off RDB, Depth 23 ft, sand, gravel substrate, sampled 6/5/02.

Freshwater Mussel Sampling – During sample collection the dive boat was navigated to the site by referencing GPS and sonar data. Once the site location was established, individual stations were selected and sampled by anchoring the boat and deploying the divers. TWRA divers employed SCUBA and surface air supply. Work began at the downstream end of each site and progressed upstream. At each anchor point, ten discrete ($0.25m^2$) quadrat samples were collected by hand. All live mussels within each $0.25m^2$ square quadrat were removed to a depth of approximately four inches. Samples were kept in separate bags, returned to the surface, and processed. Because of the low frequency of occurrence of live mussels at the dredge sites, an additional 15-minute timed search was conducted at each anchor point after completion of quantitative sampling. This was not necessary at the reference sites due to the greater number of mussels encountered. Once onboard, all mussels were identified to species, counted, measured (length), and recorded on field data sheets. All mussels were returned to the river prior to moving to the next anchor point.

Statistical Evaluation – Data from the field sheets were entered into a computer spreadsheet and analyzed via Statistical Analysis System software. Although the sampling procedure was rather involved, data evaluation was simply a matter of testing the difference between the two sample means, requiring only basic t-tests. A t-test was used to detect differences in abundance between dredge and reference site means. In addition, a two-factor ANOVA was used to test for mean abundance differences, which reduced residual variance due to variation within anchor points. This provided a tested F-value. Diversity was tested with a t-test of the mean total number of different species reported at each sample site between dredge and reference site samples.

RESULTS

Nine dredge and three reference sites were sampled for freshwater mussels during this study. Bottom contours were mapped at each dredge site by the USACE and the data interpolated by TWRA's GIS division into three-dimensional representations of the riverbed (**Appendix A = 9 site, 3-D contours**). One-by-twenty-meter underwater video transects were filmed to provide a visual record of the bottom characteristics of each site. Six hundred $0.25m^2$

quadrat samples were collected and processed from the twelve study sites (Table 2). Additionally, timed collections totaling 675 minutes were conducted at the nine dredged sites (15 minutes per anchor point) attempting to locate additional mussels (Table 3).

Correlation analysis indicated no significant relationship ($r = 0.2059$, $p>0.10$) between mean mussel abundance and time (in years) since the last dredge event. Statistical analysis of the quantitative data indicated significantly lower abundances ($p<0.01$) and poorer diversity ($p<0.01$) occurred at the dredge sites than at the reference locations. An analysis of the quadrat data from the nine dredge sites revealed freshwater mussel species richness totaled 15 taxa, ranged from 0 to 9 per site, and had a mean number of species of 3.67 ($p<0.0001$, SD = 2.916) (Figure 2). Ebony shell (*Fusconaia ebena*) was the most abundant taxa (54.6%), followed by pink heelsplitter (*Potamilus alatus*, 10%), mapleleaf (*Quadrula quadrula,* 8.2 %) and threeridge (*Amblema plicata*, 6.4%) (Table 2). Abundance totaled 110 mussels and ranged from 0 to 42 individuals per site (Figure 3). Average site density ranged from 0 to 3.36 mussels/m^2 (Figure 4). Mean density from 450 - 0.25m^2 quadrat samples was estimated at 1.02 mussel/m^2 ($p<0.0001$, SD = 3.042) (**Appendix B, SAS printout**).

Timed sampling resulted in the collection of an additional 235 mussels representing 17 taxa (Table 3). *Fusconaia ebena* was the most abundant taxa (57.9%), but ranked second in frequency of occurrence to *Potamilus alatus* (10.6 % abundance). Four taxa (*Arcidens confragosa*, *Obliquaria reflexa*, *Quadrula nodulata*, *Toxolasma parvus*) taken during timed sampling did not occur in quantitative samples, and two species (*Fusconaia flava*, *Leptodea fragilis*) taken during quantitative sampling did not occur in the timed samples. Hubbs (2002) reported an average catch per unit of effort (CPUE) of nine mussels per minute from commercial mussel beds within this river reach, however the CPUE for the dredged sites averaged only 0.35 mussels per minute during this study.

Abundance and diversity values were significantly higher at reference sites than at dredged sites. Total abundance was 2,044 mussels. Mean density (54.51 mussels/m^2; $p<0.0001$, SD = 58.335) and diversity (15 taxa; $p<0.0001$, SD = 1) were significantly higher than at the dredged sites. Species richness from 150 - 0.25m^2 square quadrats was higher at 19 taxa, and exhibited little variance with a range of 14 to 16 total species. Ebony shell (*Fusconaia ebena*) was the most abundant taxa (83.9%), followed by pimpleback (*Quadrula pustulosa*, 4.6%), elephant ear (*Elliptio crassidens*, 2.1 %) and butterfly (*Ellipsaria lineolata*, 1.3%). No timed samples were collected at the reference sites.

CONCLUSIONS

Results obtained during this study indicated freshwater mussel abundance at evaluated dredge sites had not increased with years since the earliest dredging event within the time frame examined. Significantly lower mussel abundance and diversity values observed at dredge sites indicate that bottom substrates altered by dredging and resource extraction operations do not provide substrate characteristics necessary for establishment of mussel populations similar to those found inhabiting the reference sites. This conclusion is supported by the significantly higher abundance and diversity values reported from the three reference sites, which were located adjacent to the evaluated dredge sites and displayed characteristics expected of pre-extraction and pre-dredging habitat conditions at dredge sites. Ebony shell (*Fusconaia ebena*) was the most abundant freshwater mussel taxa collected during this study. It comprised 54.6% and 57.9% of the sample populations at dredge sites (quantitative and timed samples respectively), and 83.9% at reference sites. *Fusconaia ebena* is the dominant freshwater mussel taxa in Kentucky Reservoir. It has adapted well to the altered habitats available and its higher population densities and frequencies of occurrence provide a greater capability to colonize unoccupied habitats. However, this rigorous specie was not able to establish itself in populations at evaluated dredge sites comparable to populations found at reference sites.

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FIGURES

Kentucky Lake Mussel Survey Sites
Commercial Sand and Gravel Dredging Areas

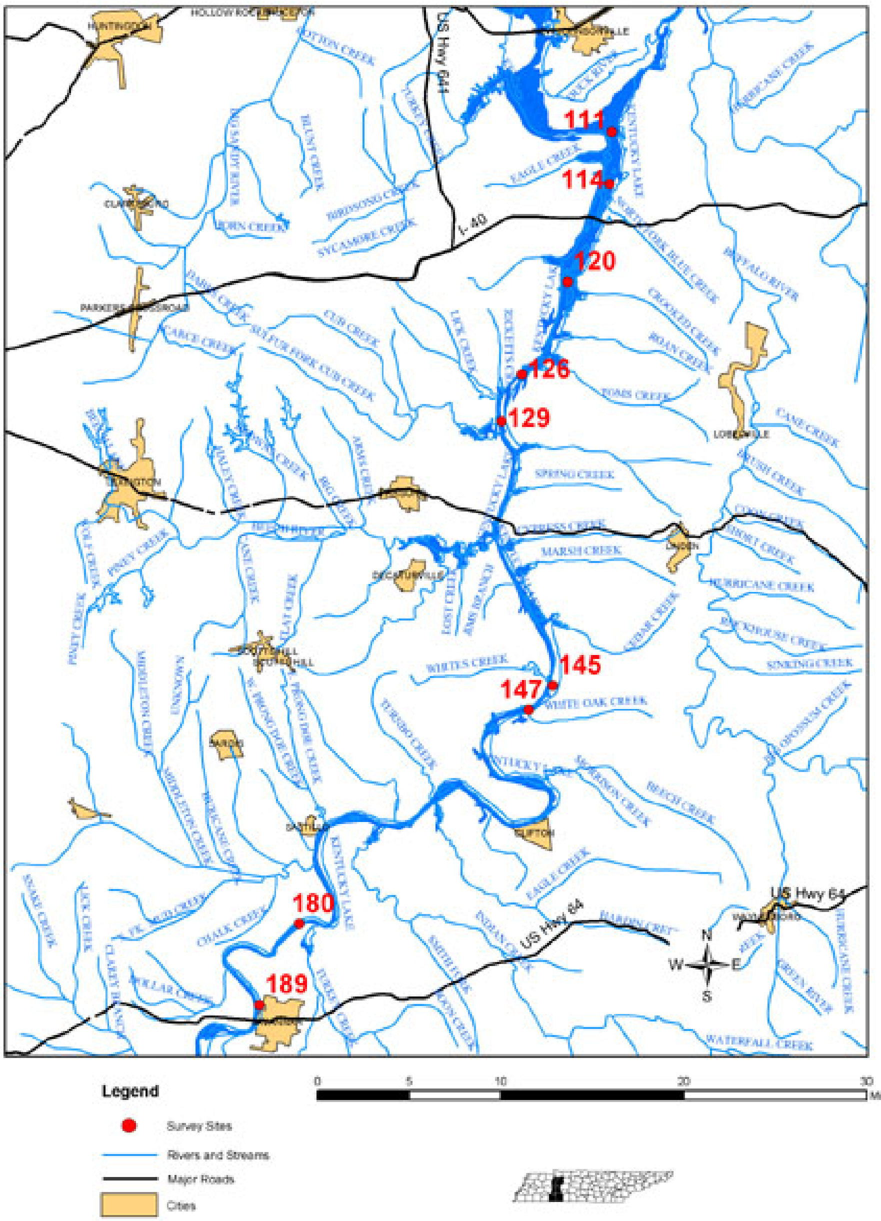
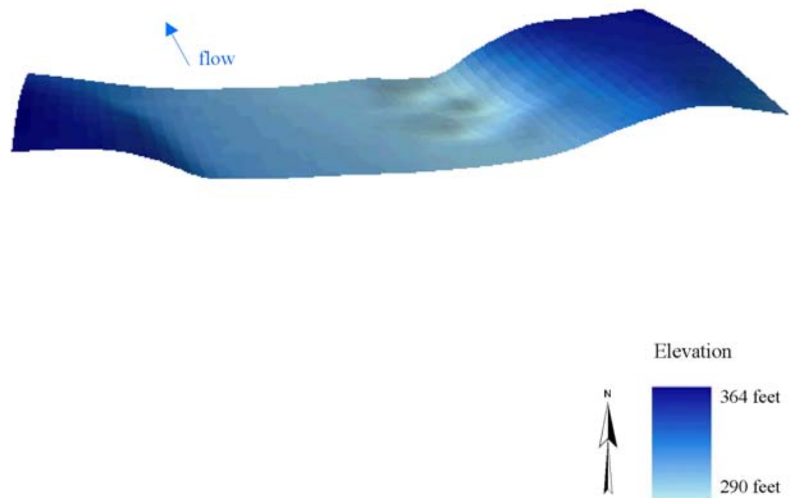


Figure 1. Kentucky Reservoir abandoned dredge study sites.

