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An Analysis of Freshwater Mussels (Unionidae) in the Lower Ohio River at Two Beds Near Olmsted, Illinois: 1992 Studies

*by Barry S. Payne, Andrew C. Miller, Deborah Shafer
Environmental Laboratory*

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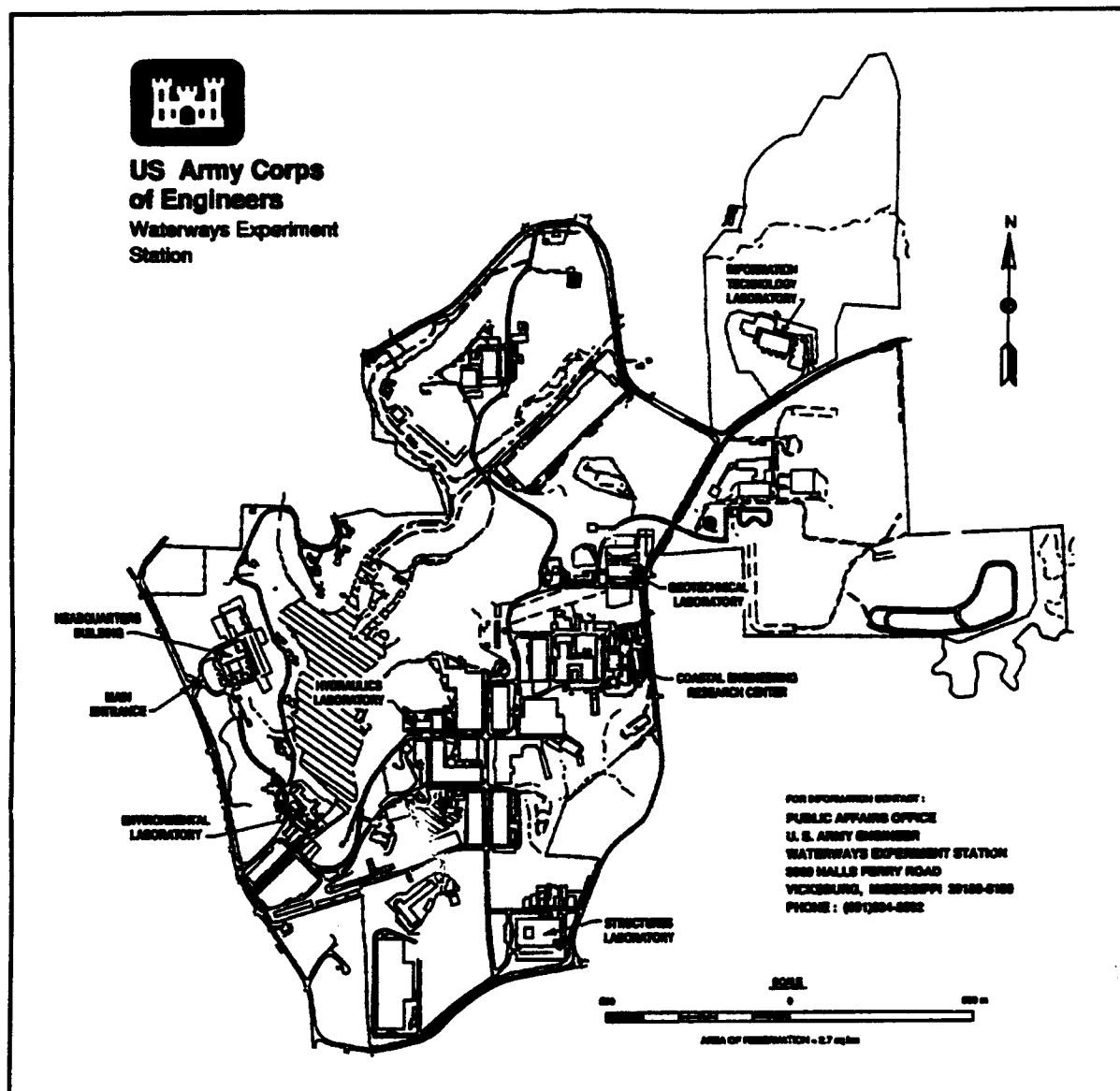
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Preface

The study herein was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) in August, 1992, for the U.S. Army Engineer District, Louisville, Louisville, KY. The purpose was to use qualitative and quantitative methods to collect freshwater mussels (Unionidae) as well as the Asian clam, *Corbicula fluminea*, from two mussel beds in the lower Ohio River. Data on density, size demography of dominant populations, species diversity, and community composition will be used to analyze the environmental effects of construction and operation of Olmsted Lock and Dam.

Divers for this study were Messrs. Larry Neill, Robert Warden, Robert T. James, and Jeff Montgomery from the Tennessee Valley Authority. Assistance in the field was provided by Mr. Mark Farr, North Eastern Louisiana University. Ms. Deborah Shafer, WES, was the Diving Inspector for this work. Mr. Mike Turner, Louisville District, monitored the contract. Figures were prepared by Ms. Sarah Wilkerson, Environmental Laboratory (EL), WES, and tables were prepared by Ms. Geralline Wilkerson, EL.

During the conduct of this study, Dr. John Harrison was Director, EL, Dr. Conrad J. Kirby was Chief, Ecological Research Division, EL, and Dr. Edwin Theriot was Chief of the Aquatic Ecology Branch, EL. Authors of this report were Drs. Barry S. Payne and Andrew C. Miller and Ms. Deborah Shafer, EL, WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. nautical)	1.852	kilometers

1 Introduction

Background

The U.S. Army Engineer District, Louisville, will replace Locks and Dams 52 and 53 on the lower Ohio River (LOR) (U.S. Army Corps of Engineers 1991). The replacement structure will consist of two 110- by 1,200-ft¹ locks, a 2,200-ft-wide navigable pass controlled by 220 remotely operated hydraulic wickets, and a short section of fixed weir tying the project into the Kentucky shore. During periods of normal and low flow, vessels will use the new locks that are on the right descending bank (RDB) on the Illinois side of the river. During high flow, vessels will use the navigable pass located in the center of the channel. The new project will be at River Mile (RM) 964.4, which is downriver of Lock and Dam 52 (located at RM 938.9) and Lock and Dam 53 (located at RM 962.8). Following completion of the Olmsted Replacement Project, Locks and Dams 52 and 53 will be removed.

When completed, the Olmsted project will increase water levels by a maximum of 10 ft in a reach upriver of the dam for approximately 42 percent of the year. This increased stage height will occur only during normal and low flow. During periods of high water (58 percent of the year), dam sections will be lowered to a horizontal position on the river bottom; water levels will be similar to those during preproject conditions. In addition, the hydraulic regimen immediately downriver of the project will be altered, and existing commercial traffic patterns will be affected. Commercial vessels will have to pass close to the RDB when entering or exiting the lock. During high water, commercial vessels will operate in the thalweg, as they have always done.

Dense and diverse mussel beds exist in this reach of the LOR (Williams 1969; Williams and Schuster 1982; Taylor 1989; Neff, Pearson, and Holdren 1981; Miller, Payne, and Siemsen 1986; Miller and Payne 1988; Payne and Miller 1989; and Miller and Payne 1991). Downriver of Lock and Dam 53, a bed begins at approximately RM 966.2 and ends at

¹ A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

approximately RM 969.2. Upriver of Lock and Dam 53, a bed exists between RM 947.4 and RM 957.8. The densest portions of the mussel beds are between these river miles although some mussels can often be found outside the beds. The endangered *Plethobasus cooperianus* (U.S. Fish and Wildlife Service 1991) has been collected at both beds.

Freshwater mussels, a resource with economic, ecological, and cultural value, can be affected by changes in water levels, sediment resuspension caused by dredging and disposal of dredged material, and movement of navigation vessels. Their sedentary lifestyle and reliance on suspended particulate organic material for food make them particularly susceptible to fluctuating water levels, sediment scour, elevated suspended sediment, and turbulence. The biological consequences of these disturbances can be measured on organisms held in the laboratory (Holland 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller, and Conley 1987; Payne and Miller 1987). However, caution must be used when extrapolating results of laboratory experiments to the field (Payne and Miller 1987). Physiological responses that occur in a laboratory often do not occur under natural conditions.

Planners and biologists should evaluate the effects of physical disturbances such as those caused by dredging and movement of commercial navigation vessels on naturally occurring populations, not on individual organisms held in the laboratory. Field studies are the best means of understanding effects of physical disturbances on naturally occurring populations of mussels. These studies can be designed to evaluate physical effects of water resource development on recruitment, rate of growth, density, species richness, and diversity. These parameters provide the most useful measures of the overall health and ultimate survival of a mussel community. A predetermined set of criteria can be evaluated yearly to determine if man-made disturbances are negatively affecting native mussels.

Purpose and Scope

The objective of this work is to characterize important biotic variables (mussel density, evidence of recent recruitment, community structure, and spatial distribution) at two mussel beds in the Ohio River located immediately upriver and downriver of the Olmsted Lock and Dam Replacement Project. The purpose is to provide quantitative data on common, uncommon, and endangered mussels that can be used to assess the environmental effects of increased water depths, altered hydraulic regimen caused by dam operation, changes in the traffic pattern of commercial vessels, and benthic scour or sediment resuspension caused by construction, vessel fleeting, and queuing. In addition, these quantitative and qualitative data provide an opportunity to evaluate effects of colonization and spread of the recently introduced zebra mussel (*Dreissena polymorpha*) on native freshwater mussels.

2 Study Area and Methods

Study Area

The Ohio River originates in Pittsburgh, PA, at the confluence of the Allegheny and Monongahela Rivers. It flows 981 miles to the northwest and then the southwest before it joins the Mississippi River near Cairo, IL. The Ohio River drains 203,900 square miles and falls 450 ft before it joins the lower Mississippi River.

For this project, study sites were located in the lower Ohio River between Paducah, KY, and Mound City, IL (Figure 1). The two mussel beds previously reported by Williams (1969) and Williams and Schuster (1982) were studied. One bed is upriver of Dam No. 52 near Paducah, KY, and the other is downriver of Dam No. 52 near Mound City, IL. Williams

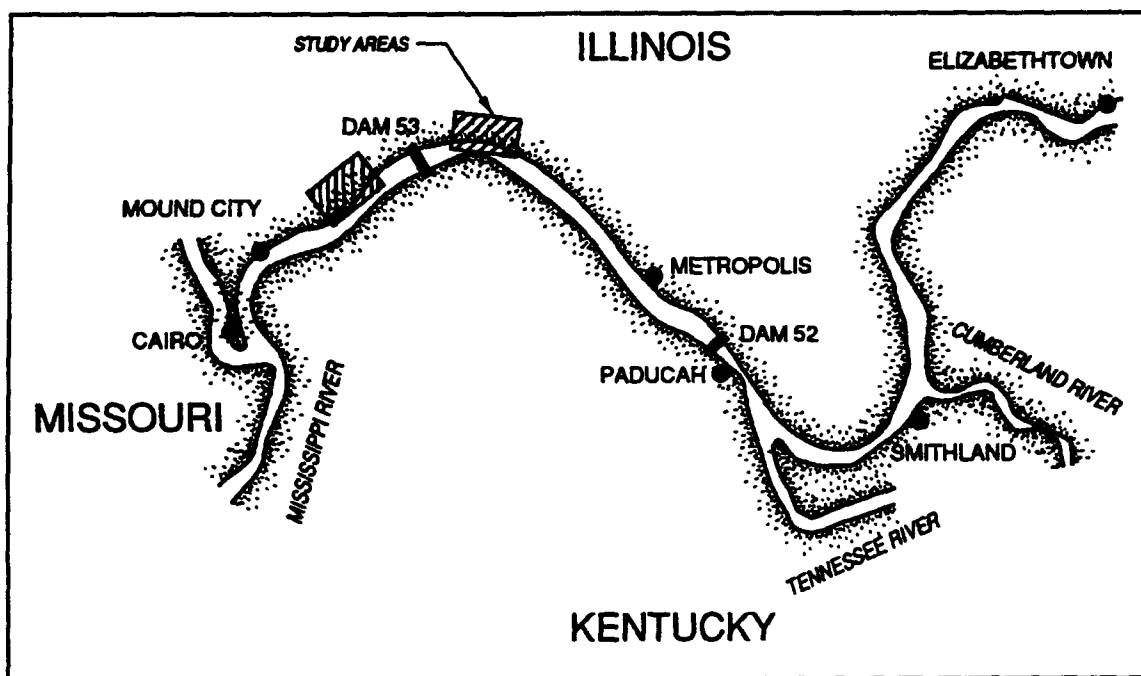


Figure 1. Study area

(1969) reported that the mussel bed located downriver of Lock and Dam No. 53 extended from RM 966.0 to 969.2 and the bed located immediately upriver of Lock and Dam No. 52 extended from RM 947.4 to 957.8. Both beds are on the Illinois side of the river. In 1982, Williams and Schuster (1982) resurveyed this river reach and provided additional data on both beds.

In the bed located upriver of Lock and Dam No 53, quantitative methods were used to collect mussels at RM 957.7, and qualitative methods were used to collect samples at RM 957.6 and 957.8 (Table 1, Figure 2). In the bed located downriver of Lock and Dam 52, quantitative methods were used to collect samples at RM 967.4, 967.5, and 967.6. Qualitative methods were used to collect samples at RM 966.4, 967.4, 967.5, and 969.3 (Table 1 and Figure 3).

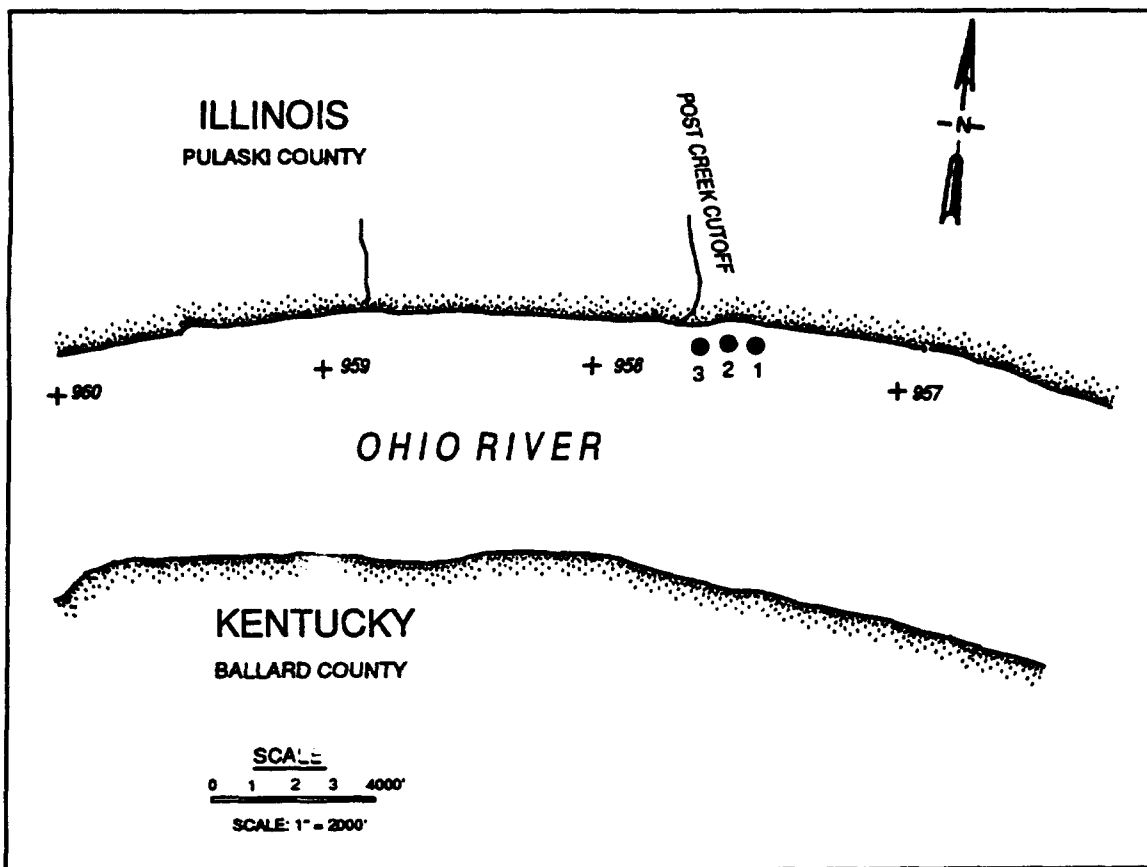


Figure 2. Sites surveyed upriver of Lock and Dam 53

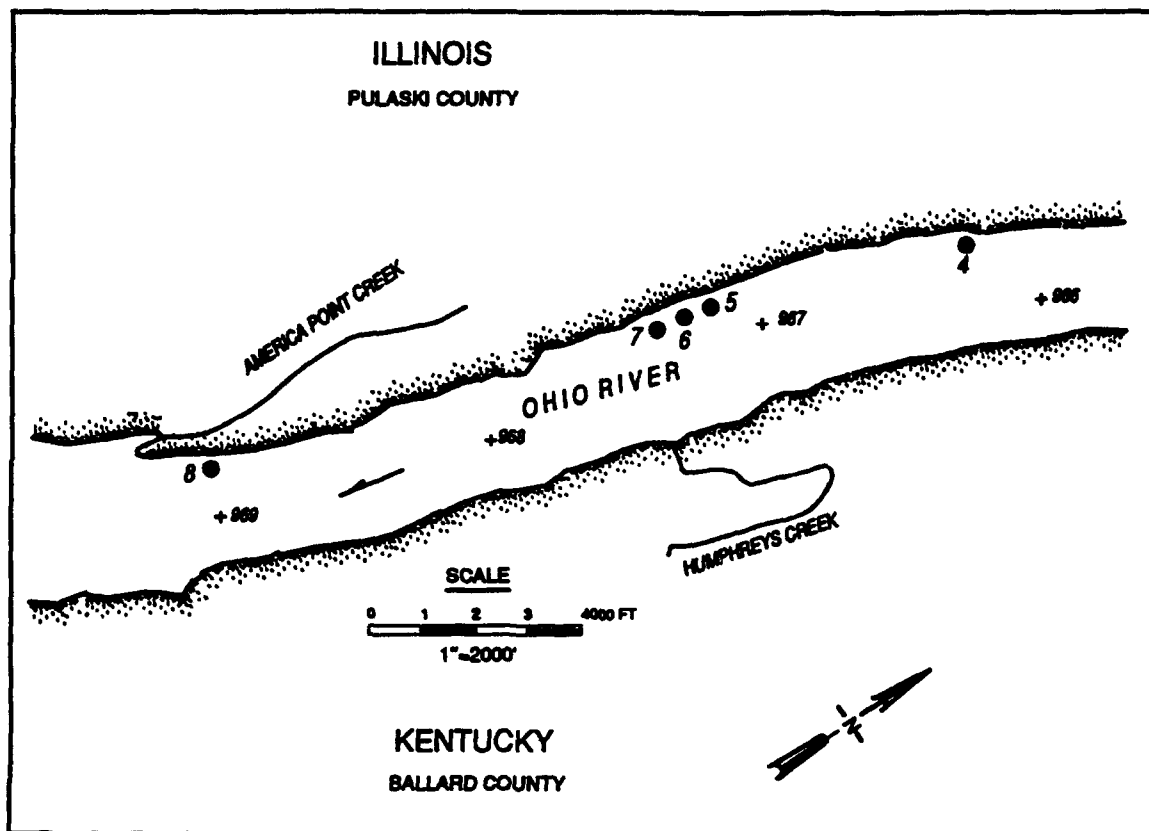


Figure 3. Sites surveyed downriver of Lock and Dam 53

Methods

Preliminary reconnaissance

All underwater work was accomplished by a dive crew equipped with surface-supplied air and communication equipment. Before intensive sampling was initiated, a single diver conducted a preliminary reconnaissance of the immediate area. He obtained information on substrate type, water velocity, and presence of mussels. Qualitative 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 having two divers collect simultaneously. Each diver placed a specific number of live mussels in each of six nylon bags; five mussels were placed in three bags and twenty were placed in each of the other nine bags. The divers were instructed to obtain mussels without bias toward size or type. They attempted to exclude the Asiatic clam *Corbicula fluminea*. 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 laboratory for analysis and plotting. Shells of voucher specimens for each species were placed in plastic zipper lock bags and labeled with high-frag-content paper. Mussels not needed for voucher were returned to the river. Methods for sampling mussels are 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). Taxonomy is consistent with Turgeon et al. (1988).

Quantitative mussel collections

Quantitative samples (that included unionids as well as *C. fluminea*) were obtained at RM 957.7, 967.4, 967.5, and 967.6 in the LOR. At each site, 10 quadrats (0.25 sq m) 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 measured to the nearest 0.1 mm with 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 th species (Shannon and Weaver 1949). 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 as Green (1979) and Hurlbert (1984). Species area curves and dominance-diversity curves were constructed from qualitative and quantitative biological data. More information on methods used for this survey can be found in McNaughton and Wolf (1973), Isom and Gooch (1986), Kovalak, Dennis, and Bates (1986), Hughes (1986), and Miller and Payne (1988).

3 The Bivalve Community

Bivalve Community Characteristics

Community composition

Mussel beds upriver and downriver of Lock and Dam 53 had similar species richness and composition (Table 2). Upriver of Lock and Dam 53, qualitative and quantitative sampling yielded 19 and 22 species, respectively. A total of 25 species were included among the 720 individuals collected by both methods combined. Downriver of Lock and Dam 53, qualitative and quantitative sampling yielded 18 and 21 species, respectively. A total of 22 species were represented among 1,869 individuals collected by both methods combined. Results of qualitative sampling at both of these beds (percent abundance and percent occurrence of species) are included in Appendix A (Tables A1-A4).

Minor differences in species composition between mussel beds or sampling method (quantitative versus qualitative) were ascribed to the low chance of obtaining locally rare species, with a single exception. *Truncilla donaciformis*, a species that grows to small adult size, was absent from qualitative samples (Table 2) but was abundant in quantitative samples both upriver (16 percent) and downriver (15 to 26 percent) of Lock and Dam 53 (Tables 3, 4, 5, and 6). Small adult size caused this species to be totally excluded from qualitative samples, although hundreds were collected from total substrate samples. Other species obtained using quantitative but not qualitative methods included *Actinonaias ligamentina*, *Anodonta imbecillis*, and *Ligumia recta* (in both beds) and *Plethobasus cyphus* (upriver of Lock and Dam 53). However, these species were always represented by just one or two individuals (Tables 3, 4, 5, and 6). Species obtained in qualitative but not quantitative samples included *Lasmigona complanata* (in both beds) and *Plethobasus cyphus*, *P. cooperianus*, and *Potamilus purpuratus* (upriver of Lock and Dam 53). Again, these species were always represented by just one or two individuals (Tables A1 and A3).

Species diversity (2.36) and evenness (0.80) for near and farshore sites combined were high upriver of Lock and Dam 53 (Table 3). Results from quantitative sampling upriver of the lock indicated that five species individually comprised more than 10 percent of the community. These numerically dominant species were as follows: *Fusconaia ebena* (21 percent), *Truncilla donaciformis* (16 percent), *Quadrula pustulosa* (12 percent), *T. truncata* (12 percent), and *Obliquaria reflexa* (10 percent). *Ellipsaria lineolata* (7.3 percent) and *Quadrula quadrula* (6.1 percent) were moderately abundant. Five of these seven species were also among the most abundant taxa in qualitative samples from this bed (Table A1). Not surprisingly, the diminutive *T. donaciformis* and its slightly larger congener, *T. truncata*, despite their abundance in total substrate samples, were either not present or greatly underrepresented in qualitative samples (Table A1). In the more accurate quantitative samples, five species comprised between 1.2 and 4.2 percent, and an additional seven species each comprised 0.61 percent of the community.

Figure 4 graphically portrays the relation of individual species' abundances on their dominance rank in the community upriver of Lock and Dam 53. The low slope of this curve (spanning just 1.5 orders of magnitude over 20 species) reflects an equitable distribution of individuals among species in this community. Also apparent in Figure 4 is the close

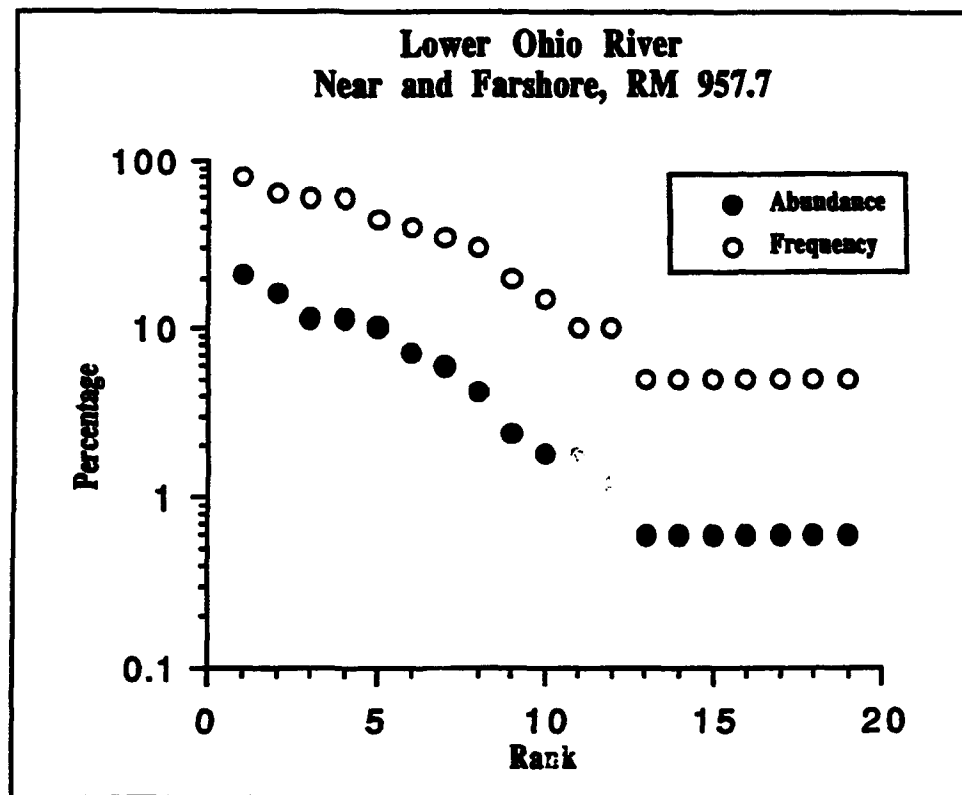


Figure 4. Percent abundance and percent occurrence of mussels collected using quantitative methods at the mussel bed located upriver of Lock and Dam 53

correlation of the relative abundance of species (filled circles) to their frequency of occurrence in samples (open circles). Thus, never was moderate or high abundance coupled with low frequency of occurrence.

