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TECHNICAL REPORT EL-91-8

# AN INVESTIGATION OF FRESHWATER MUSSELS (UNIONIDAE) IN THE TENNESSEE RIVER BELOW KENTUCKY LOCK AND DAM

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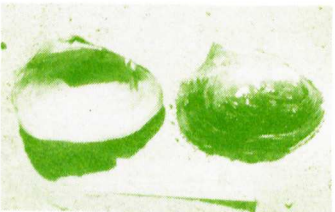
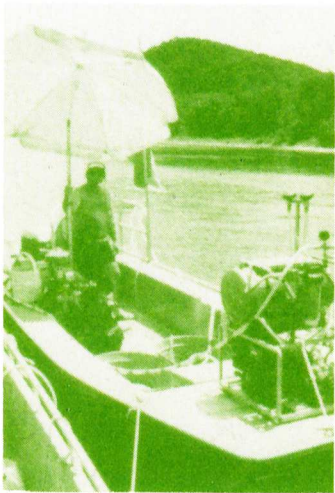
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DEPARTMENT OF THE ARMY

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*Megalonaias nervosa*, *F. ebena*, and *Quadrula quadrula*) within the area that will be dredged was estimated at \$101,707. Total density of snails ranged from 8.0 to 86.8 individuals per square meter; the fauna was dominated by *Pleurocera canaliculatum*, with lesser numbers of *Lithasia armigera* and *L. verrucosa*. Impacts due to construction and operation of the second lock can be partially offset by creating submerged habitat with dredged material along an eroding bank downriver of the lock and dam (RM 19.0 to 21.0).

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# Preface

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A mollusc survey was conducted by the US Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), during the period 31 August to 3 September 1990. The work was sponsored by the US Army Engineer District, Nashville (CEORN). Authors of the report were Dr. Andrew C. Miller and Dr. Barry S. Payne of the Aquatic Habitat Group (AHG), Environmental Resources Division (ERD), EL.

Divers were Messrs. Larry Neill, Brad Bole, Robert Warden, and Dennis Baxter of the Tennessee Valley Authority (TVA). Assistance in the field was provided by Mr. Richard Tippit, CEORN; Dr. John Jenkinson, TVA; and Dr. Jim Sickel, Murray State University, Murray, KY. Other participants were Mr. Phil Pierce, Headquarters, US Army Corps of Engineers; Mr. Joe Cathey, CEORN; Mr. Richard Biggins, US Fish and Wildlife Service (USFWS), Asheville, NC; and Mr. Jim Widlak, USFWS, Cookeville, TN. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

During the conduct of the study, Dr. John Harrison was Chief, EL; Dr. Conrad J. Kirby was Chief, ERD; and Mr. Edwin A. Theriot was Chief, AHG.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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# 1 Introduction

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## Background

A rich, dense, and commercially harvestable assemblage of freshwater mussels (Family: Unionidae) occurs in the lower Tennessee River (LTR) between Kentucky Lock and Dam (river mile (RM) 22.4) and the Ohio River (Isom 1969, Williams 1969, Sickel 1985). The bed is located between Kentucky Lock and Dam and RM 11.0 (Sickel 1985) and provides habitat for approximately 35 species of unionids including at least two Federally listed endangered species. With the exception of a few species, composition of the assemblage remains similar to that reported by earlier workers (Ortmann 1925, van der Schalie 1939) prior to completion of major hydropower dams upriver. This river reach has extensive stable sand and gravel shoals that are kept free of sediment by continuous flow of water from Kentucky Dam. Kentucky Lock and Dam is a multiple-purpose project that was completed in September 1944.

The US Army Engineer District, Nashville, proposes to construct a 1,200-ft (366-m) lock on the landward side of an existing 600-ft (183-m) lock at Kentucky Lock and Dam. The navigation channel will be shifted toward the right descending bank (RDB) to provide a safe entrance and exit to the lock. In addition to excavation for the new lock and approach channel, approximately 59,000 cu yd (45,000 cu m) of material will be removed from a dredge cut located at RM 21.50, RDB. A suitable site for disposal of dredged material will be found downriver of the dam. Two new mooring cells will be located between the lock and the Interstate (I)-24 bridge, RM 21.1. Placement of the new lock will require permanent relocation of the Paducah and Louisville Railroad, which presently crosses Kentucky Dam just downriver of the lower gate on the existing lock. A replacement railroad bridge will be constructed just downriver of the dam. The Nashville District is concerned that the impacts of construction of the lock and operation of commercial navigation vessels could negatively affect freshwater mussels in this river reach.

## **Purpose and Scope**

The purpose of the study was to describe the community composition, density, areal extent, recruitment rates, and presence of endangered species of freshwater mussels in areas in the LTR likely to be affected by construction and operation of the second lock at Kentucky Lock and Dam.

## 2 Study Area and Methods

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### Study Area

The Tennessee River originates at the junction of French Broad and Holston Rivers near Knoxville, TN. It flows southwest into Alabama, then north through Mississippi, Tennessee, and Kentucky to Paducah, KY, where it enters the Ohio River at RM 933. The river is 652 miles (1,050 km) long with an average discharge of 64,794 cfs (1,835 cu m/sec) at Paducah (66 years of record; Tom, Sholar, and Zettwoch 1986). The river consists of a series of run-of-the-river reservoirs used for commercial navigation and hydropower generation. Kentucky Lock and Dam, located at RM 22.4, is the last dam on the Tennessee River before its confluence with the Ohio River.

### Sampling Areas

Mussels were collected at six areas in the LTR on 31 August through 3 September 1990 (Figure 1, Table 1). Study areas were located from immediately below the dam (RM 22.29) to RM 19.70. All study areas were within a state mussel sanctuary, located between RM 17.8 and 22.4, where commercial shell harvesting is prohibited. The following paragraphs provide brief descriptions of each area.

#### Cofferdam

Four qualitative samples were taken from an area where a cofferdam (CD) was placed for construction of Kentucky Lock and Dam. Samples were collected between RM 22.34 and 22.04 on the RDB. The bottom consisted of crushed unionid and *Corbicula* shells, coarse and fine particulate material, and bedrock. Logs, brush, and trash were also present. The divers found no mussels at the base of riprap close to shore, but found live individuals in deeper water. Four sites were surveyed in this area (Figure 2).

### **Bank excavation zone**

Three qualitative samples were collected from a bank excavation zone (BE) located between RM 22.00 and 21.66, RDB. The bottom consisted of clay, as well as sand and coarser materials. Three qualitative samples were taken (Figure 3).

### **Dredge cut**

Qualitative collections for mussels were obtained from 10 sites in the dredge cut (DC), between RM 21.72 and 21.06, RDB. No live mussels were found at sites 1 and 2; the remaining eight sites supported moderate to high mussel densities. In addition, six quantitative samples were obtained at each of six sites in the DC (sites Q1-Q6, Figure 4). Substrate at sites in the dredge cut where quantitative samples were collected consisted mainly of gravel (60.4 to 83.3 percent), with lesser amounts of sand (15.9 to 38.9 percent) and fines (0.2 to 1.1 percent). Sediments were composed mainly of inorganic particles; organic matter ranged from 0.62 to 4.90 percent by weight (Table 2).

### **Near shore zone**

On the landward side of the DC, six qualitative samples were obtained from a nearshore zone (NS) close to the RDB (Figure 4). Substrate consisted of fine to coarse sand and gravel.

### **Bridge relocation area**

Qualitative samples were obtained at five sites in an area proposed for relocation of the railroad bridge (BR) (Figure 5). Samples were collected on a transect beginning at RM 21.60 on the left descending bank (LDB) and on-line with RM 21.75 on the RDB. Mussels were common to abundant at the four sites closest to the LDB. Live mussels were virtually absent at site 5, located approximately 650 ft from the LDB.

### **Dredged material disposal area**

Downriver of the I-24 bridge, two qualitative samples were obtained from a potential dredged material disposal area (DD). Mussels were collected at RM 19.70 and 19.80 (Figure 1). Substrate consisted of sand with small amounts of gravel, detritus, and logs.

## Methods

### Preliminary reconnaissance

All underwater work was accomplished by a dive crew equipped with surface air supply and communication equipment. Before intensive sampling was initiated, a single diver made a preliminary survey to obtain information on substrate type, water velocity, and presence of live mussels. Intensive sampling was initiated if the substrate appeared stable and if there was moderate to high mussel density (i.e., greater than 3 to 5 individuals/square meter).

### Qualitative mussel collections

The majority of the qualitative samples were obtained by three divers working simultaneously. Each diver placed a specific number of live mussels in each of four nylon bags; five mussels were placed in the first bag, and 20 mussels were placed in each of three other bags. Divers were instructed to obtain mussels without bias to a specific size or species. In addition, they attempted to exclude the Asiatic clam, *Corbicula fluminea*, from qualitative samples. If *C. fluminea* was inadvertently collected, it was later eliminated. All mussels were brought to the surface, counted, and identified. Data were recorded on standard data sheets and returned to the US Army Engineer Waterways Experiment Station for analysis and plotting. Shells of voucher specimens for each species were placed in plastic zipper-lock bags and labeled with high-rag content paper. Mussels not needed for voucher were returned to the river. Methods of sampling were based on techniques described in Coker (1919), Brice and Lewis (1979), Miller and Nelson (1983), Isom and Gooch (1986), Kovalak, Dennis, and Bates (1986), and Miller and Payne (1988). Mussel identification was based on taxonomic keys and descriptive information in Murray and Leonard (1962), Parmalee (1967), Starrett (1971), and Burch (1975).

### Quantitative mussel collections

Ten quantitative samples (including unionids as well as *C. fluminea*) were obtained at each of six sites in the DC. At each site, 0.25-sq m quadrats were positioned approximately 1 m apart and arranged in a 2 by 5 matrix. A diver excavated all sand, gravel, shells, and live clams to a depth of 10 to 15 cm. Material was sent to the surface in a 20-L bucket and transported to shore. Sediment was screened through a sieve series (finest screen with apertures of 6.4 mm). All live mussels and *C. fluminea* removed from samples were placed in 4-L zipper-lock bags. Each bivalve was then identified, and total shell length was measured to the nearest 0.1 mm with vernier calipers.

## Data analysis

Species diversity was determined with the following formula:

$$H' = -\sum p_j \log p_j$$

where  $p_j$  is the proportion of the population that is of the  $j^{\text{th}}$  species (Shannon and Weaver 1949). Natural logarithms ( $\log_{2.3026}$ ) were used as suggested by Magurran (1988).

All calculations were done with programs written in BASIC or SAS (Statistical Analytical System) on an IBM XT or AT personal computer. Discussion of statistical procedures that were used can be found in Green (1979), Hurlbert (1984), and Magurran (1988). Species area curves and dominance-diversity curves were constructed from qualitative and quantitative biological data. More information on these methods can be found in McNaughton and Wolf (1973), Hughes (1986), Isom and Gooch (1986), Kovalak, Dennis, and Bates (1986), and Miller and Payne (1988).

## Sediment analyses

At each site where quantitative samples were obtained, divers collected sediment samples for analysis of grain size and organic content. Grain-size analysis is a process in which the proportion of material in each size class present is determined. A wet sediment sample is passed through a set of 19 sieves (sieve opening range, 50 to 0.025 mm). The material on each screen is dried to 105° C and weighed. Material that passes through the finest sieve is tested with a hydrometer that measures the silt-clay fraction (particles with a diameter between 0.025 and 0.001 mm). Results of the sieve and hydrometer analysis are expressed as a percentage of the total sample weight. More information on the procedure for determining grain size analysis can be found in Engineer Manual 1110-2-1906 (Headquarters, Department of the Army 1986).

Total organic content was determined on three replicates of each sample. Material was dried at 65° C and weighed. Samples were heated at 550° C for 24 hr. The loss on ignition is a measure of organic content and is expressed as a percentage of sample dried at 65° C.