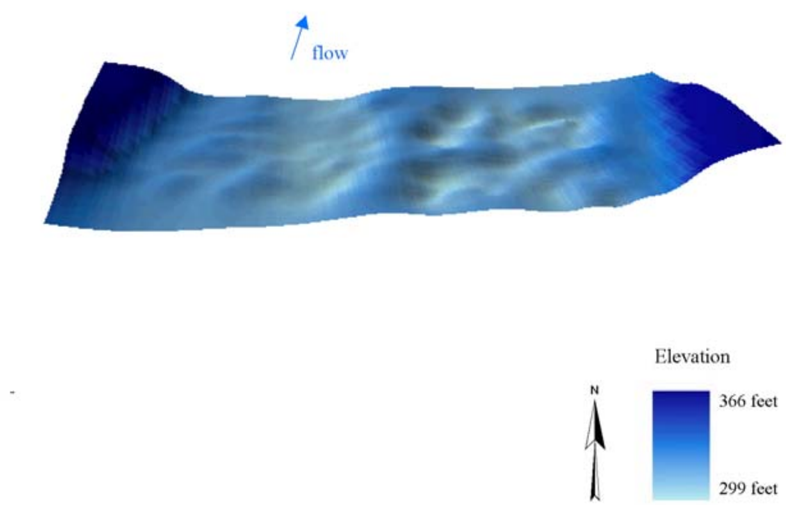
Figure 2. River Bottom Contours at Tennessee River Mile 111.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

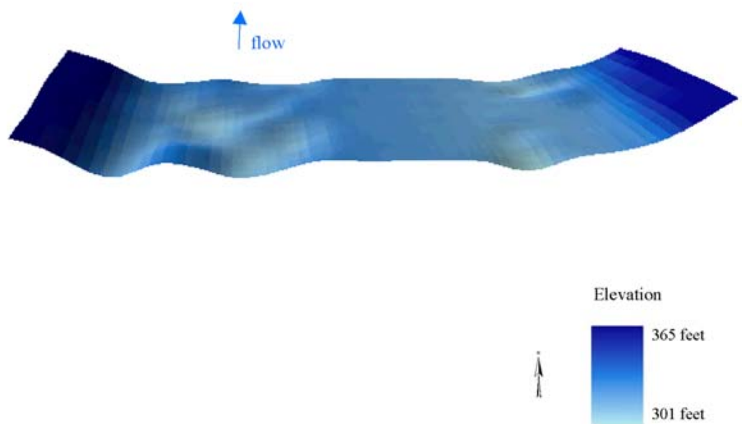
Figure 3. River Bottom Contours at Tennessee River Mile 114.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

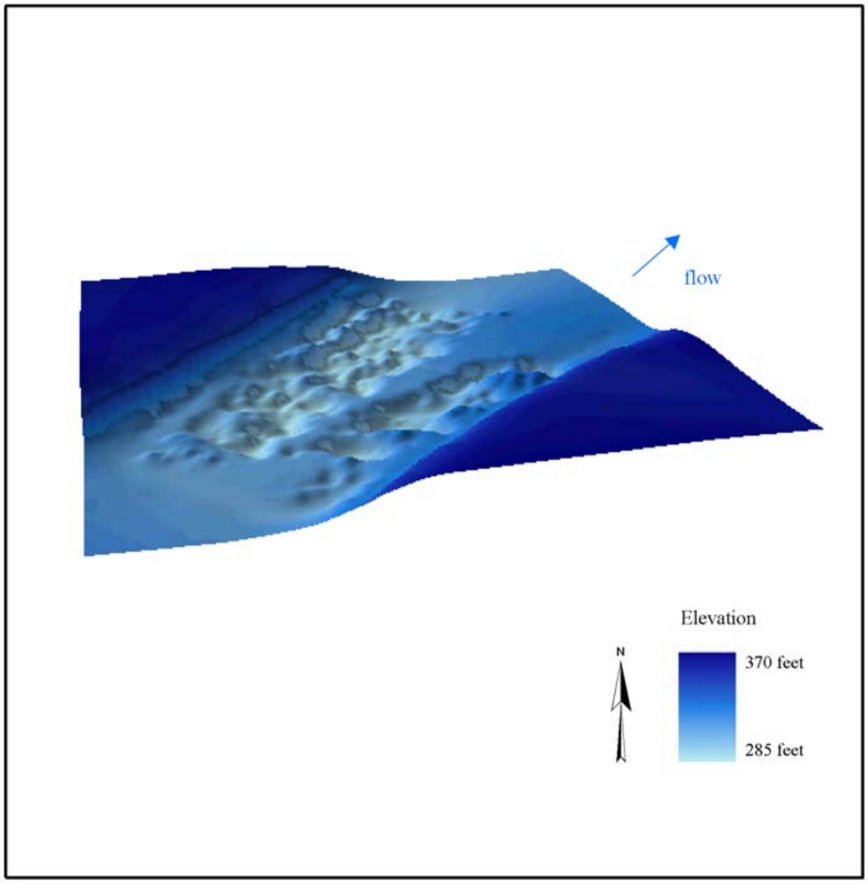
Figure 4. River Bottom Contours at Tennessee River Mile 120.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

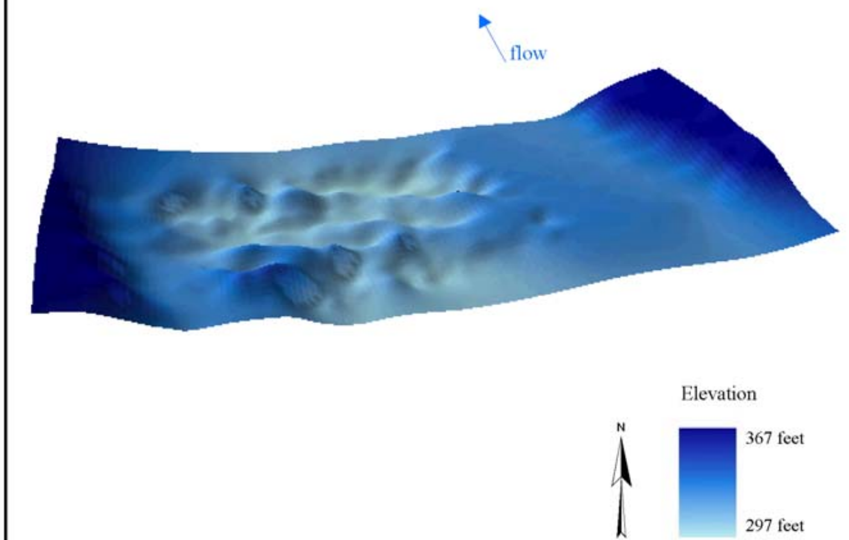
Figure 5. River Bottom Contours at Tennessee River Mile 126.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

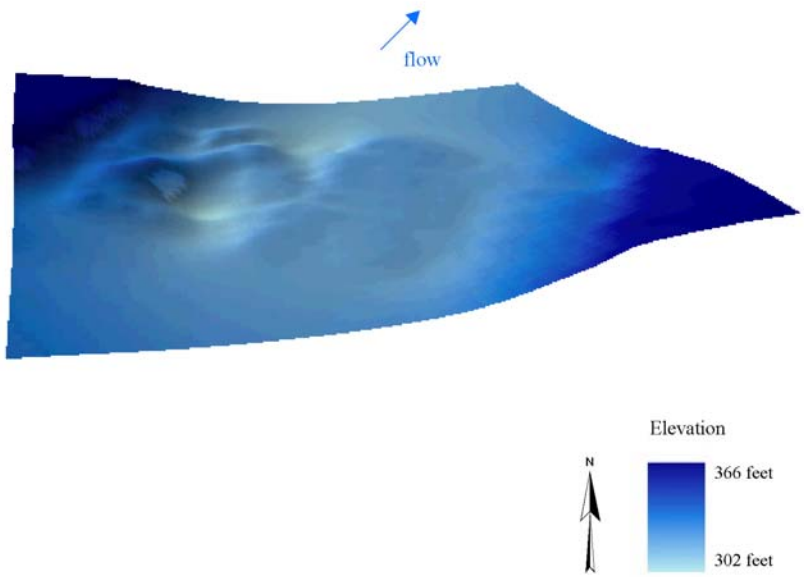
Figure 6. River Bottom Contours at Tennessee River Mile 129.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

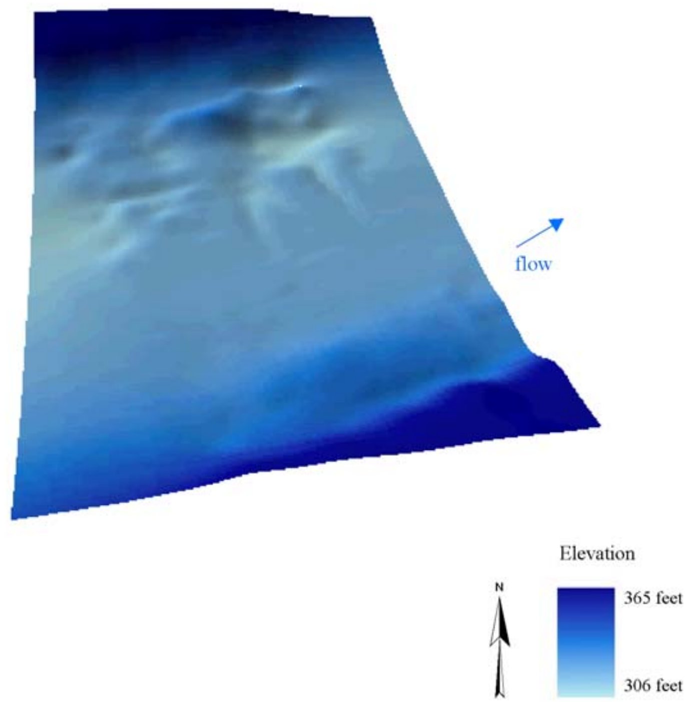
Figure 7. River Bottom Contours at Tennessee River Mile 145.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