Downriver of Lock and Dam 53, species diversity and evenness were high nearshore (Table 4) and moderate at both midshore (Table 5) and farshore locations (Table 6). Diversity (total of sites 0.1 mile apart) equaled 1.93, 1.65, and 1.55 at nearshore, midshore, and farshore locations, respectively. Evenness was 0.78, 0.59, and 0.51 as distance from shore increased. Relative abundance (again, total for closely adjacent sites) of *F. ebena*, the dominant mussel, equaled 41 percent, 47 percent, and 55 percent at nearshore, midshore, and farshore locations, respectively. Relative abundance of *F. ebena* and *T. donaciformis* varied widely among replicate sites, especially those nearest shore (Table 4) and at midshore (Table 5). Community composition downriver of Lock and Dam 53 was most consistent among replicate farshore sites (Table 6).

Relative abundance of *F. ebena* was higher and diversity and evenness were lower downriver of Lock and Dam 53 (Tables 4, 5, and 6) than upriver (Table 3). However, the general pattern of species relative abundance was similar between these beds. At farshore sites, downriver of Lock and Dam 53, where community composition was most consistent (Table 6), the seven most abundant species occurred in approximately the same abundance as they were upriver of this structure. Two of these species were particularly dominant downriver of Lock and Dam 53: *Fusconaia ebena* (55 percent) and *T. donaciformis* (20 percent). *Truncilla truncata* (5.6 percent), *O. reflexa* (4.4 percent), *E. lineolata* (3.9 percent), *Q. p. pustulosa* (3.8 percent), and *Q. quadrula* (1.5 percent) were moderately abundant. The 14 remaining species individually comprised less than 1.2 percent of the community.

Plots of species relative abundance on dominance rank for sites downriver of Lock and Dam 53 (Figures 5, 6, and 7) reflected the lower diversity and evenness of mussels compared with sites upriver of Lock and Dam 53 (Figure 4). Downriver of Lock and Dam 53, species relative abundance spanned approximately 2.5 orders of magnitude among 21 species at the farshore location (Figure 7). The high abundance of *F. ebena* and *T. truncata* downriver of Lock and Dam 53 was evident in the initially sharp decline in slope of abundance plotted on rank. As was observed upriver of Lock and Dam 53, moderate or high species abundance was never combined with low frequency of occurrence (Figures 5, 6, and 7).

Some differences in detailed aspects of community composition upriver versus downriver of Lock and Dam 53 were evident in relative abundance of common-to-abundant mussels in qualitative samples (Figure 8). *Fusconaia ebena* and *M. nervosa* comprised a greater fraction of the community downriver of Lock and Dam 53. *Quadrula p. pustulosa*, *Q. quadrula*, *Q. metanevra*, and *O. reflexa* had greater relative abundance upriver of Lock and Dam 53. *Ellipsaria lineolata* and *Amblema p. plicata* were of equal relative abundance upriver and downriver of Lock and Dam 53.

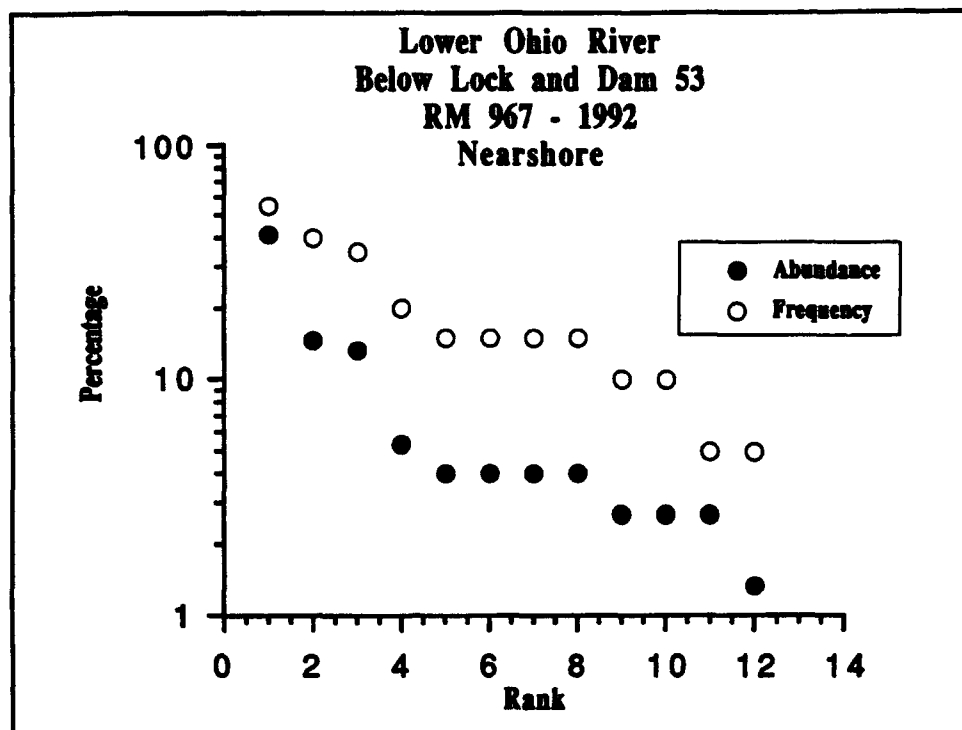


Figure 5. Percent abundance and percent occurrence of mussels collected at nearshore sites in the lower Ohio River downriver of Lock and Dam 53 (includes RM 967.4, 967.5, and 967.6)

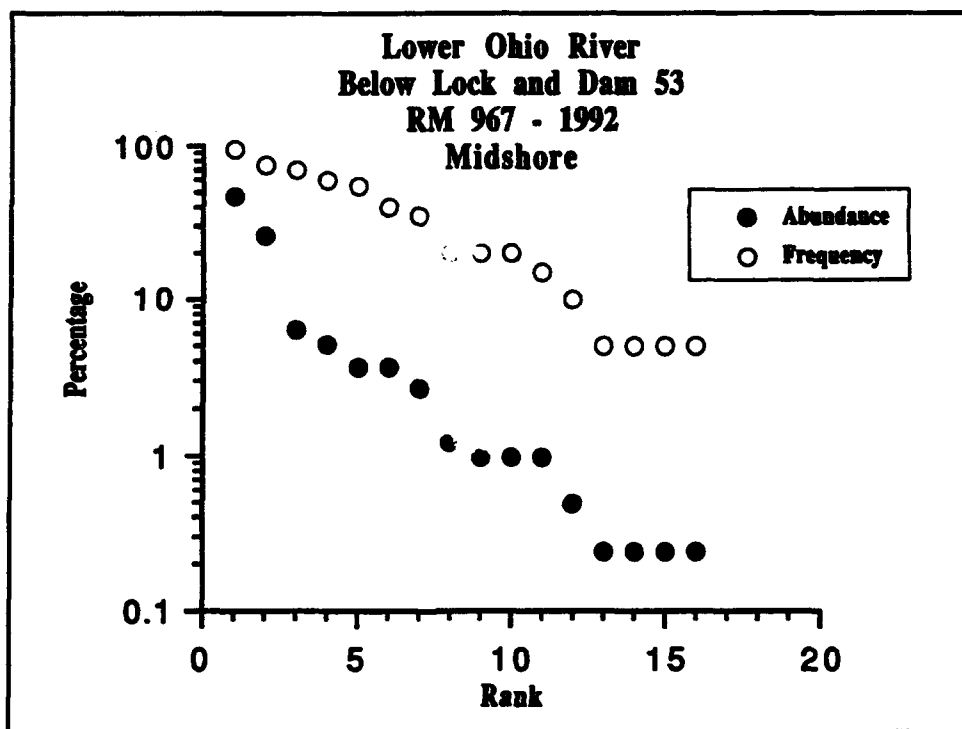


Figure 6. Percent abundance and percent occurrence of mussels collected at midshore sites in the lower Ohio River downriver of Lock and Dam 53 (includes RM 967.4, 967.5, and 967.6)

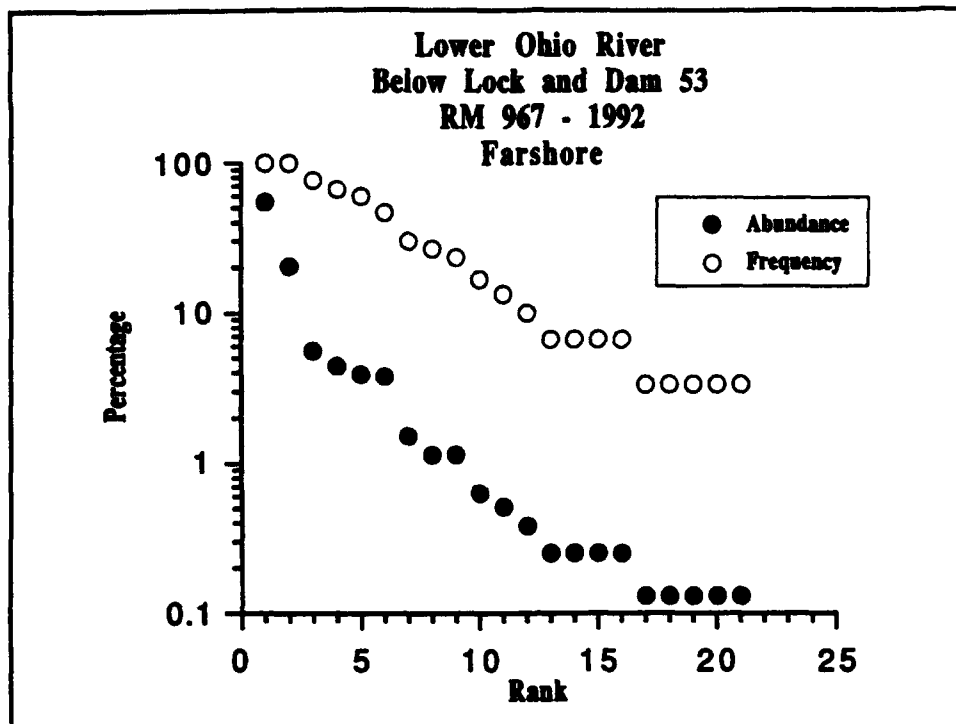


Figure 7. Percent abundance and percent occurrence of mussels collected at farshore sites in the lower Ohio River downriver of Lock and Dam 53 (includes RM 967.4, 967.5, and 967.6)

The combined quantitative samples downriver of Lock and Dam 53 appeared to include virtually all species present; acquisition of new species slowed to a negligible rate as sampling effort increased (Figure 9). Twenty-one species were obtained among 1,274 individuals collected by quantitative methods. Twelve species were obtained before the first 100 mussels were collected. A cumulative total of 17 species were obtained before 400 mussels were collected. All twenty-one species were obtained before 1,000 mussels were taken. The remaining 274 individuals from quantitative sampling yielded no new species. Furthermore, an additional 595 individuals from qualitative sampling yielded just one additional species to those twenty-one collected by quantitative methods (Table 2).

Results of qualitative collections downriver of Lock and Dam 53 suggested considerable variation in species relative abundance among sites. These sites were upriver (RM 966.4), mid-river (RM 967.4 and RM 967.5), and downriver (RM 969.3) (Table A3). *Fusconaia ebena* was not very abundant downriver (13 percent) relative to midriver (37 to 68 percent) or upriver (43 percent). Dominance downriver was shared by *Quadrula p. pustulosa* (17 percent), *Q. quadrula* (16 percent), *F. ebena* (13 percent), and *Ellipsaria lineolata* (12 percent). However, considerable variation in detailed aspects of community composition was suggested even among samples separated by only 0.1 miles (RM 967.4 versus RM 967.5) (Table A3). For example, relative abundance of *F. ebena* was 68 percent at RM 967.4, but only 37 percent at RM 967.5. Quantitative

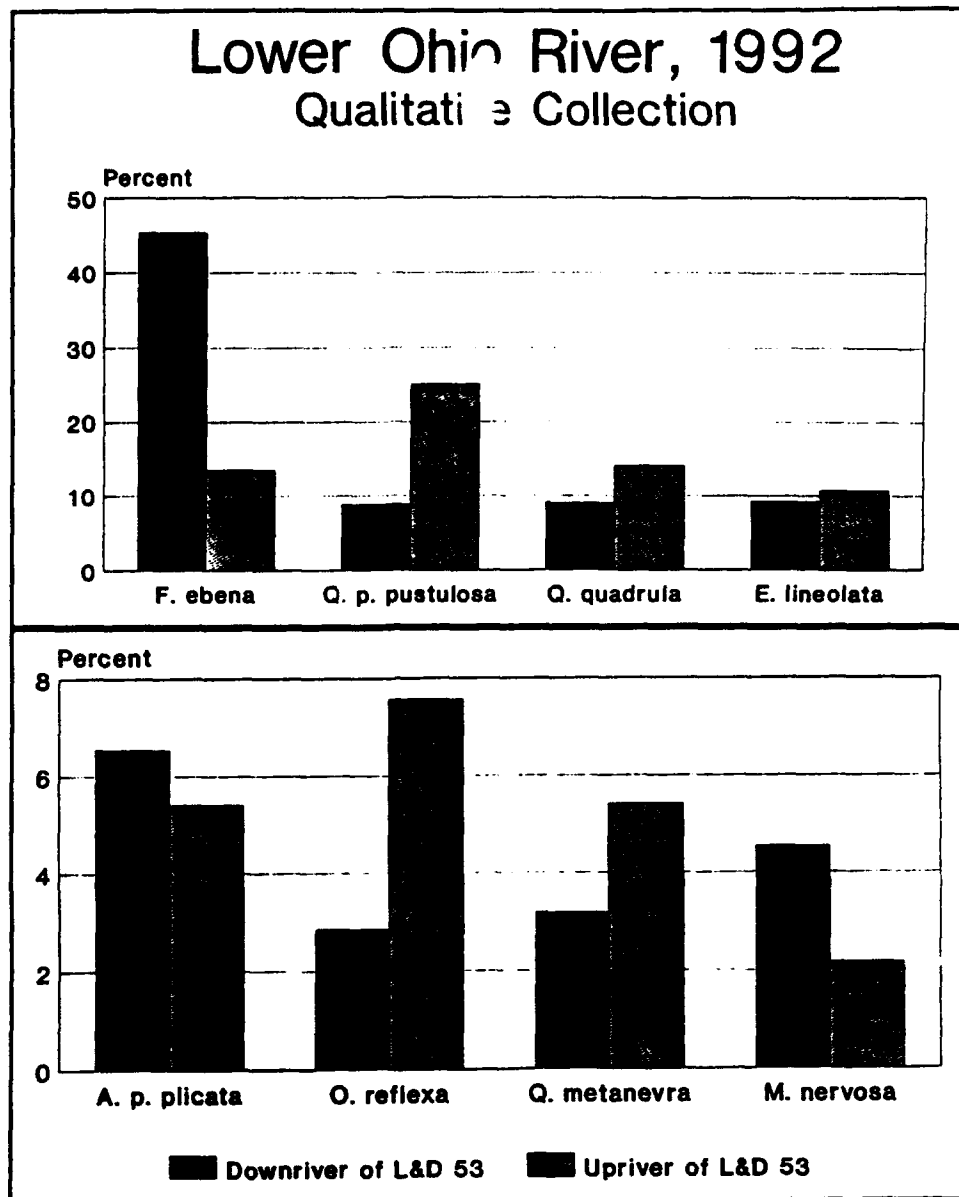


Figure 8. Percent abundance of eight dominant species of unionids at mussel beds upriver and downriver of Lock and Dam 53

samples at RM 967.4 and RM 967.5 also indicated considerable variation (Tables 4, 5, and 6).

More obvious differences in density occurred in the nearshore-to-farshore direction. Density of native unionids and *Corbicula fluminea* varied significantly among nearshore, midshore, and farshore sites (Table 7; Figure 10). Numerical density of mussels downriver of Lock and Dam 53 was 5.5 and 7.0 times higher at midshore and farshore locations, respectively. Biomass density differences were not nearly as clear (i.e., they were significant at the 0.1 but not 0.05 level) nor as substantial. Biomass density was 1.4 and 2.0 times higher midshore and farshore, respectively,

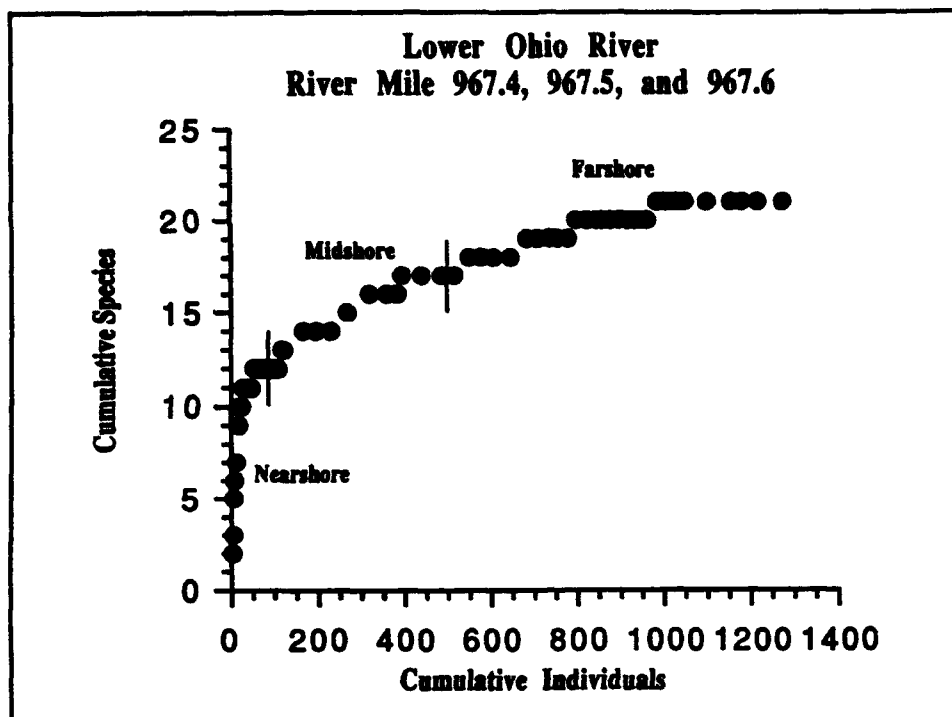


Figure 9. Relationship between number of individuals and number of mussel species collected using quantitative methods in the lower Ohio River

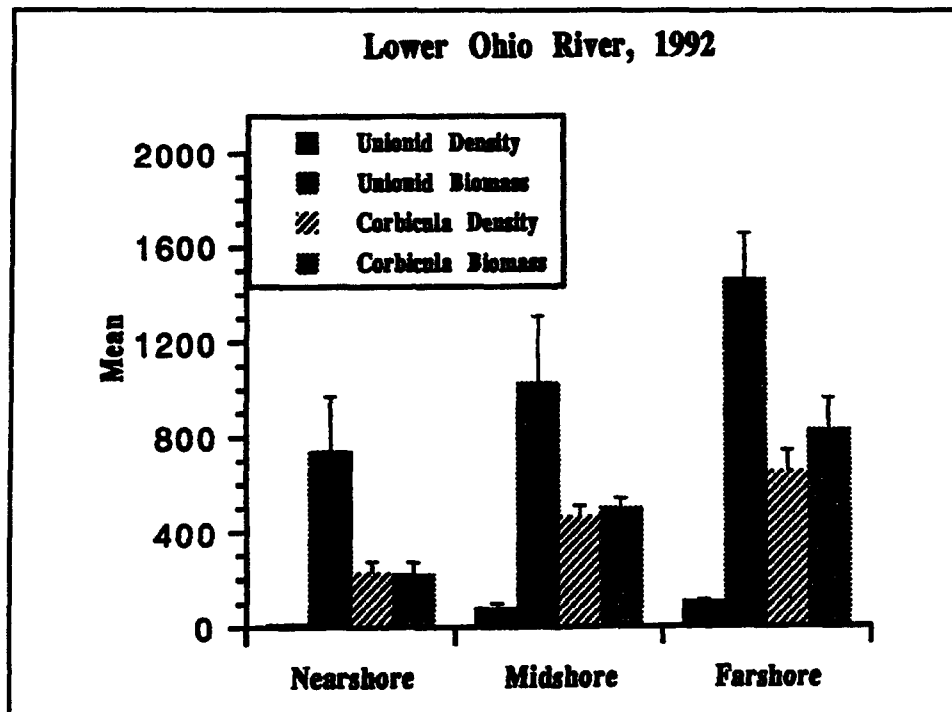


Figure 10. Numerical density (individuals/square meter) and biomass density (grams/square meter) for unionids and *Corbicula fluminea* collected in the lower Ohio River

than nearshore. Numerical density of *C. fluminea* followed the same pattern as observed among native unionids. *Corbicula fluminea* were 2.0 and 2.9 times more numerous midshore and farshore than nearshore. Biomass density of *C. fluminea* was 3.7 and 1.6 times higher farshore than midshore or nearshore, respectively.

The ratio of biomass-to-numerical density, an estimate of the average size of individuals (Table 7), indicated that those few unionids occurring nearshore were relatively large (49.7 g) compared with midshore (12.6 g) and farshore (13.9 g) assemblages. The percent abundance of recent recruits (i.e., individuals less than 30 mm long) averaged 48.0 nearshore, 86.1 midshore, and 87.7 farshore. The reverse pattern was observed among Asian clams. Density of *C. fluminea* nearshore, midshore, and farshore averaged 0.98 g, 1.08 g, and 1.27 g, respectively.

Presence of *Plethobasus cooperianus*

The endangered species *Plethobasus cooperianus* occurs but is rare in both the bed upriver and downriver of Lock and Dam 53. *Plethobasus cooperianus* was obtained in qualitative samples upriver of Lock and Dam 53 in 1992, but was not obtained in either quantitative samples (both beds) or qualitative samples downriver of Lock and Dam 53 (Table 2). However, *P. cooperianus* was obtained in qualitative samples downriver of Lock and Dam 53 in 1983 (Miller, Payne, and Siemsen 1986) and 1987 (unpublished data) and in quantitative samples obtained in 1990 (Miller and Payne 1991). In 1991, a single individual was obtained from a total of thirty 0.25-m² total substrate samples collected. A total of two hundred and sixty-nine 0.25-m² total substrate samples have been taken from the lower bed since 1983, and only a single *P. cooperianus* has been obtained from these quantitative samples (Miller, Payne, and Siemsen 1986; Miller and Payne 1988; Payne and Miller 1989; Miller and Payne 1991; and unpublished data). Based on the total sampling effort, *P. cooperianus* density is approximately one individual per 67 m² in the bed downriver of Lock and Dam 53.

Size Demography of Abundant Populations

Upriver of Lock and Dam 53

Fusconaia ebena. The population of *F. ebena* upriver of Lock and Dam 53 was dominated by a single year class (probably 1991) of recent recruits that ranged from 10 to 22 mm in length (Appendix B—Figure B1). In addition, five larger mussels were obtained; four of these ranged from 62 to 72 mm in length. The size structure of this population suggests infrequently strong annual recruitment.

***Truncilla donaciformis*.** This population was comprised entirely of individuals ranging from 12 to 26 mm in length (Figure B2). It is likely that this cohort represents 1991 recruitment.

***Corbicula fluminea*.** The Asian clam population was dominated by two cohorts (Figures C1 and C2). The smallest, comprising 71 percent and 63 percent of the nearshore and farshore assemblages, respectively, was centered at 8 to 11 mm in length. A larger cohort, centered at 15 to 19 mm in length, contributed an additional 24 percent and 32 percent to the nearshore and farshore collections of *C. fluminea*. Less than 5 percent of the population both near and farshore was comprised of individuals greater than 19 mm long.

Downriver of Lock and Dam 53

***Fusconaia ebena*.** In general, the size demography of this population (Figures B3, B4, B5, and B6) was similar to that observed upriver of Lock and Dam 53 (Figure B1). However, there was substantial variation within the population downriver of Lock and Dam 53 with respect to the relative abundance of small versus large individuals. At the nearshore site (Figure B3), *F. ebena* had approximately equal representation of mussels 8 to 16 mm long and 44 to 86 mm long. At the midshore site (Figure B4), mussels 8 to 26 mm long were approximately nine times more abundant than mussels 56 to 76 mm long. Similarly, at the farshore site (Figure B5), small mussels (8 to 34 mm) outnumbered large mussels (40 to 88 mm) by a factor of 11. Overall, the size structure of the *F. ebena* population downriver of Lock and Dam 53 indicated two major cohorts: very recent recruits (presumably 1991) centered at 8 to 20 mm in length, and a cohort of moderately large and old mussels centered at 60 to 70 mm in length (Figure B6).