## 3 The Bivalve Community

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### Unionid Community Characteristics

Twenty-three species and 4,768 freshwater mussels (Family: Unionidae) were obtained in 287 qualitative collections between the I-24 bridge and Kentucky Lock and Dam (RM 22.29 to 21.16) (Table 3). The fauna was dominated by two thick-shelled species, *Amblema plicata* and *Fusconaia ebena*, which represented 39.43 and 39.41 percent of the fauna and were taken in 95.47 and 90.24 percent of the samples, respectively. Eight species comprised from 1 to 10 percent of the collection, and 15 species comprised less than 1 percent of the collection. With the exception of *A. plicata* and *F. ebena*, all remaining unionids were found in less than 50 percent of the samples; 14 species were found in less than 10 percent of the samples. Thin-shelled species, *Anodonta grandis*, *Anodonta imbecillis*, *Lampsilis teres*, and *Leptodea fragilis*, usually associated with fine sand or silt substratum, were uncommon and together comprised 0.5 percent of the assemblage. No live specimens of the two endangered species, *Lampsilis abrupta* and *Plethobasus cooperianus*, which had previously been collected in this river reach (Sickel 1985), were found.

Based on a comparatively small collection taken at two sites (RM 19.7 and 19.8) downriver of the I-24 Bridge (24 samples and 446 individuals collected), two additional mussels, *Arcidens confragosus* and *Fusconaia flava*, were added to the species list (Table 4). *Pleurobema cordatum* was uncommon above the bridge (0.25 percent, rank no. 17), whereas it was more common below the bridge (2.69 percent, rank no. 6). However, the same four species, *F. ebena*, *A. plicata*, *Quadrula pustulosa*, and *Q. quadrula*, dominated at both locations, and together comprised 87.56 and 83.63 percent upriver and downriver of the bridge, respectively. With the exception of a slightly higher species richness, and minor differences in relative abundances of some species, the unionid assemblage was relatively similar upriver and downriver of the bridge.

The relative abundances of the two dominant unionids, *A. plicata* and *F. ebena*, varied among the six sampling areas (Figure 6). *Fusconaia ebena* was strongly dominant in the nearshore zone, whereas *A. plicata* was strongly dominant in the cofferdam area. In this area, *A. plicata*

dominated at upriver sites (1 and 2), but became less common downriver (sites 3 and 4, Figure 6). The cofferdam area was unique in that it supported comparatively low percentages of *Q. pustulosa* and *Q. quadrula* (Figure 7). Differences may have been because the substrate was disturbed when Kentucky Lock and Dam was built. It was similar only to the bank excavation zone in that it supported relatively low percentages of *Obliquaria reflexa* and *P. cordatum* (Figure 7). Relative species abundance and frequency of occurrence values for all five sampling areas are given in Tables 5 and 6, respectively.

Species diversity ( $\log_{2.3026}$ ) ranged from 0.995 to 1.674 and evenness ranged from 0.377 to 0.557 (Figure 8 and Table 5). Low and high values for both indices characterized mussel assemblages in the cofferdam and dredged material disposal areas. The relationship among abundances can be illustrated graphically by plotting species rank with its individual abundance (Figure 9). The low diversity and evenness at the cofferdam was primarily the result of extreme dominance of a single species, *A. plicata*. Low values at the bank excavation zone are primarily the result of dominance by two species. The remaining four areas exhibited moderately high species diversity and evenness (see Figure 9).

The relative similarity of species assemblages among sampling areas was quantified with the Jaccard coefficient (Table 7). Based upon presence of similar species within both areas, the nearshore zone and dredged material disposal area were most similar (0.947). Community characteristics in the cofferdam area differed greatly from all other sites; comparatively low values (0.609, 0.684, 0.619, 0.632, and 0.619) related this area to the dredge cut, nearshore zone, bank excavation zone, bridge relocation area, and dredge disposal area, respectively. In addition to very low species richness, percentages of *A. plicata* and *Elliptio crassidens* were comparatively high, and percentages of *F. ebena*, *Q. pustulosa*, and *Q. quadrula* were comparatively lower in the cofferdam than in the other sampling areas (Table 5).

A plot of cumulative species versus cumulative individuals illustrates the relationship between sampling effort and the ability to find uncommon species. Considering mussels from all areas upriver of the I-24 bridge, a total of 4,768 individuals and 23 species were collected (Table 3). However, as Figure 10 illustrates, after 1,200 individuals had been collected, 23 species (the total number collected during this survey) had been identified. It is unlikely that additional species would be found with more sampling effort. If species were present and not collected, they would have comprised less than 0.02 percent of the assemblage. The relationship between sampling effort and species identified is similar for all sites, with the exception of the bank excavation zone (Figure 11). This site, and to some extent the nearshore zone, is characterized by a high dominance of *A. plicata* and *F. ebena* (Figure 9). Dominance of these two unionids had an effect on the ability of obtaining new species.



## Bivalve Density

Ten quantitative (0.25-sq m) total substrate samples were taken at each of six sites between RM 21.66 and 21.53 in the DC (Table 1, Figure 4). Total unionid densities were moderate to high at sites 1 through 4 (46.8 to 128.0 individuals/sq m) (see Table 8 and Figure 12). Sites 5 and 6, downriver of RM 21.56, exhibited comparatively low-density unionid populations (9.2 and 10.4 individuals/sq m). Densities of *C. fluminea* were low and ranged from 6.0 to 26.4 individuals/sq m (Table 8 and Figure 12).

## Demographic Analysis of Dominant Bivalve Populations

### *Amblema plicata*

Individuals of this population range from 6 to 128 mm total shell length (SL) (Figure 13a). The most abundant mussels occurred in two broad ranges: 10 to 52 mm (63 percent of total population) and 56 to 88 mm (31 percent). Several overlapping cohorts (year classes) were included within each of these two SL ranges. Among smaller mussels, a recently recruited cohort (probably the 1989 year class) was apparent with an average SL of 12 to 16 mm. Mussels ranging from 20 to 46 mm SL probably represented three largely overlapped cohorts. Two relatively abundant cohorts centered at 22 to 26 mm and 36 to 44 mm SL, with an intermediate and less abundant cohort averaging between 28 and 34 mm. Individual cohorts could not be distinguished among the moderately large mussels ranging from 56 to 88 mm. However, peaks of abundance at 56 to 58 mm, 62 to 64 mm, and 72 to 74 mm may represent the average SL of the three relatively abundant cohorts. The relative paucity of mussels from 46 to 56 mm in this river reach is probably the consequence of 1 or 2 consecutive years of poor recruitment. Individuals greater than 100 mm comprised less than 2 percent of the total population. Although *A. plicata* can grow to well over 100 mm, few individuals appear to survive long enough to attain this size.

### *Fusconaia ebena*

The size structure of the *F. ebena* population was similar to that of *A. plicata* (Figure 13b). *Fusconaia ebena* was characterized by two relatively abundant and broad size classes, each consisting of multiple but indistinct cohorts. The first group, which consisted of smaller mussels (ranging from 12 to 56 mm), comprised 70 percent of the population (compared to 63 percent in the 10- to 52-mm range of *A. plicata*). Mussels from 56 to 88 mm accounted for 28 percent of the total sample (compared

to 31 percent in the 56- to 88-mm range of *A. plicata*). Individuals greater than 92 mm accounted for only 2 percent of the population.

The general similarity of size structure among the two most abundant populations, *F. ebena* and *A. plicata*, may reflect interspecific similarity in temporal variation in recruitment. The paucity of mussels from 50 to 60 mm (relative to abundant size classes above and below this 10-mm SL range) in both populations may correspond to an interspecific simultaneity of a poor year or two of recruitment.

### ***Obliquaria reflexa***

*Obliquaria reflexa* attains moderate size and age compared to both *A. plicata* and *F. ebena*. This species ranged in total SL from 12 to 52 mm, but the majority of the population consisted of individuals 24 to 48 mm (Figure 13c). It appears that four consecutive year classes might be included among individuals within this size range: a moderately abundant cohort with average SL equal to 26 to 28 mm; two slightly more abundant cohorts with average SL of 32 to 36 and 38 to 42 mm; and a moderately abundant cohort with average SL of 44 to 48 mm. However, such detailed interpretation of the size structure of overlapping cohorts of this moderately large sample (75 individuals) is speculative. If correctly interpreted, these cohorts are spaced at intervals of 6 to 7 mm. This spacing may correspond to an annual increment of SL increase of 24 to 48 mm SL.

### ***Quadrula pustulosa***

The population of *Quadrula pustulosa* consisted of a relatively equal abundance of several cohorts spanning 14 to 68 mm (Figure 13d). Detailed analysis of cohort structure was not possible for this population. The relatively equal abundance of many different size classes suggests that annual recruitment has been reasonably consistent for this species of moderate size and longevity.

### ***Truncilla donaciformis***

Population size demography of this small and short-lived unionid indicated a single abundant cohort from 16 to 26 mm (Figure 13e). A minor cohort may occur with average SL of 12 to 13 mm, but too few individuals were collected to positively determine that more than a single year class comprised this population.

### ***Corbicula fluminea***

This low-density population (Table 8) consisted almost entirely of very small individuals between 4 and 13 mm (Figure 13f). These small bivalves probably represent spring recruits. *Corbicula fluminea* generally shows spring and fall peaks of recruitment (McMahon 1983), unlike native unionids which have a single recruitment period per year. Larger *C. fluminea* (18 to 24 mm) probably represent recruitment from the fall of 1989. Stable and thriving populations of *C. fluminea* sampled during the late summer usually show three to five cohorts, including many individuals from 20 to 35 mm. The lack of complex size structure and large individuals, plus the low density, indicates a population supported only by a low recruitment rate with subsequently poor survival.

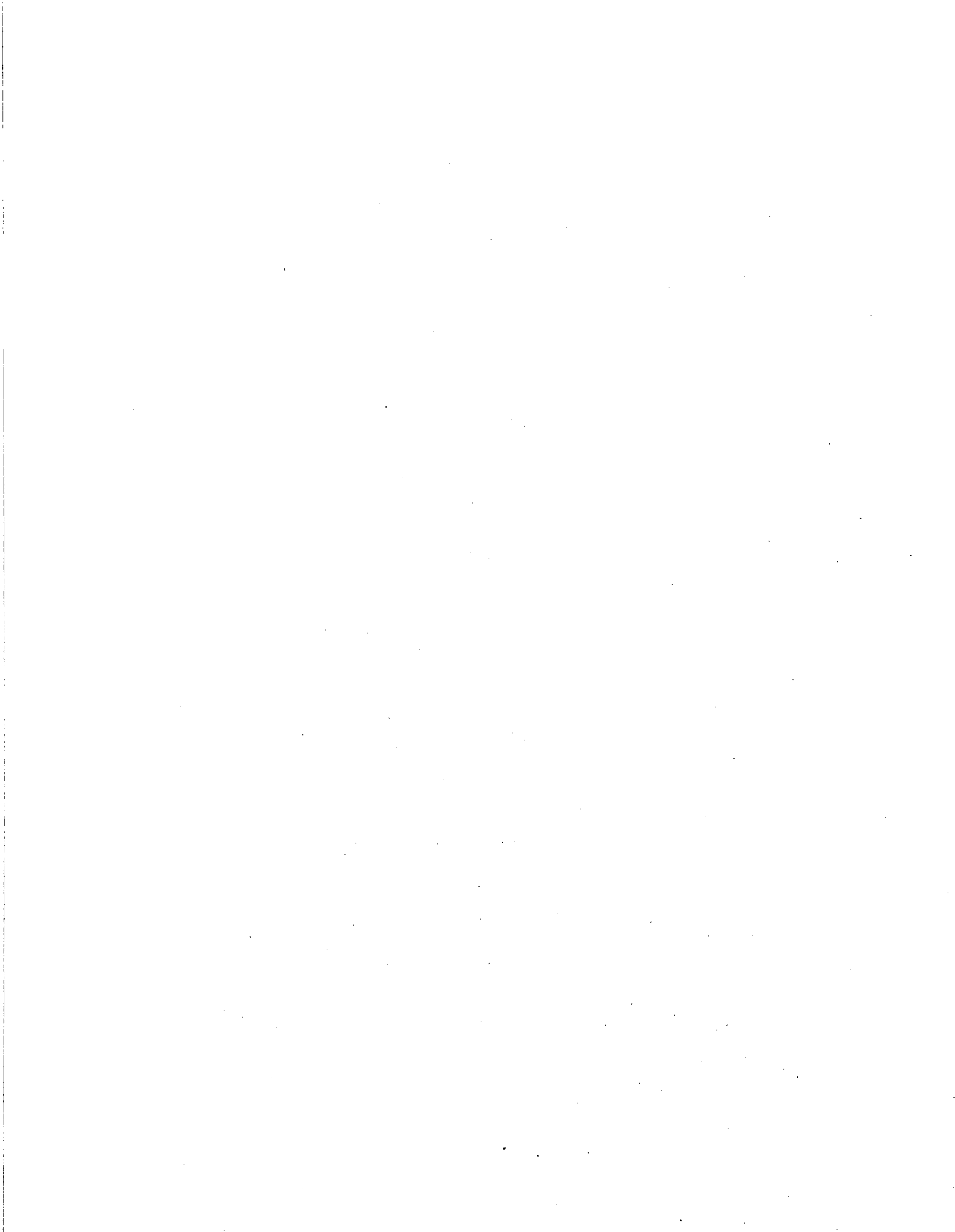
## **Snails in the Project Area**

Snails were counted and identified from the quantitative samples collected at six sites in the dredge cut. Total density of snails ranged from 8.0 to 86.8 individuals/sq m (Table 8). The fauna was dominated by *Pleurocera canaliculatum*, with lesser numbers of *Lithasia armigera* and *L. verrucosa*. No endangered species of snails were found.