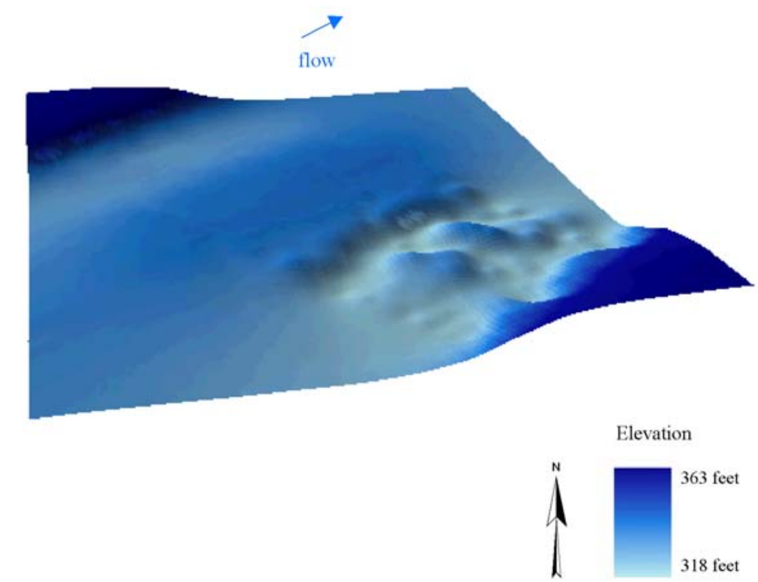
Figure 8. River Bottom Contours at Tennessee River Mile 147.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

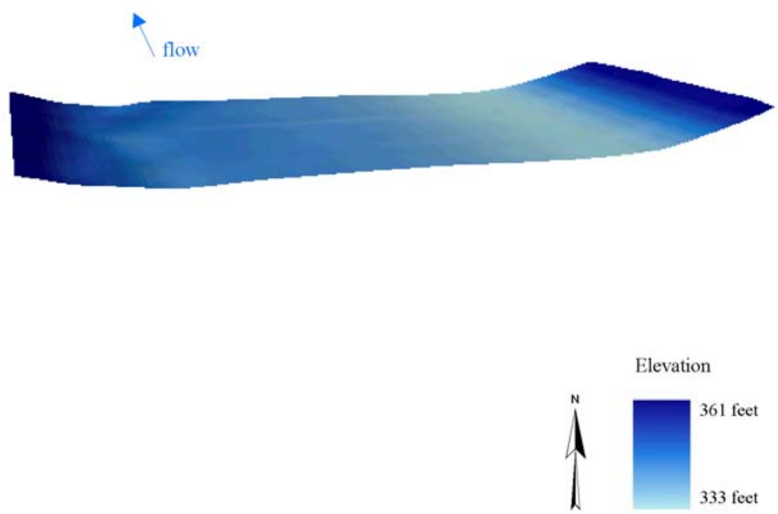
Figure 9. River Bottom Contours at Tennessee River Mile 180.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.

Vertical exaggeration equals two.

Figure 10. River Bottom Contours at Tennessee River Mile 189.



Three-dimensional images derived from bathymetric surveys completed by the United States Army Corp of Engineers.
This image most likely represents an undisturbed site immediately upstream of Tennessee river mile 189

Vertical exaggeration equals two.

23

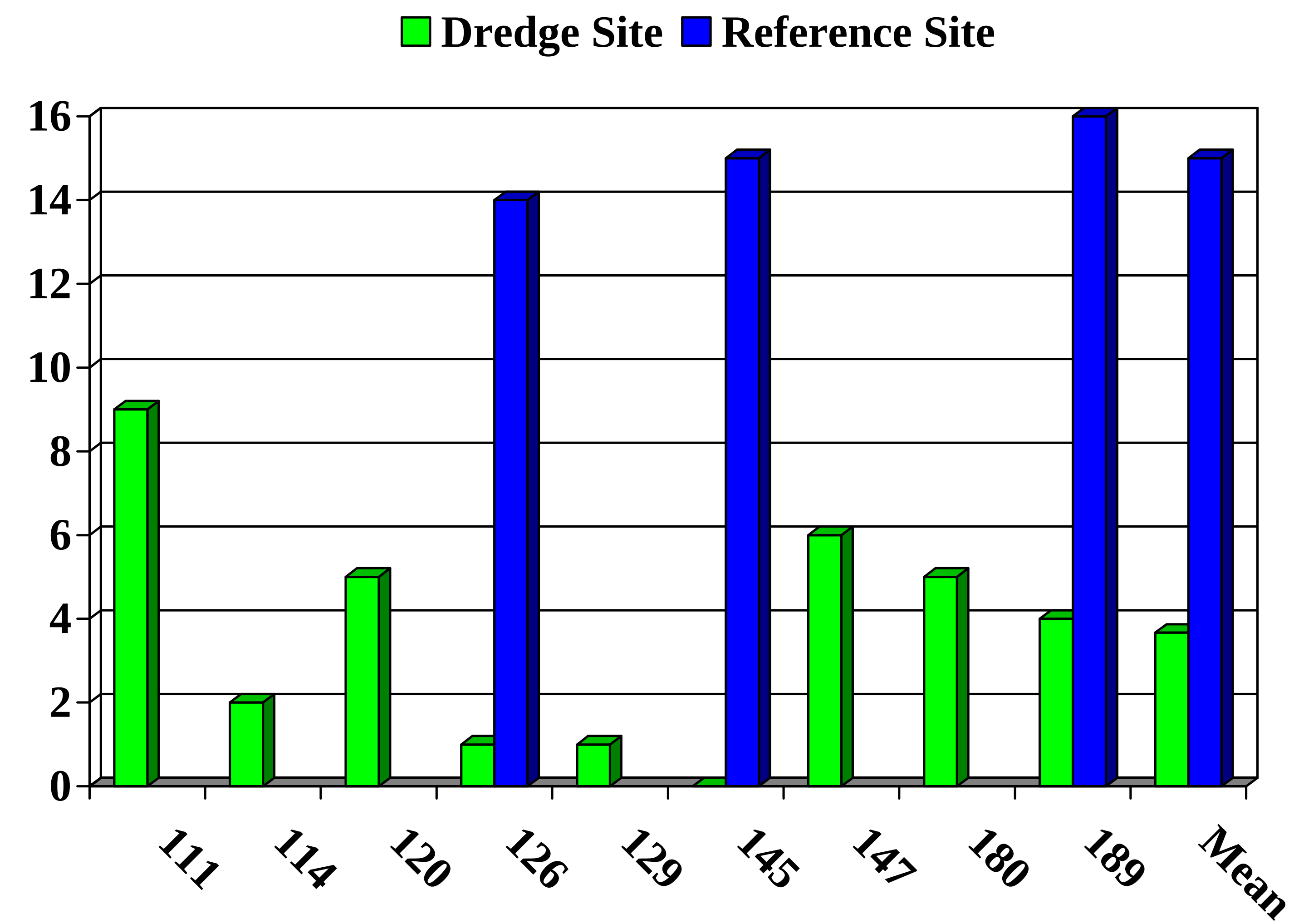


Figure 11. Freshwater mussel diversity from 0.25m^2 samples at dredge and reference sites.

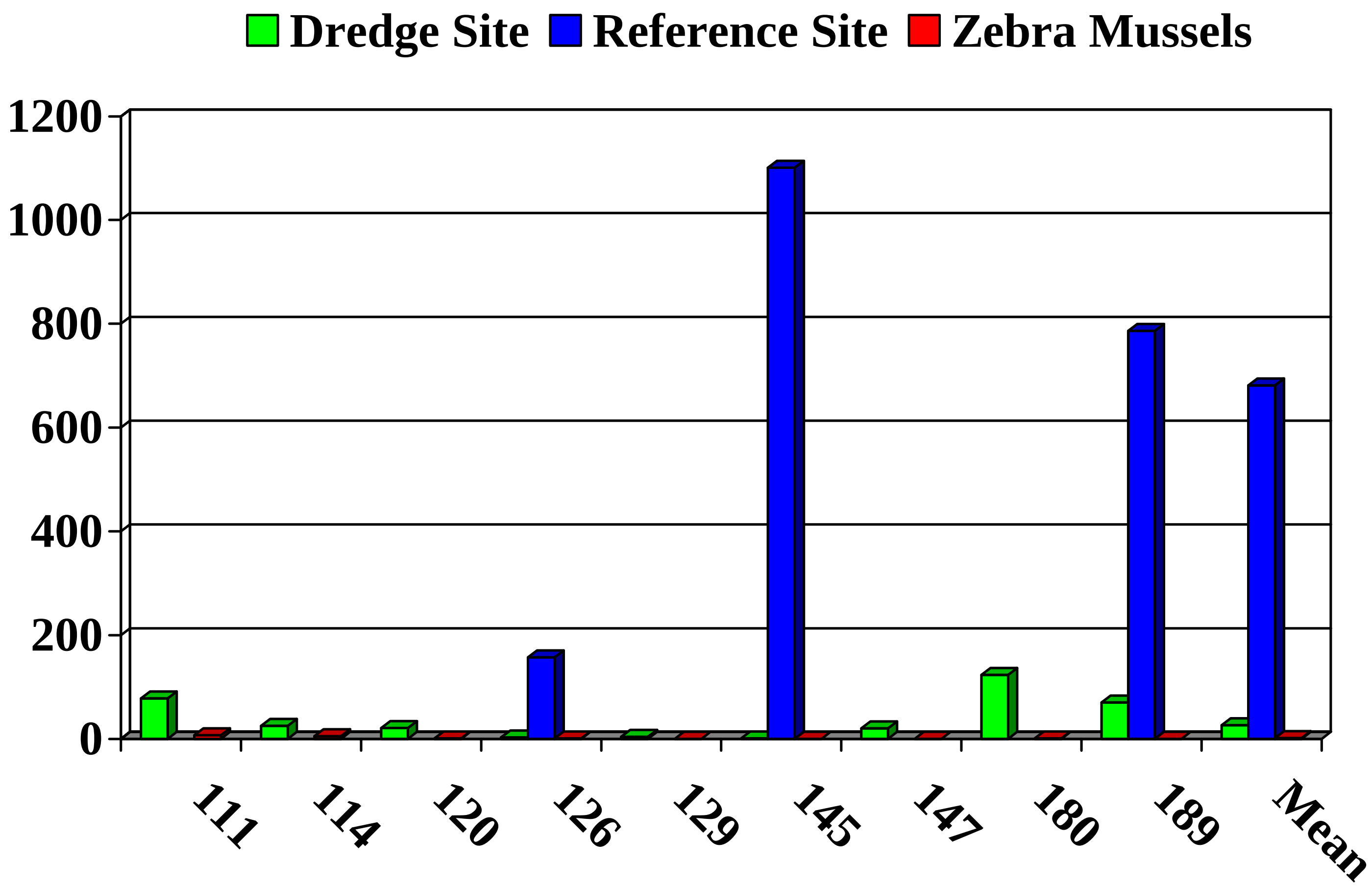


Figure 12. Freshwater mussel abundance from 0.25m^2 and 15-minute timed samples at dredge sites and 0.25m^2 samples at reference sites.