***Truncilla donaciformis*.** This population was comprised virtually entirely of individuals 12 to 24 mm long, regardless of nearshore-to-farshore distance (Figures B7, B8, B9, and B10). This size structure was virtually identical to that observed upriver of Lock and Dam 53 (Figure B2). Presumably, these small *T. donaciformis* represent 1991 recruitment. A few large *T. donaciformis* (44 to 46 mm long) were collected downriver of Lock and Dam 53.

***Ellipsaria lineolata*.** This population was dominated (59 percent) by relatively small recent recruits ranging from 28 to 42 mm long (Figure B11). The remainder of this population ranged from 48 to 74 mm long.

***Obliquaria reflexa*.** This population was also dominated by small, young individuals (Figure B12). Approximately 82 percent of the population was less than 26 mm long. The maximum size of individuals in this population was 50 mm.

***Quadrula pustulosa pustulosa*.** This population had relatively equal abundance of small and moderately large individuals (Figure B13). Sixty percent of the sample ranged from 12 to 32 mm in length; the remaining 40 percent ranged from 40 to 52 mm long.

***Truncilla truncata*.** Although this species can grow to moderately large size (ca. 50 mm), this population was comprised entirely of individuals 14 to 38 mm long (Figure B14). The principal cohort of this population was centered at 18 to 28 mm.

***Corbicula fluminea*.** Demography of the Asian clam at this bed was similar to that observed upriver of Lock and Dam 53 (Appendix C—Figures C3-C9). There was a slight decrease in the ratio of large-to-small *C. fluminea* in a farshore-to-nearshore direction.

Changes in Water Velocity Associated with Vessel Passage

Background

Water velocity was measured at two locations on the LOR that support dense and diverse mussel communities for a total of twelve vessel passages in August of 1992. The first site (at RM 967.4) is located 4.6 miles downriver of Lock and Dam 53; the second site (at RM 957.8) is located 5 miles upriver of Lock and Dam 53. Each set of data associated with a vessel passage event is labeled a test. Physical data for each vessel passage can be found in Appendix D, Table D1. Tables D2-D13 contain summary statistics for each passage; individual velocity plots for each event can be found in Figures D1-D21. There are two sets of plots (nearshore and farshore sensors) for each test arranged as follows: (a) X- and Y-axis velocity in feet/second, (b) combined velocity in feet/second, and (c) direction of flow in degrees.

Divers deployed two Marsh McBirney electromagnetic current meters near the substrate-water interface along a transect line running from nearshore to farshore. However, only one nearshore meter was deployed at the time of vessel passage during Tests 1-6. The meters were placed in the densest portions of the mussel beds at sites where qualitative and quantitative mussel samples were collected.

At the first site, nearshore and farshore meters were placed 200 and 700 ft, respectively, from the RDB. The vessel distance for Tests 1-6 was approximately 1,500 ft. At the second site, nearshore and farshore meters were placed 130 and 750 ft, respectively, from the RDB. Vessel distance for Tests 7-12 was approximately 1,200 ft from the RDB. Water velocity was recorded for at least 200 sec immediately prior to and following each test to compare with conditions during passage.

In most cases the sensors were placed so that the X- and Y-axes were oriented parallel to and at right angles to the direction of flow. Data were recorded at 1-sec intervals for each individual X-Y flow component, as well as total combined velocity and compass bearing. For each test, mean velocity, standard deviation, minimum and maximum values, and range, for both individual X-Y components and combined velocity, are in Tables D2-D13.

Results

With the exception of Test 9, there were little or no measurable effects from vessel passage either in the upstream or downstream direction. Examination of summary statistics in Tables D2-D13 shows little, if any, increase in the standard deviation or range of the individual X-Y velocity components or the combined velocity during vessel passage.

A slight reduction in both X-Y and combined velocity was noted during Test 9. This effect was most pronounced in Sensor 940, which was located nearest the channel. The minimum combined velocity for Sensor 946 (nearshore) decreased 20 percent from 2.009 to 1.613 ft/second. Similarly, the minimum combined velocity for Sensor 940 (farshore) decreased 24 percent from 1.953 to 1.489 ft/second. The tow for Test 9 passed in the downstream direction, fully loaded in a 4 by 2 configuration.

Two factors that may account for the noticeable decrease in combined velocity for this vessel passage and not in others are (a) speed of passage and (b) loaded versus unloaded condition. The average speed of all recorded upriver passages was 7.0 ft/second; the average speed of all recorded downriver passages was 9.6 ft/second. Tests 8 and 9 had higher speeds of 13.2 and 13.7 ft/second, respectively. The lack of noticeable effects during Test 8 is probably due to the fact that there were only three unloaded barges present.

Previous navigation traffic studies conducted in the upper Mississippi River have shown that upbound and downbound passages have different effects on water velocity (Miller and Payne 1991). Upbound passages have little effect on minimum velocity; however, the return flow caused by displacement of water from the hull tends to increase the maximum velocity. The reverse seems to be true for downbound passages. Maximum velocity is not noticeably affected, but the return flow caused by vessel passage tends to reduce the minimum velocity. The range in velocity readings for any test is usually greater during vessel passage than under ambient conditions. However, the range of both X, Y, and combined velocity values in these data sets was very often less than during ambient conditions (Tables D2-D13). This lends further support to the conclusion that the measurable effects of vessel passages on water velocity at the substrate-water interface are negligible.

4 Discussion

Existing conditions have been quantified for two historically prominent mussel beds that extend from Ohio RM 947.4 to 957.8 and from RM 966.0 to 969.2 first described by Williams (1969). These beds are just upriver and downriver of Lock and Dam 53, located at RM 962.6. The Olmsted Replacement Project that replaces Locks and Dams 52 and 53 will be built at RM 962.8, just 0.2 miles downriver of existing Lock and Dam 53. Water levels at the bed upriver of existing Lock and Dam 53 will be approximately 10 ft higher (only during normal and low stage) than at present. Concern exists that sedimentation and altered hydraulic conditions might deleteriously affect the bed downriver of Lock and Dam 53.

Planners and biologists ultimately must evaluate the effects of this project on populations of species in their natural habitats using field studies. Quantitative data provided herein on density, relative species abundance, community composition, and population demography can be used as a basis for monitoring the effects of the Olmsted Replacement Project.

The present study yielded 26 species of native mussels among 2,589 individuals collected from the beds upriver and downriver of Lock and Dam 53. Included among these individuals was a single individual of the endangered species *Plethobasus cooperianus*, which was obtained in qualitative samples from the upper bed. The community in the bed downriver of Lock and Dam 53 was generally similar in species richness and dominance rank of species to the bed upriver of Lock and Dam 53. However, *F. ebena*, the dominant species in the LOR, had lower relative abundance upriver (21 percent) than downriver of Lock and Dam 53 (41 to 55 percent). Consequently, species diversity and evenness was lower downriver than upriver of Lock and Dam 53.

A total of 2,880 mussels were obtained from quantitative samples taken from the bed downriver of Lock and Dam 53 in 1983, 1985, 1986, 1987, 1988, 1990, 1991, and 1992 (Miller, Payne, and Siem 1986; Miller and Payne 1988; Payne and Miller 1989; Miller and Payne 1991; and unpublished data). A total of 29 species were included among these 4,406 individuals. An additional 4,586 individuals have been collected from all qualitative samples taken from the lower bed since 1983. These qualitative samples yielded only a single species that has not been

obtained in total substrate samples—*Lasmigona complanata complanata*. Based on a total collection of 7,466 mussels from 1983 to 1991, richness of this mussel bed equals 30 species. In 1992, a total of 1,867 individuals were collected by quantitative and qualitative methods downriver of Lock and Dam 53. No species were obtained that had not been collected in 1983 to 1991. Thus, based on a cumulative total of 9,335 individuals, richness in the bed below Lock and Dam 53 equals 30 species. All species obtained upriver of Lock and Dam 53 in 1992 have been obtained downriver of Lock and Dam 53 at some time from 1983 to 1991. Table 2 lists all mussels collected on this and previous surveys.

This LOR community is generally similar to but slightly richer in composition than that of the lower Tennessee River (Miller and Payne 1991). The Tennessee River empties into the Ohio River in Pool 52 at RM 934.5 (less than 30 miles upriver of Lock and Dam 53). Twenty-three species of native mussels were obtained among 4,768 individuals collected in the lower Tennessee River between the Interstate-24 bridge and Kentucky Lock and Dam. This appeared to be a complete list; no new species were obtained as collection increased from 1,500 to 4,768 individuals (Miller and Payne 1991). *Fusconaia ebena* (36 percent) and *A. p. plicata* (29 percent) shared dominance of the lower Tennessee River community. *Truncilla donaciformis* (11 percent), *O. reflexa* (7.9 percent), *Q. p. pustulosa* (7.2 percent) also individually comprised more than 5 percent of the lower Tennessee River community. Annual recruitment of *F. ebena* appeared to be considerably more consistent in the lower Tennessee River than the LOR (Miller and Payne 1991). The only species obtained in that survey not obtained in the lower Ohio was *Anodonta grandis*. Species obtained in the LOR but not in the lower Tennessee River were as follows: *Actinonaias ligamentina*, *Arcidens confragosus*, *Fusconaia flava*, *Lampsilis ovata*, *Potamilus laevis*, *Obovaria olivaria*, *Plethobasus cooperianus*, *Plethobasus cyphyus*, and *Potamilus purpuratus*.

In the LOR, both nearshore-to-farshore and along-shore variation was seen in the structure of the mussel bed downriver of Lock and Dam 53, although nearshore-to-farshore differences were more striking. Nearshore-to-farshore differences involved lower unionid density nearshore relative to midshore and farshore. Midshore and farshore sites were carefully located to be just farshore and well farshore, respectively, of the lowest water stage associated with the major drought of 1988. However, the nearshore sites were located on a portion of the bed that was exposed to air for weeks during this major drought. This exposure is almost certain to account for the patterns in density observed in the nearshore-to-farshore direction. Thus, monitoring of the shallow portion of the bed downriver of Lock and Dam 53 provides an indication of recovery pattern and rate. Data from the midshore and farshore sites provide information on the unaffected and major portion of the mussel bed. Sites sampled on the bed upriver of Lock and Dam 53 were not exposed during the 1988 drought.

Extensive sampling is required to obtain all species present in a bed because cumulative species are obtained as a linear function of the logarithm of cumulative sampling effort (in terms of number of samples, area sampled, or individuals sampled) (McNaughton and Wolf 1973). It is difficult to determine the presence or absence of especially rare taxa (Miller and Payne 1988). Despite legitimate interests of conservation biologists in maintenance of species richness, quantitative studies of locally rare species are often impractical. For example, it is impossible to develop any detailed information on population biology of *P. cooperianus* in the LOR. Because of chance alone, extensive surveys of the bed downriver of Lock and Dam 53 will sometimes include this species (e.g., Miller, Payne, and Siemsen 1986) but at other times will not (for example, in the present study). Species richness estimates should always include information on the total number of individuals collected (Magurran 1988).

Evaluation of community structure is more practical and insightful if focus is on patterns of relative abundance, density, and size demography of relatively abundant species. Protection and conservation of species richness in large river mussel beds, including the rarest species, is likely to benefit from quantitative evaluation of relative abundance, density, and recruitment patterns among 10 or so of the most abundant taxa. For example, successful recruitment of *F. ebena* in 1991 does not appear to have been a population-specific phenomenon; strong recruitment was also apparent in *E. lineolata*, *O. reflexa*, *Q. pustulosa*, *T. donaciformis*, and *T. truncata* populations (Appendix B). It is noteworthy that species diversity and evenness indices are particularly sensitive to the relative abundances of the most abundant taxa (Magurran 1988).

The mussel community of the LOR is dominated by *F. ebena*, which also dominates the lower Tennessee River (Miller and Payne 1991; Williams 1969), and was once the dominant unionid throughout the upper Mississippi River prior to construction of the Keokuk Dam at Keokuk, IA (Cooker 1914; Theler 1987). This dam prevented upstream migration of the skipjack Herring *Alosa chrysochloris*, the fish host of the parasitic glochidea larvae of *F. ebena* (Coker 1914). In the Ohio River, *F. ebena* declines in abundance with upstream distance and thus number of dams interfering with skipjack herring migration (Williams 1969; Williams and Schuster 1982). Although the existing Lock and Dam 53 is underwater during much of the year, *F. ebena* was less abundant in the bed immediately upstream versus immediately downstream of this structure (Tables 3, 4, 5, and 6). Also, Miller and Payne (1991) observed lower relative abundance of *F. ebena* in the lower Tennessee River, which empties into the Ohio River upriver of Lock and Dam 53, than downriver of Lock and Dam 53. *Fusconaia ebena* is greatly reduced in abundance in the middle Ohio River; this species comprises less than 5 percent of the mussel community at RM 444 near Cincinnati, OH.

Fusconaia ebena is commonly found in gravelly shoals and is deleteriously affected by high lift dams. This species was more prevalent in large rivers prior to construction of the modern inland navigation systems. In

addition, this species, with its massive, white-nacred shell, is a commercially important species in the export of shell nuclei to the Orient for the cultured pearl trade (Miller and Payne 1991). Although not listed as threatened or endangered, *F. ebena* is an important species in the LOR community.

A striking feature of both mussel beds is the extreme dominance of a single cohort of small, recent recruits to the *F. ebena* population (Figures B1 and B6). Payne and Miller (1989) observed the same characteristic of the bed downriver of Lock and Dam 53 when they first studied it in 1983. The dominant species of this bed, *F. ebena*, was heavily dominated by a single year class of recent recruits (1981) during that previous survey. Approximately 70 percent of the *F. ebena* population was comprised of that single cohort. Studies of that population continued through 1987 have indicated no subsequent recruitment of noteworthy strength (Payne and Miller 1989). As of mid-September 1990, there was still no evidence of recent strong recruitment after 1981 (Miller and Payne 1991). However, approximately 90 percent of this population (when sampled in the present study) consisted of small (10 to 20 mm) mussels representing 1991 recruitment.

Thus, in recent history strong annual recruitment to this population, the dominant unionid in the LOR has occurred only twice—in 1981 and 1991. This pattern of recruitment must be understood when conducting an assessment of conditions in any particular year. Sporadic recruitment success in turn leads to sporadic increases in population density. In the LOR, recruitment patterns appear to be such that baseline characterization requires something in the order of 10 years of observations that have now been made.

Long-term monitoring has provided important information on *F. ebena* growth rate. The 1981 cohort, first sampled by Payne and Miller in 1983, although greatly lower in absolute and relative abundance by 1992, remains a recognizable feature in 1992 of the *F. ebena* population downriver of Lock and Dam 53. This cohort has grown in average length as follows: 15.8 mm in late September 1983; 29.5 mm in late October 1985; 47.3 mm in late September 1987; 58.5 in mid-September 1990; 64.1 mm in early October 1991; and 65.6 mm in mid-August 1992. It is anticipated that the 1991 cohort with average length of 13.8 mm in mid-August 1992 will attain an average length of approximately 66 mm by fall of 2002.

The Asian clam *C. fluminea* has been abundant in the LOR since at least 1957 (Sinclair and Isom 1961). Considerable speculation was made that *C. fluminea* would competitively displace native unionid and sphaeriid bivalves (see McMahon (1983) and references within). Unionids have maintained high density, diversity, and show occasionally strong recruitment in the LOR despite at least 25 years of occurrence with an abundant *C. fluminea* population. In the present study, unionid and *C. fluminea* density were positively correlated in the bed downriver of Lock and Dam 53 (Figure 10). Another exotic pest bivalve, the zebra mussel

Dreissena polymorpha, has now become part of the bivalve fauna in the LOR. In the present study, a single individual was found byssally attached to piece of gravel in the bed downriver of Lock and Dam 53. A second individual was found on a unionid during a qualitative search for mussels. Because *D. polymorpha*, unlike *C. fluminea*, can byssally attach to unionids in high density, there is potentially much more direct competition between the former species and the native mussels.

Catastrophic declines of unionids have been reported in Lake St. Clair and Lake Erie because of intense fouling of live unionids by zebra mussels (Mackie 1993). However, in these instances, unionids may have offered the only suitable preferred surface for attachment relative to sand and mud. Furthermore, *D. polymorpha* produces a true veliger larva via external fertilization (Hopkins and Leach 1993). This mode of reproduction has allowed rapid colonization along the fringes of the Great Lakes.

Release of eggs and sperm to the water column by dioecious adults followed by external development of fertilized eggs into planktonic veligers, although typical among marine bivalves and retained by *D. polymorpha*, is a mode of reproduction that has been suppressed in all bivalves that have successfully evolved into rivers. Native unionids are mostly dioecious, but only sperm are released to the water column. Females draw the sperm into their mantle cavity, fertilization of eggs occurs, and embryos are brooded in the gill until they are released as glochidea larvae that attach to fish hosts. Metamorphosis occurs on the fish, and benthic juveniles detach. *Corbicula fluminea* and native spheroids are both hermaphroditic and brood embryos to a benthic stage (a much more advanced stage in spheroids than *C. fluminea*). It is reasonable to question the ability of *D. polymorpha* to achieve and sustain high density populations in lotic riverine habitats when one considers its potentially inappropriate mode of reproduction.

Drought, natural patterns of recruitment, and species introductions are natural factors that potentially affect native mussels in the LOR. Effects of construction and operation of the Olmsted Lock and Dam project can best be monitored by regularly monitoring density, diversity, and size demography of dominant native mussel populations in the LOR.

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Table 1
Location and Number of Samples Collected Using Qualitative and
Quantitative Methods in the Lower Ohio River, August 1992

River Mile	Distance to Shore, ft	Water Depth, ft	No. of Qualitative Samples	No. of Quantitative Samples	Date	Site No.
957.6	450	15	12	NC ¹	19 Aug 92	1
957.6	575	17	12	NC	19 Aug 92	1
957.7	400	15	NC	10	17 Aug 92	2
957.7	550	17	NC	10	19 Aug 92	2
957.8	700	18	12	NC	17 Aug 92	3
966.4	170	14	12	NC	18 Aug 92	4
967.4	240	14.5	NC	10	16 Aug 92	5
967.4	350	17.3	NC	10	16 Aug 92	5
967.4	750	18.5	NC	10	16 Aug 92	5
967.4	600	17	12	NC	16 Aug 92	5
967.5	750	17	12	NC	18 Aug 92	6
967.5	275	16	NC	10	15 Aug 92	6
967.5	350	18	NC	10	15 Aug 92	6
967.5	750	23	NC	10	15 Aug 92	6
967.6	900	17	NC	10	18 Aug 92	7
969.3	900	21	7	NC	18 Aug 92	8

¹NC = none collected.

Table 2
Freshwater Mussels Collected Using Qualitative (Qual) and
Quantitative (Quant) Methods in the Lower Ohio River, August 1992

Species	Upriver of Lock and Dam 53		Downriver of Lock and Dam 53	
	Qual	Quant	Qual	Quant
<i>Actinonaias ligamentina</i> (Lamarck, 1819)		X		X
<i>Amblema p. plicata</i> (Say, 1817)	X	X	X	X
<i>Anodonata imbecillis</i> (Say, 1829)		X		
<i>Cyclonaias tuberculata</i> (Rafinesque, 1820)	X	X		X
<i>Ellipsaria lineolata</i> (Rafinesque, 1820)	X	X	X	X
<i>Elliptio crassidens</i> (Lamarck, 1819)	X	X	X	X
<i>Fusconaia ebena</i> (I. Lea, 1831)	X	X	X	X
<i>Lampsilis teres</i> (Rafinesque, 1820)	X			
<i>Lasmigonia c. complanata</i> (Barnes, 1823)	X		X	
<i>Leptodea fragilis</i> (Rafinesque, 1820)	X	X	X	X
<i>Ligumia recta</i> (Lamarck, 1819)			X	X
<i>Megaloniais nervosa</i> (Rafinesque, 1820)	X	X	X	X
<i>Obliquaria reflexa</i> (Rafinesque, 1820)	X	X	X	X
<i>Obovaria olivaria</i> (Rafinesque, 1820)	X	X	X	X
<i>Plethobasis cyphus</i> (Rafinesque, 1820)	X			X
<i>Plethobasis cooperianus</i> (I. Lea, 1834)	X			
<i>Pleurobema cordatum</i> (Rafinesque, 1820)	X	X	X	X
<i>Potamilus purpuratus</i> (Lamarck, 1819)	X			
<i>Potamilus alatus</i> (Say, 1817)	X		X	X
<i>Quadrula p. pustulosa</i> (I. Lea, 1831)	X	X	X	X
<i>Quadrula quadrula</i> (Rafinesque, 1820)	X	X	X	X
<i>Quadrula metanevra</i> (Rafinesque, 1820)	X	X	X	X
<i>Quadrula nodulata</i> (Rafinesque, 1820)	X	X	X	X

(Continued)

Note: The following species have been collected downriver of Lock and Dam 53 during previous study years: *Arcidens contragosus* (Say, 1829), *Fusconaia flava* (Rafinesque, 1820), *Lampsilis ovata* (Say, 1817), *Potamilus ohioensis* (Rafinesque, 1820).

Table 2 (Concluded)				
Species	Upriver of Lock and Dam 53		Downriver of Lock and Dam 53	
	Qual	Quant	Qual	Quant
<i>Tritogonia verucosa</i> (Rafinesque, 1820)	X	X	X	X
<i>Truncilla truncata</i> (Rafinesque, 1820)	X	X	X	X
<i>Truncilla donaciformis</i> (I. Lea, 1848)		X		X
Total species	22	19	18	21

Table 3
Percent Abundance and Percent Occurrence of Bivalves Collected
at RM 957.8 Upriver of Lock and Dam 53, Lower Ohio River, August
1992, Using Quantitative Methods

Species	Abundance			Occurrence		
	Nearshore	Farshore	Total	Nearshore	Farshore	Total
<i>F. ebena</i>	31.82	14.14	21.21	80.00	80.00	80.00
<i>T. donaciformis</i>	7.58	22.22	16.36	30.00	100.00	65.00
<i>Q. p. pustulosa</i>	9.09	13.13	11.52	40.00	80.00	60.00
<i>T. truncata</i>	9.09	13.13	11.52	40.00	80.00	60.00
<i>O. reflexa</i>	10.61	10.10	10.30	30.00	50.00	40.00
<i>E. lineolata</i>	10.61	5.05	7.27	60.00	30.00	45.00
<i>Q. quadrula</i>	3.03	8.08	6.06	20.00	50.00	35.00
<i>L. fragilis</i>	3.03	5.05	4.24	20.00	40.00	30.00
<i>Q. metanevra</i>	4.55	1.01	2.42	30.00	10.00	20.00
<i>A. p. plicata</i>	3.03	1.01	1.82	10.00	10.00	10.00
<i>Q. nodulata</i>	1.52	2.02	1.82	10.00	20.00	15.00
<i>M. nervosa</i>	1.52	1.01	1.21	10.00	10.00	10.00
<i>E. crassidens</i>	1.52	0.00	0.61	10.00	0.00	5.00
<i>C. tuberculata</i>	0.00	1.01	0.61	0.00	10.00	5.00
<i>O. olivaria</i>	1.52	0.00	0.61	10.00	0.00	5.00
<i>A. imbecillis</i>	0.00	1.01	0.61	0.00	10.00	5.00
<i>A. ligamentina</i>	0.00	1.01	0.61	0.00	10.00	5.00
<i>T. verrucosa</i>	0.00	1.01	0.61	0.00	10.00	5.00
<i>P. cordatum</i>	1.52	0.00	0.61	10.00	0.00	5.00
Total individuals	66	99	165			
Total sites				10	10	20
Total species	15	16	19			
Species diversity	2.25	2.28	2.36			
Evenness	0.83	0.82	0.80			
Dominance	0.14	0.12	0.12			

Table 4
Percent Abundance and Percent Occurrence of Bivalves Collected
at Nearshore Sites Downriver of Lock and Dam 53, Lower Ohio
River, August 1992, Using Quantitative Methods

Species	Percent Abundance			Percent Occurrence		
	RM 957.4	RM 957.5	Total	RM 957.4	RM 957.5	Total
<i>F. ebena</i>	4.76	55.56	41.33	10.00	100.00	55.00
<i>T. donaciformis</i>	38.10	5.56	14.67	50.00	30.00	40.00
<i>Q. metanevra</i>	0.00	18.52	13.33	0.00	70.00	35.00
<i>O. reflexa</i>	9.52	3.70	5.33	20.00	20.00	20.00
<i>O. olivaria</i>	0.00	5.56	4.00	0.00	30.00	15.00
<i>T. truncata</i>	9.52	1.85	4.00	20.00	10.00	15.00
<i>Q. p. pustulosa</i>	4.76	3.70	4.00	10.00	20.00	15.00
<i>E. lineolata</i>	4.76	3.70	4.00	10.00	20.00	15.00
<i>A. p. plicata</i>	9.52	0.00	2.67	10.00	0.00	5.00
<i>L. recta</i>	4.76	1.85	2.67	10.00	10.00	10.00
<i>P. alatus</i>	9.52	0.00	2.67	20.00	0.00	10.00
<i>L. fragilis</i>	4.76	0.00	1.33	10.00	0.00	5.00
Total individuals	21	54	75			
Total sites				10	10	20
Total species	10	9	12			
Species diversity	1.99	1.47	1.93			
Evenness	0.86	0.67	0.78			
Dominance	0.15	0.34	0.21			