## **Commercial Value of Mussels in the Dredge Cut**

Construction and operation of the new lock will require removal of approximately 45,000 cu m of material, primarily from the upper end of the dredge cut between stations 61+00 (RM 21.38) and 45+00 (RM 21.70) (Figure 4). The total area of river bottom to be dredged will be approximately 21,148 sq m. Based on this information, and data from the quantitative collections, an estimate of the value of four commercial species (*A. plicata*, *M. nervosa*, *Q. quadrula*, and *F. ebena*) has been made (Table 9).

Total density in the dredge cut for these species was *A. plicata* (4.4 individuals/sq m), *M. nervosa* (0.0667 individual/sq m), *Q. quadrula* (0.4667 individual/sq m), and *F. ebena* (4.6667 individuals/sq m). The minimum harvestable size for each species was obtained from the Kentucky Department of Fish and Wildlife Resources, and the average SL and total mass for harvestable individuals were based on data from this survey and the upper Mississippi River, respectively. Based on prices of "green" (unshucked) mussels, the total value of *A. plicata*, *M. nervosa*, *Q. quadrula*, and *F. ebena* was estimated at \$53,576, \$1,749, and \$3,360, and \$43,022, respectively. The total commercial value of these three species was estimated at \$101,707 (Table 9).



## 4 Discussion

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### Characterization of the Bivalve Community

#### Unionid assemblage

The mussel assemblage in the LTR consisted almost entirely of thick-shelled species. The fauna was dominated by *A. plicata*, *F. ebena*, and *Quadrula* spp., with lesser numbers of *Elliptio* spp., *M. nervosa*, and *P. cordatum*. Thin-shelled and moderately thick-shelled species (*L. fragilis*, *Potamilus alatus*, and *Anodonta* spp.) were uncommon and comprised less than 1 percent of the qualitative collection. Within their range, these thin-shelled species are found in appropriate substrate in large rivers (Murray and Leonard 1962, Parmalee 1967, Starrett 1971). Each species has multiple fish hosts (Fuller 1974) and would be more common in the LTR if suitable conditions of substrate and velocity existed. However, coarse gravel substrate and erosive flows at high discharge will stress thin-shelled species. If present, few are likely to reach adult size. The mussel assemblage in the LTR would probably support more thin-shelled species if mean water velocities were less and sediments contained a higher percentage of silt and sand.

In comparing data collected during this survey with those of previous authors (see Sickel 1985), it is apparent that the basic community structure, i.e., dominance of thick-shelled species such as *F. ebena*, *A. plicata*, and *Quadrula* spp., has remained virtually unchanged since the early 1900's. Selected species (*Quadrula metanevra*, *Plethobasus cooperianus*, and *Pleurobema cordatum*) appear to now be less common, or even absent, in this river reach. It is difficult, however, to compare community data among surveys in which different collecting methods were employed.

#### Presence of *C. fluminea*

Williams (1969) sampled the LTR between Kentucky Lock and Dam and the Ohio River with an 8-ft (2.4-m) brail and a Petersen dredge. Based on quantitative samples, Williams estimated that *C. fluminea*

comprise 99.41 percent of the bivalve community; densities ranged from 17 to 1,147 individuals/sq yd (14.2 to 959.0 individuals/sq m). In the present survey, density ranged from 6.0 to 26.4 individuals/sq m in the dredge cut (Table 8 and Figure 12). Although quantitative data on *C. fluminea* were not collected throughout the LTR, it is apparent that its densities have diminished considerably since the survey conducted by Williams (1969). Physical conditions in this reach of the LTR have not changed since that survey (i.e., Kentucky Lock and Dam became operational in September 1944). This recent change in bivalve community composition must be related to biotic rather than abiotic factors. The exact cause of the decline in *C. fluminea* has not been determined.

### Species richness

Total species richness in the survey area is similar to that at other mussel beds in large rivers. In the lower Ohio River near Olmsted, IL, 23 species of freshwater mussels were collected (Payne and Miller 1989). In a survey of the upper Mississippi River, Miller et al. (1990) collected over 15,000 bivalves in 667 qualitative samples at 58 locations and identified 34 species. However, total species richness at any one location was usually between 15 and 25. Smaller rivers usually support fewer species. Using quantitative techniques at dense beds in the Sunflower and Big Black Rivers in central Mississippi, 13 and 15 species were identified, respectively (Miller and Hartfield, unpublished data; Payne and Miller, unpublished data).

### Relative species abundance

The fauna in this mussel bed exhibits moderate to low evenness. Evenness can range from near zero to near 1.0; at these sites, values ranged from 0.377 to 0.557. Low evenness was the result of relatively high abundances of the dominant species (38.9 to 73.4 percent, Table 5 and Figure 9). Based on similar qualitative collections at six sites in a dense and diverse mussel bed in the Ohio River near Cincinnati, OH, evenness ranged from 0.756 to 0.817 (Miller and Payne, in preparation). Abundances of the dominant species in the Ohio River ranged from a low of 22.44 percent to a high of 33.33 percent (i.e., the fauna was not strongly dominated by one or two species).

### Density

In comparison with other large-river mussel beds, the range in unionid density (9.2 to 128.0 individuals/sq m with an overall average of 63.0 individuals/sq m) can be considered low to high. At an inshore and offshore site in the LTR at RM 18.6 on the LDB sampled in 1986 (32 quantitative samples collected at each site), total mussel density was 187.7 and 79.7 individuals/sq m, respectively (Way, Miller, and Payne 1989). In a survey

of the upper Mississippi River, Miller et al. (1990) reported that total mussel density ranged from 5.2 to 333.2 individuals/sq m at 16 sites (10 quantitative samples taken at each site). At half of the sites, total density was greater than 50 individuals/sq m; at four sites, it was greater than 100 individuals/sq m. In the Big Black River in central Mississippi, unionid density was 84.4 and 112.0 individuals/sq m at the upstream and downstream slope of a gravel shoal, respectively (Payne and Miller, unpublished data).

### Presence of endangered species

This reach of the LTR is within the reported range of the following Federally listed endangered or threatened freshwater mussel species: *Pleurobema plenum*, *Plethobasus cooperianus*, *Lampsilis abrupta*, *Obovaria retusa*, *Potamilus capax*, *Plethobasus cicatricosus*, *Cyprogenia irrorata*, and *Epioblasma torulosa torulosa* (USFWS 1987). However, only two species (*P. cooperianus* and *L. abrupta*) have been collected in this reach of the LTR. Three specimens of the former species were found at RM 20.7 by Sickel (1985). This species was also found in this reach of the LTR in 1931 by Ellis (van der Schalie 1939). Sickel (1985) reported one specimen of *L. abrupta* at RM 14.75 and one at RM 21.3 (Sickel 1987). The only other report of this species from the Kentucky Dam tailwater was at RM 22.0 (Tennessee Valley Authority 1978, as cited in Sickel 1985).

Miller, Payne, and Siemsen (1986) collected *P. cooperianus* at a rich and dense mussel bed in the lower Ohio River near Cairo, IL. In the fall of 1990 these investigators obtained two live specimens in three samples of 200 individuals. It is apparent that *P. cooperianus* continues to exist in specific reaches of large rivers in densities high enough to be easily collected. However, in the LTR immediately downriver of Kentucky Lock, it is likely that it is either absent or extremely uncommon.

In the present survey, almost 5,000 mussels were collected using qualitative techniques. After 1,000 individuals had been taken, 23 species had been identified; collecting an additional 4,000 individuals yielded no new species. The relationship between cumulative species and cumulative individuals (Figure 10) suggests that over 10,000 mussels would have to be collected to obtain a list of 32 species. Sickel (1985) collected 34 species of mussels between RM 7.5 and 22.0. The total number collected was 4,384. Live specimens of two Federally endangered species were collected. Sickel (1987) collected 9,367 mussels from the RDB upriver of the I-24 bridge. Twenty-seven species were collected, including one live *L. abrupta*. It is possible that even if 10,000 individuals were collected between the I-24 bridge and Kentucky Lock and Dam, no new species would be found.

## Dredged Material Disposal

The results of this study indicate that it would be difficult to select a disposal area that does not support a dense and diverse mussel assemblage. One alternative for disposal would be to dredge and dispose material during slightly high-stage conditions so that material could be placed at the toe of the steep and eroding right bank in a reach downriver of the I-24 bridge (RM 19.0 to 21.0). A zone exists from the toe of this bank out toward the channel that has unsuitably fine-grained substrate for riverine unionids. No mussels were found in this shallow zone; thus, disposal along the toe of the bank would not harm a resident community. Furthermore, such a disposal operation might have two beneficial aspects: bank protection to prevent or lessen erosion, and creation of additional mussel habitat. Such benefits of shoreline disposal have been observed in the lower Tennessee River near Wolf Island (Payne and Tippit 1989).

During dredging for the new lock, it may be possible to first remove only the topmost layer of sediment (e.g., 12 in. (30 cm)) and take live mussels from this material as it is dredged. Assuming that mussel survival would be high, such a harvest during dredging would provide mussels that could be placed at newly created habitat.



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**Table 1**  
**Areas Sampled for Freshwater Mussels**  
**in the Lower Tennessee River, August-September 1990**

Sample Area	Site No.	River Mile	Station <sup>1</sup>	Distance to Shore <sup>2</sup> , ft	No. of Samples
Cofferdam (CD)	1	22.39	15+50	50	12
	2	22.21	19+50	50	12
	3	22.13	23+50	50	12
	4	22.05	27+50	50	12
Bank excavation (BE)	1	21.94	33+00	75	12
	2	21.86	37+00	75	12
	3	21.74	43+00	75	12
Dredge cut qualitative (DC)	1	21.30	65+00	400	0 <sup>3</sup>
	2	21.38	61+00	300	0
	3	21.47	56+50	200	8
	4	21.51	54+75	150	12
	5	21.55	52+50	125	12
	6	21.57	51+57	100	12
	7	21.59	50+75	100	12
	8	21.60	50+00	100	12
	9	21.62	49+00	100	12
	10	21.65	47+50	100	12
Dredge cut quantitative (Q)	1	21.66	47+00	100	10
	2	21.63	48+50	100	10
	3	21.61	49+50	125	10
	4	21.58	51+00	150	10
	5	21.56	52+00	200	10
	6	21.53	53+75	250	10
Nearshore (NS)	1	21.16	72+00	100	12
	2	21.26	67+00	100	12
	3	21.36	62+00	100	12
	4	21.46	57+00	100	12
	5	21.56	52+00	100	3
	6	21.64	48+00	100	12
Bridge relocation (BR)	1	21.75	42+50	200	12
	2	21.75	42+50	350	12
	3	21.75	42+50	400	12
	4	21.75	42+50	425	12
	5	21.75	42+50	650	0
Dredge disposal (DD)	1	19.70	NA <sup>4</sup>	100	12
	2	19.80	NA	100	12

Note: All samples were collected on the RDB except those from the bridge relocation area, which were from the LDB.