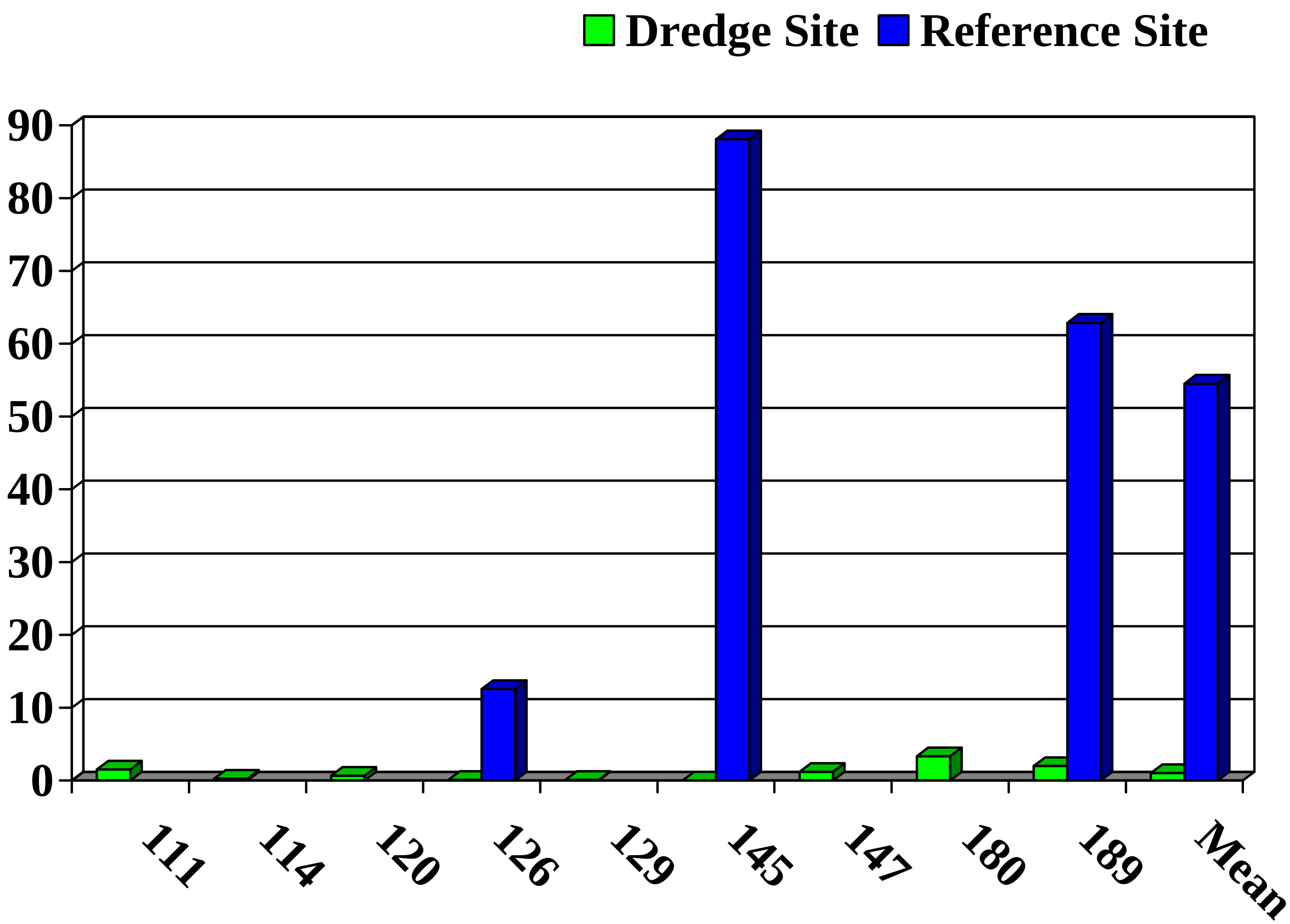


Figure 13. Freshwater mussel densities from $0.25m^2$ samples at dredge and reference sites.

TABLES

Table 1. Permitted commercial sand and gravel dredging reaches, Kentucky Reservoir portion of the lower Tennessee River.

TN. River Mile Reach	Restricted Conditions	Permitted Miles
110.0 to 120.0	General	10.0
126.0 to 128.5	General	2.5
128.5 to 130.0	Left descending side only	1.5
130.0 to 135.0	General	5.0
136.0 to 140.0	General	4.0
143.5 to 144.0	Left descending side only	0.5
144.0 to 145.5	General	1.5
147.0 to 148.5	General	1.5
150.0 to 152.0	General	2.0
155.5 to156.5	General	1.0
172.0 to 173.0	General	1.0
173.0 to 176.5	Left descending side only	3.5
176.5 to 182.0	General	5.5
184.0 to 189.0	General	5.0
191.0 to 192.0	General	1.0
193.0 to 194.0	General	1.0
194.0 to 195.0	Left descending side only	1.0
195.0 to 195.4	General	0.4
TOTAL		**47.9**

General Restrictions

1. Dredging is prohibited within 100 feet from shoreline and in depths of ten feet or less (based upon water surface elevation at time of dredging).
2. Dredging is prohibited within ½ mile upstream and ¼ mile downstream of public water intakes.
3. Dredging is prohibited within 200 feet of any ferry crossing or within 500 feet of any bridge pier.
4. Dredging is prohibited within 300 feet of any pipeline, cable crossing, dock, loading or unloading terminal, or other authorized installation or structure, without consent of the owner.
5. Dredging is prohibited in areas of obvious aquatic weed mass.
6. The permitted activity must not interfere with public right to free navigation on all waters of the State held to be navigable in the technical or legal sense.

Table 2. Mussel species collected during quantitative sampling by site.

	Dredge Sites										Reference Sites			
River Mile	111	114	120	126	129	145	147	180	189	**Total**	126	145	189	**Total**
Species														
Amblema plicata	2						5			**7**		2	3	**5**
Arcidens confragosa										**0**	1			**1**
Cyclonaias tuberculata										**0**	1		5	**6**
Elliptio crassidens							1			**1**	8	29	6	**43**
Ellipsaria lineolata			1					1		**2**	5	11	10	**26**
Fusconaia ebena	4						3	36	17	**60**	96	983	636	**1715**
Fusconaia flava	1									**1**				**0**
Leptodea fragilis			1							**1**	3	11	4	**18**
Ligumia recta								1		**1**		1	3	**4**
Megalonaias nervosa			1				1		1	**3**	7	5	2	**14**
Obliquaria reflexa										**0**	2	10	13	**25**
Pleurobema cordatum	1									**1**	1	5	3	**9**
Potamilus alatus	1	2	3		1		2	2		**11**	5	5	2	**12**
Quadrula apiculata	2	1	2							**5**	3	1		**4**
Quadrula metanevra									2	**2**			20	**20**
Quadrula nodulata										**0**	3			**3**
Quadrula pustulosa	1							2	1	**4**	9	18	68	**95**
Quadrula quadrula	5			1			3			**9**	13	4	4	**21**
Truncillia donaciformis										**0**		10	5	**15**
Truncilia truncata	2									**2**		6	2	**8**
Total Species	**9**	**2**	**5**	**1**	**1**	**0**	**6**	**5**	**4**	**15**	**14**	**15**	**16**	**19**
Total Mussels	**19**	**3**	**8**	**1**	**1**	**0**	**15**	**42**	**21**	**110**	**157**	**1101**	**786**	**2044**
***Density #/m^2**	**1.52**	**0.24**	**0.64**	**0.08**	**0.08**	**0**	**1.2**	**3.36**	**2**	**1.02**	**12.56**	**88.08**	**62.88**	**54.51**

*Density = sum of all mussels divided by 12.5m^2 per site (50 quadrats 0.25m$^{2)}$

Table 3. Mussel species collected during timed sampling by site.