Table 5
Percent Abundance and Percent Occurrence of Bivalves Collected
at Midshore Sites Downriver of Lock and Dam 53, Lower Ohio
River, August 1992, Using Quantitative Methods

Species	Percent Abundance			Percent Occurrence		
	RM 967.4	RM 967.5	Total	RM 967.4	RM 967.5	Total
<i>F. ebena</i>	17.02	50.83	46.94	50.00	100.00	75.00
<i>T. donaciformis</i>	46.81	23.20	25.92	90.00	100.00	95.00
<i>T. truncata</i>	12.77	5.52	6.36	50.00	90.00	70.00
<i>O. reflexa</i>	8.51	4.70	5.13	40.00	80.00	60.00
<i>E. lineolata</i>	4.26	3.59	3.67	20.00	90.00	55.00
<i>Q. p. pustulosa</i>	0.00	4.14	3.67	0.00	70.00	35.00
<i>A. p. plicata</i>	6.38	2.21	2.69	20.00	60.00	40.00
<i>Q. metanevra</i>	0.00	1.38	1.22	0.00	40.00	20.00
<i>Q. quadrula</i>	2.13	0.83	0.98	10.00	30.00	20.00
<i>O. olivaria</i>	0.00	1.10	0.98	0.00	30.00	15.00
<i>L. fragilis</i>	2.13	0.83	0.98	10.00	30.00	20.00
<i>C. tuberculata</i>	0.00	0.55	0.49	0.00	20.00	10.00
<i>M. nervosa</i>	0.00	0.28	0.24	0.00	10.00	5.00
<i>P. cyphus</i>	0.00	0.28	0.24	0.00	10.00	5.00
<i>L. recta</i>	0.00	0.28	0.24	0.00	10.00	5.00
<i>Q. nodulata</i>	0.00	0.28	0.24	0.00	10.00	5.00
Total individuals	47	362	409			
Total sites				10	10	20
Total species	8	16	16			
Species diversity	1.60	1.60	1.65			
Evenness	0.77	0.58	0.59			
Dominance	0.26	0.32	0.30			

Table 6
Percent Abundance and Percent Occurrence of Bivalves Collected at Farshore
Sites Downriver of Lock and Dam 53, Lower Ohio River, August 1992, Using
Quantitative Methods

Species	Percent Abundance				Percent Occurrence			
	RM 967.4	RM 967.5	RM 967.6	Total	RM 967.4	RM 967.5	RM 967.6	Total
<i>F. ebena</i>	66.78	39.13	53.05	54.94	100.00	100.00	100.00	100.00
<i>T. donaciformis</i>	11.86	22.83	27.01	20.38	100.00	100.00	100.00	100.00
<i>T. truncata</i>	5.76	5.98	5.14	5.57	80.00	70.00	80.00	76.67
<i>O. reflexa</i>	1.69	8.15	4.82	4.43	40.00	80.00	80.00	66.67
<i>E. lineolata</i>	5.42	5.98	1.29	3.92	80.00	60.00	40.00	60.00
<i>Q. p. pustulosa</i>	1.36	9.24	2.89	3.80	40.00	60.00	40.00	46.67
<i>Q. quadrula</i>	3.05	0.54	0.64	1.52	60.00	10.00	20.00	30.00
<i>L. fragilis</i>	0.68	2.72	0.64	1.14	20.00	40.00	20.00	26.67
<i>Q. metanevra</i>	0.34	1.63	1.61	1.14	10.00	30.00	30.00	23.33
<i>A. p. plicata</i>	0.68	1.09	0.32	0.63	20.00	20.00	10.00	16.67
<i>O. olivaria</i>	0.34	0.00	0.96	0.51	10.00	0.00	30.00	13.33
<i>C. tuberculata</i>	0.00	1.09	0.32	0.38	0.00	20.00	10.00	10.00
<i>L. recta</i>	0.68	0.00	0.00	0.25	20.00	0.00	0.00	6.67
<i>M. nervosa</i>	0.34	0.00	0.32	0.25	10.00	0.00	10.00	6.67
<i>Q. nodulata</i>	0.34	0.00	0.32	0.25	10.00	0.00	10.00	6.67
<i>A. Ligamentina</i>	0.00	1.09	0.00	0.25	0.00	20.00	0.00	6.67
<i>E. crassidens</i>	0.00	0.00	0.32	0.13	0.00	0.00	10.00	3.33
<i>D. polymorpha</i>	0.34	0.00	0.00	0.13	10.00	0.00	0.00	3.33
<i>T. verrucosa</i>	0.34	0.00	0.00	0.13	10.00	0.00	0.00	3.33
<i>P. alatus</i>	0.00	0.00	0.32	0.13	0.00	0.00	10.00	3.33
<i>P. cordatum</i>	0.00	0.54	0.00	0.13	0.00	10.00	0.00	3.33
Total individuals	295	184	311	790				
Total sites					10	10	10	40
Total species	16	13	16	21				
Species diversity	1.30	1.83	1.43	1.55				
Evenness	0.47	0.72	0.52	0.51				
Dominance	0.47	0.22	0.36	0.35				

Table 7
Summary Statistics for Data on Unionidae and *Corbicula fluminea*
Collected in the Lower Ohio River, RM 967.4, 967.5, and 967.6,
August 1992. Means with similar superscripts are not significantly
different ($P > 0.05$) (Density = Individuals/sq m; Biomass = g/sq m)

Parameter	Nearshore	Midshore	Farshore	Pr > F
Unionid density	15.0 ^b	81.8 ^a	105.2 ^a	0.0001
Standard error	2.4	16.4	8.8	
No. Unionid species/quadrat	2.4 ^b	5.3 ^a	6.1 ^a	0.0001
Unionid biomass	745.6 ^a	1,031.2 ^{ab}	1,459.7 ^a	0.0771
Standard error	226.4	277.3	191.6	
<i>C. fluminea</i> density	229.4 ^b	466.6 ^a	653.8 ^a	0.0004
Standard error	46.1	41.2	88.2	
<i>C. fluminea</i> biomass	224.5 ^b	506.1 ^b	830.1 ^a	0.0003
Standard error	47.1	35.0	132.6	

Appendix A

Results of Qualitative Sampling for Freshwater Mussels, Lower Ohio River, 1992

Table A1
Percent Abundance of Unionids Collected Using Qualitative
Sampling Methods Upriver of Lock and Dam 53, Ohio River Mile
957.8, August 1992

Species	Site 1	Site 2	Site 3	Total
<i>Q. p. pustulosa</i>	29.10	23.59	22.22	25.05
<i>Q. quadrula</i>	20.11	8.21	14.04	14.05
<i>F. ebena</i>	7.94	23.08	8.77	13.51
<i>E. lineolata</i>	8.47	14.87	8.19	10.63
<i>O. reflexa</i>	10.58	4.10	8.19	7.57
<i>A. p. plicata</i>	4.23	4.10	8.19	5.41
<i>Q. metanevra</i>	4.23	3.59	8.77	5.41
<i>P. alatus</i>	3.17	2.05	8.19	4.32
<i>L. fragilis</i>	1.59	5.64	3.51	3.60
<i>M. nervosa</i>	1.59	1.54	3.51	2.16
<i>T. verrucosa</i>	2.65	1.03	1.75	1.80
<i>C. tuberculata</i>	1.59	2.05	0.58	1.44
<i>T. truncata</i>	1.06	1.54	1.17	1.26
<i>P. cordatum</i>	1.06	1.54	0.58	1.08
<i>E. crassidens</i>	0.53	0.51	1.17	0.72
<i>O. olivaria</i>	1.06	1.03	0.00	0.72
<i>P. cyphus</i>	0.00	1.03	0.00	0.36
<i>L. complanata</i>	0.00	0.00	0.58	0.18
<i>L. teres</i>	0.00	0.00	0.58	0.18
<i>P. cooperianus</i>	0.00	0.51	0.00	0.18
<i>P. purpuratus</i>	0.53	0.00	0.00	0.18
<i>Q. nodulata</i>	0.53	0.00	0.00	0.18
Total individuals	189	195	171	555

Table A2
Percent Occurrence of Unionids Collected Using Qualitative
Sampling Methods Upriver of Lock and Dam 53, Ohio River Mile
957.8, August 1992

Species	Site 1	Site 2	Site 3	Total
<i>Q. p. pustulosa</i>	100.00	91.67	90.91	94.29
<i>Q. quadrula</i>	91.67	75.00	90.91	85.71
<i>F. ebena</i>	66.67	83.33	63.64	71.43
<i>E. lineolata</i>	66.67	75.00	63.64	68.57
<i>A. p. plicata</i>	58.33	58.33	63.64	60.00
<i>O. reflexa</i>	75.00	41.67	45.45	54.29
<i>Q. metanevra</i>	50.00	41.67	72.73	54.29
<i>P. alatus</i>	33.33	33.33	72.73	45.71
<i>L. fragilis</i>	25.00	58.33	18.18	34.29
<i>M. nervosa</i>	16.67	25.00	45.45	28.57
<i>T. verrucosa</i>	25.00	16.67	18.18	20.00
<i>C. tuberculata</i>	16.67	25.00	9.09	17.14
<i>T. truncata</i>	8.33	25.00	18.18	17.14
<i>P. cordatum</i>	16.67	16.67	9.09	14.29
<i>O. olivaria</i>	16.67	16.67	0.00	11.43
<i>E. crassidens</i>	8.33	8.33	9.09	8.57
<i>P. cyphus</i>	0.00	16.67	0.00	5.71
<i>L. complanata</i>	0.00	0.00	9.09	2.86
<i>L. teres</i>	0.00	0.00	9.09	2.86
<i>P. cooperianus</i>	0.00	8.33	0.00	2.86
<i>P. purpuratus</i>	8.33	0.00	0.00	2.86
<i>Q. nodulata</i>	8.33	0.00	0.00	2.86
Total samples	12	12	11	35

Table A3
Percent Species Abundance of Unionids Collected at the Olmsted
Mussel Bed Using Qualitative Sampling Methods, Ohio River Miles
966.4-969.4, Downriver of Lock and Dam 53, August 1992

Species	Location on Mussel Bed				
	RM 966.4	RM 967.4	RM 967.5	RM 969.3	Total
<i>F. ebena</i>	43.00	67.50	36.56	12.63	45.38
<i>E. lineolata</i>	7.25	11.00	7.53	11.58	9.24
<i>Q. quadrula</i>	10.14	4.50	9.68	15.79	9.08
<i>Q. p. pustulosa</i>	1.45	9.00	17.20	16.84	8.91
<i>C. tuberculata</i>	0.00	0.00	1.08	0.00	0.17
<i>A. p. plicata</i>	12.56	0.00	8.60	5.26	6.55
<i>M. nervosa</i>	11.11	0.00	1.08	3.16	4.54
<i>O. reflexa</i>	2.42	1.00	1.08	9.47	2.86
<i>L. fragilis</i>	2.42	1.50	1.08	5.26	2.35
<i>Q. metanevra</i>	0.00	3.00	7.53	6.32	3.19
<i>P. alatus</i>	4.83	0.00	2.15	1.05	2.18
<i>T. verrucosa</i>	2.42	0.00	0.00	1.05	1.01
<i>L. recta</i>	0.48	0.50	1.08	3.16	1.01
<i>L. ventricosa</i>	0.00	0.00	1.08	0.00	0.17
<i>O. olivaria</i>	1.45	0.50	0.00	1.05	0.84
<i>P. cordatum</i>	0.00	0.50	2.15	4.21	1.18
<i>E. crassidens</i>	0.00	0.50	2.11	2.11	0.50
<i>L. complanata</i>	0.48	0.00	0.00	0.00	0.17
<i>Q. nodulata</i>	0.00	0.50	2.15	0.00	0.50
<i>T. truncata</i>	0.00	0.00	0.00	1.05	0.17
Total individuals	207	200	93	95	595

Table A4
Percent Occurrence of Unionids Collected at the Olmsted Mussel
Bed Using Qualitative Sampling Methods, Ohio River Miles
966.4-969.4, Downriver of Lock and Dam 53, August 1992

Species	Location of Mussel Bed				
	RM 966.4	RM 967.4	RM 967.5	RM 969.3	Total
<i>F. ebena</i>	100.00	100.00	100.00	85.71	97.37
<i>Q. quadrula</i>	91.67	50.00	57.14	85.71	71.05
<i>E. lineolata</i>	66.67	66.67	57.14	71.43	65.79
<i>Q. p. pustulosa</i>	16.67	66.67	85.71	85.71	57.89
<i>C. tuberculata</i>	0.00	0.00	14.29	0.00	2.63
<i>A. p. plicata</i>	75.00	0.00	71.43	57.14	47.37
<i>L. fragilis</i>	33.33	25.00	14.29	57.14	31.58
<i>M. nervosa</i>	75.00	0.00	14.29	28.57	31.58
<i>O. reflexa</i>	41.67	16.67	14.29	57.14	31.58
<i>P. alatus</i>	66.67	0.00	28.57	14.29	28.95
<i>Q. metanevra</i>	0.00	41.67	71.43	57.14	36.84
<i>T. verrucosa</i>	41.67	0.00	0.00	14.29	15.79
<i>L. recta</i>	8.33	8.33	14.29	42.86	15.79
<i>L. ventricosa</i>	0.00	0.00	14.29	0.00	2.63
<i>P. cordatum</i>	0.00	8.33	28.57	57.14	18.42
<i>O. olivaria</i>	16.67	8.33	0.00	14.29	10.53
<i>E. crassidens</i>	0.00	8.33	0.00	28.57	7.89
<i>L. complanata</i>	8.33	0.00	0.00	0.00	2.63
<i>Q. nodulata</i>	0.00	8.33	28.57	0.00	7.89
<i>T. truncata</i>	0.00	0.00	0.00	14.29	2.63
Total samples	12	12	15	7	46

Appendix B
Length-Frequency Histograms for
Unionidae Collected in the Lower
Ohio River, 1992

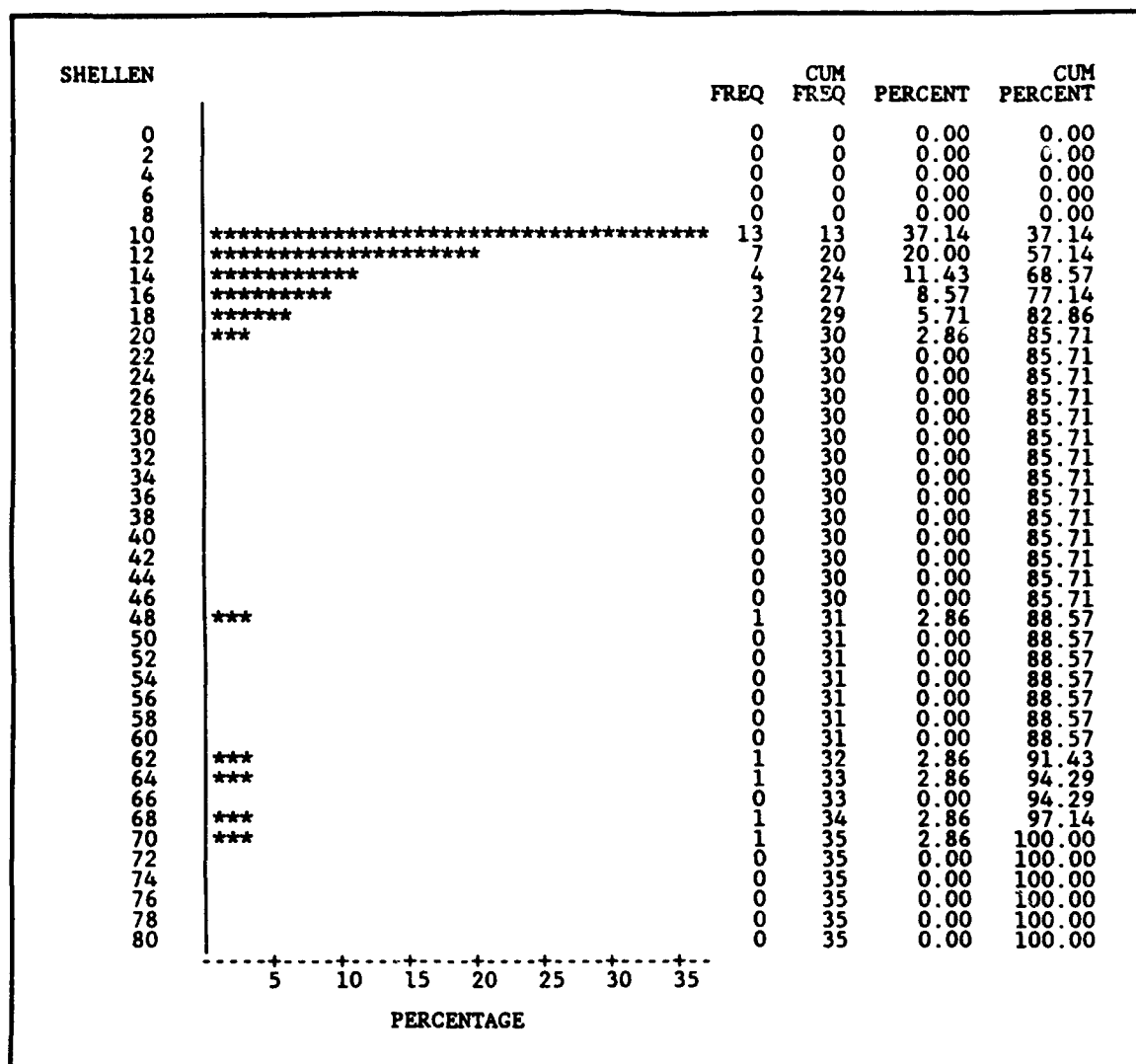


Figure B1. Length-frequency histogram for *Fusconaia ebena*, lower Ohio River Mile 957.7, nearshore and farshore sites combined, August 1992

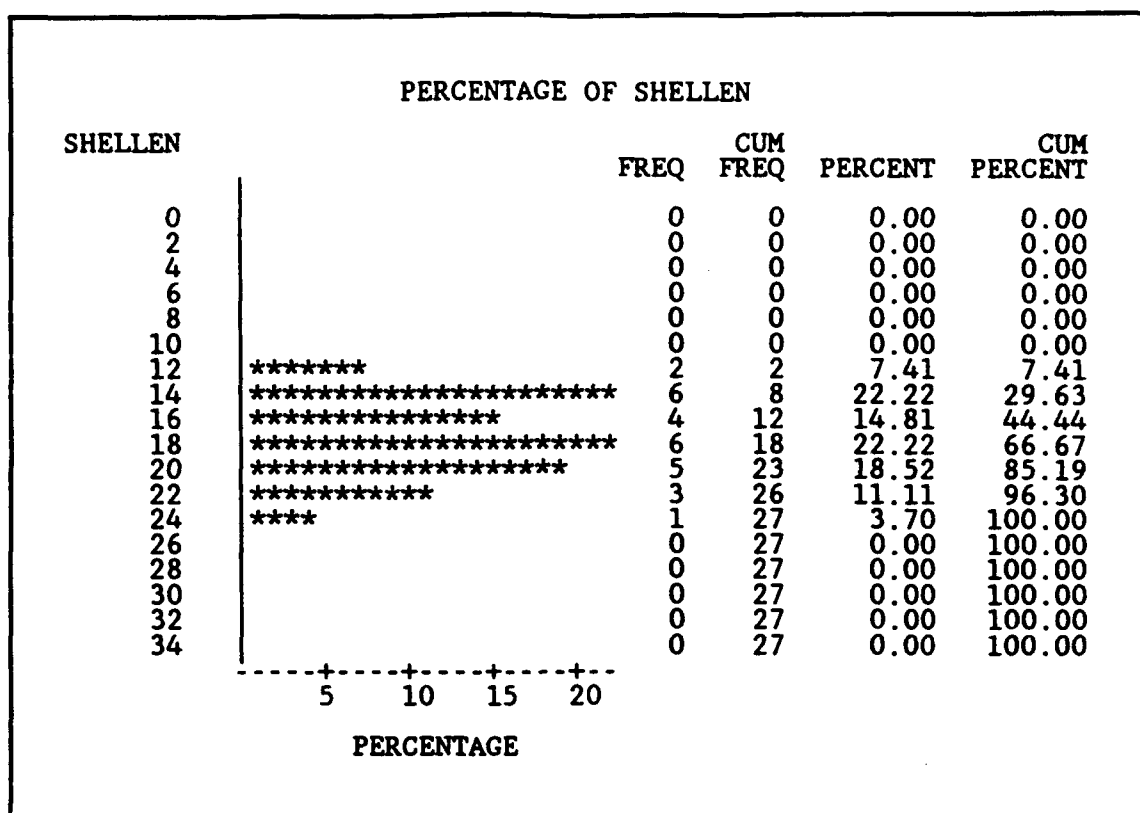


Figure B2. Length-frequency histogram for *Truncilla donaciformis*, lower Ohio River Mile 957.7, nearshore and farshore sites combined, August 1992

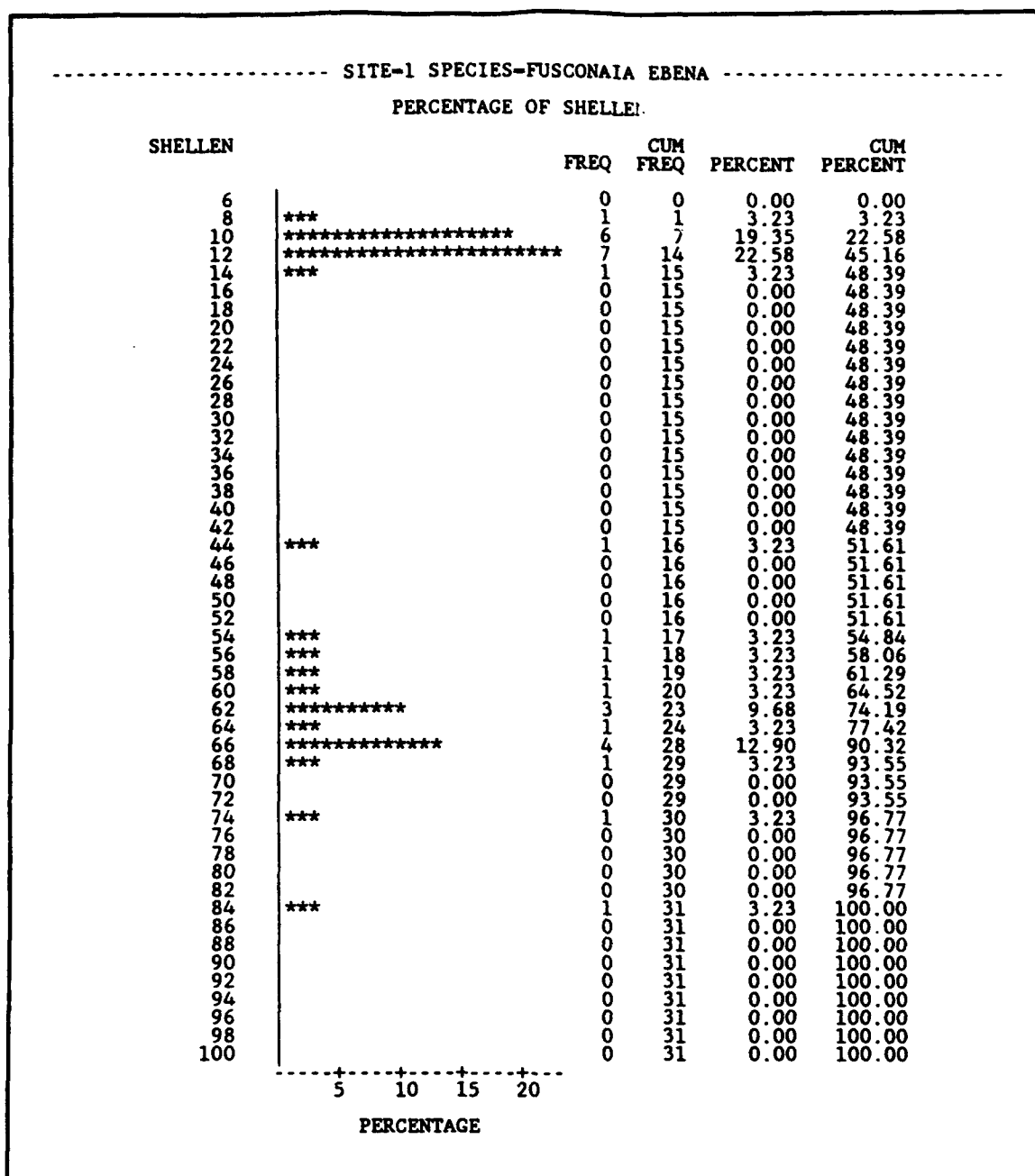


Figure B3. Length-frequency histogram for *Fusconaia ebena*, lower Ohio River Mile 967, nearshore site, August 1992 (includes RM 967.4, 967.5, and 967.6)