<sup>1</sup> Refers to 100-ft (30.5-m) increments along the shore (see Figures 2-5).

<sup>2</sup> To convert feet to meters, multiply by 0.3048.

<sup>3</sup> No qualitative samples were taken at Sites 1 and 2 in the dredge cut because of low densities.

<sup>4</sup> Not available.

**Table 2**  
**Percent Organic Material (Loss on Ignition at 550° C)**  
**and Percent Gravel, Sand, and Fines in Sediments Obtained**  
**at Six Sites in the Dredge Cut Where Quantitative Mussel**  
**Samples Were Collected**

Site	Organic Matter	Gravel <sup>1</sup>	Sand <sup>2</sup>	Fines <sup>3</sup>
1	1.56	61.5	37.6	0.8
2	1.51	66.1	32.7	1.1
3	1.44	64.8	34.1	1.1
4	4.90	83.3	15.9	0.8
5	1.08	82.8	17.0	0.2
6	0.62	60.4	38.9	0.7

<sup>1</sup> Particles greater than 5.0 mm in diameter.  
<sup>2</sup> Particles between 0.075 and 5.0 mm in diameter  
<sup>3</sup> Particles less than 0.075 mm in diameter.

**Table 3**  
**Summary of Relative Species Abundance and Frequency of Occurrence**  
**for Freshwater Mussels Collected Using Qualitative Techniques at Five**  
**Study Areas Upriver of the I-24 Bridge in the Lower Tennessee River**  
**(RM 22.2-21.2), August-September 1990**

Species	Total Mussels	Species Abundance	Total Sites	Frequency of Occurrence	Species Rank
<i>Amblema p. plicata</i> (Say, 1817)	1,880	0.3943	274	0.9547	1
<i>Fusconaia ebena</i> (I. Lea, 1831)	1,879	0.3941	259	0.9024	2
<i>Quadrula p. pustulosa</i> (I. Lea, 1831)	241	0.0505	141	0.4913	3
<i>Quadrula quadrula</i> (Rafinesque, 1820)	175	0.0367	113	0.3937	4
<i>Obliquaria reflexa</i> (Rafinesque, 1820)	165	0.0346	82	0.2857	5
<i>Megaloniais nervosa</i> (Rafinesque, 1820)	73	0.0153	58	0.2021	6
<i>Cycloniais tuberculata</i> (Rafinesque, 1820)	59	0.0124	51	0.1777	7
<i>Elliptio crassidens</i> (Lamarck, 1819)	57	0.0120	47	0.1638	8
<i>Elliptio dilatata</i> (Rafinesque, 1820)	35	0.0073	31	0.1080	9
<i>Ellipsaria lineolata</i> (Rafinesque, 1820)	30	0.0063	27	0.0941	10.5
<i>Truncilla truncata</i> (Rafinesque, 1820)	30	0.0063	26	0.0906	10.5
<i>Potamilus alatus</i> (Say, 1817)	27	0.0057	23	0.0801	12
<i>Truncilla donaciformis</i> (I. Lea, 1828)	26	0.0055	22	0.0767	13
<i>Quadrula nodulata</i> (Rafinesque, 1820)	18	0.0038	18	0.0627	14
<i>Leptodea fragilis</i> (Rafinesque, 1820)	17	0.0036	17	0.0592	15
<i>Tritogonia verrucosa</i> (Rafinesque, 1820)	16	0.0034	15	0.0523	16
<i>Pleurobema cordatum</i> (Rafinesque, 1820)	12	0.0025	9	0.0314	17
<i>Ligumia recta</i> (Lamarck, 1819)	9	0.0019	9	0.0314	18
<i>Lampsilis teres</i> (Rafinesque, 1820)	7	0.0015	6	0.0209	19
<i>Anodonta imbecillis</i> (Say, 1829)	4	0.0008	4	0.0139	20
<i>Quadrula metanevra</i> (Rafinesque, 1820)	3	0.0006	3	0.0105	21.5
<i>Anodonta grandis</i> (Say, 1829)	3	0.0006	3	0.0105	21.5
<i>Lasmigona c. complanata</i> (Barnes, 1823)	2	0.0004	2	0.0070	23
Total samples = 287					
Total mussels = 4,768					
Total species = 23					

**Table 4**  
**Relative Species Abundance and Frequency of Occurrence for**  
**Freshwater Mussels Collected Using Qualitative Techniques at**  
**Two Locations Considered for Disposing Dredged Material in**  
**the Lower Tennessee (RM 19.7 and 19.8), September 1990**

Species	Total Mussels	Species Abundance	Total Samples	Frequency of Occurrence	Species Rank
<i>F. ebena</i>	178	0.3991	24	1.0000	1
<i>A. plicata</i>	130	0.2915	23	0.9583	2
<i>Q. pustulosa</i>	41	0.0919	19	0.7917	3
<i>Q. quadrula</i>	24	0.0538	14	0.5833	4
<i>M. gigantea</i>	23	0.0516	10	0.4167	5
<i>P. cordatum</i>	12	0.0269	8	0.3333	6
<i>O. reflexa</i>	10	0.0224	7	0.2917	7
<i>E. crassidens</i>	4	0.0090	3	0.1250	8.5
<i>E. dilatata</i>	4	0.0090	4	0.1667	8.5
<i>E. lineolata</i>	3	0.0067	2	0.0833	11
<i>T. truncata</i>	3	0.0067	3	0.1250	11
<i>L. fragilis</i>	3	0.0067	3	0.1250	11
<i>P. alatus</i>	2	0.0045	2	0.0833	14.0
<i>T. donaciformis</i>	2	0.0045	2	0.0833	14.0
<i>L. teres</i>	2	0.0045	2	0.0833	14.0
<i>C. tuberculata</i>	1	0.0022	1	0.0417	18
<i>Q. nodulata</i>	1	0.0022	1	0.0417	18
<i>A. confragosus</i> <sup>1</sup>	1	0.0022	1	0.0417	18
<i>F. flava</i> <sup>2</sup>	1	0.0022	1	0.0417	18
<i>L. recta</i>	1	0.22	1	4.17	18
Total species = 20 Total mussels = 446 Total samples = 24 Diversity (H') = 1.764 Evenness (J) = 0.589					
<sup>1</sup> <i>Arcidens confragosus</i> (Say, 1829). <sup>2</sup> <i>Fusconaia flava</i> (Rafinesque, 1820).					



**Table 5**  
**Relative Species Abundance for Freshwater Mussels Collected Using Qualitative Techniques at Study Areas Upriver of the I-24 Bridge in the Lower Tennessee River (RM 22.2-21.2), August-September 1990**

Species	Dredge Cut		Nearshore		Cofferdam		Bank Excavation		Bridge Relocation	
	N	Species Abundance	N	Species Abundance	N	Species Abundance	N	Species Abundance	N	Species Abundance
<i>A. plicata</i>	593	0.3899	224	0.2168	588	0.7341	264	0.4444	211	0.2548
<i>F. ebena</i>	545	0.3583	595	0.5760	119	0.1486	236	0.3973	384	0.4638
<i>Q. pustulosa</i>	100	0.0657	66	0.0639	6	0.0075	18	0.0303	51	0.0616
<i>Q. quadrula</i>	74	0.0487	35	0.0339	16	0.0200	12	0.0202	38	0.0459
<i>O. reflexa</i>	48	0.0316	21	0.0203	2	0.0025	2	0.0034	92	0.1111
<i>M. gigantea</i>	28	0.0184	19	0.0184	11	0.0137	10	0.0168	5	0.0060
<i>C. tuberculata</i>	19	0.0125	15	0.0145	7	0.0087	12	0.0202	6	0.0072
<i>E. crassidens</i>	5	0.0033	9	0.0087	29	0.0362	12	0.0202	2	0.0024
<i>E. dilatata</i>	8	0.0053	6	0.0058	9	0.0112	8	0.0135	4	0.0048
<i>E. lineolata</i>	13	0.0085	10	0.0097	0	0.0000	3	0.0051	4	0.0048
<i>T. truncata</i>	13	0.0085	4	0.0039	0	0.0000	2	0.0034	11	0.0133
<i>P. alatus</i>	12	0.0079	3	0.0029	8	0.0100	2	0.0034	2	0.0024
<i>T. donaciformis</i>	16	0.0105	6	0.0058	1	0.0012	0	0.0000	3	0.0036
<i>Q. nodulata</i>	5	0.0033	5	0.0048	1	0.0012	1	0.0017	6	0.0072
<i>L. fragilis</i>	7	0.0046	3	0.0029	0	0.0000	3	0.0051	4	0.0048
<i>T. verrucosa</i>	11	0.0072	0	0.0000	0	0.0000	2	0.0034	3	0.0036
<i>P. cordatum</i>	2	0.0013	6	0.0058	2	0.0025	2	0.0034	0	0.0000
<i>L. recta</i>	6	0.0039	1	0.0010	0	0.0000	1	0.0017	1	0.0012
<i>L. teres</i>	3	0.0020	3	0.0029	0	0.0000	1	0.0017	0	0.0000
<i>A. imbecillis</i>	4	0.0026	0	0.0000	0	0.0000	0	0.0000	0	0.0000
<i>Q. metanevra</i>	2	0.0013	0	0.0000	0	0.0000	1	0.0017	0	0.0000
<i>A. grandis</i>	1	0.0007	0	0.0000	1	0.0012	1	0.0017	0	0.0000
<i>L. complanata</i>	2	0.0013	0	0.0000	0	0.0000	0	0.0000	0	0.0000
Total species	23		18		14		20		17	
Total mussels	1,517		1,031		800		593		827	
Diversity (H')	1.674		1.435		0.995		1.400		1.577	
Evenness (J)	0.534		0.496		0.377		0.467		0.557	

Table 6

Frequency of Occurrence for Freshwater Mussels Collected Using Qualitative Techniques at Study Areas Upriver of the I-24 Bridge in the Lower Tennessee River (RM 22.2-21.2), August-September 1990

Species	Dredge Cut		Nearshore		Cofferdam		Bank Excavation		Bridge Relocation	
	N	Frequency of Occurrence	N	Frequency of Occurrence	N	Frequency of Occurrence	N	Frequency of Occurrence	N	Frequency of Occurrence
<i>A. plicata</i>	89	0.9674	59	0.9365	48	1.0000	34	0.9444	44	0.9167
<i>F. evena</i>	87	0.9457	61	0.9683	28	0.5833	36	1.0000	47	0.9792
<i>Q. pustulosa</i>	52	0.5652	38	0.6032	6	0.1250	13	0.3611	32	0.6667
<i>Q. quadrula</i>	47	0.5109	22	0.3492	12	0.2500	9	0.2500	23	0.4792
<i>O. reflexa</i>	32	0.3478	16	0.2540	2	0.0417	2	0.0556	30	0.6250
<i>M. gigantea</i>	21	0.2238	14	0.2222	9	0.1875	10	0.2778	4	0.0833
<i>C. tuberculata</i>	16	0.1739	12	0.1905	7	0.1458	11	0.3056	5	0.1042
<i>E. crassidens</i>	5	0.0543	8	0.1270	20	0.4167	12	0.3333	2	0.0417
<i>E. dilatata</i>	7	0.0761	5	0.0794	7	0.1458	8	0.2222	4	0.0833
<i>T. truncata</i>	13	0.1413	2	0.0317	0	0.0000	2	0.0556	10	0.2083
<i>E. lineolata</i>	12	0.1304	7	0.1111	0	0.0000	3	0.0833	4	0.0833
<i>P. alatus</i>	10	0.1087	3	0.0476	6	0.1250	2	0.0556	2	0.0417
<i>T. donaciformis</i>	13	0.1413	5	0.0794	1	0.0208	0	0.0000	3	0.0625
<i>Q. nodulata</i>	5	0.0543	5	0.0794	1	0.0208	1	0.0278	6	0.1250
<i>L. fragilis</i>	7	0.0761	3	0.0476	0	0.0000	3	0.0833	4	0.0833
<i>T. verrucosa</i>	10	0.1087	0	0.0000	0	0.0000	2	0.0556	3	0.0625
<i>L. recta</i>	6	0.0652	1	0.0159	0	0.0000	1	0.0278	1	0.0208
<i>P. cordatum</i>	2	0.0217	4	0.0635	2	0.0417	1	0.0278	0	0.0000
<i>L. teres</i>	3	0.0326	2	0.0317	0	0.0000	1	0.0278	0	0.0000
<i>A. imbecillis</i>	4	0.0435	0	0.0000	0	0.0000	0	0.0000	0	0.0000
<i>Q. metanevra</i>	2	0.0217	0	0.0000	0	0.0000	1	0.0278	0	0.0000
<i>A. grandis</i>	1	0.0109	0	0.0000	1	0.0208	1	0.0278	0	0.0000
<i>L. complanata</i>	2	0.0217	0	0.0000	0	0.0000	0	0.0000	0	0.0000
Total samples	92		63		48		36		48	

**Table 7**  
**Jaccard's Similarity Index for Areas Surveyed in the Lower**  
**Tennessee River, August-September 1990**

Area <sup>1</sup>	DC	NS	CD	BE	BR	DD
DC	1.000	0.783	0.609	0.870	0.739	0.720
NS		1.000	0.684	0.810	0.842	0.947
CD			1.000	0.619	0.632	0.619
BE				1.000	0.762	0.739
BR					1.000	0.762
DD						1.000

<sup>1</sup> DC = dredge cut; NS = nearshore zone, landward of DC; CD = cofferdam;  
 BE = bank excavation; BR = bridge relocation; and DD = dredge disposal.