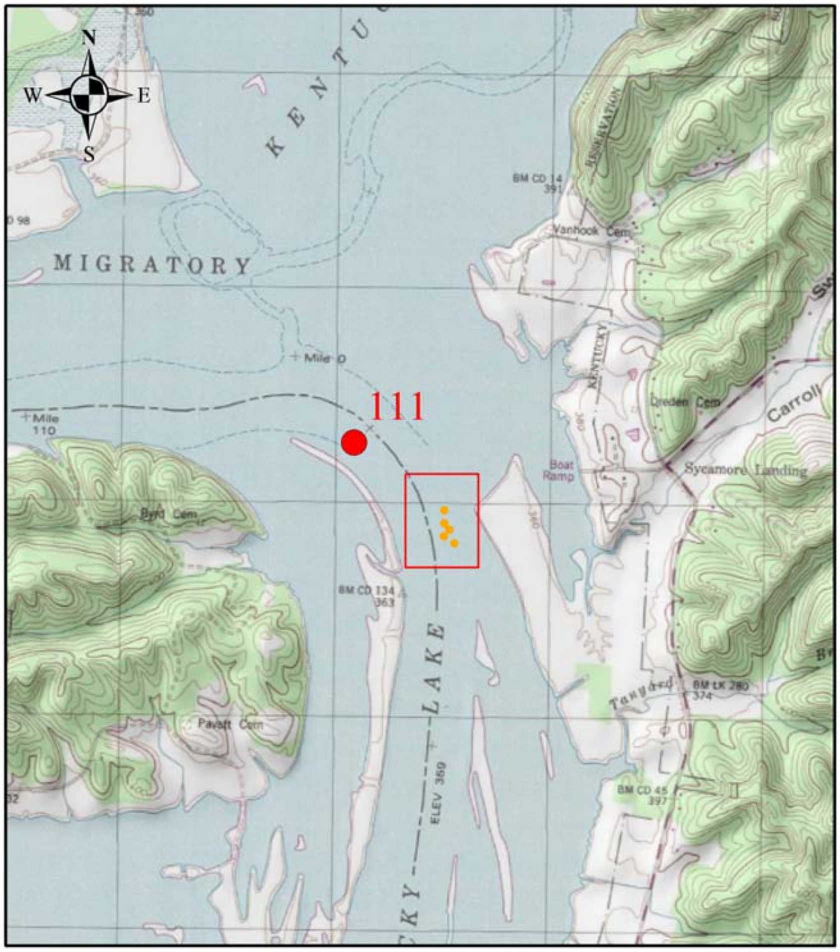
Dredge Sites													
River Mile	111	114	120	126	129	145	147	180	189	**Total**	**% Abundance**	**Frequency**	**Frequency Rank**
Species													
Amblema plicata	3						1			**4**	**1.7**	**2**	**4**
Arcidens confragosa		1								**1**	**0.4**	**1**	**5**
Elliptio crassidens	3							1		**4**	**1.7**	**2**	**4**
Ellipsaria lineolata	1									**1**	**0.4**	**1**	**5**
Fusconaia ebena	14	2	9				1	65	45	**136**	**57.9**	**6**	**2**
Ligumia recta								1		**1**	**0.4**	**1**	**5**
Megalonaias nervosa	9	4						1		**14**	**6.0**	**3**	**3**
Obliquaria reflexa							1	1		**2**	**0.8**	**2**	**4**
Pleurobema cordatum	1							1		**2**	**0.8**	**2**	**4**
Potamilus alatus	14	4	2	1	2		1	1		**25**	**10.6**	**7**	**1**
Quadrula apiculata	3	5			1					**9**	**3.8**	**3**	**3**
Quadrula metanevra								2		**2**	**0.8**	**1**	**5**
Quadrula nodulata	1									**1**	**0.4**	**1**	**5**
Quadrula pustulosa			2					6	2	**10**	**4.3**	**3**	**3**
Quadrula quadrula	9	6				1	1	1	2	**20**	**8.5**	**6**	**2**
Toxolasma parvus				1						**1**	**0.4**	**1**	**5**
Truncilia truncata	1							1		**2**	**0.8**	**1**	**5**
Total Species	**11**	**6**	**3**	**2**	**2**	**1**	**5**	**11**	**3**	**17**			
Total mussels	**59**	**22**	**13**	**2**	**3**	**1**	**5**	**81**	**49**	**235**			
***Catch per unit effort**	**0.79**	**0.29**	**0.17**	**0.03**	**0.04**	**0.01**	**0.07**	**1.08**	**0.65**	**0.35**			
Nonindigenous Mollusks													
Corbicula fluminea	X	X	X	X	X	X	X	X	X				
Dreissena polymorpha	7	5	1	1	0	0	0	1	0	15			

* Catch per unit effort = sum of total mussels divided by 75 minutes sampling effort per site

APPENDICES

Appendix A
Site Specific Anchor Point Distribution

A1. Sample Stations at Site 1 - Tennessee River Mile 111



Hustburg Quadrangle

● River Mile

Anchor Site

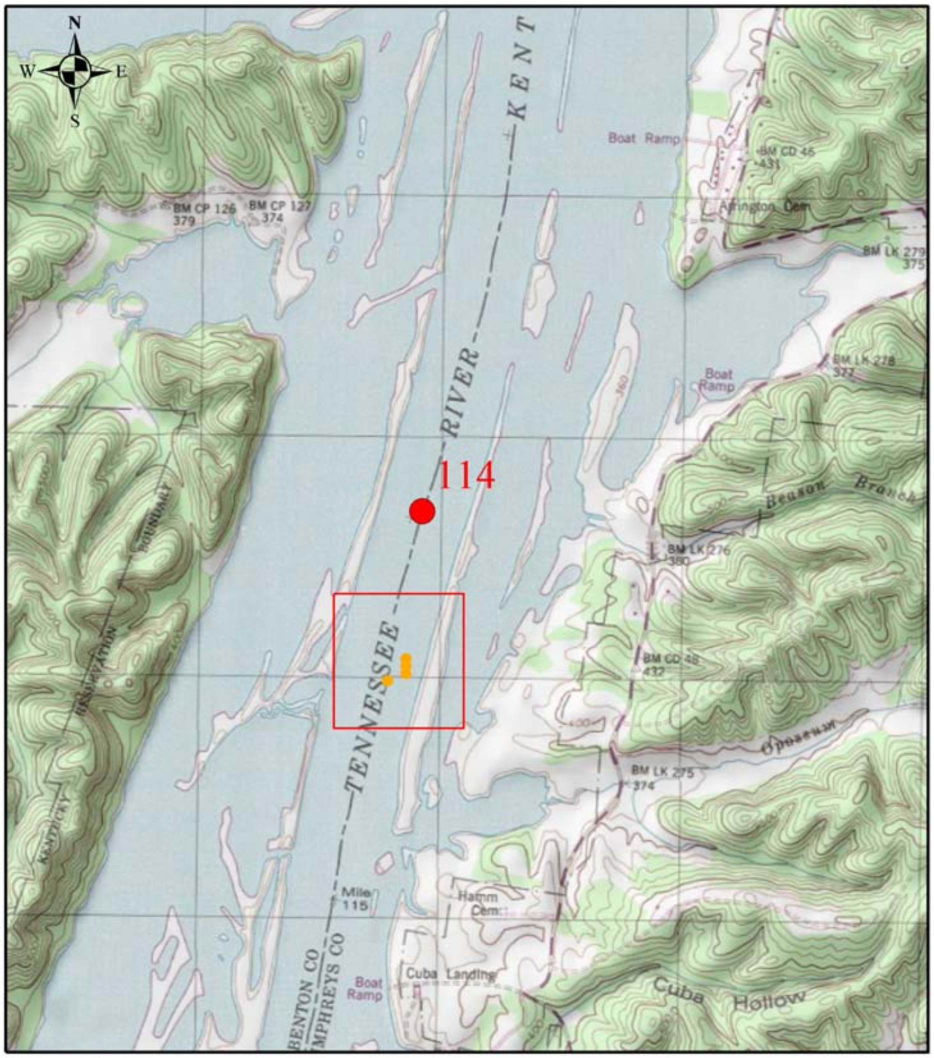
● Dredge

★ Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A2. Sample Stations at Site 2 - Tennessee River Mile 114



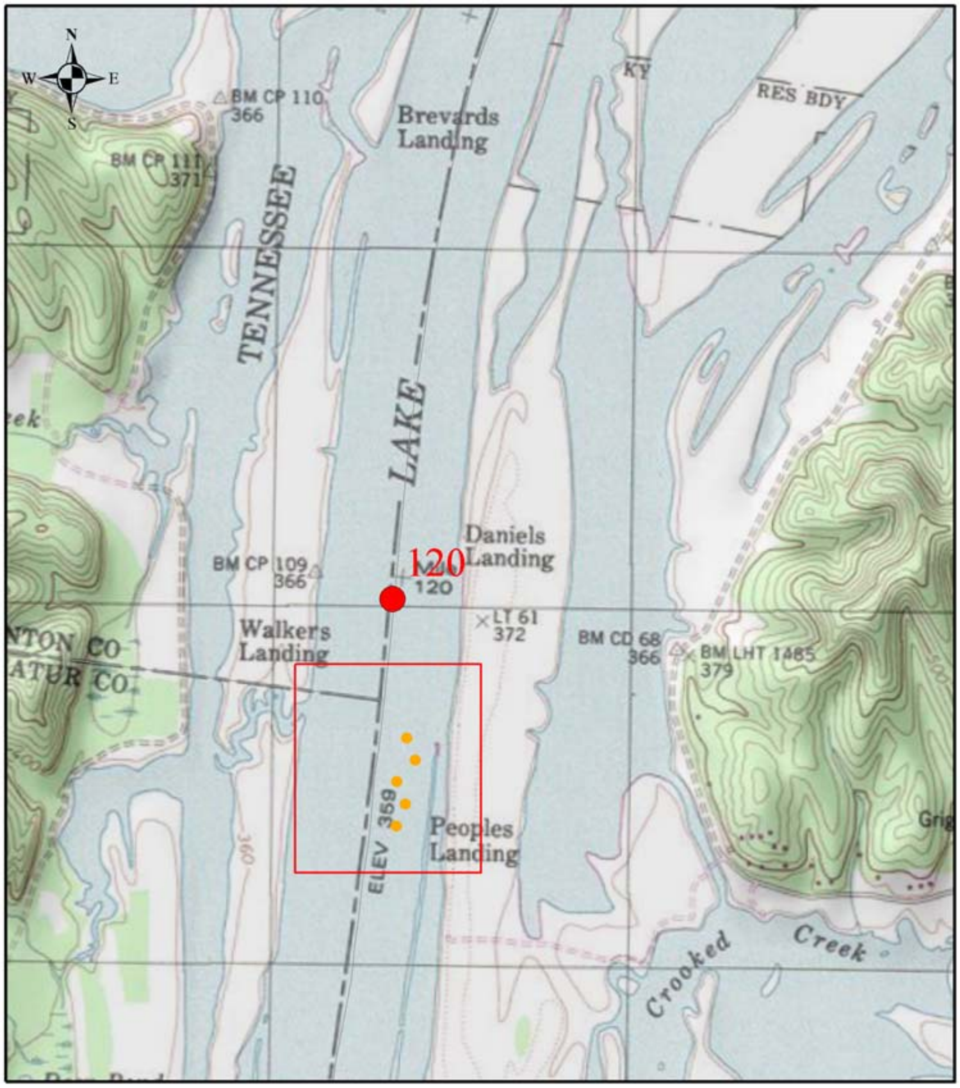
Hustburg Quadrangle

River Mile Anchor Site
Dredge
Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A3. Sample Stations at Site 3 - Tennessee River Mile 120