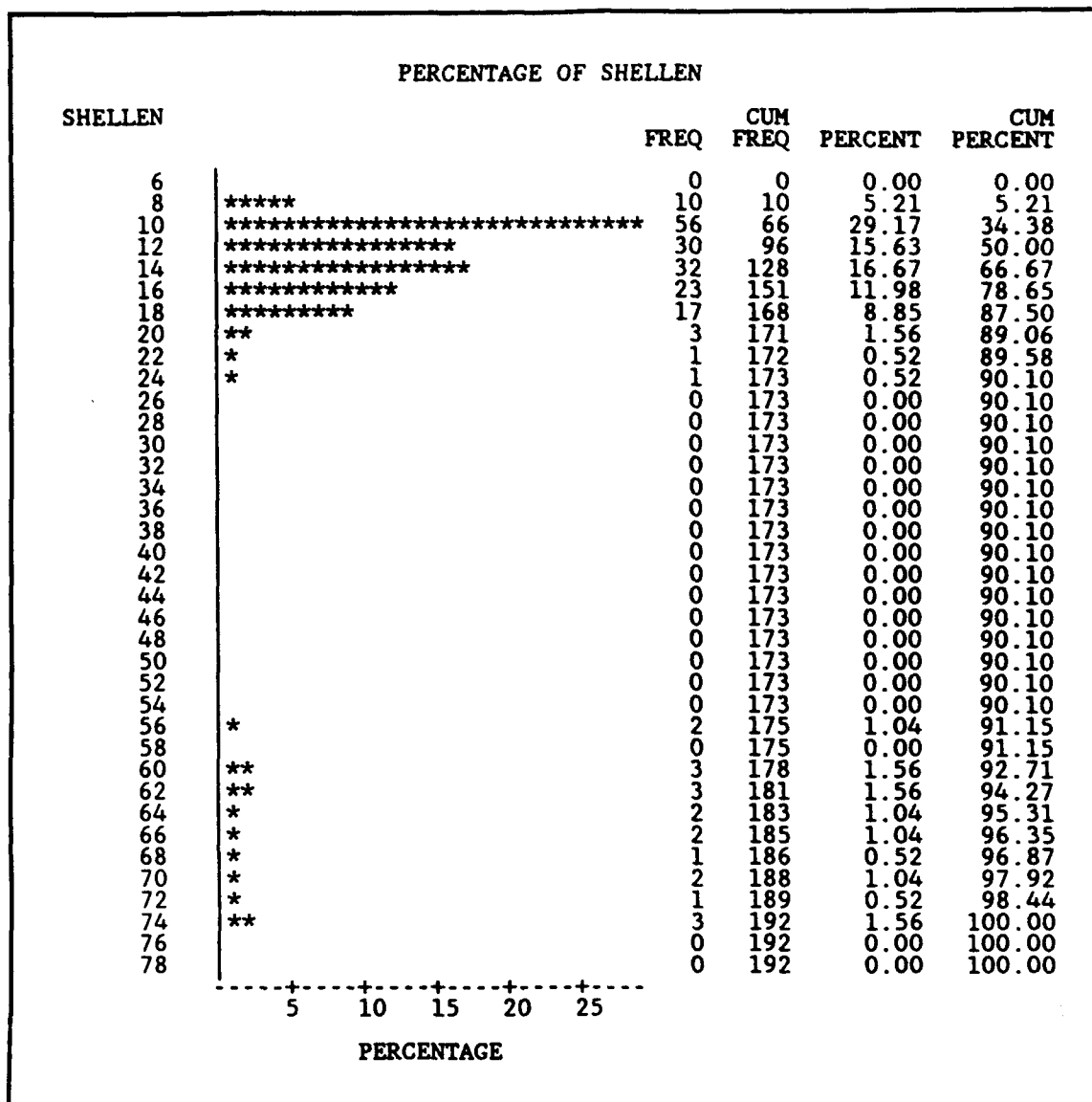


Figure B4. Length-frequency histogram for *Fusconaia ebena*, lower Ohio River Mile 967, midshore site, August 1992 (includes RM 967.4, 967.5, and 967.6)



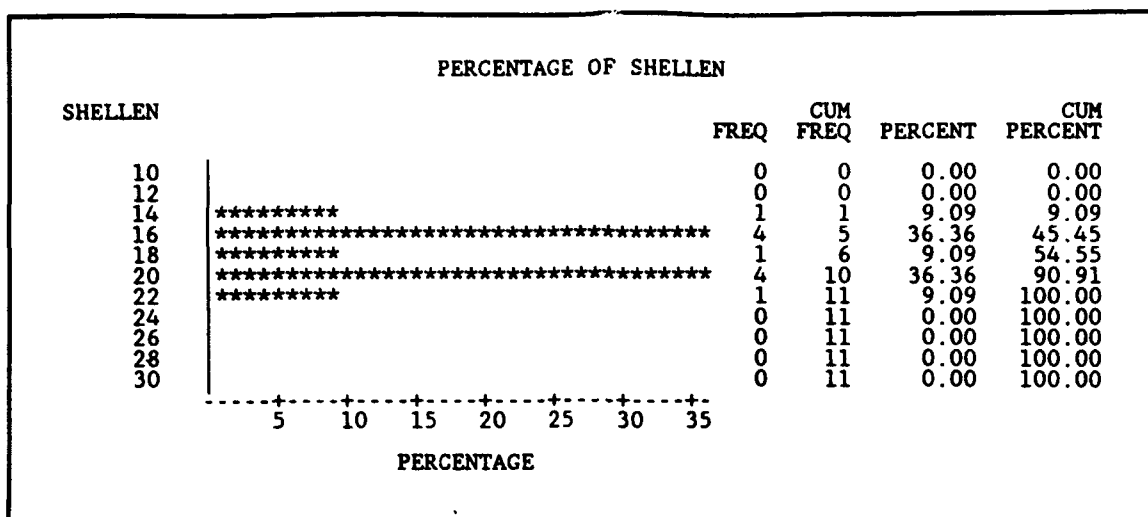


Figure B7. Length-frequency histogram for *Truncilla donaciformis*, lower Ohio River Mile 967, nearshore site, August 1992 (includes RM 967.4, 967.5, and 967.6)

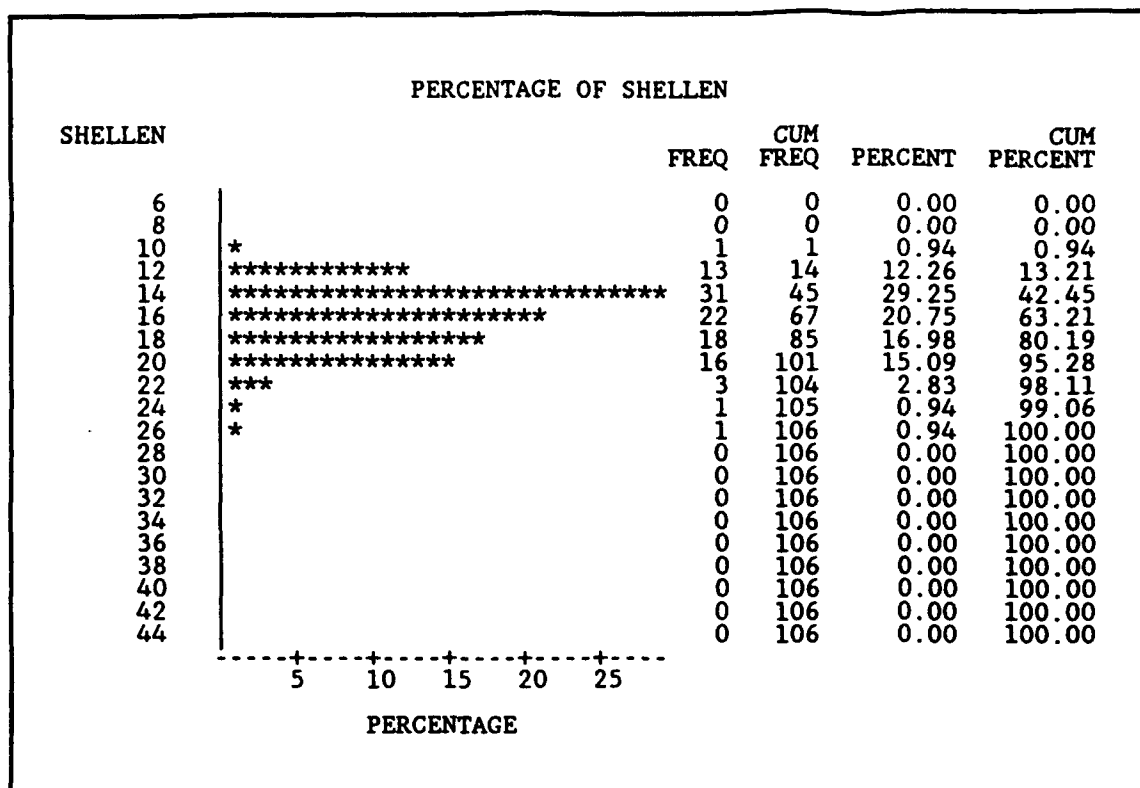


Figure B8. Length-frequency histogram for *Truncilla donaciformis*, lower Ohio River Mile 967, midshore site, August 1992 (includes RM 967.4, 967.5, and 967.6)

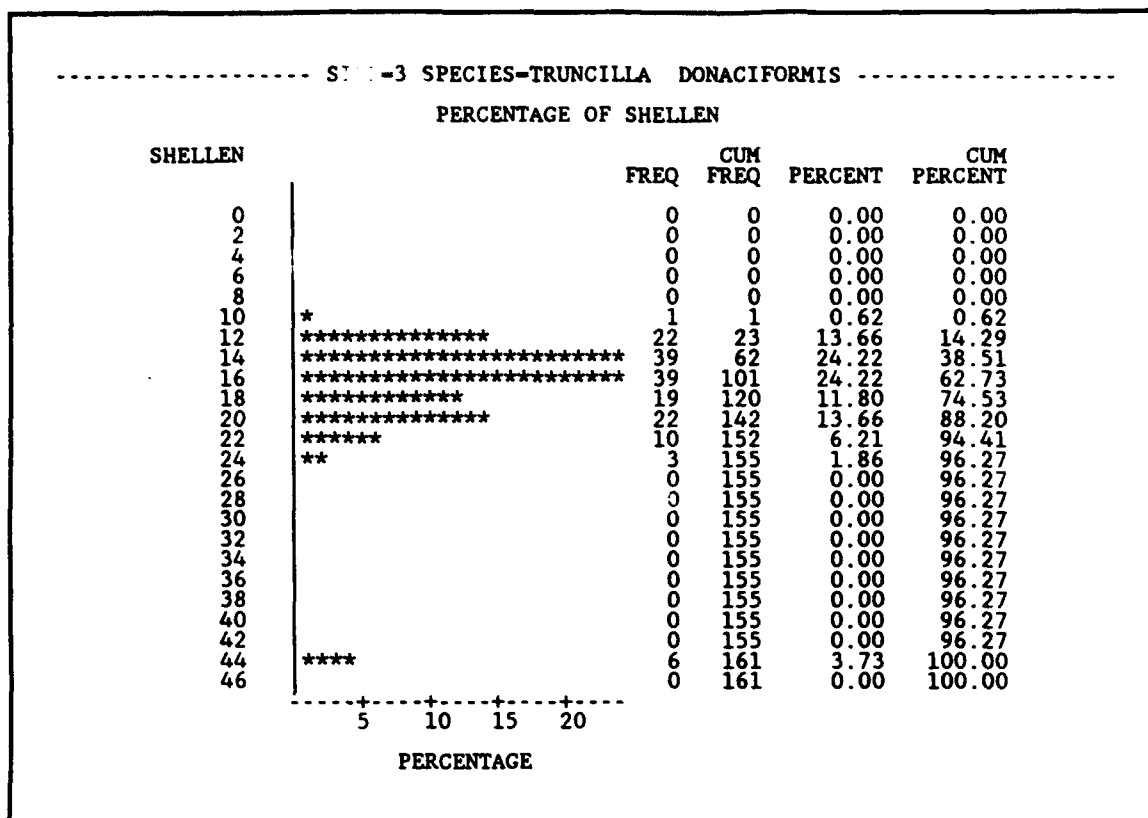


Figure B9. Length-frequency histogram for *Truncilla donaciformis*, lower Ohio River Mile 967, farshore site, August 1992 (includes RM 967.4, 967.5, and 967.6)

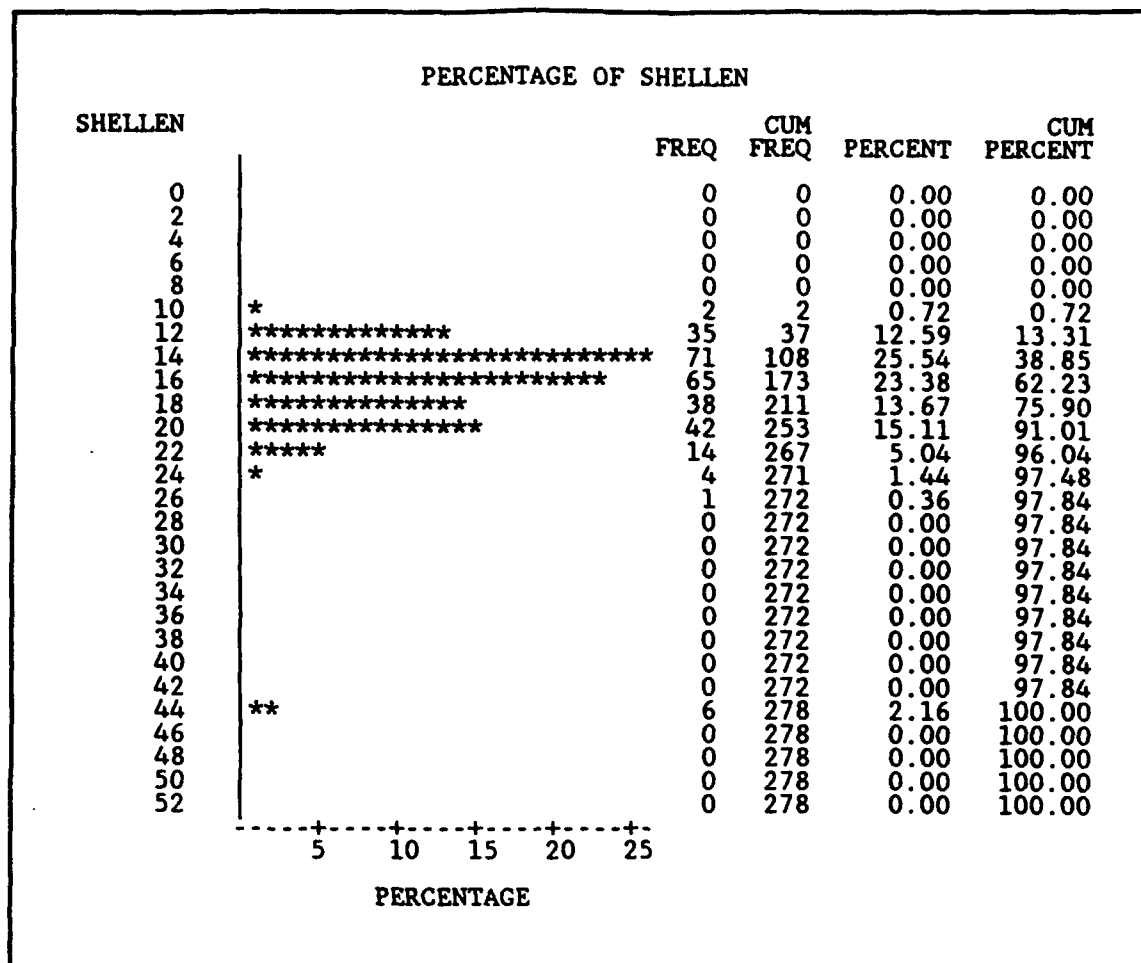


Figure B10. Length-frequency histogram for *Truncilla donaciformis*, lower Ohio River Mile 967, nearshore, midshore, and farshore sites combined, August 1992 (includes RM 967.4, 967.5, and 967.6)

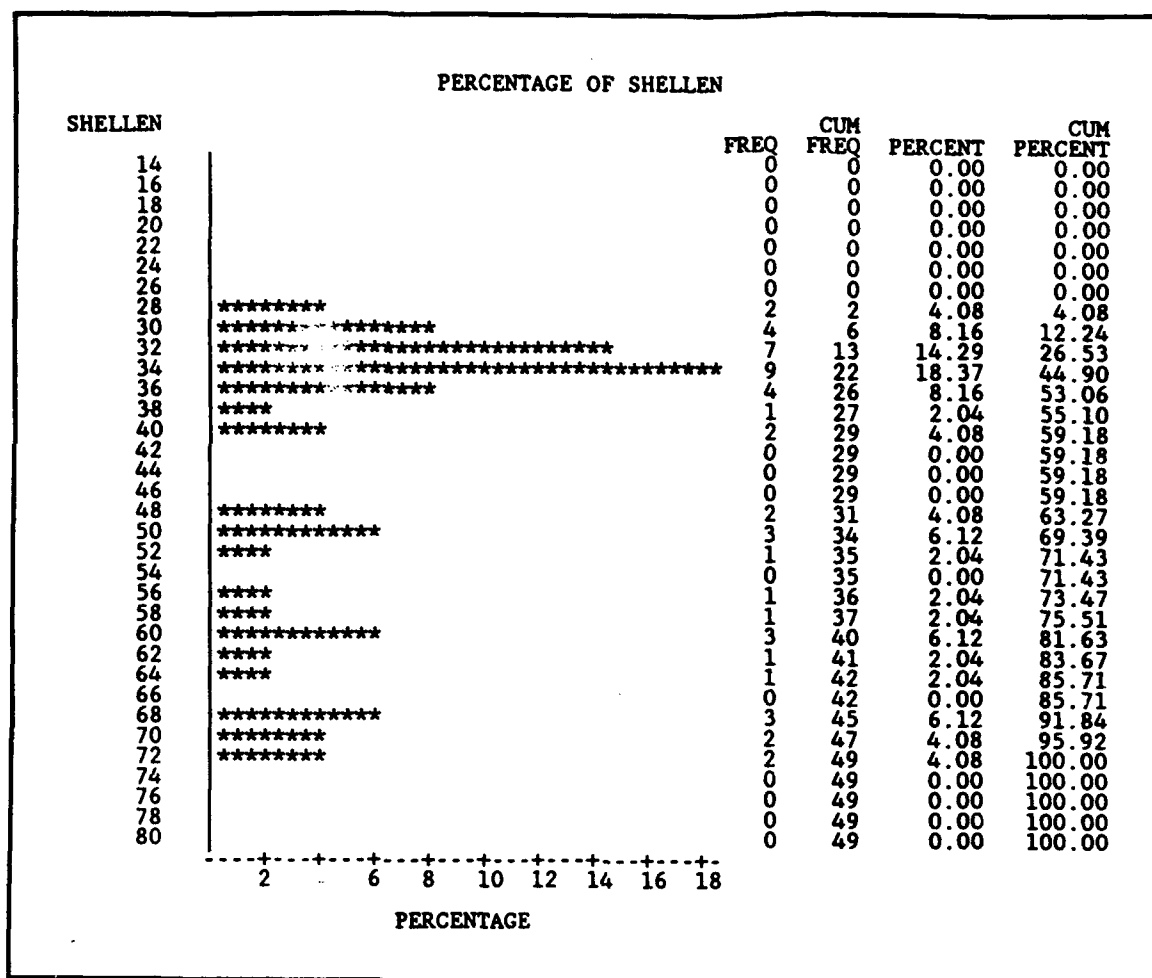


Figure B11. Length-frequency histogram for *Ellipsaria lineolata*, lower Ohio River Mile 967, nearshore, midshore, and farshore sites combined, August 1992 (includes RM 967.4, 967.5, and 967.6)

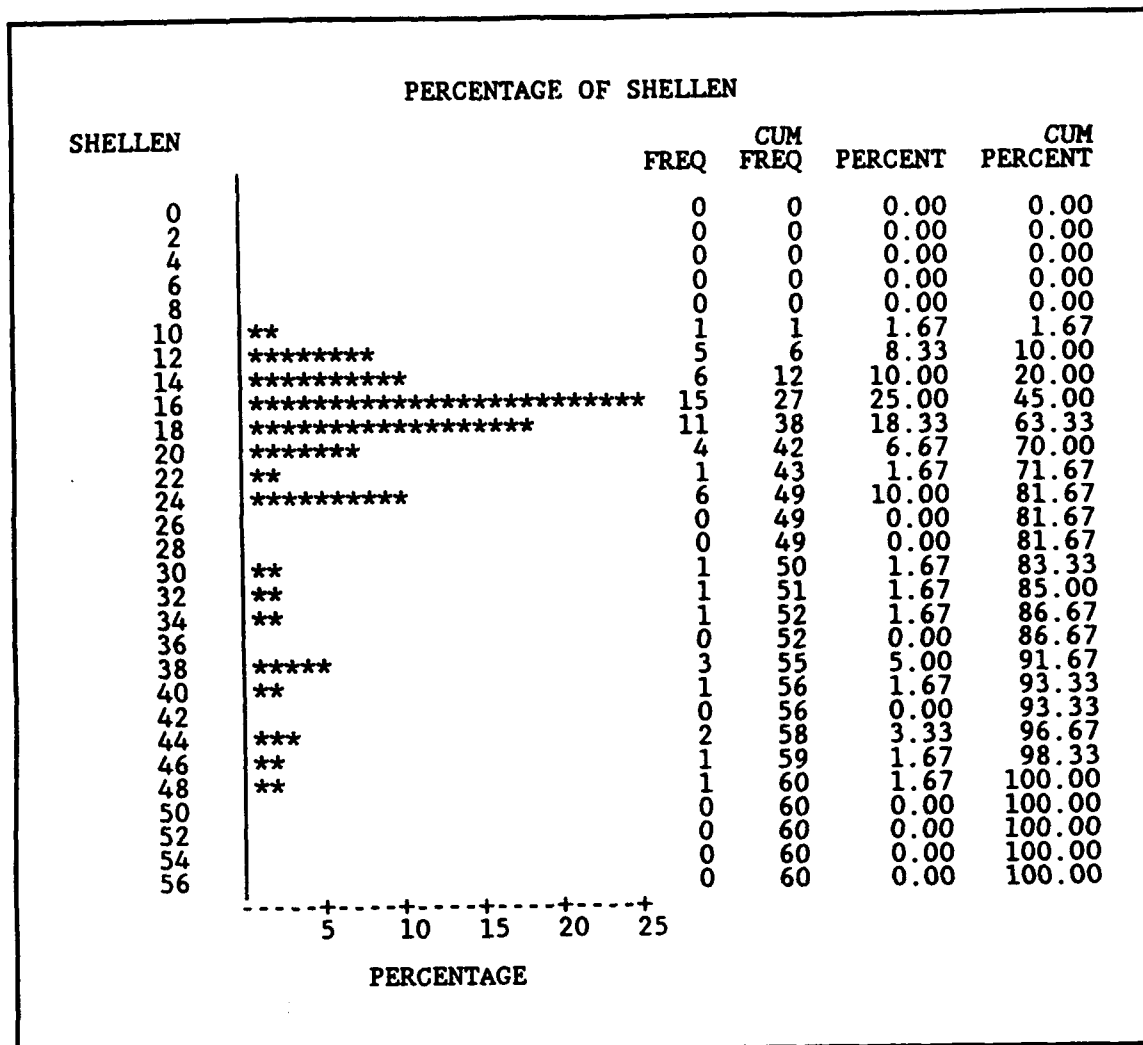


Figure B12. Length-frequency histogram for *Obliquaria reflexa*, lower Ohio River Mile 967, nearshore, midshore, and farshore sites combined, August 1992 (includes RM 967.4, 967.5, and 967.6)

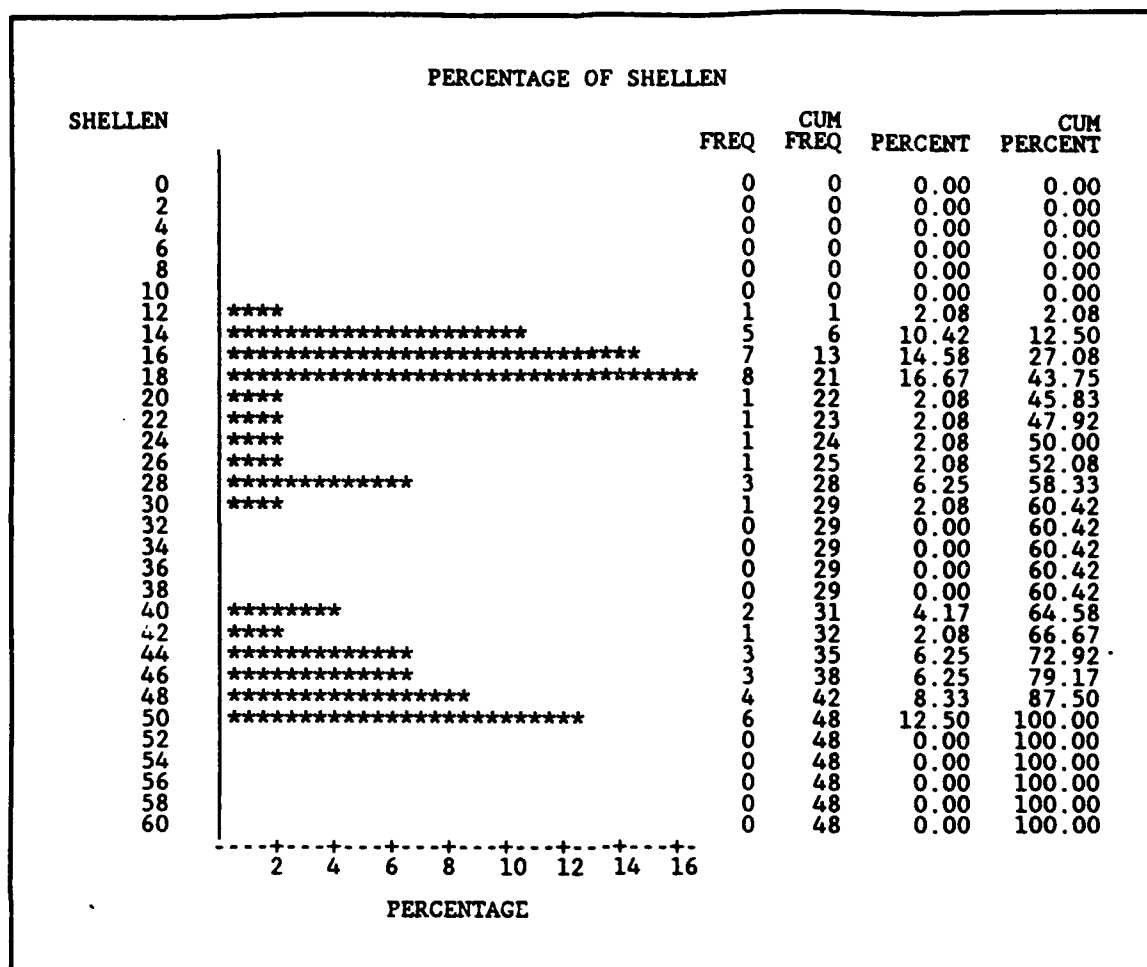


Figure B13. Length-frequency histogram for *Quadrula pustulosa*, lower Ohio River Mile 967, nearshore, midshore, and farshore sites combined, August 1992 (includes RM 967.4, 967.5, and 967.6)