**Table 8**  
**Relative Species Abundance and Summary Statistics for Results of 10 Quantitative (0.025-sq m) Total Substrate**  
**Samples Collected at Each of Six Sites in the Dredge Cut, the Lower Tennessee River, August-September 1990**

Species	1	2	3	4	5	6	Total
<i>F. ebena</i>	0.3932	0.2370	0.3938	0.4274	0.0769	0.3478	0.3577
<i>A. plicata</i>	0.2479	0.3270	0.2750	0.2742	0.5000	0.3043	0.2899
<i>T. donaciformis</i>	0.0769	0.1469	0.1219	0.0685	0.1154	0.1739	0.1090
<i>O. reflexa</i>	0.1453	0.0806	0.0750	0.0524	0.1154	0.0435	0.0794
<i>Q. pustulosus</i>	0.0598	0.0900	0.0469	0.0927	0.1154	0.0435	0.0720
<i>Q. quadrula</i>	0.0171	0.0379	0.0156	0.0202	0.0000	0.0000	0.0212
<i>L. fragilis</i>	0.0085	0.0284	0.0125	0.0121	0.0385	0.0435	0.0169
<i>T. truncata</i>	0.0427	0.0095	0.0156	0.0121	0.0000	0.0000	0.0159
<i>E. dilatata</i>	0.0000	0.0190	0.0125	0.0121	0.0385	0.0000	0.0127
<i>E. lineolata</i>	0.0000	0.0000	0.0156	0.0081	0.0000	0.0000	0.0074
<i>A. imbecillis</i>	0.0000	0.0095	0.0063	0.0040	0.0000	0.0435	0.0063
<i>M. nervosa</i>	0.0000	0.0000	0.0031	0.0081	0.0000	0.0000	0.0032
<i>T. verrucosa</i>	0.0085	0.0047	0.0031	0.0000	0.0000	0.0000	0.0032
<i>C. tuberculata</i>	0.0000	0.0000	0.0031	0.0040	0.0000	0.0000	0.0021
<i>Q. nodulata</i>	0.0000	0.0047	0.0000	0.0040	0.0000	0.0000	0.0021
<i>L. teras</i>	0.0000	0.0047	0.0000	0.0000	0.0000	0.0000	0.0011
Total individuals	117	211	320	248	29	23	945
Total species	9	13	14	14	7	7	16
Diversity (H')	1.644	1.872	1.706	1.66	1.54	1.58	
Evenness (J)	0.748	0.73	0.647	0.629	0.792	0.811	
Unionid density (No./sq m)	46.8	84.4	128.0	99.2	10.4	9.2	
Snail density (No./sq m)	29.6	69.2	86.8	68.0	8.0	9.2	
<i>C. fluminea</i> density (No./sq m)	7.2	6.0	6.0	11.6	26.4	14.8	

<b>Table 9</b>				
<b>Estimated Commercial Value of Three Species of Harvestable Mussels That Would Be Lost by Dredging to Construct a Second Lock at Kentucky Lock and Dam</b>				
	<i>A. plicata</i>	<i>M. nervosa</i>	<i>Q. quadrula</i>	<i>F. ebena</i>
<b>Minimum harvestable size:</b> Inches Millimeters	2.75 69.8	3.75 95.25	2.50 63.5	2.5 63.5
<b>Number of mussels in the DC (≥ harvestable size):</b> (No./sq m) Total No. in the DC	4.4 93,051	0.0667 1,411	0.4667 9,869	4.6667 98,691
<b>Morphometric characteristics:</b> Average SL of an individual harvestable mussel in the DC (mm) Average mass of an individual harvestable mussel in the DC (g)	80.8 163.2	114.0 281.1	66.8 103.8	74.0 197.7
<b>Total mass of harvestable mussels in the DC:</b> Grams Pounds	$1.58 \times 10^7$ 33,484.9	$3.96 \times 10^5$ 874.6	$1.02 \times 10^6$ 2,100.0	$1.95 \times 10^7$ 43,022.00
<b>Commercial value (unshucked):</b> Price per pound (\$) Value of mussels in the DC	1.60 \$53,576.00	2.00 \$1,749.00	1.60 \$3,360.00	1.50 \$43,022.00
<b>Total value for all four species:</b>	\$101,707.00			
<p>Notes: 1. Only the northern section of the cut will be dredged; see text for details.</p> <p>2. Average density and size of mussels in the dredge cut was estimated from quantitative data and length frequency histograms from this survey.</p> <p>3. Total mass (TM) and shell length relationships, developed from collections made in the upper Mississippi River, are as follows:  <i>A. plicata</i> TM = <math>0.0005741 \cdot SL^{(2.8593)}</math> R = 0.9803  <i>M. gigantea</i> TM = <math>0.0001292 \cdot SL^{(3.0812)}</math> R = 0.9833  <i>Q. quadrula</i> TM = <math>0.0004174 \cdot SL^{(2.957)}</math> R = 0.9827</p> <p>4. Total mass (TM) and shell length (SL) relationships, developed from collections made in the lower Tennessee River (in 1986), are as follows:  <i>F. ebena</i> TM = <math>0.0008668 \cdot SL^{(2.8665)}</math> R = 0.9858</p>				



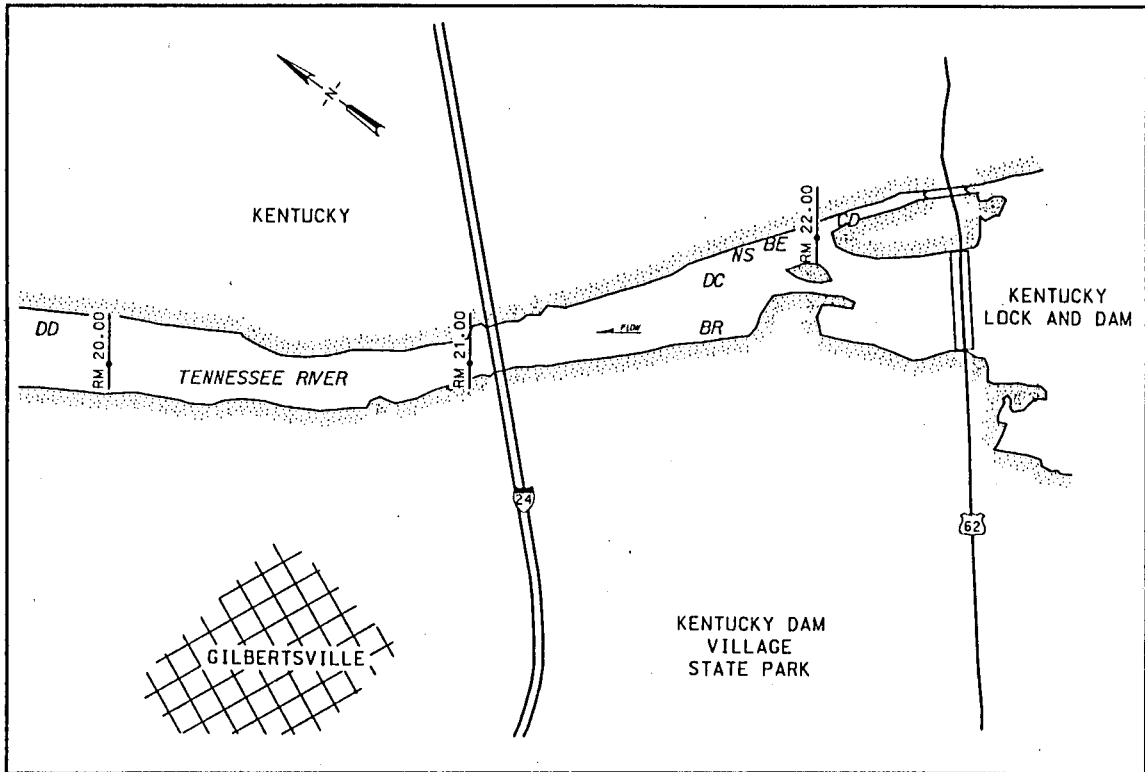


Figure 1. Study areas on the lower Tennessee River, August-September 1990 (see Table 1 for code definitions)