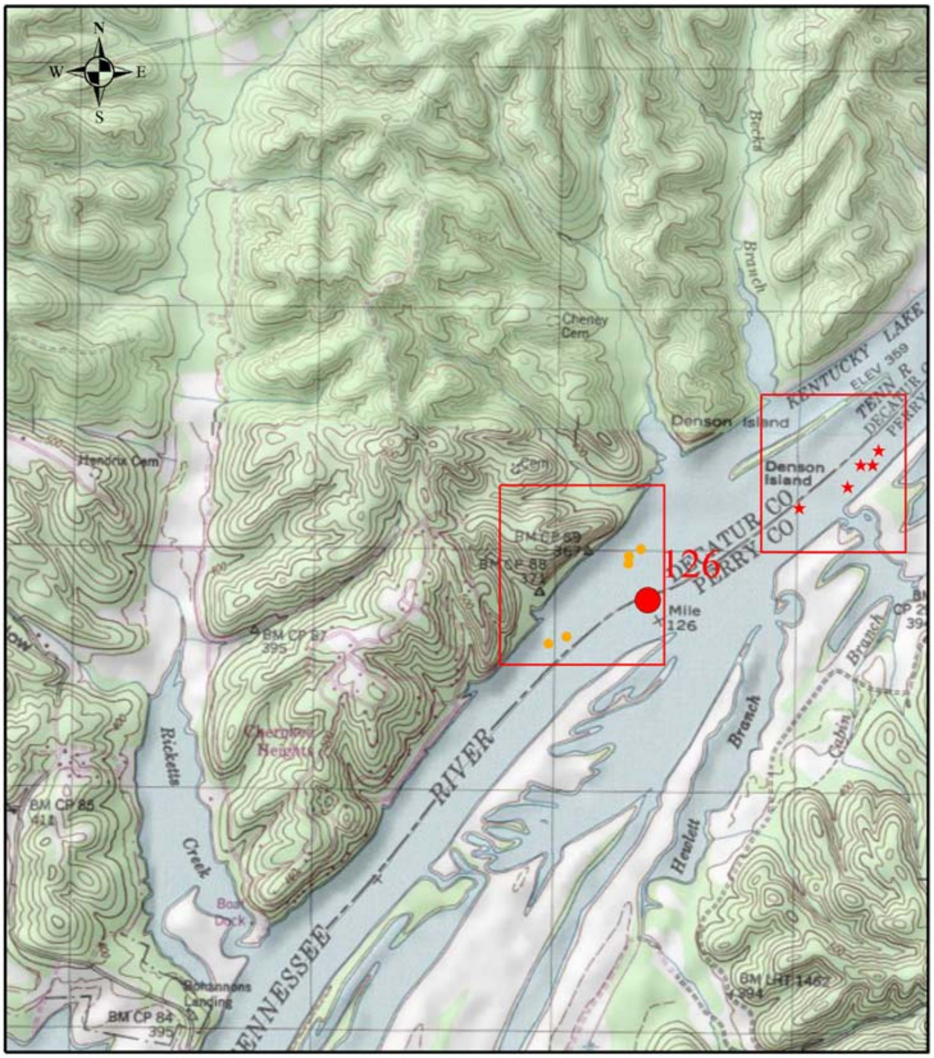


Daniels-Landing Quadrangle

●	River Mile Anchor Site
●	Dredge
★	Reference
	1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A4. Sample Stations at Site 4 - Tennessee River Mile 126



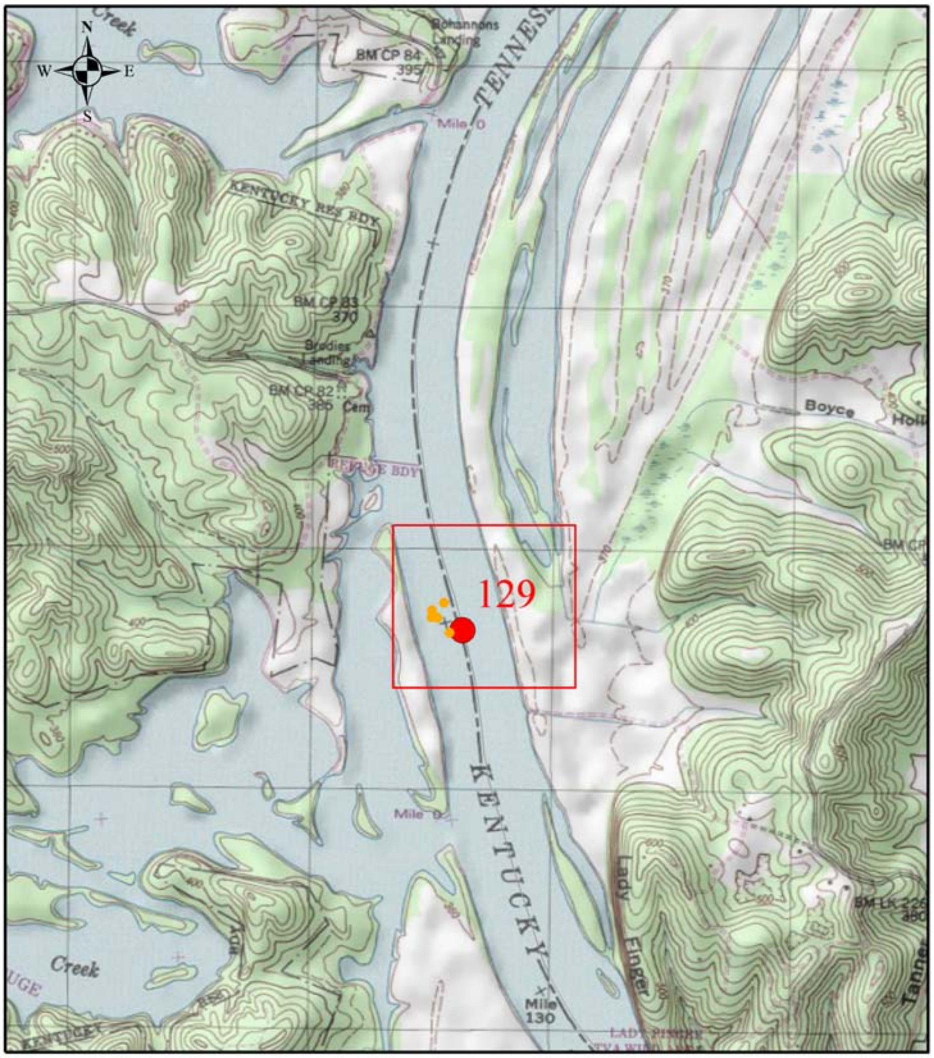
Jeanette Quadrangle

● River Mile Anchor Site
● Dredge
★ Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A5. Sample Stations at Site 5 - Tennessee River Mile 129



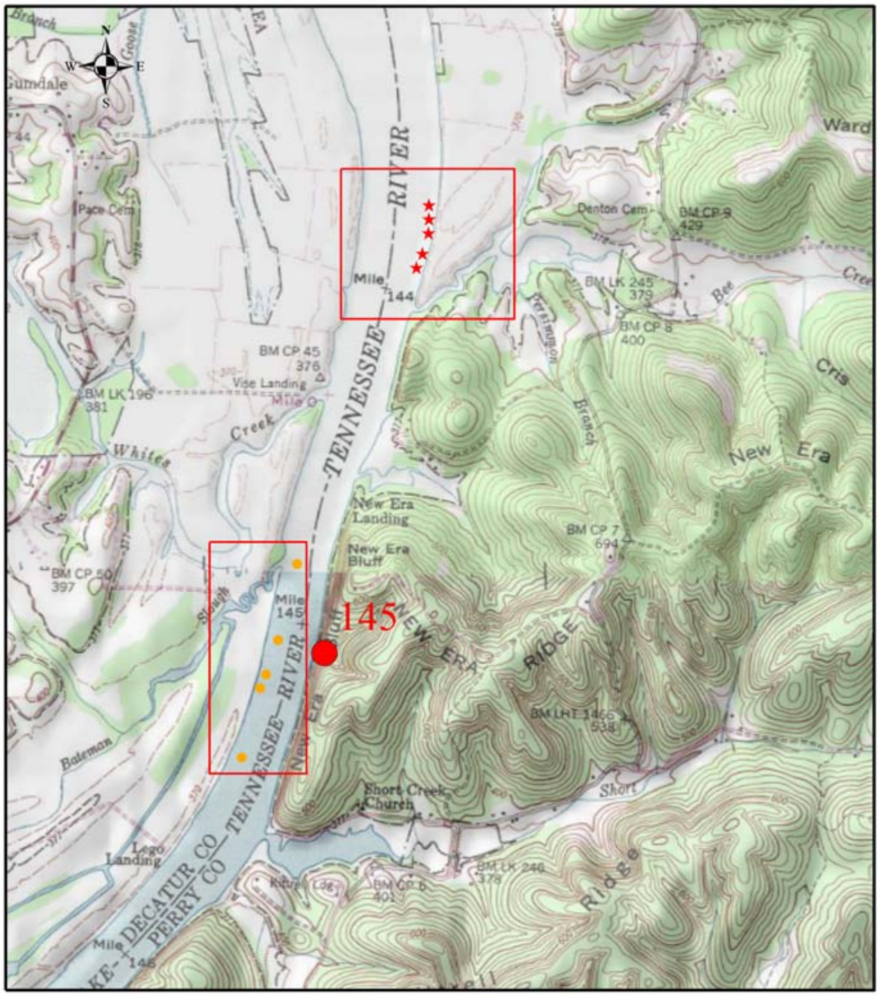
Jeanette Quadrangle

River Mile Anchor Site
Dredge
Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A6. Sample Stations at Site 6 - Tennessee River Mile 145