Appendix C
Length-Frequency Histograms for
***Corbicula Fluminea*, Lower Ohio**
River, 1992

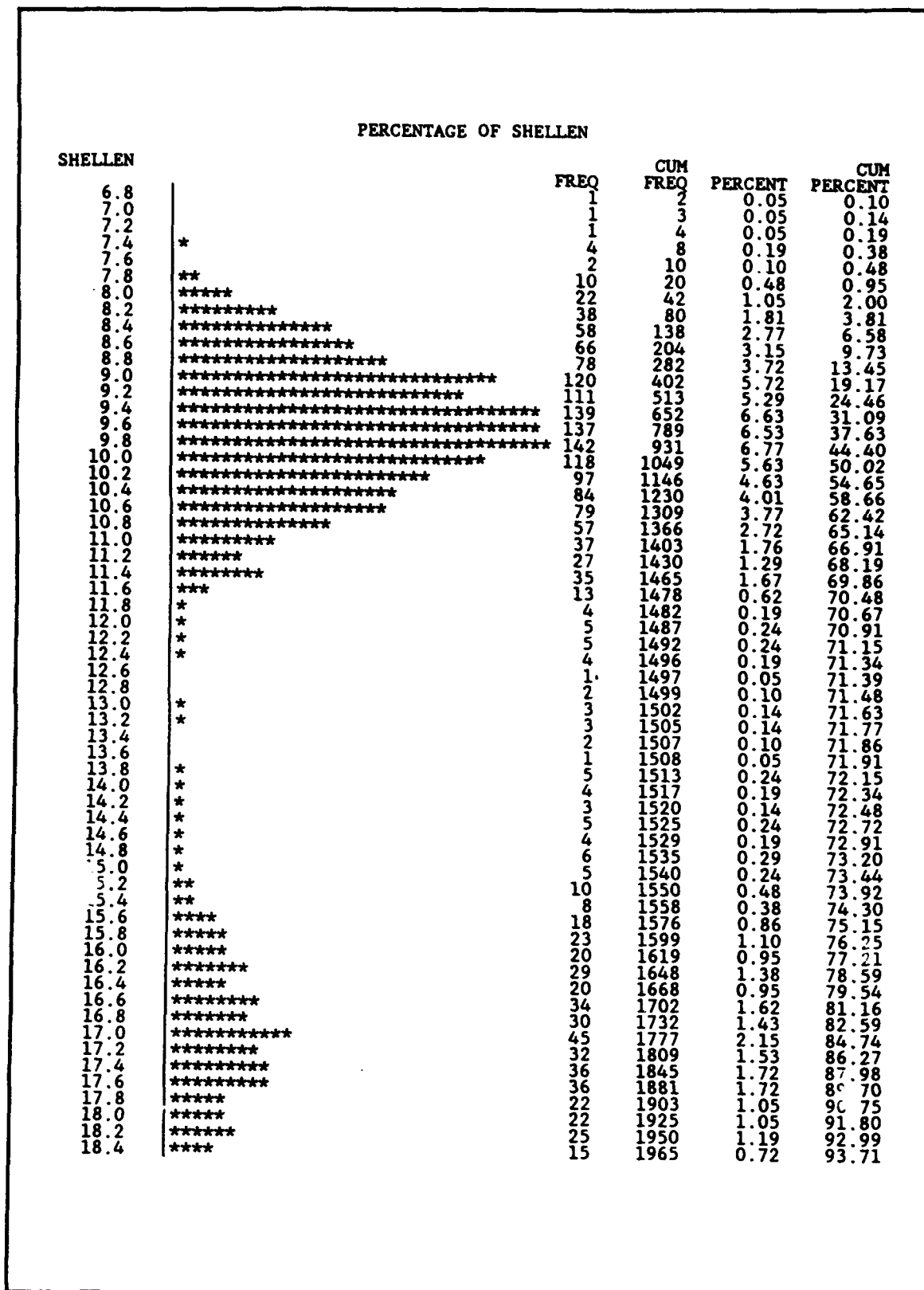


Figure C1. Length-frequency histogram for *Corbicula fluminea*, nearshore site, lower Ohio River Mile 957.7, 1992 (Continued)

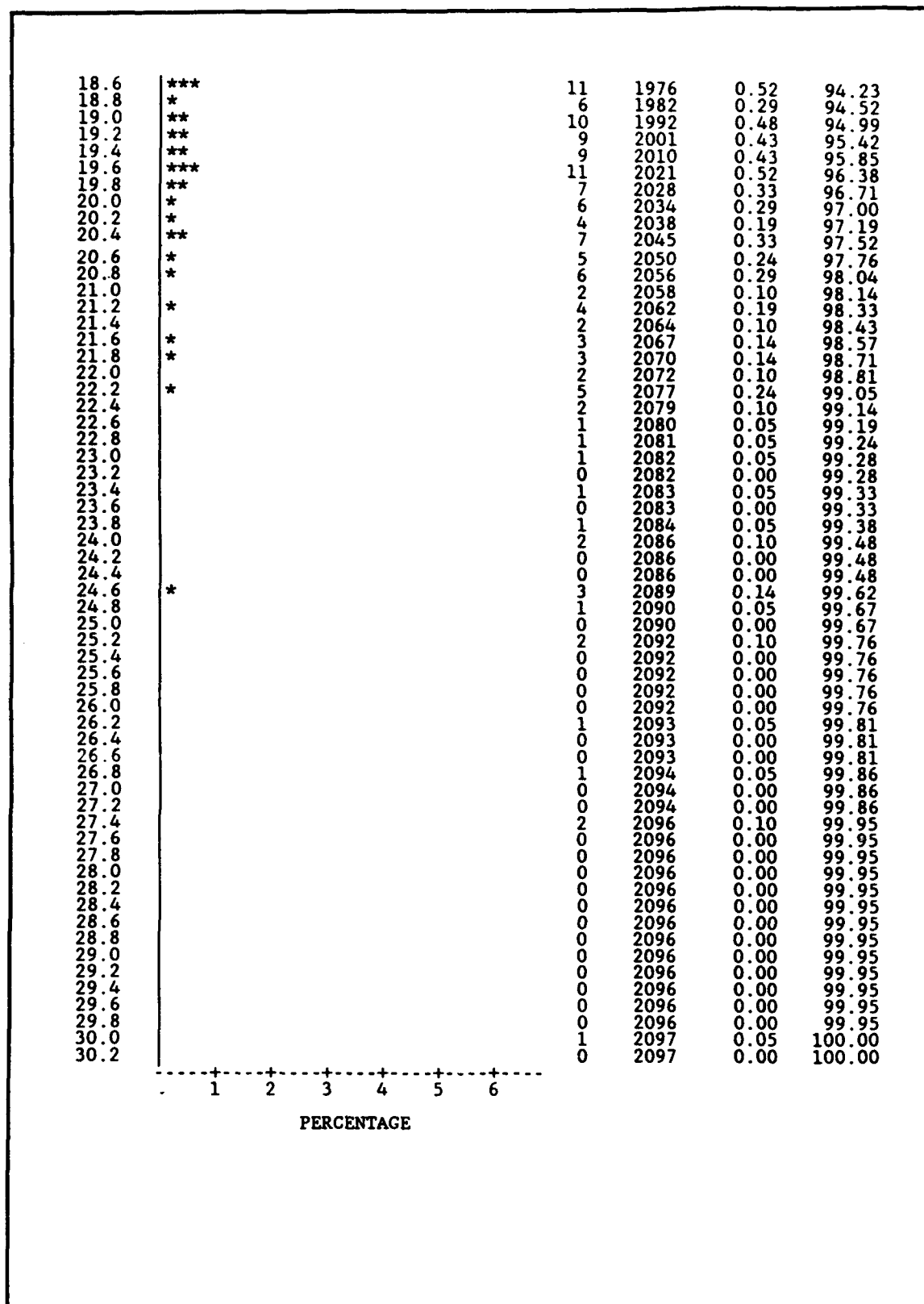


Figure C1. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.6		0	1	0.00	0.04
6.8		1	2	0.04	0.09
7.0		2	4	0.09	0.17
7.2		0	4	0.00	0.17
7.4	*	4	8	0.17	0.35
7.6	***	13	21	0.56	0.91
7.8	*****	22	43	0.95	1.86
8.0	*****	37	80	1.60	3.46
8.2	*****	66	146	2.85	6.31
8.4	*****	91	237	3.93	10.24
8.6	*****	119	356	5.14	15.38
8.8	*****	129	485	5.57	20.96
9.0	*****	123	608	5.32	26.27
9.2	*****	124	732	5.36	31.63
9.4	*****	133	865	5.75	37.38
9.6	*****	119	984	5.14	42.52
9.8	*****	104	1088	4.49	47.02
10.0	*****	74	1162	3.20	50.22
10.2	*****	93	1255	4.02	54.24
10.4	*****	68	1323	2.94	57.17
10.6	*****	45	1368	1.94	59.12
10.8	*****	36	1404	1.56	60.67
11.0	****	19	1423	0.82	61.50
11.2	****	19	1442	0.82	62.32
11.4	**	9	1451	0.39	62.71
11.6	*	6	1457	0.26	62.96
11.8	*	4	1461	0.17	63.14
12.0		0	1461	0.00	63.14
12.2		0	1461	0.00	63.14
12.4		2	1463	0.09	63.22
12.6		2	1465	0.09	63.31
12.8		0	1465	0.00	63.31
13.0		2	1467	0.09	63.40
13.2	*	3	1470	0.13	63.53
13.4		2	1472	0.09	63.61
13.6	*	3	1475	0.13	63.74
13.8	*	4	1479	0.17	63.92
14.0	*	5	1484	0.22	64.13
14.2	**	7	1491	0.30	64.43
14.4	*	6	1497	0.26	64.69
14.6	*	6	1503	0.26	64.95
14.8	***	13	1516	0.56	65.51
15.0	**	10	1526	0.43	65.95
15.2	***	13	1539	0.56	66.51
15.4	****	19	1558	0.82	67.33
15.6	***	16	1574	0.69	68.02
15.8	*****	32	1606	1.38	69.40
16.0	*****	39	1645	1.69	71.09
16.2	*****	41	1686	1.77	72.86
16.4	*****	58	1744	2.51	75.37
16.6	*****	59	1803	2.55	77.92
16.8	*****	51	1854	2.20	80.12
17.0	*****	47	1901	2.03	82.15
17.2	*****	47	1948	2.03	84.18
17.4	*****	45	1993	1.94	86.13

Figure C2. Length-frequency histogram for *Corbicula fluminea*, farshore site, lower Ohio River Mile 957.7, 1992 (Continued)

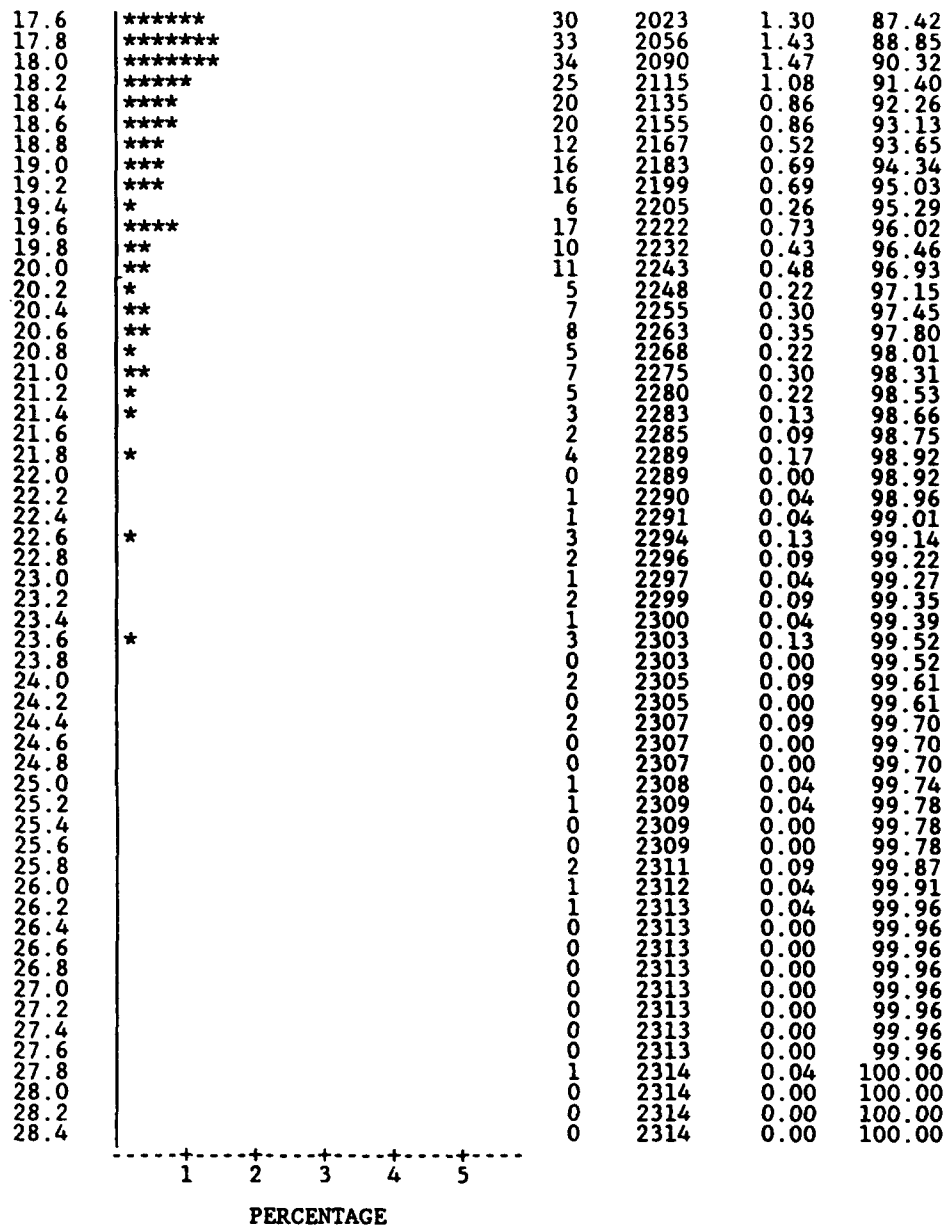


Figure C2. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.0		0	0	0.00	0.00
6.2		0	0	0.00	0.00
6.4		0	0	0.00	0.00
6.6		0	0	0.00	0.00
6.8		1	1	0.10	0.10
7.0		0	1	0.00	0.10
7.2		0	1	0.00	0.10
7.4	*	2	3	0.19	0.29
7.6	*****	9	12	0.86	1.15
7.8	*****	10	22	0.96	2.11
8.0	*****	31	53	2.97	5.07
8.2	*****	32	85	3.06	8.13
8.4	*****	48	133	4.59	12.73
8.6	*****	57	190	5.45	18.18
8.8	*****	61	251	5.84	24.02
9.0	*****	73	324	6.99	31.00
9.2	*****	1	395	6.79	37.80
9.4	*****	47	442	4.50	42.30
9.6	*****	63	505	6.03	48.33
9.8	*****	65	570	6.22	54.55
10.0	*****	60	633	6.03	60.57
10.2	*****	54	687	5.17	65.74
10.4	*****	28	715	2.68	68.42
10.6	*****	37	752	3.54	71.96
10.8	*****	34	786	3.25	75.22
11.0	*****	19	805	1.82	77.03
11.2	*****	22	827	2.11	79.14
11.4	*****	16	843	1.53	80.67
11.6	*****	9	852	0.86	81.53
11.8	**	5	857	0.48	82.01
12.0	**	4	861	0.38	82.39
12.2		1	862	0.10	82.49
12.4		0	862	0.00	82.49
12.6		1	863	0.10	82.58
12.8		1	864	0.10	82.68
13.0		1	865	0.10	82.78
13.2		1	866	0.10	82.87
13.4		0	866	0.00	82.87
13.6		0	866	0.00	82.87
13.8	*	2	868	0.19	83.06
14.0	*	2	870	0.19	83.25
14.2	*	2	872	0.19	83.44
14.4		0	872	0.00	83.44
14.6	*****	11	883	1.05	84.50
14.8	***	6	889	0.57	85.07
15.0	***	6	895	0.57	85.65
15.2	*****	2	907	1.15	86.79
15.4	****	8	915	0.77	87.56
15.6	*****	14	929	1.34	88.90
15.8	*****	16	945	1.53	90.43
16.0	*****	14	959	1.34	91.77
16.2	*****	12	971	1.15	92.92
16.4	*****	18	989	1.72	94.64
16.6	*****	11	1000	1.05	95.69
16.8	****	9	1009	0.86	96.56
17.0	***	6	1015	0.57	97.13
17.2	**	5	1020	0.48	97.61
17.4	*	3	1023	0.29	97.89
17.6	**	5	1028	0.48	98.37
17.8	*	3	1031	0.29	98.66
18.0		1	1032	0.10	98.76

Figure C3. Length-frequency histogram for *Corbicula fluminea*, nearshore site, lower Ohio River Mile 967.4, 1992 (Continued)

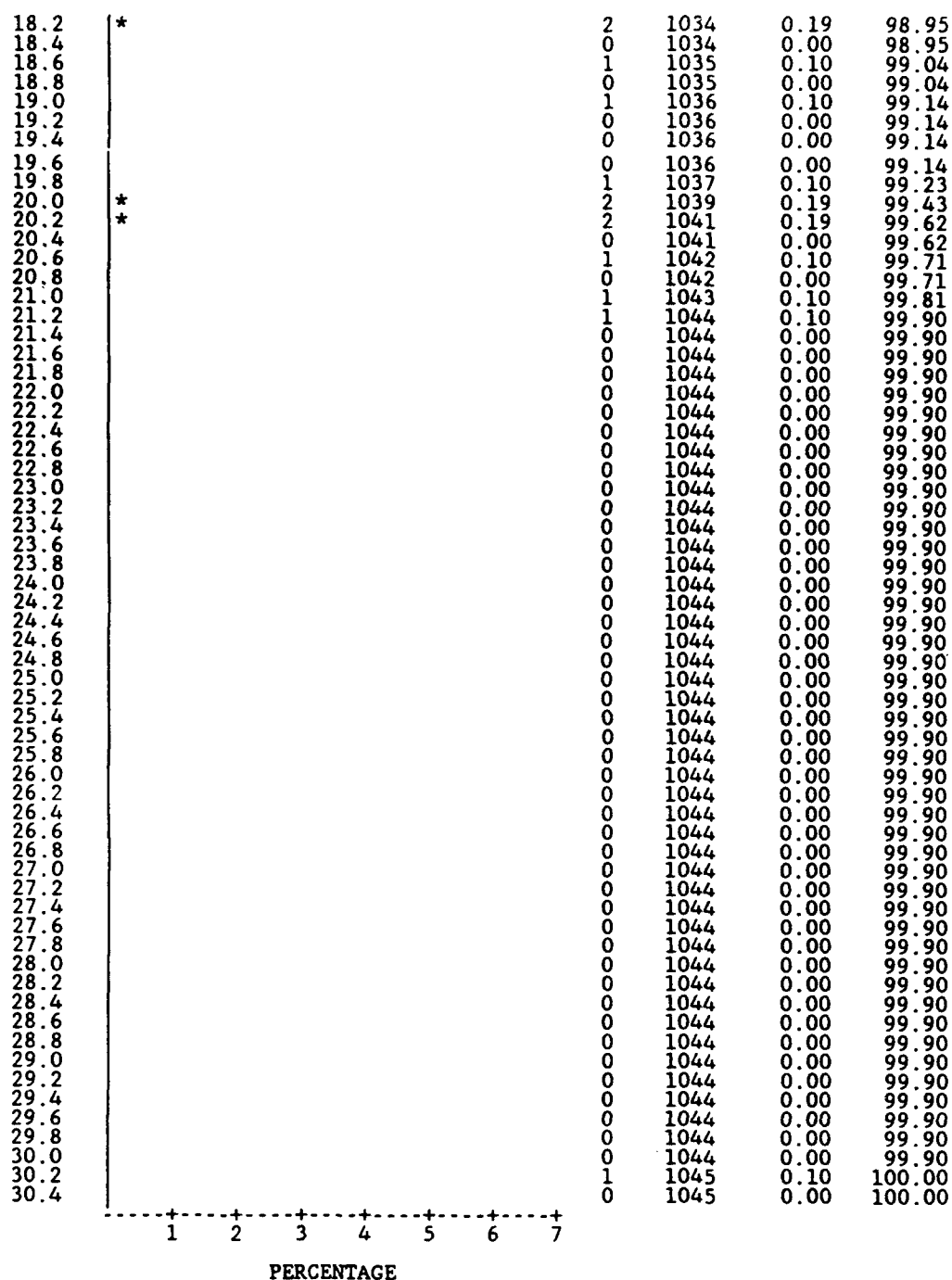


Figure C3. (Concluded)

SHELLEN		MIDSHORE SITE	FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.2			0	0	0.00	0.00
6.4			1	1	0.07	0.07
6.6			0	1	0.00	0.07
6.8			0	1	0.00	0.07
7.0	*		3	4	0.20	0.27
7.2			1	5	0.07	0.34
7.4	*		2	7	0.14	0.48
7.6	**		5	12	0.34	0.82
7.8	*****		14	26	0.95	1.77
8.0	*****		16	42	1.09	2.86
8.2	*****		40	82	2.72	5.57
8.4	*****		46	128	3.13	8.70
8.6	*****		61	189	4.15	12.85
8.8	*****		65	254	4.42	17.27
9.0	*****		77	331	5.23	22.50
9.2	*****		91	422	6.19	28.69
9.4	*****		85	507	5.78	34.47
9.6	*****		84	591	5.71	40.18
9.8	*****		74	665	5.03	45.21
10.0	*****		70	735	4.76	49.97
10.2	*****		61	796	4.15	54.11
10.4	*****		63	859	4.28	58.40
10.6	*****		52	911	3.54	61.93
10.8	*****		39	950	2.65	64.58
11.0	*****		35	985	2.38	66.96
11.2	*****		21	1006	1.43	68.39
11.4	*****		17	1023	1.16	69.54
11.6	*		3	1026	0.20	69.75
11.8	*		3	1029	0.20	69.95
12.0	*		3	1032	0.20	70.16
12.2			1	1033	0.07	70.22
12.4	*		3	1036	0.20	70.43
12.6			0	1036	0.00	70.43
12.8	*		3	1039	0.20	70.63
13.0			1	1040	0.07	70.70
13.2	*		2	1042	0.14	70.84
13.4			1	1043	0.07	70.90
13.6	*		4	1047	0.27	71.18
13.8	*		2	1049	0.14	71.31
14.0	*		3	1052	0.20	71.52
14.2	**		7	1059	0.48	71.99
14.4	***		13	1072	0.88	72.88
14.6	**		5	1077	0.34	73.22
14.8	***		8	1085	0.54	73.76
15.0	****		13	1098	0.88	74.64
15.2	*****		15	1113	1.02	75.66
15.4	*****		16	1129	1.09	76.75
15.6	*****		18	1147	1.22	77.97

Figure C4. Length-frequency histogram for *Corbicula fluminea*, midshore site, lower Ohio River Mile 967.4, 1992 (Continued)