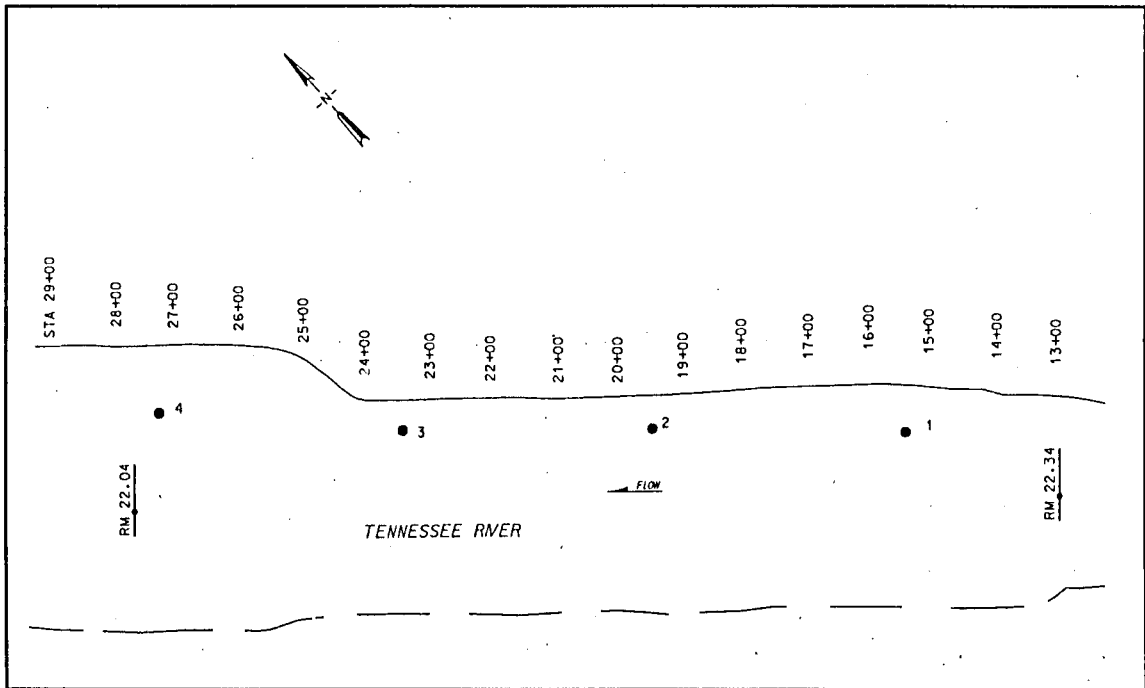


Figure 2. Sites sampled in the cofferdam area

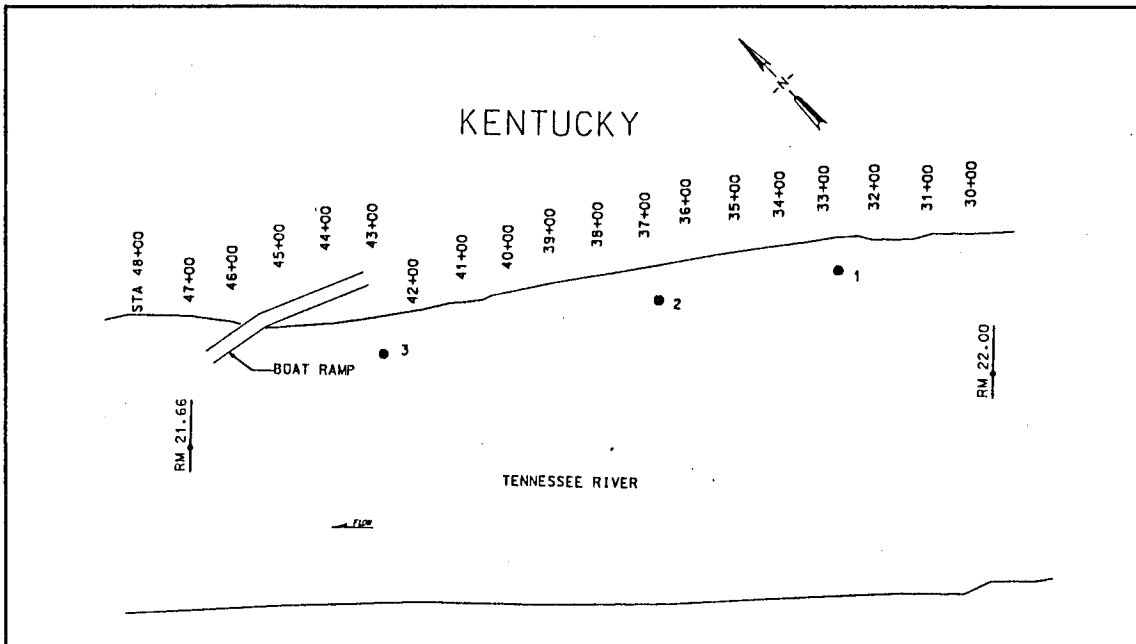


Figure 3. Sites sampled in the bank excavation zone

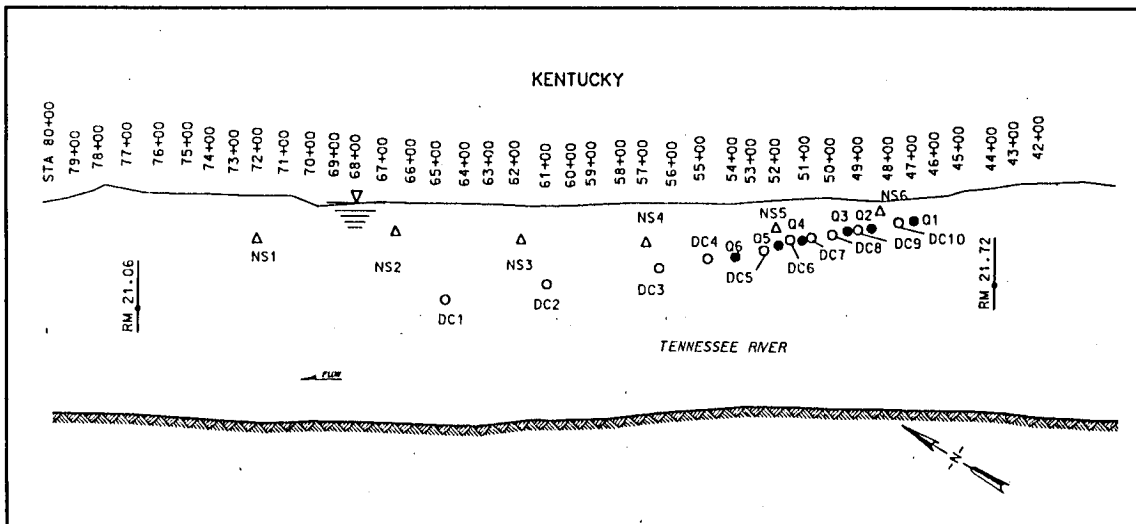


Figure 4. Sites sampled in the nearshore zone and dredge cut area (qualitative and quantitative). Sites where quantitative samples were collected (Q1-Q6) are noted with solid circles



Figure 5. Sites sampled in the bridge relocation area

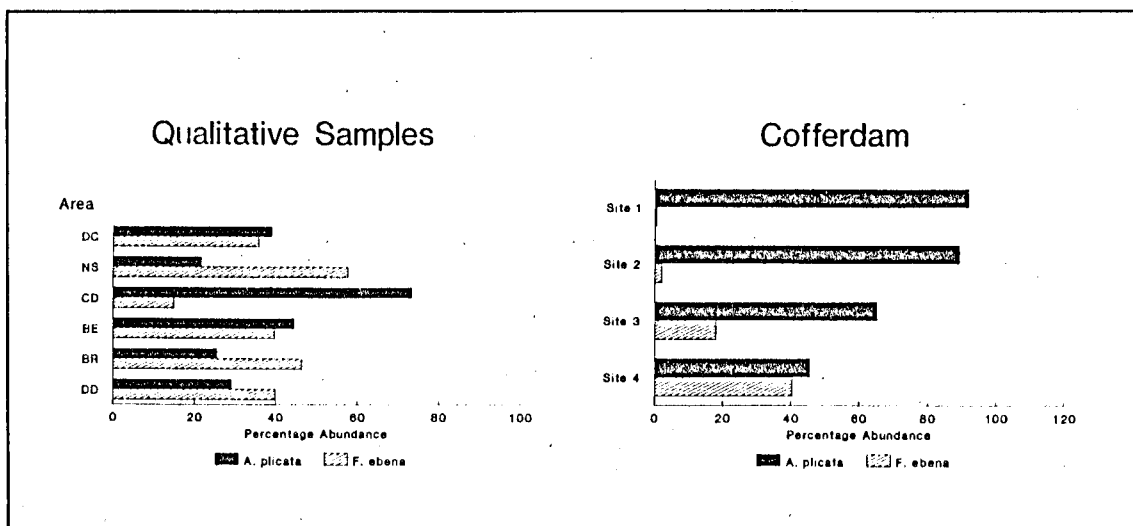
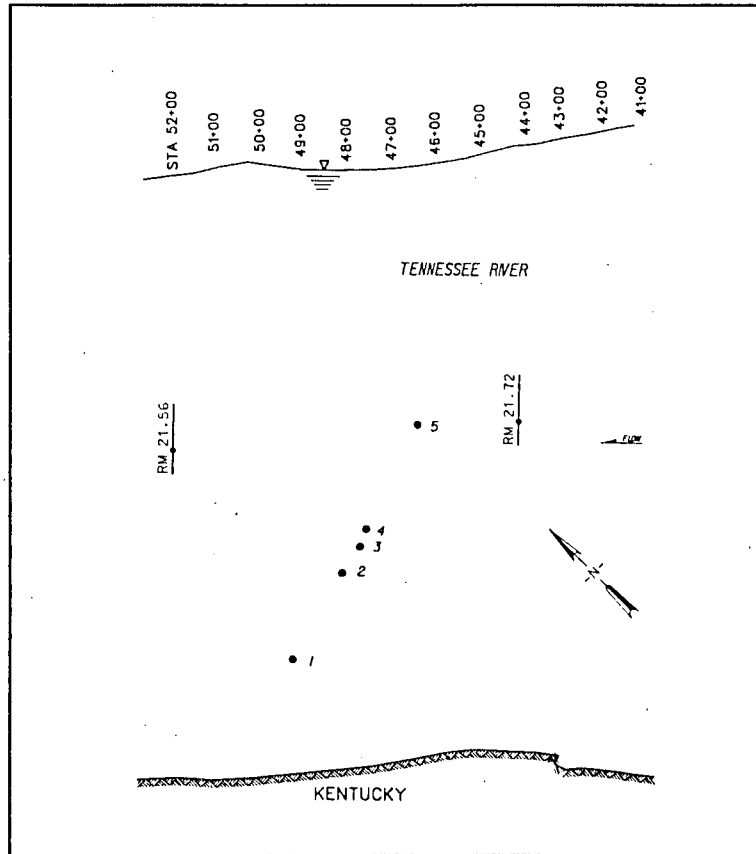


Figure 6. Percentage abundances of *A. plicata* and *F. ebena* in the lower Tennessee River

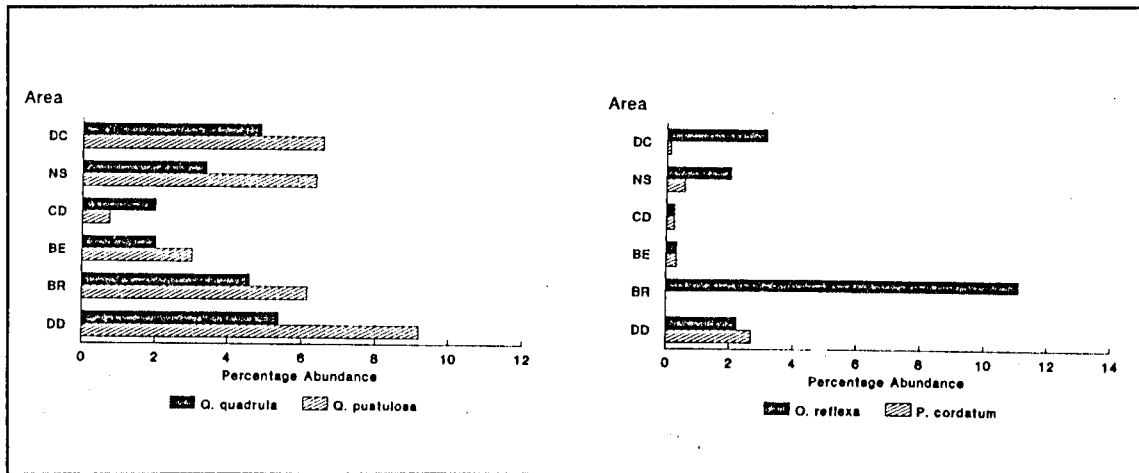


Figure 7. Percentage abundance of *Q. quadrula*, *Q. pustulosa*, *O. reflexa*, and *P. cordatum* at six study areas in the lower Tennessee River

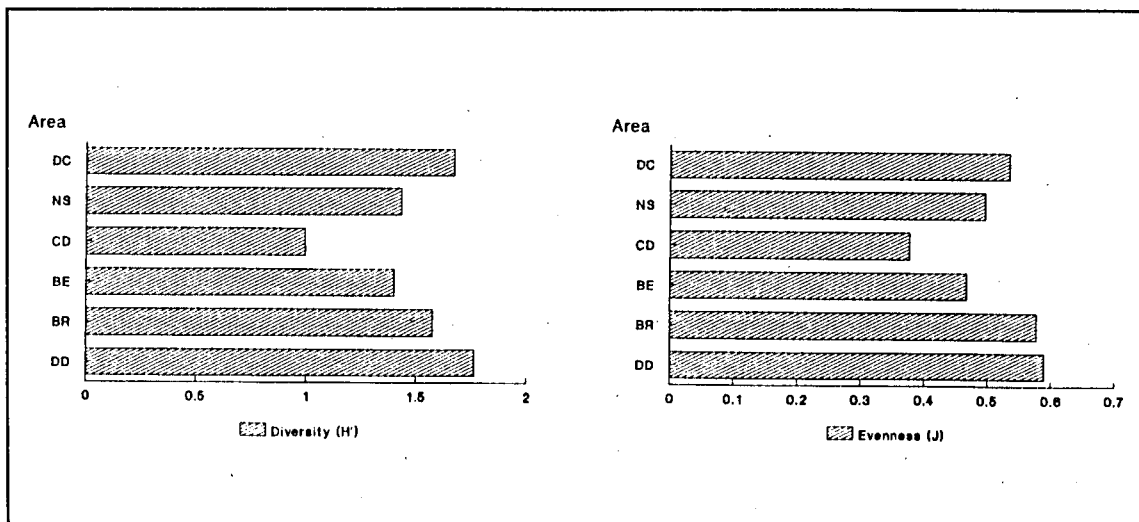


Figure 8. Unionid community characteristics at six study areas in the lower Tennessee River