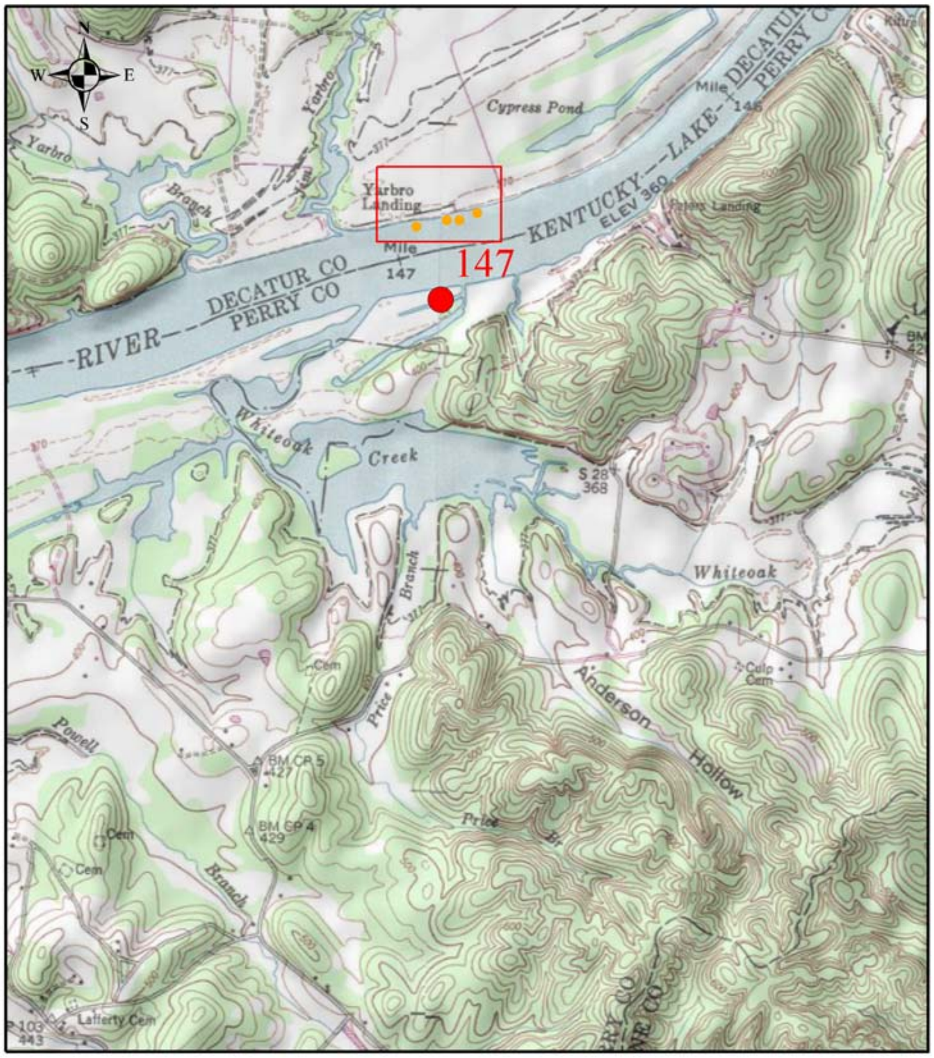


Clifton Quadrangle

River Mile Anchor Site
Dredge
Reference
1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A7. Sample Stations at Site 7 - Tennessee River Mile 147



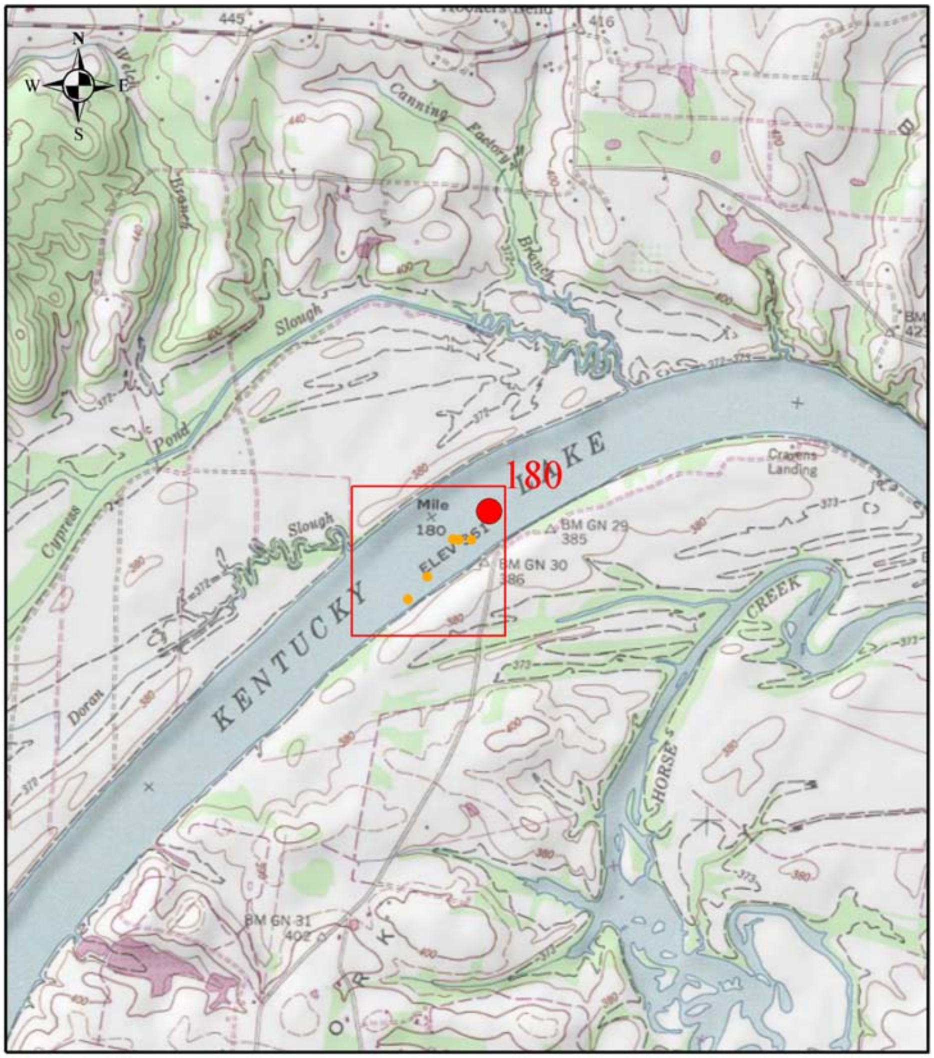
Bath-Springs and Clifton Quadrangles

River Mile Anchor Site
Dredge
Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A8. Sample Stations at Site 8 - Tennessee River Mile 180



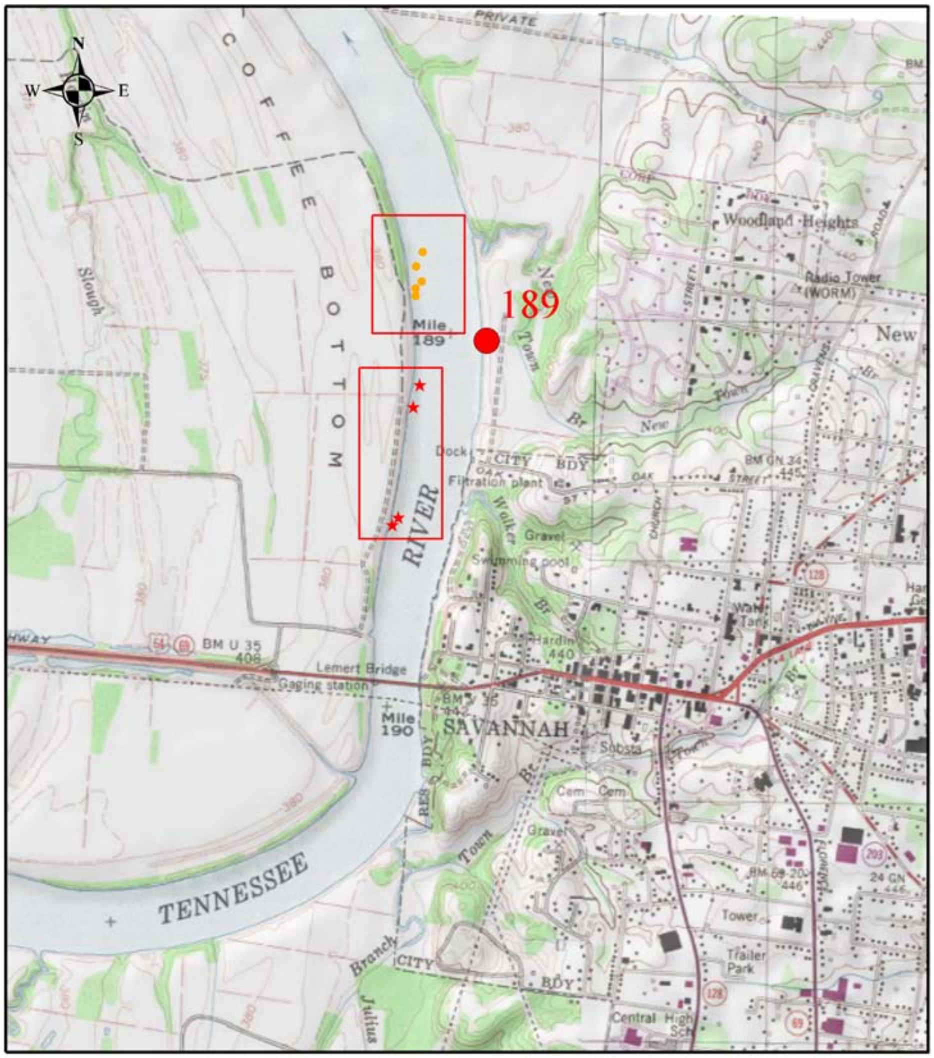
Hookers-Bend Quadrangle

River Mile Anchor Site
Dredge
Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

A9. Sample Stations at Site 9 - Tennessee River Mile 189



Pittsburg-Landing Quadrangle

River Mile Anchor Site

Dredge

Reference

1:24000 map scale

Five anchor points (sample stations) were established at each site. Anchor point coordinates were determined with a Global Positioning System (GPS).

Appendix B

Statistical Analysis of Mussel Population Data

Below is a SAS printout for the analyses used to test differences between the reference and dredge samples. Although the sampling procedure was rather involved (i.e. quadrats within anchor points within site within survey strata), it was really just a simple matter of testing the difference between two sample means; requiring only basic t-tests. A two-factor ANOVA for was also used for good measure, but it was not necessary since the data gave up the expected results without relentless torture.