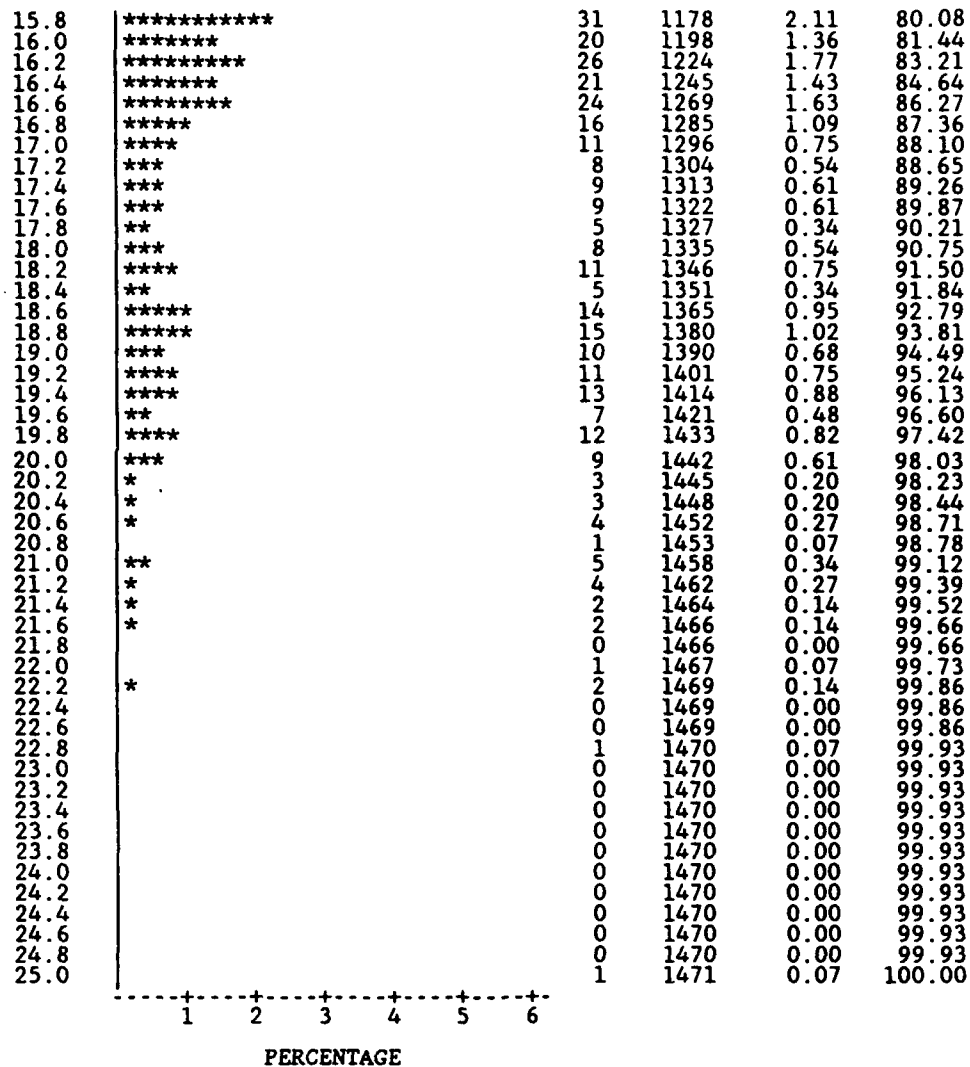


Figure C4. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.8		1	2	0.07	0.14
7.0	*	3	5	0.20	0.34
7.2	*	3	8	0.20	0.54
7.4		1	9	0.07	0.61
7.6	*	3	12	0.20	0.81
7.8	**	5	17	0.34	1.15
8.0	**	7	24	0.47	1.62
8.2	****	11	35	0.74	2.36
8.4	*****	18	53	1.22	3.58
8.6	*****	15	68	1.01	4.59
8.8	*****	30	98	2.03	6.62
9.0	*****	34	132	2.30	8.91
9.2	*****	60	192	4.05	12.96
9.4	*****	58	250	3.92	16.88
9.6	*****	58	308	3.92	20.80
9.8	*****	59	367	3.98	24.78
10.0	*****	68	435	4.59	29.37
10.2	*****	53	488	3.58	32.95
10.4	*****	62	550	4.19	37.14
10.6	*****	45	595	3.04	40.18
10.8	*****	48	643	3.24	43.42
11.0	*****	42	685	2.84	46.25
11.2	*****	38	723	2.57	48.82
11.4	*****	17	740	1.15	49.97
11.6	*****	16	756	1.08	51.05
11.8	*****	12	768	0.81	51.86
12.0	**	7	775	0.47	52.33
12.2	**	5	780	0.34	52.67
12.4	*	2	782	0.14	52.80
12.6		1	783	0.07	52.87
12.8	*	2	785	0.14	53.00
13.0		0	785	0.00	53.00
13.2		0	785	0.00	53.00
13.4	*	2	787	0.14	53.14
13.6		0	787	0.00	53.14
13.8		1	788	0.07	53.21
14.0	*	3	791	0.20	53.41
14.2	**	7	798	0.47	53.88
14.4	*	2	800	0.14	54.02
14.6	**	7	807	0.47	54.49
14.8	**	5	812	0.34	54.83
15.0	**	5	817	0.34	55.17
15.2	****	12	829	0.81	55.98
15.4	****	12	841	0.81	56.79
15.6	*****	14	855	0.95	57.73
15.8	*****	25	880	1.69	59.42
16.0	*****	27	907	1.82	61.24
16.2	*****	21	928	1.42	62.66
16.4	*****	33	961	2.23	64.89
16.6	*****	26	987	1.76	66.64
16.8	*****	34	1021	2.30	68.94
17.0	*****	27	1048	1.82	70.76
17.2	*****	31	1079	2.09	72.86
17.4	*****	34	1113	2.30	75.15
17.6	*****	21	1134	1.42	76.57
17.8	*****	21	1155	1.42	77.99

Figure C5. Length-frequency histogram for *Corbicula fluminea*, farshore site, lower Ohio River Mile 967.4, 1992 (quadrats 1-5 only) (Continued)

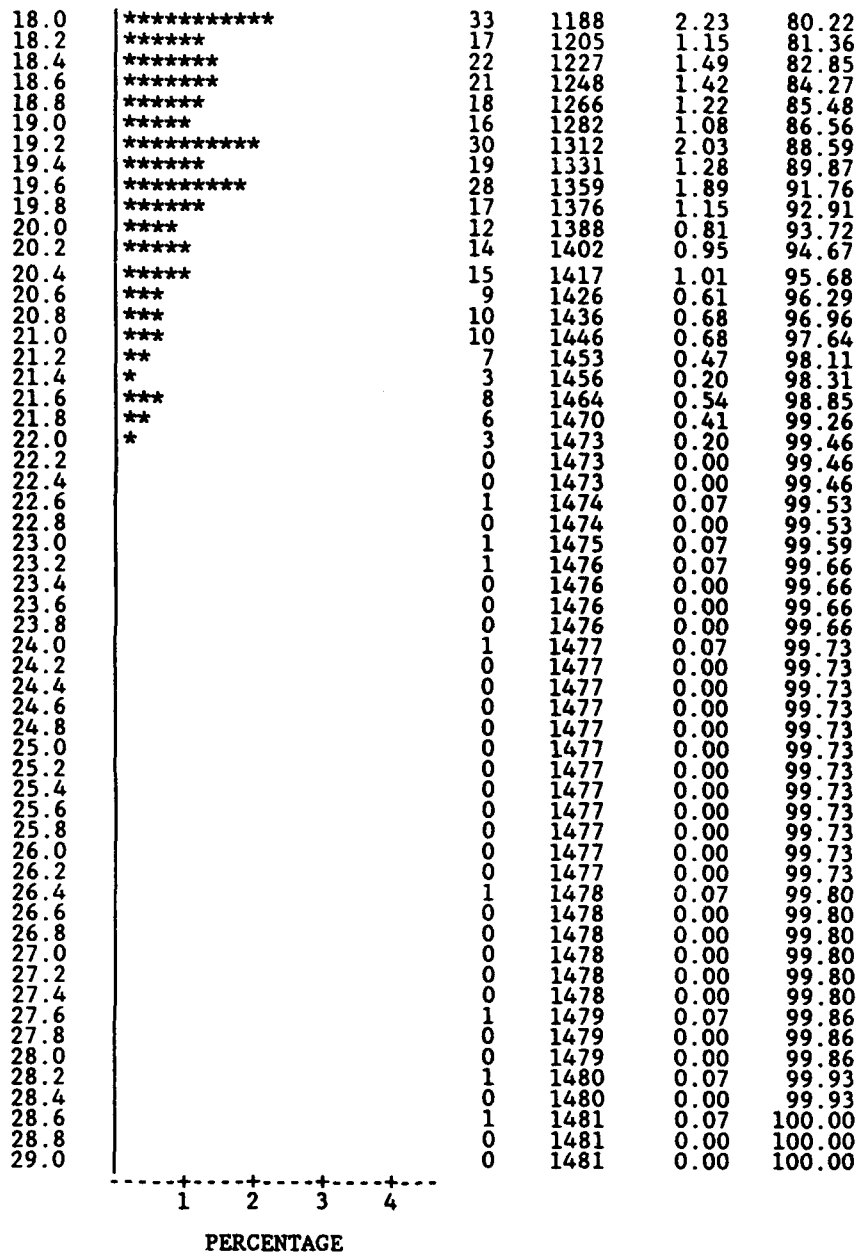


Figure C5. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
7.0		0	0	0.00	0.00
7.2	**	1	1	0.98	0.98
7.4		0	1	0.00	0.98
7.6		0	1	0.00	0.98
7.8	**	1	2	0.98	1.96
8.0	****	2	4	1.96	3.92
8.2	*****	6	10	5.88	9.80
8.4	*****	8	18	7.84	17.65
8.6	*****	4	22	3.92	21.57
8.8		0	22	0.00	21.57
9.0		0	22	0.00	21.57
9.2	*****	4	26	3.92	25.49
9.4	*****	10	36	9.80	35.29
9.6	*****	3	39	2.94	38.24
9.8	*****	3	42	2.94	41.18
10.0	**	1	43	0.98	42.16
10.2	****	2	45	1.96	44.12
10.4	****	2	47	1.96	46.08
10.6	*****	5	52	4.90	50.98
10.8	*****	3	55	2.94	53.92
11.0	*****	6	61	5.88	59.80
11.2	**	1	62	0.98	60.78
11.4	*****	4	66	3.92	64.71
11.6	*****	4	70	3.92	68.63
11.8	****	2	72	1.96	70.59
12.0		0	72	0.00	70.59
12.2	****	2	74	1.96	72.55
12.4		0	74	0.00	72.55
12.6		0	74	0.00	72.55
12.8	**	1	75	0.98	73.53
13.0	****	2	77	1.96	75.49
13.2		0	77	0.00	75.49
13.4	**	1	78	0.98	76.47
13.6	****	2	80	1.96	78.43
13.8	**	1	81	0.98	79.41
14.0		0	81	0.00	79.41
14.2	*****	3	84	2.94	82.35
14.4	****	2	86	1.96	84.31
14.6	**	1	87	0.98	85.29
14.8	**	1	88	0.98	86.27
15.0	**	1	89	0.98	87.25
15.2	**	1	90	0.98	88.24
15.4	****	2	92	1.96	90.20

Figure C6. Length-frequency histogram for *Corbicula fluminea*, nearshore site, lower Ohio River Mile 967.5, 1992 (Continued)

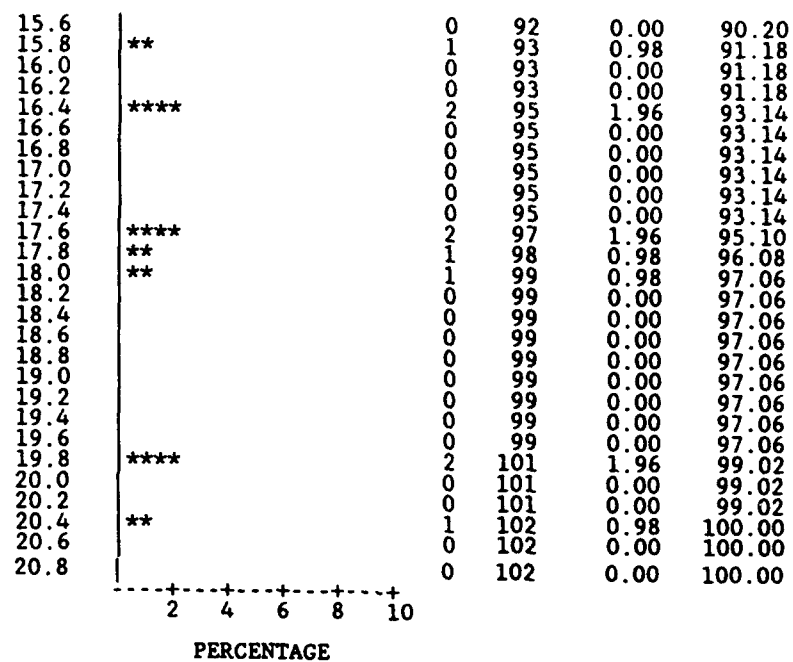


Figure C6. (Concluded)

PERCENTAGE OF SHELLS				
SHELLS		FREQ	CUM FREQ	PERCENT
5.2		0	0	0.00
5.4		0	0	0.00
5.6	*	1	1	0.12
5.8		0	1	0.00
6.0		0	1	0.00
6.2		0	1	0.00
6.4		0	1	0.00
6.6		0	1	0.00
6.8	*	0	1	0.00
7.0	**	1	2	0.12
7.2	*	3	5	0.35
7.4	*	1	6	0.12
7.6	**	1	7	0.12
7.8	****	3	10	0.35
8.0	****	7	17	0.81
8.2	*****	10	24	0.81
8.4	*****	18	34	1.16
8.6	*****	28	52	2.09
8.8	*****	28	80	3.25
9.0	*****	11	91	1.28
9.2	*****	20	111	2.32
9.4	*****	33	144	3.83
9.6	*****	31	175	3.60
9.8	*****	38	213	4.41
10.0	*****	30	243	3.48
10.2	*****	27	270	3.13
10.4	*****	45	315	5.22
10.6	*****	37	352	4.29
10.8	*****	36	388	4.18
11.0	*****	33	421	3.83
11.2	*****	23	444	2.67
11.4	*****	27	471	3.13
11.6	*****	19	490	2.20
11.8	**	10	500	1.16
12.0	**	3	503	0.35
12.2	**	3	506	0.35
12.4	*	3	509	0.35
12.6	*	1	510	0.12
12.8	**	1	511	0.12
13.0		3	514	0.35
13.2		0	514	0.00
13.4	*	0	514	0.00
13.6		2	516	0.23
13.8	**	0	516	0.00
14.0		3	519	0.35
14.2	*	0	519	0.00
14.4	**	2	521	0.23
14.6	**	4	525	0.46
14.8	**	3	528	0.35
15.0	***	3	531	0.35
15.2	***	5	536	0.58
15.4	*****	5	541	0.58
15.6	*****	8	549	0.93
15.8	*****	8	557	0.93
16.0	*****	16	573	1.86
16.2	*****	15	588	1.74
16.4	*****	20	608	2.32
16.6	*****	17	625	1.97
16.8	*****	14	639	1.62
17.0	*****	15	654	1.74
17.2	*****	12	666	1.39
17.4	*****	17	683	1.97
		16	699	1.86

Figure C7. Length-frequency histogram for *Corbicula fluminea*, midshore site, lower Ohio River Mile 967.5, 1992 (Continued)

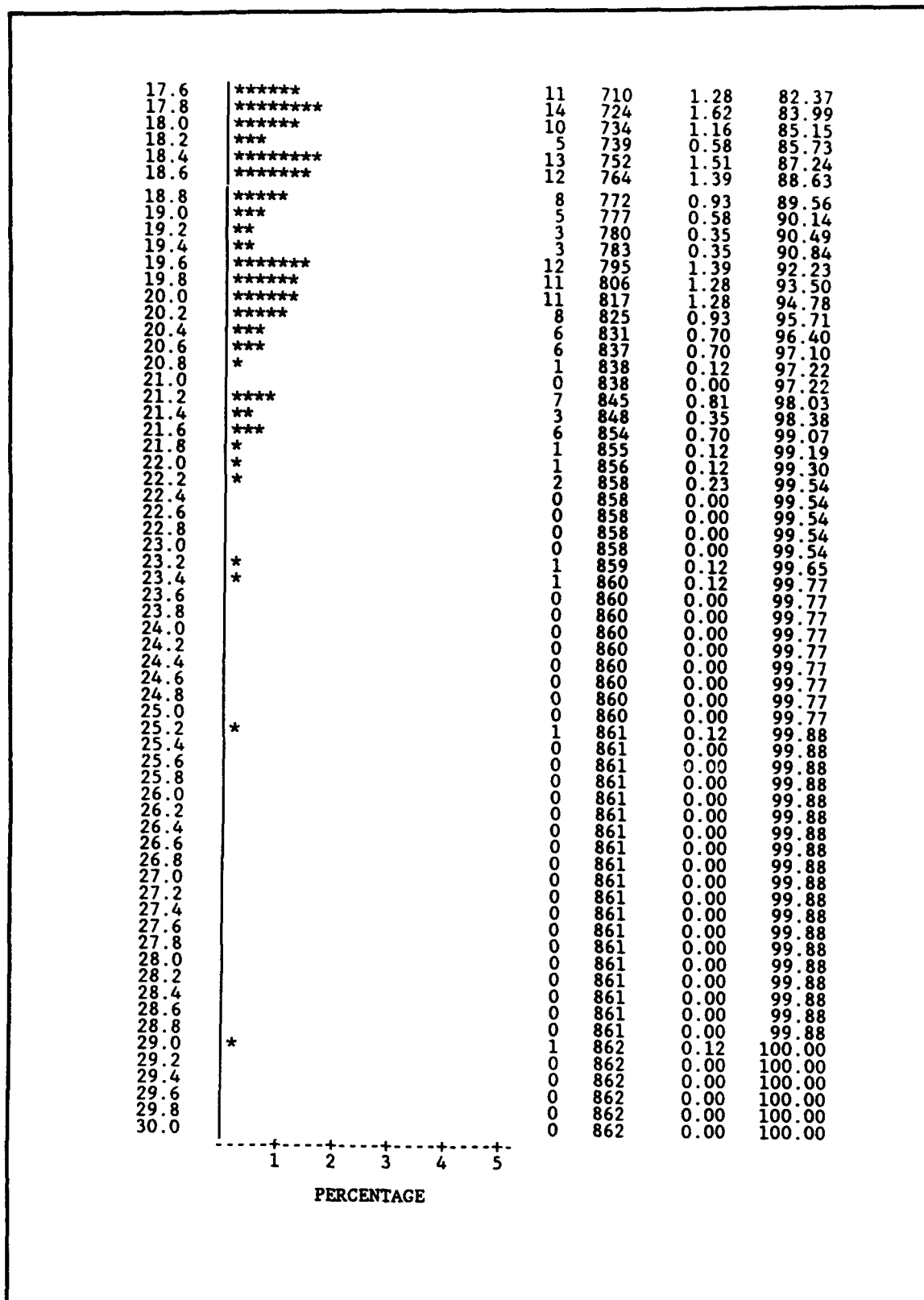


Figure C7. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.4		0	3	0.00	0.22
6.6		1	4	0.07	0.29
6.8		1	5	0.07	0.36
7.0		0	5	0.00	0.36
7.2	*	2	7	0.14	0.50
7.4	*	2	9	0.14	0.65
7.6	**	5	14	0.36	1.01
7.8	***	8	22	0.58	1.58
8.0	****	10	32	0.72	2.30
8.2	*****	14	46	1.01	3.31
8.4	*****	31	77	2.23	5.54
8.6	*****	32	109	2.30	7.85
8.8	*****	29	138	2.09	9.94
9.0	*****	51	189	3.67	13.61
9.2	*****	45	234	3.24	16.85
9.4	*****	63	297	4.54	21.38
9.6	*****	63	360	4.54	25.92
9.8	*****	58	418	4.18	30.09
10.0	*****	61	479	4.39	34.49
10.2	*****	69	548	4.97	39.45
10.4	*****	56	604	4.03	43.48
10.6	*****	49	653	3.53	47.01
10.8	*****	34	687	2.45	49.46
11.0	*****	34	721	2.45	51.91
11.2	*****	29	750	2.09	54.00
11.4	*****	26	776	1.87	55.87
11.6	*****	21	797	1.51	57.38
11.8	****	10	807	0.72	58.10
12.0	**	5	812	0.36	58.46
12.2		1	813	0.07	58.53
12.4	*	2	815	0.14	58.68
12.6		1	816	0.07	58.75
12.8	*	2	818	0.14	58.89
13.0	*	2	820	0.14	59.04
13.2		1	821	0.07	59.11
13.4		0	821	0.00	59.11
13.6		1	822	0.07	59.18
13.8	*	2	824	0.14	59.32
14.0	***	8	832	0.58	59.90
14.2	**	6	838	0.43	60.33
14.4	*	3	841	0.22	60.55
14.6	***	8	849	0.58	61.12
14.8	****	11	860	0.79	61.92
15.0	*****	19	879	1.37	63.28
15.2	*****	20	899	1.44	64.72
15.4	*****	18	917	1.30	66.02
15.6	*****	32	949	2.30	68.32
15.8	*****	33	982	2.38	70.70
16.0	*****	25	1007	1.80	72.50
16.2	*****	20	1027	1.44	73.94
16.4	*****	24	1051	1.73	75.67
16.6	*****	28	1079	2.02	77.68
16.8	*****	19	1098	1.37	79.05
17.0	****	12	1110	0.86	79.91

Figure C8. Length-frequency histogram for *Corbicula fluminea*, farshore site, lower Ohio River Mile 967.5, 1992 (Continued)

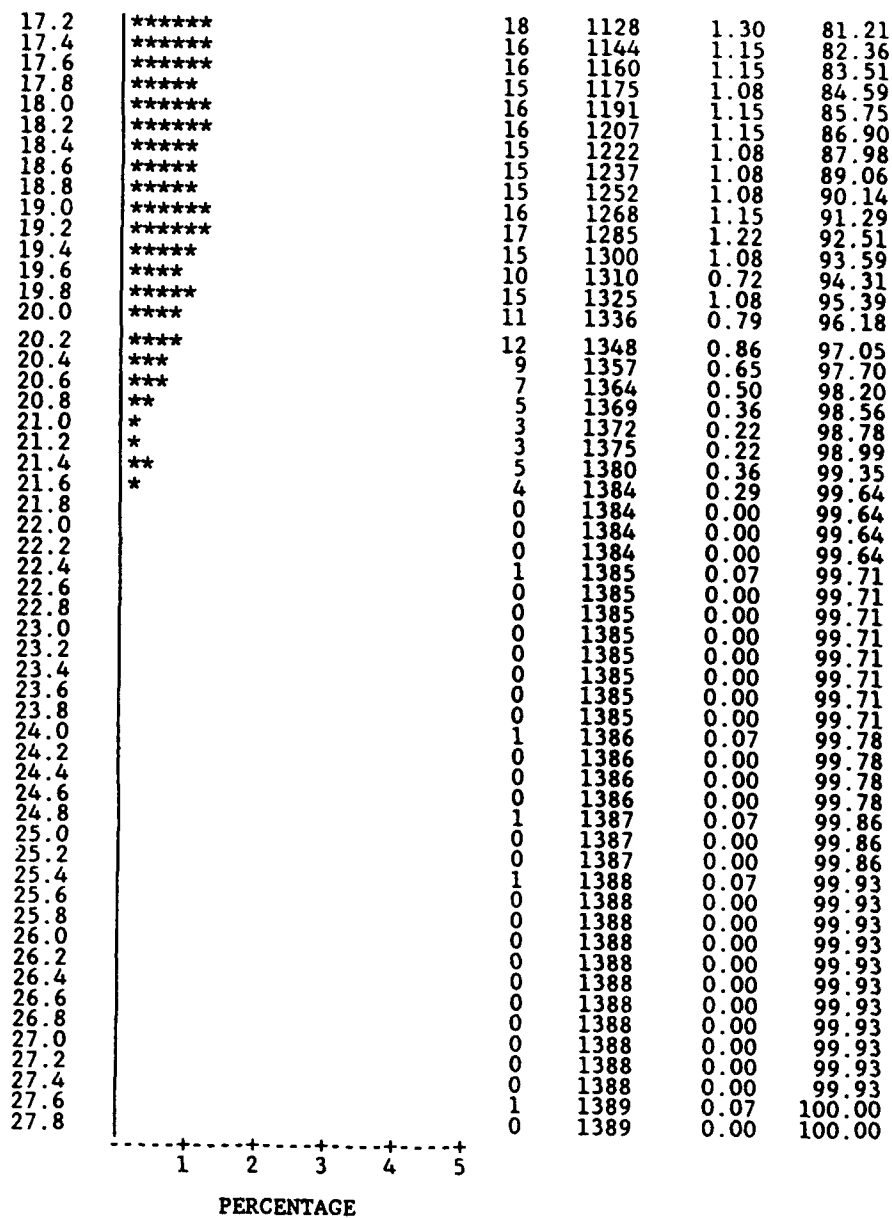


Figure C8. (Concluded)