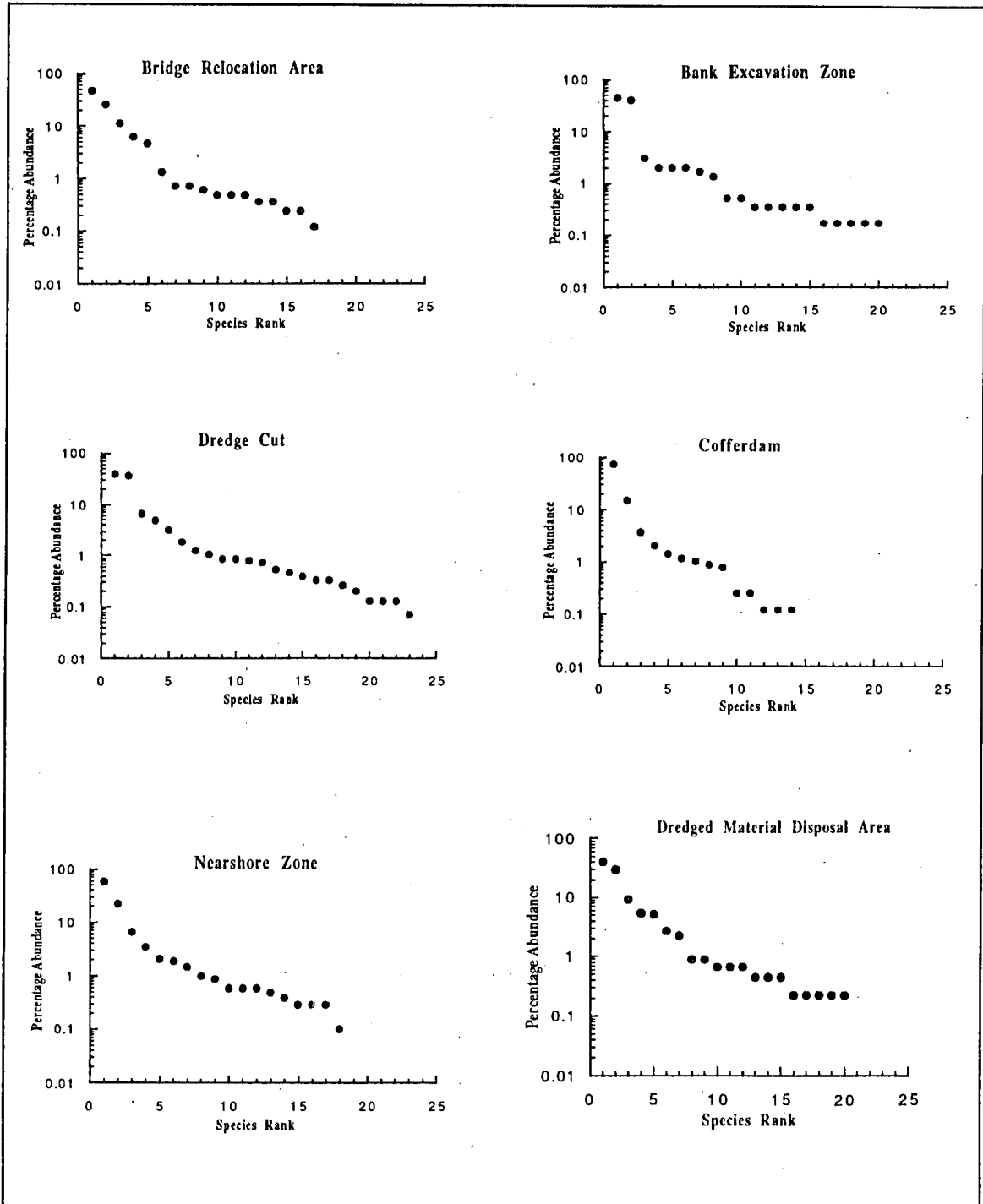


Figure 9. Relationship between percentage abundance and species rank at six study areas in the lower Tennessee River

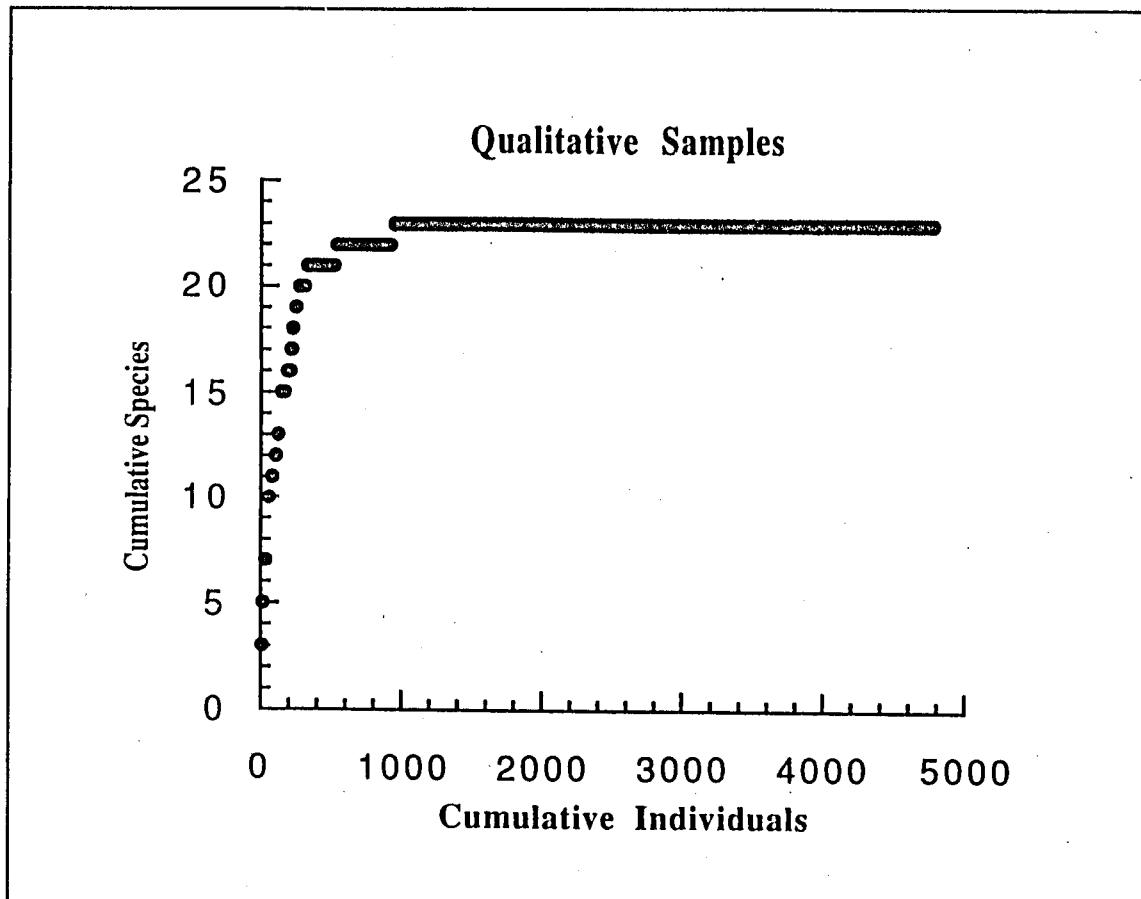


Figure 10. Relationship between cumulative species and cumulative individuals for all sites sampled qualitatively in the lower Tennessee River upriver of the I-24 bridge

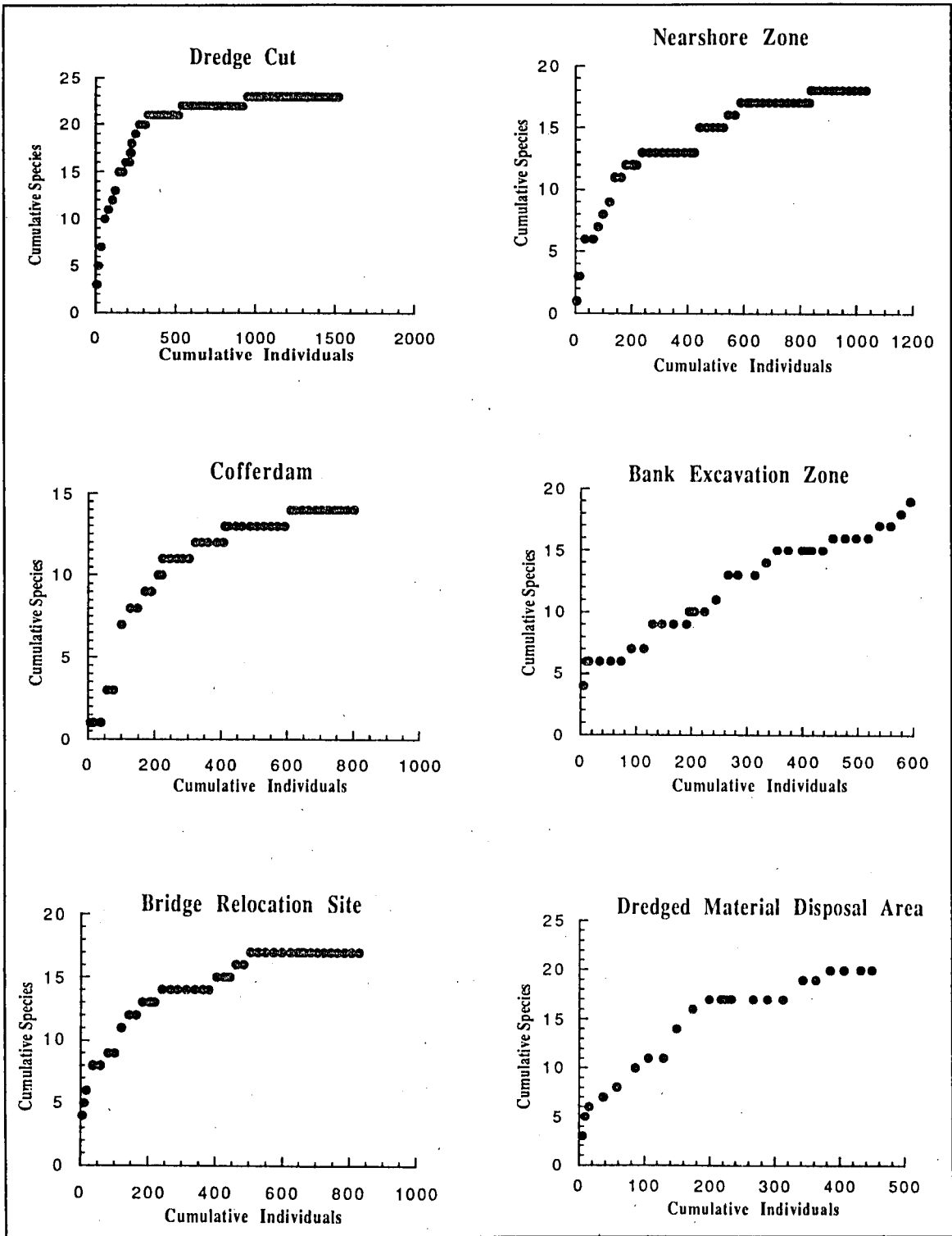


Figure 11. Relationship between cumulative species and cumulative individuals at six study areas in the lower Tennessee River