Dredge sites presented significantly lower abundances (p<0.01) and poorer diversity (p<0.01) than did the reference locations. A t-test was used to detect differences in abundance between dredge and reference means. In addition, a two-factor ANOVA was used to test for abundance differences that reduced residual variance due to variation within anchor points. This provides a tested F-value if one is needed. Diversity was tested with a simple t-test of mean number of species found at each location. The diversity data were taken directly off the totals in the quad_sum_sp.xls data set so corbicula and zebra mussels should not be included.

Look below for annotations at the beginning of each analysis **in bold**.

This t-test tested for differences between the mean number of mussels in all quadrats by reference and dredge locations (Zero counts included). The test for equality of variances indicated that the variances were unequal so the second (satterthwait) t-test should be used. In either case, the differences were highly significant.

T-TEST TO DETECT DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN DREDGE
AND REFERENCE SAMPLE SITES
THIS IS A SIMPLE TEST WHICH USES THE MEANS OF ALL DREDGE AND
REFERENCE QUADRAT SAMPLES FOR TESTING
COUNTS HAVE BEEN CONVERTED TO NUMBER PER SQUARE METER

The TTEST Procedure

Statistics

Variable	SITE_TYP	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev
COUNT_M3	DREDGE	450	0.7404	1.0222	1.304	2.855	3.0416
COUNT_M3	REFERENC	150	45.228	54.64	64.052	52.396	58.335
COUNT_M3	Diff (1-2)		-59.03	-53.62	-48.2	27.67	29.237

Statistics

Variable	SITE_TYP	Upper CL Std Dev	Std Err	Minimum	Maximum
COUNT_M3	DREDGE	3.2544	0.1434	0	24
COUNT_M3	REFERENC	65.803	4.763	0	292
COUNT_M3	Diff (1-2)	30.994	2.7565		

T-Tests

Variable	Method	Variances	DF	t Value	Pr > |t|
COUNT_M3	Pooled	Equal	598	-19.45	<.0001
COUNT_M3	Satterthwaite	Unequal	149	-11.25	<.0001

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
COUNT_M3	Folded F	149	449	367.84	<.0001

ANOVA confirms the results of the previous t-test. The only difference is that the ANOVA allows the partitioning of the within-anchor-point variation to build a stronger model, for what it's worth since the t-test was highly significant. The Duncan's test is redundant with the t-test.

```
 TWO-FACTOR ANOVA TO TEST FOR DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN
                    DREDGE AND REFERENCE SAMPLE SITES
   THE VARIATION WITHIN ANCHOR POINTS AT EACH SITE WAS USED IN THE MODEL
                      TO REDUCE RESIDUAL VARIATION
           COUNTS HAVE BEEN CONVERTED TO NUMBER PER SQUARE METER

                             The GLM Procedure

                         Class Level Information

                Class         Levels    Values

                SITE_TYP           2    DREDGE REFERENC

                ANCH_PT            5    1 2 3 4 5

                      Number of observations    600
```

TWO-FACTOR ANOVA TO TEST FOR DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN
DREDGE AND REFERENCE SAMPLE SITES
THE VARIATION WITHIN ANCHOR POINTS AT EACH SITE WAS USED IN THE MODEL
TO REDUCE RESIDUAL VARIATION
COUNTS HAVE BEEN CONVERTED TO NUMBER PER SQUARE METER

The GLM Procedure

Dependent Variable: COUNT_M3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	380370.0622	42263.3402	54.89	<.0001
Error	590	454240.7111	769.8995		
Corrected Total	599	834610.7733			

R-Square	Coeff Var	Root MSE	COUNT_M3 Mean
0.455745	192.3318	27.74706	14.42667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SITE_TYP	1	323422.4356	323422.4356	420.08	<.0001
ANCH_PT	4	16008.9067	4002.2267	5.20	0.0004
SITE_TYP*ANCH_PT	4	40938.7200	10234.6800	13.29	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SITE_TYP	1	323422.4356	323422.4356	420.08	<.0001
ANCH_PT	4	44409.1200	11102.2800	14.42	<.0001
SITE_TYP*ANCH_PT	4	40938.7200	10234.6800	13.29	<.0001

TWO-FACTOR ANOVA TO TEST FOR DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN DREDGE AND REFERENCE SAMPLE SITES
THE VARIATION WITHIN ANCHOR POINTS AT EACH SITE WAS USED IN THE MODEL TO REDUCE RESIDUAL VARIATION
COUNTS HAVE BEEN CONVERTED TO NUMBER PER SQUARE METER

The GLM Procedure

Duncan's Multiple Range Test for COUNT_M3

NOTE: This test controls the Type I comparison wise error rate, not the Experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	590
Error Mean Square	769.8995
Harmonic Mean of Cell Sizes	225

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	5.138

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	SITE_TYP
A	54.640	150	REFERENC
B	1.022	450	DREDGE

The test for diversity differences between dredge and reference sites simply tests the mean of the total number of different species recorded at each sample site between dredge and reference site samples. In this case, the variances were equal so the first (pooled) t-test is appropriate. The difference in diversity was highly significant.

T-TEST TO DETECT DIFFERENCES MUSSEL SPECIES DIVERSITY BETWEEN
DREDGE AND NON-DREDGED REFERENCE SAMPLE SITES
THE TEST WAS MADE ON MEAN NUMBER OF MUSSEL SPECIES
AT EACH SAMPLE SITE

The TTEST Procedure

Statistics

Variable	SITE_TYP	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev
NUMSP	DREDGE	9	1.4256	3.6667	5.9077	1.9693	2.9155
NUMSP	REF	3	12.516	15	17.484	0.5207	1
NUMSP	Diff (1-2)		-15.26	-11.33	-7.403	1.8486	2.6458

Statistics

Variable	SITE_TYP	Upper CL Std Dev	Std Err	Minimum	Maximum
NUMSP	DREDGE	5.5854	0.9718	0	9
NUMSP	REF	6.2847	0.5774	14	16
NUMSP	Diff (1-2)	4.6431	1.7638		

T-Tests

Variable	Method	Variances	DF	t Value	Pr > |t|
NUMSP	Pooled	Equal	10	-6.43	<.0001
NUMSP	Satterthwaite	Unequal	9.77	-10.03	<.0001

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
NUMSP	Folded F	8	2	8.50	0.2190

Printouts of the SAS programs used.

1) Abundance Tests:

```
OPTIONS LS = 75 PS = 52;
OPTIONS NODATE;
OPTIONS NONUMBER;

** This program was written by Pat Black to Quantify **
** Freshwater mussel data taken to detect differences **
** in abundance and species composition from Kentucky Lake**
** DATE WRITTEN:      2-3-2003**
** LAST UPDATE:       2-3-2003**
** WRITTEN FOR:       Sue Marden**;

LIBNAME SUE 'C:\PROJECT FILES\SUE\MUSSELS';

DATA QUADRAT;

INFILE 'C:\PROJECT FILES\SUE\MUSSELS\QUADRAT.CSV' DSD MISSOVER;

INPUT SITE $ ANCH_PT SITE_TYP $ MONTH DAY YEAR SAM_TYPE $ COM_NAME $ SCI_NAME
$
      Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10;
RUN;


DATA TRANPOSE;
  SET QUADRAT;


ARRAY Q[10] Q1-Q10;
 DO QUADRAT = 1 TO 10;
 COUNT = Q[QUADRAT];
 OUTPUT;
END;

DROP Q1-Q10;
RUN;

DATA KENTMUSS;
  SET TRANPOSE;

IF SITE = "RF191" THEN DELETE;

*PROC PRINT;
*RUN;

PROC SORT;
   BY SITE ANCH_PT QUADRAT;

PROC MEANS NOPRINT;
  VAR COUNT;
  BY SITE ANCH_PT QUADRAT;
```

```
  ID SITE_TYP MONTH DAY YEAR;
OUTPUT OUT = QUADSUM SUM = COUNTB;
RUN;

*PROC PRINT;
*RUN;

TITLE 'T-TEST TO DETECT DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN DREDGE';
TITLE2 'AND REFERENCE SAMPLE SITES';
TITLE3 'THIS IS A SIMPLE TEST WHICH USES THE MEANS OF ALL DREDGE AND';
TITLE4 'REFERENCE QUADRAT SAMPLES FOR TESTING';

PROC TTEST;
   CLASS SITE_TYP;
   VAR COUNTB;
   RUN;

TITLE 'TWO-FACTOR ANOVA TO TEST FOR DIFFERENCES IN MUSSEL ABUNDANCE BETWEEN';
TITLE2 'DREDGE AND REFERENCE SAMPLE SITES';
TITLE3 'THE VARIATION WITHIN ANCHOR POINTS AT EACH SITE WAS USED IN THE
MODEL';
TITLE4 'TO REDUCE RESIDUAL VARIATION';

PROC GLM;
   CLASS SITE_TYP ANCH_PT;
   MODEL COUNTB = SITE_TYP ANCH_PT SITE_TYP*ANCH_PT;
   MEANS SITE_TYP /DUNCAN;
RUN;


OPTIONS LS = 75 PS = 52;
OPTIONS NODATE;
OPTIONS NONUMBER;
```

2) Diversity Test:

```
** This program was written by Pat Black to Quantify **
** Freshwater mussel data taken to detect differences **
** in abundance and species composition from Kentucky Lake**
** DATE WRITTEN:      2-10-2003**
** LAST UPDATE:       2-10-2003**
** WRITTEN FOR:       Sue Marden**;

LIBNAME SUE 'C:\PROJECT FILES\SUE\MUSSELS';

DATA QUADRAT;

INFILE 'C:\PROJECT FILES\SUE\MUSSELS\NUMSP.CSV' DSD MISSOVER;

INPUT SITE $ SITE_TYP $ NUMSP;
RUN;
```

```
TITLE 'T-TEST TO DETECT DIFFERENCES MUSSEL SPECIES DIVERSITY BETWEEN';
TITLE2 'DREDGE AND NON-DREDGED REFERENCE SAMPLE SITES';
TITLE3 'THE TEST WAS MADE ON MEAN NUMBER OF MUSSEL SPECIES';
TITLE4 'AT EACH SAMPLE SITE';

PROC TTEST;
   CLASS SITE_TYP;
   VAR NUMSP;
RUN;
```