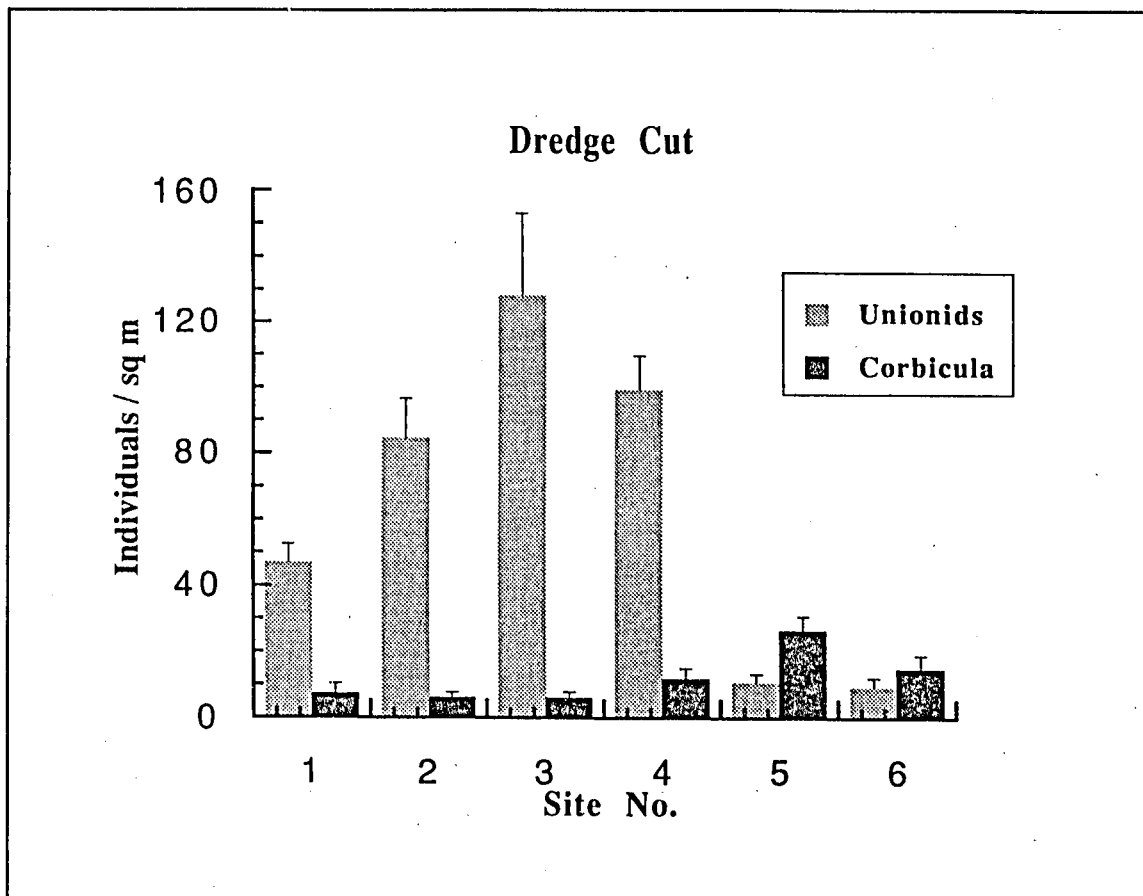
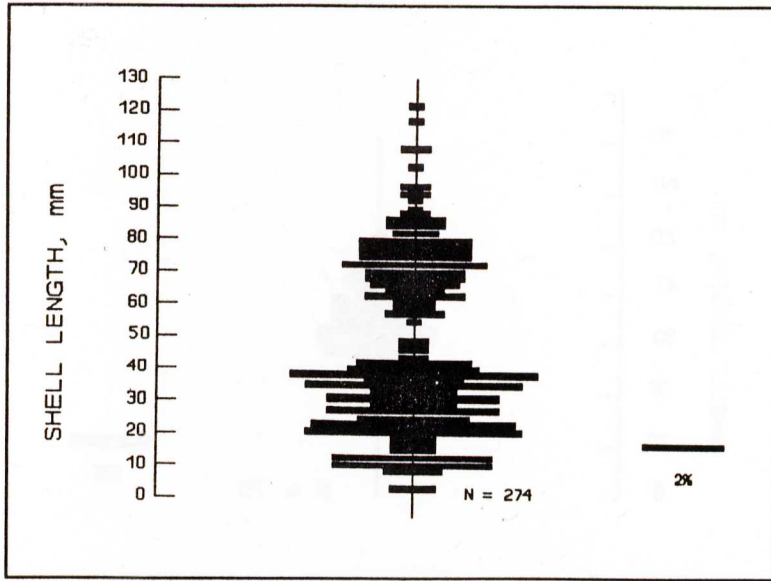
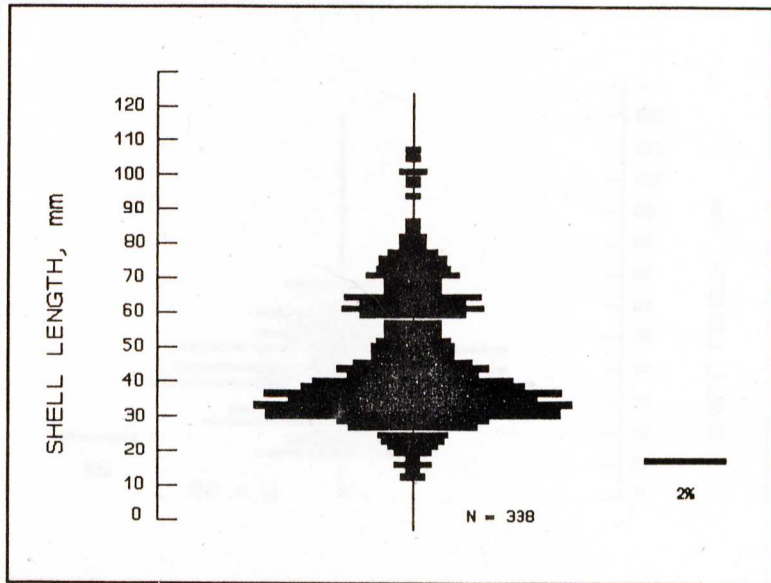


Figure 12. Total density (individuals/square meter) of unionids and *Corbicula fluminea* at six sites in the dredge cut, lower Tennessee River

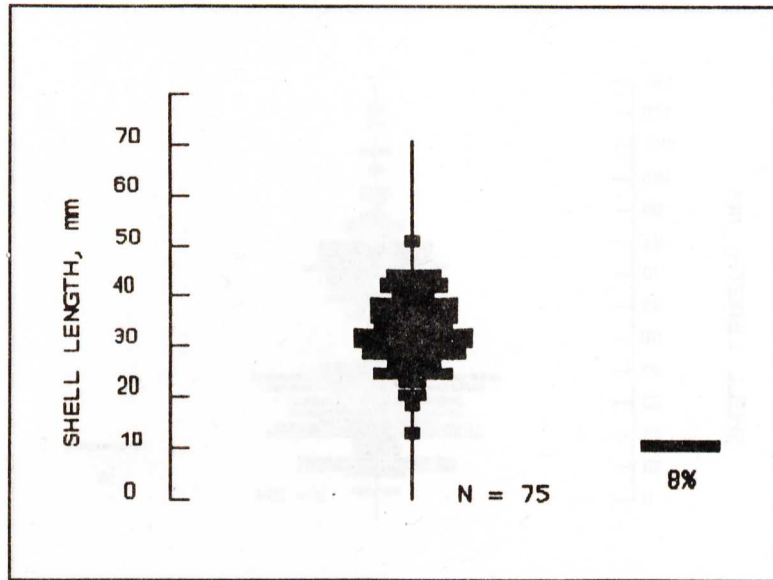


a. *A. plicata*

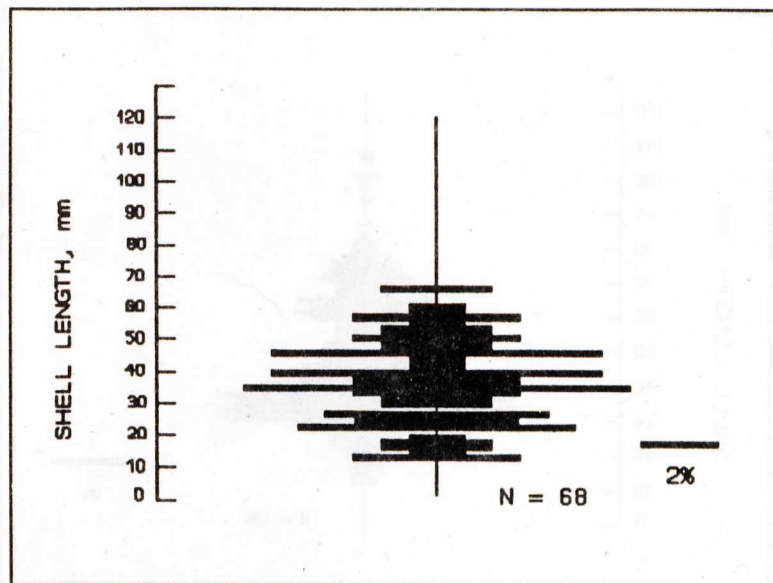


b. *F. ebena*

Figure 13. Shell length frequency histograms  
(Sheet 1 of 3)



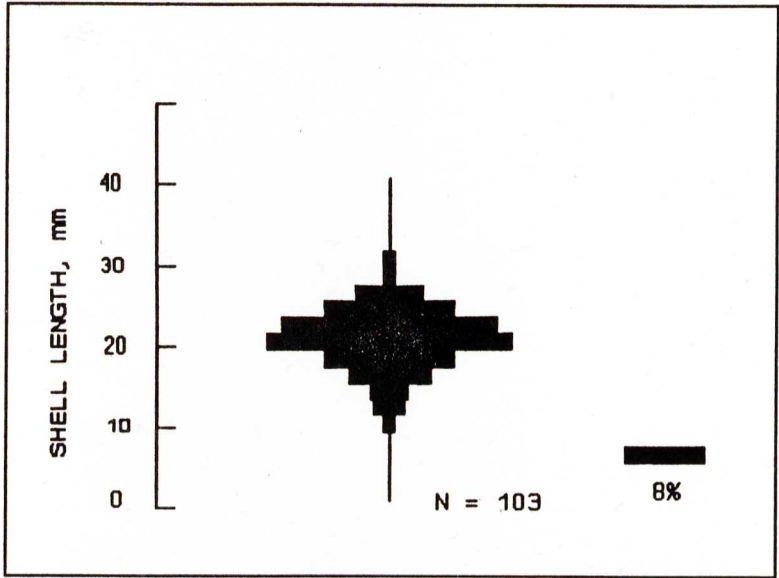
c. *O. reflexa*



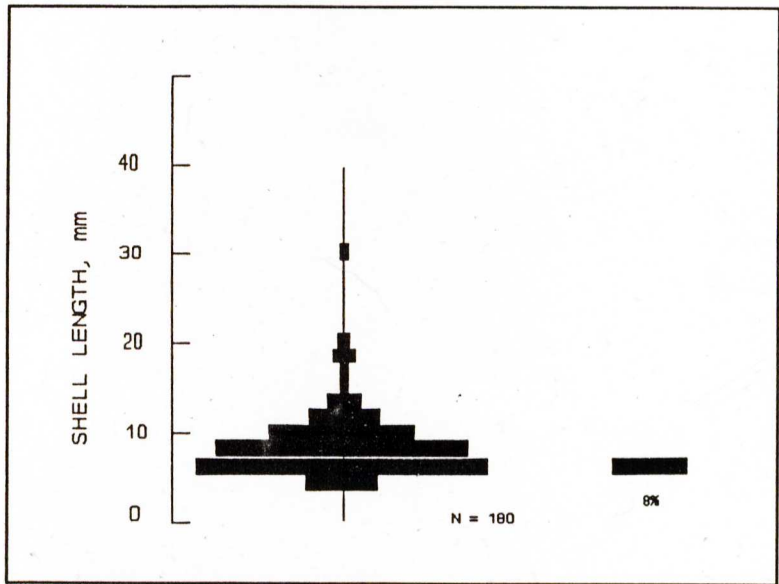
d. *Q. pustulosa*

Figure 13. (Sheet 2 of 3)





e. *T. donaciformis*



f. *C. fluminea*

Figure 13. (Sheet 3 of 3)