PERCENTAGE OF SHELLS					
SHELLS		FREQ	CUM FREQ	PERCENT	CUM PERCENT
6.4		0	0	0.00	0.00
6.6		0	0	0.00	0.00
6.8		0	0	0.00	0.00
7.0	**	2	2	0.43	0.43
7.2	*	1	3	0.22	0.65
7.4	*	1	4	0.22	0.86
7.6		0	4	0.00	0.86
7.8	**	2	6	0.43	1.29
8.0	***	3	9	0.65	1.94
8.2	*****	5	14	1.08	3.01
8.4	*****	8	22	1.72	4.73
8.6	*****	8	30	1.72	6.45
8.8	*****	6	36	1.29	7.74
9.0	*****	14	50	3.01	10.75
9.2	*****	18	68	3.87	14.62
9.4	*****	18	86	3.87	18.49
9.6	*****	26	112	5.59	24.09
9.8	*****	12	124	2.58	26.67
10.0	*****	26	150	5.59	32.26
10.2	*****	20	170	4.30	36.56
10.4	*****	29	199	6.24	42.80
10.6	*****	30	229	6.45	49.25
10.8	*****	25	254	5.38	54.62
11.0	*****	20	274	4.30	58.92
11.2	*****	34	308	7.31	66.24
11.4	*****	29	337	6.24	72.47
11.6	*****	21	358	4.52	76.99
11.8	*****	22	380	4.73	81.72
12.0	*****	12	392	2.58	84.30
12.2	*****	17	409	3.66	87.96
12.4	*****	12	421	2.58	90.54
12.6	*****	7	428	1.51	92.04
12.8	*****	5	433	1.08	93.12
13.0	**	2	435	0.43	93.55
13.2		0	435	0.00	93.55
13.4		0	435	0.00	93.55
13.6	*	1	436	0.22	93.76
13.8		0	436	0.00	93.76
14.0		0	436	0.00	93.76
14.2		0	436	0.00	93.76
14.4		0	436	0.00	93.76
14.6		0	436	0.00	93.76
14.8	*	1	437	0.22	93.98
15.0		0	437	0.00	93.98
15.2	**	2	439	0.43	94.41
15.4	**	2	441	0.43	94.84
15.6		0	441	0.00	94.84
15.8	*	1	442	0.22	95.05
16.0		0	442	0.00	95.05
16.2		0	442	0.00	95.05
16.4		0	442	0.00	95.05
16.6	**	2	444	0.43	95.48
16.8	*	1	445	0.22	95.70
17.0		0	445	0.00	95.70
17.2	**	2	447	0.43	96.13
17.4	**	2	449	0.43	96.56
17.6		0	449	0.00	96.56
17.8		0	449	0.00	96.56
18.0		0	449	0.00	96.56

Figure C9. Length-frequency histogram for *Corbicula fluminea*, farshore site, lower Ohio River Mile 967.6, 1992 (Continued)

Appendix D

Results of Water Velocity Studies in the Lower Ohio River, 1992

Table D1
Summary Information for 1992 Velocity data, Lower Ohio River

Date	Event Num	Test Num	River Mile	Vessel Name	Config LxW	Total Barges	Vessel Cond	Vessel Dist	Vessel Direct
16 Aug 92	Test	0	967.4	Ambient	None	None	None	None	None
16 Aug 92	1	1	967.4	No Data	3x3	6	Loaded	1,500	Up
16 Aug 92	2	2	967.4	Richard A. Baker	5x3	15	Loaded	1,500	Down
16 Aug 92	3	3	967.4	Jesse Brent	3x2	6	Loaded	1,500	Up
16 Aug 92	4	4	967.4	Lewis H. Meece	6x6-2	34	L/UL	1,500	?
16 Aug 92	5	5	967.4	Joe McAllister	5x3	15	Unloaded	1,500	Up
16 Aug 92	6	6	967.4	Larry Y. Strain	5x5	25	Loaded	1,500	Down
7 Aug 92	1	7	957.8	Enterprise Star	5x3	15	Unloaded	1,200	Up
17 Aug 92	2	8	957.8	Myrtle E. Griffin	2x2-1	3	Unloaded	1,200	Down
17 Aug 92	3	9	957.8	F. R. Bigelow	4x2	8	Loaded	1,200	Down
17 Aug 92	4	10	957.8	T. S. Kunsman	7x3	21	Loaded	1,200	Up
17 Aug 92	5	11	957.8	Miss Margret	4x3	12	Loaded	1,000	Down
17 Aug 92	6	12	957.8	Mid South Towing	4x3	12	Loaded	1,200	Up

Test Num	Start	Front of Barge Passes	End of Barge Passes	End of Tug Passes	Stop	Time From Start		Num Barges	Total Len (ft)	Time to pass (Sec)	ft/sec	mi/hr
						Tow Front Passes	Tow End Passes					
1	133,610	134,322	134,519	134,537	135,000	433	550	3	555	117	4.74	3.24
2	135,740	140,230	140,403	140,433	141,000	291	384	5	925	93	9.95	6.78
3	143,410	143,744	143,845	143,857	144,500	215	276	3	555	61	9.10	6.21
4	144,500	145,103	145,406	145,406	150,500	364	547	6	1,110	183	6.07	4.14
5	153,400	153,813	154,044	154,103	154,700	254	405	5	925	151	6.13	4.18
6	161,610	162,120	162,338	162,408	163,000	311	449	5	925	138	6.70	4.57
7	94,400	95,438	95,615	95,628	100,400	639	736	5	925	97	9.54	6.50
8	112,610	112,845	112,927	112,934	113,500	156	198	3	555	42	13.21	9.01
9	115,520	115,818	115,912	115,926	120,500	119	173	4	740	54	13.70	9.35
10	132,700	133,057	133,503	133,528	134,200		484	7	1,235	246	5.26	3.59
11	132,700	133,539	133,712	133,723	134,200		613	4	740	93	7.96	5.43
12	134,000	134,310	134,455	134,512	140,600	15	296	4	740	105	7.05	4.81

(Continued)

Table D1 (Concluded)

File	Sensor 940			Sensor 946		
	Code	Dist	Depth	Code	Dist	Depth
	B3	700	18	B4	200	9
LOR2271	B3	700	18	B4	200	9
LOR2272	B3	700	18	B4	200	9
LOR2273	B3	700	18	B4	200	9
LOR2274	B3	700	18	B4	200	9
LOR2275	B3	700	18	B4	200	9
LOR2276	B3	700	18	B4	200	9
LOR2281	B3	750	20	B4	130	5
LOR2282	B3	750	20	B4	130	5
LOR2283	B3	750	20	B4	130	5
LOR2284	B3	750	20	B4	130	5
LOR2284	B3	750	20	B4	130	5
LOR2285	B3	750	20	B4	130	5

Table D2
File: 2271 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 1		Combined Velocity	Flow Direction
Mean	-0.3585	1.4609	1.5074	219.8280
SD	0.0987	0.1650	0.1666	3.6843
Min	-0.5740	1.0520	1.1050	207.5000
Max	-0.0400	1.7860	1.8460	226.8000
Range	0.5340	0.7340	0.7410	19.3000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9476	0.6190	1.1338	184.9315
SD	0.0932	0.0855	0.1072	3.3969
Min	0.7300	0.4380	0.9110	177.2000
Max	1.2550	0.8830	1.4540	192.8000
Range	0.5250	0.4450	0.5430	15.6000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 1			
Mean	-0.3698	1.4424	1.4933	220.3701
SD	0.1211	0.1800	0.1851	4.3646
Min	-0.6900	1.0650	1.1040	209.4000
Max	-0.0730	1.8320	1.9420	233.8000
Range	0.6170	0.7670	0.8380	24.4000
N = 200				
Seconds: 434-634				
Farshore Sensor 940				
Mean	1.0377	0.6931	1.2497	185.5498
SD	0.1120	0.0882	0.1248	3.1590
Min	0.7200	0.5010	0.9580	178.7000
Max	1.2880	0.9160	1.4960	193.3000
Range	0.5680	0.4150	0.5380	14.6000
N = 200				
Seconds: 434-634				

Table D3
File: 2272 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 2		Combined Velocity	Flow Direction
Mean	-0.3899	1.4725	1.5254	220.5575
SD	0.0973	0.1809	0.1888	3.0837
Min	-0.6440	1.1480	1.1760	213.8000
Max	-0.1830	1.9120	1.9770	229.5000
Range	0.4610	0.7640	0.8010	15.7000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9907	0.6424	1.1832	184.8210
SD	0.1270	0.0918	0.1367	3.7042
Min	0.7070	0.4250	0.8520	174.9000
Max	1.2880	0.8700	1.4640	194.0000
Range	0.5810	0.4450	0.6120	19.1000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 2			
Mean	-0.3642	1.4140	1.4634	220.0930
SD	0.1018	0.1775	0.1802	3.7707
Min	-0.6770	1.0220	1.1200	209.3000
Max	-0.0880	1.8980	1.9180	229.8000
Range	0.5890	0.8760	0.7980	20.5000
N = 200				
Seconds: 291-491				
Farshore Sensor 940				
Mean	0.9264	0.6053	1.1085	184.9313
SD	0.1180	0.0962	0.1378	3.4425
Min	0.6370	0.3580	0.7630	176.1000
Max	1.2610	0.8730	1.4990	193.9000
Range	0.6240	0.5150	0.7360	17.8000
N = 200				
Seconds: 291-491				

Table D4
File: 2273 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 2		Combined Velocity	Flow Direction
Mean	-0.3825	1.4387	1.4916	221.0355
SD	0.1091	0.1816	0.1900	3.6981
Min	-0.7240	1.1090	1.1400	208.6000
Max	-0.0530	1.8780	1.9310	232.5000
Range	0.6710	0.7690	0.7910	23.9000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9803	0.6329	1.1686	184.4920
SD	0.0986	0.0872	0.1147	3.2163
Min	0.7770	0.4600	0.9270	176.4000
Max	1.2280	0.8530	1.4100	192.2000
Range	0.4510	0.3930	0.4830	15.8000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 2			
Mean	-0.3523	1.5141	1.5570	219.0771
SD	0.1048	0.2610	0.2675	3.2729
Min	-0.6570	0.9360	0.9700	211.4000
Max	-0.1340	2.1310	2.1790	228.3000
Range	0.5230	1.1950	1.2090	16.9000
N = 200				
Seconds: 215-415				
Farshore Sensor 940				
Mean	1.0690	0.7104	1.2860	185.1900
SD	0.1063	0.1257	0.1437	3.6622
Min	0.8030	0.3520	0.9470	173.5000
Max	1.3160	1.0420	1.6790	193.2000
Range	0.5130	0.6900	0.7320	19.7000
N = 200				
Seconds: 215-415				

Table D5
File: 2274 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 4		Combined Velocity	Flow Direction
Mean	-0.3806	1.4007	1.4550	220.9545
SD	0.1057	0.2098	0.2120	4.0280
Min	-0.6840	1.0490	1.0710	206.6000
Max	-0.0170	1.9710	2.0210	231.1000
Range	0.6670	0.9220	0.9500	24.5000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9925	0.6479	1.1879	184.9375
SD	0.1606	0.1137	0.1800	3.9546
Min	0.5910	0.3340	0.7050	173.9000
Max	1.4040	0.8780	1.6560	194.7000
Range	0.8130	0.5440	0.9510	20.8000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 4			
Mean	-0.3959	1.5845	1.6356	219.6647
SD	0.0982	0.1959	0.2011	3.0596
Min	-0.6170	1.0950	1.1220	212.5000
Max	-0.1660	2.0240	2.0710	226.5000
Range	0.4510	0.9290	0.9490	14.0000
N = 200				
Seconds: 363-563				
Farshore Sensor 940				
Mean	1.0815	0.7210	1.3018	185.3896
SD	0.1142	0.1112	0.1417	3.2455
Min	0.8400	0.4180	0.9660	174.7000
Max	1.3570	1.0420	1.6610	193.7000
Range	0.5170	0.6240	1.2981	185.4146
N = 200				
Seconds: 363-563				

Table D6
File: 2275 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 5		Combined Velocity	Flow Direction
Mean	-0.3845	1.4782	1.5307	219.8245
SD	0.1136	0.1966	0.2028	3.8500
Min	-0.7300	1.0750	1.1420	209.8000
Max	-0.1190	1.9910	2.0960	230.7000
Range	0.6110	0.9160	0.9540	20.9000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9928	0.6563	1.1921	184.8935
SD	0.1322	0.1154	0.1614	3.4108
Min	0.7170	0.3920	0.8380	176.2000
Max	1.3010	0.8630	1.5330	193.2000
Range	0.5840	0.4710	0.6950	17.0000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 5			
Mean	-0.3940	1.3463	1.4040	221.6350
SD	0.0950	0.1974	0.1979	3.8266
Min	-0.6700	0.9230	0.9530	212.5000
Max	-0.1660	1.8670	1.8910	233.8000
Range	0.5040	0.9440	0.9380	21.3000
N = 200				
Seconds: 253-453				
Farshore Sensor 940				
Mean	0.9828	0.6368	1.1731	184.6390
SD	0.1091	0.1011	0.1319	3.4721
Min	0.6990	0.3350	0.8960	173.6000
Max	1.2650	0.8860	1.5180	193.7000
Range	0.5660	0.5510	1.2169	184.7476
N = 200				
Seconds: 253-453				

Table D7
File: 2276 LOR 16 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 6		Combined Velocity	Flow Direction
Mean	-0.3901	1.4375	1.4932	220.5390
SD	0.1196	0.1625	0.1719	4.0234
Min	-0.7570	1.0120	1.0460	208.8000
Max	-0.0860	1.7660	1.9030	228.7000
Range	0.6710	0.7540	0.8570	19.9000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	0.9820	0.6361	1.1720	184.7990
SD	0.1529	0.1029	0.1712	3.4077
Min	0.6140	0.4050	0.7630	176.8000
Max	1.2750	0.8830	1.4910	193.0000
Range	0.6610	0.4780	0.7280	16.2000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 6			
Mean	-0.3432	1.3568	1.4030	219.3294
SD	0.1083	0.1854	0.1913	3.9948
Min	-0.6510	0.9360	0.9870	208.4000
Max	-0.0630	1.8110	1.8620	228.5000
Range	0.5880	0.8750	0.8750	20.1000
N = 200				
Seconds: 311-511				
Farshore Sensor 940				
Mean	1.0092	0.6676	1.2121	185.2622
SD	0.1173	0.0964	0.1352	3.3171
Min	0.7200	0.3950	0.8480	173.3000
Max	1.2610	0.8730	1.5100	194.7000
Range	0.5410	0.4780	0.6620	21.4000
N = 200				
Seconds: 311-511				

Table D8
File: 2281 LOR 17 August 1992

Nearshore Sensor 946	Y	X	Combined Velocity	Flow Direction
	Before Test 7			
Mean	0.5442	2.6451	2.7036	248.5075
SD	0.1443	0.2571	0.2649	2.7430
Min	0.2190	2.0360	2.0820	240.3000
Max	0.9170	3.3410	3.4480	255.8000
Range	0.6980	1.3050	1.3660	15.5000
N = 200				
Seconds: 1-200				
	During Test 7			
Mean	0.5698	2.8563	2.9034	248.8562
SD	0.1606	0.3538	0.3721	2.7426
Min	0.2520	2.1320	2.1990	240.4000
Max	1.1090	3.4210	3.5050	254.3000
Range	0.8570	1.2890	1.3060	13.9000
N = 200				
Seconds: 639-839				

Table D9 File: 2282 LOR 17 August 1992				
	Y	X		
Nearshore Sensor 946	After Test 8		Combined Velocity	Flow Direction
Mean	0.4901	2.6840	2.7325	250.5500
SD	0.1452	0.2638	0.2614	3.1392
Min	0.1930	2.1050	2.1430	241.9000
Max	0.8370	3.2540	3.3010	257.1000
Range	0.6440	1.1490	1.1580	15.2000
N = 173				
Seconds: 358-531				
Farshore Sensor 940				
Mean	0.9675	2.2539	2.4544	259.2293
SD	0.1318	0.1783	0.2033	2.1048
Min	0.6310	1.7380	1.9390	252.0000
Max	1.2880	2.5650	2.8700	264.5000
Range	0.6570	0.8270	0.9310	12.5000
N = 173				
Seconds: 358-531				
Nearshore Sensor 946	During Test 8			
Mean	0.4635	2.5119	2.5569	250.5363
SD	0.1155	0.2024	0.2028	2.5740
Min	0.1660	1.8990	1.9530	243.6000
Max	0.7750	2.9950	3.0730	257.4000
Range	0.6090	1.0960	1.1200	13.8000
N = 200				
Seconds: 157-357				
Farshore Sensor 940				
Mean	0.9798	2.2293	2.4367	258.7114
SD	0.1292	0.1907	0.2125	2.0963
Min	0.6280	1.8060	1.9430	253.7000
Max	1.2980	2.7230	2.9410	265.1000
Range	0.6700	0.9170	0.9980	11.4000
N = 200				
Seconds: 157-357				

Table D10
File: 2283 LOR 17 August 1992

	Y	X		
Nearshore Sensor 946	After Test 9		Combined Velocity	Flow Direction
Mean	0.5312	2.5144	2.5720	248.7975
SD	0.1089	0.2414	0.2436	2.3257
Min	0.2820	1.9720	2.0090	242.3000
Max	0.8070	3.1010	3.1910	254.8000
Range	0.5250	1.1290	1.1820	12.5000
N = 200				
Seconds: 320-520				
Farshore Sensor 940				
Mean	1.0043	2.3181	2.5279	259.3299
SD	0.1289	0.1853	0.2076	2.0686
Min	0.6280	1.8490	1.9530	255.3000
Max	1.3070	2.6630	2.9400	264.5000
Range	0.6790	0.8140	0.9870	9.2000
N = 200				
Seconds: 320-520				
Nearshore Sensor 946	During Test 9			
Mean	0.4786	2.3465	2.3997	249.3403
SD	0.1583	0.3438	0.3460	3.8102
Min	-0.0850	1.5010	1.6130	238.3000
Max	0.8500	3.0750	3.1530	263.1000
Range	0.9350	1.5740	1.5400	24.8000
N = 200				
Seconds: 119-319				
Farshore Sensor 940				
Mean	0.9995	2.2169	2.4337	258.2254
SD	0.1329	0.2309	0.2487	2.2701
Min	0.5360	1.3510	1.4890	253.5000
Max	1.3100	2.7230	2.9260	264.0000
Range	0.7740	1.3720	1.4370	10.5000
N = 200				
Seconds: 119-319				

Table D11
File: 2284 LOR 17 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 10		Combined Velocity	Flow Direction
Mean	0.5548	2.4953	2.5593	247.3184
SD	0.1324	0.2341	0.2384	2.8195
Min	0.1640	1.9250	1.9530	240.7000
Max	0.8250	3.0610	3.1470	255.2000
Range	0.6610	1.1360	1.1940	14.5000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	1.0288	2.3351	2.5593	247.3184
SD	0.1105	0.1574	0.2384	2.8195
Min	0.6920	1.8220	1.9530	240.7000
Max	1.3210	2.6660	3.1470	255.2000
Range	0.6290	0.8440	1.1940	14.5000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 10			
Mean	0.5735	2.6463	2.7111	247.4859
SD	0.1443	0.2691	0.2739	2.9024
Min	0.2190	2.0580	2.1130	238.9000
Max	0.9360	3.4060	3.5000	255.0000
Range	0.7170	1.3480	1.3870	16.1000
N = 276				
Seconds: 238-514				
Farshore Sensor 940				
Mean	1.0567	2.4446	2.7111	247.4859
SD	0.1346	0.1971	0.2739	2.9024
Min	0.6490	1.9480	2.1130	238.9000
Max	1.3580	2.8680	3.5000	255.0000
Range	0.7090	0.9200	1.3870	16.1000
N = 276				
Seconds: 238-514				

Table D12
File: 2284 LOR 17 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 11		Combined Velocity	Flow Direction
Mean	0.5548	2.4953	2.5593	247.3184
SD	0.1324	0.2341	0.2384	2.8195
Min	0.1640	1.9250	1.9530	240.7000
Max	0.8250	3.0610	3.1470	255.2000
Range	0.6610	1.1360	1.1940	14.5000
N = 200				
Seconds: 1-200				
Farshore Sensor 940				
Mean	1.0288	2.3351	2.5593	247.3184
SD	0.1105	0.1574	0.2384	2.8195
Min	0.6920	1.8220	1.9530	240.7000
Max	1.3210	2.6660	3.1470	255.2000
Range	0.6290	0.8440	1.1940	14.5000
N = 200				
Seconds: 1-200				
Nearshore Sensor 946	During Test 11			
Mean	0.6109	2.5026	2.5797	245.8174
SD	0.1497	0.2321	0.2398	3.0869
Min	0.0400	1.8650	1.9430	238.8000
Max	0.9760	3.1000	3.1930	258.5000
Range	0.9360	1.2350	1.2500	19.7000
N = 200				
Seconds: 515-715				
Farshore Sensor 940				
Mean	1.0826	2.3126	2.5797	245.8174
SD	0.1484	0.2340	0.2398	3.0869
Min	0.6970	1.8400	1.9430	238.8000
Max	1.4090	2.8550	3.1930	258.5000
Range	0.7120	1.0150	1.2500	19.7000
N = 200				
Seconds: 515-715				

Table D13
File: 2285 LOR 17 August 1992

	Y	X		
Nearshore Sensor 946	Before Test 12		Combined Velocity	Flow Direction
Mean	0.5277	2.4312	2.4917	247.3342
SD	0.1632	0.2546	0.2685	3.1827
Min	0.2160	1.8060	1.8350	239.5000
Max	1.0220	3.0010	3.1380	253.8000
Range	0.8060	1.1950	1.1940	1.1940
N = 190				
Seconds: 1-190				
Farshore Sensor 940				
Mean	1.0098	2.3714	2.5791	259.8095
SD	0.1175	0.1593	0.1764	1.9999
Min	0.7570	1.9980	2.1370	254.6000
Max	1.3410	2.9080	3.0790	265.4000
Range	0.5840	0.9100	0.9420	10.8000
N = 190				
Seconds: 1-190				
Nearshore Sensor 946	During Test 12			
Mean	0.5429	2.7186	2.6355	259.3428
SD	0.1715	0.3710	0.2046	2.0578
Min	0.0000	1.8220	2.1200	253.7000
Max	0.9340	3.6240	3.1330	264.0000
Range	0.9340	1.8020	1.0130	10.3000
N = 200				
Seconds: 192-392				
Farshore Sensor 940				
Mean	1.0566	2.4126	2.6355	259.3428
SD	0.1208	0.1910	0.2046	2.0578
Min	0.7100	1.9520	2.1200	253.7000
Max	1.3870	2.8680	3.1330	264.0000
Range	0.6770	0.9160	1.0130	10.3000
N = 200				
Seconds: 192-392				

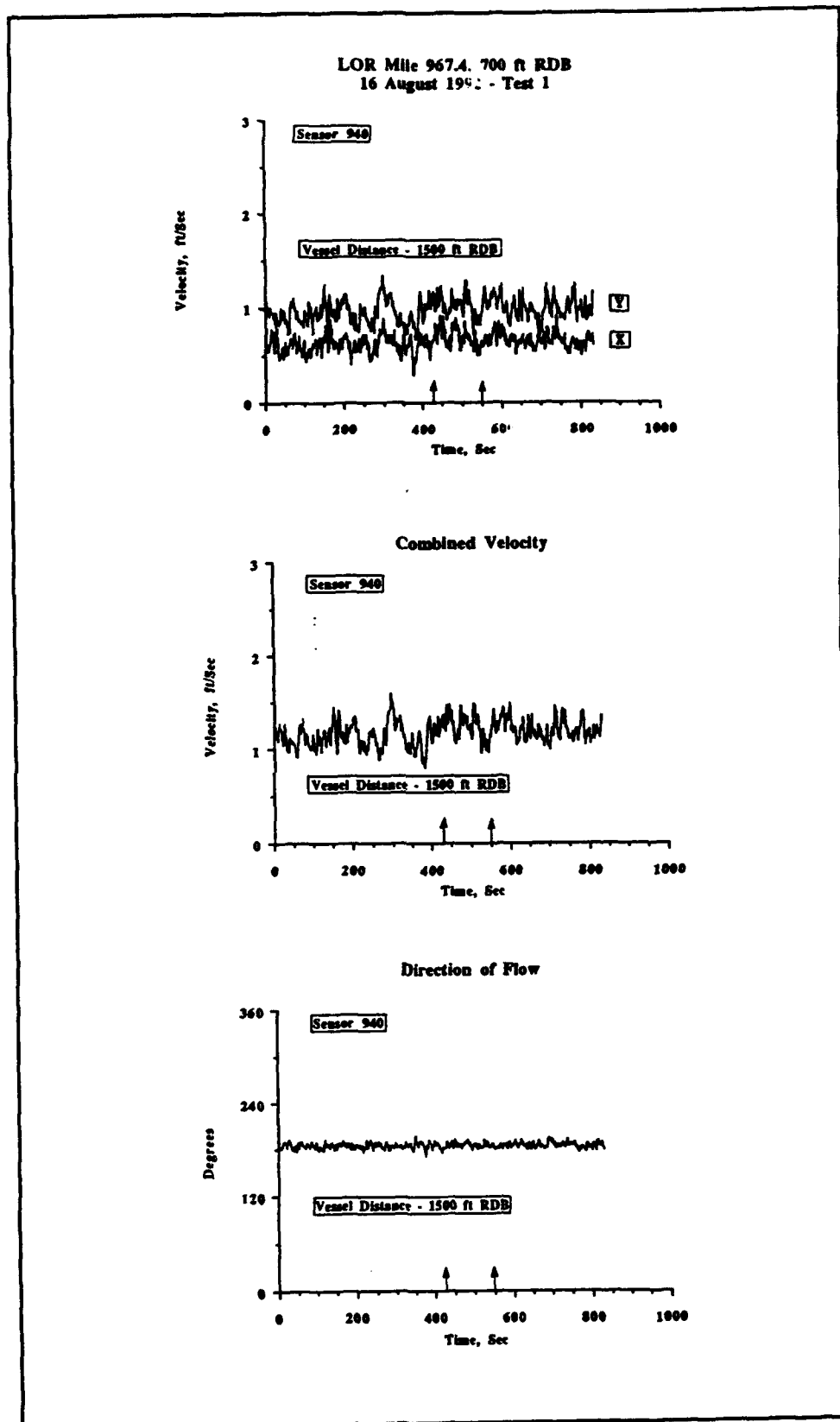


Figure D1. Test 1, LOR Mile 967.4, 700 ft RDB, 16 August 1992

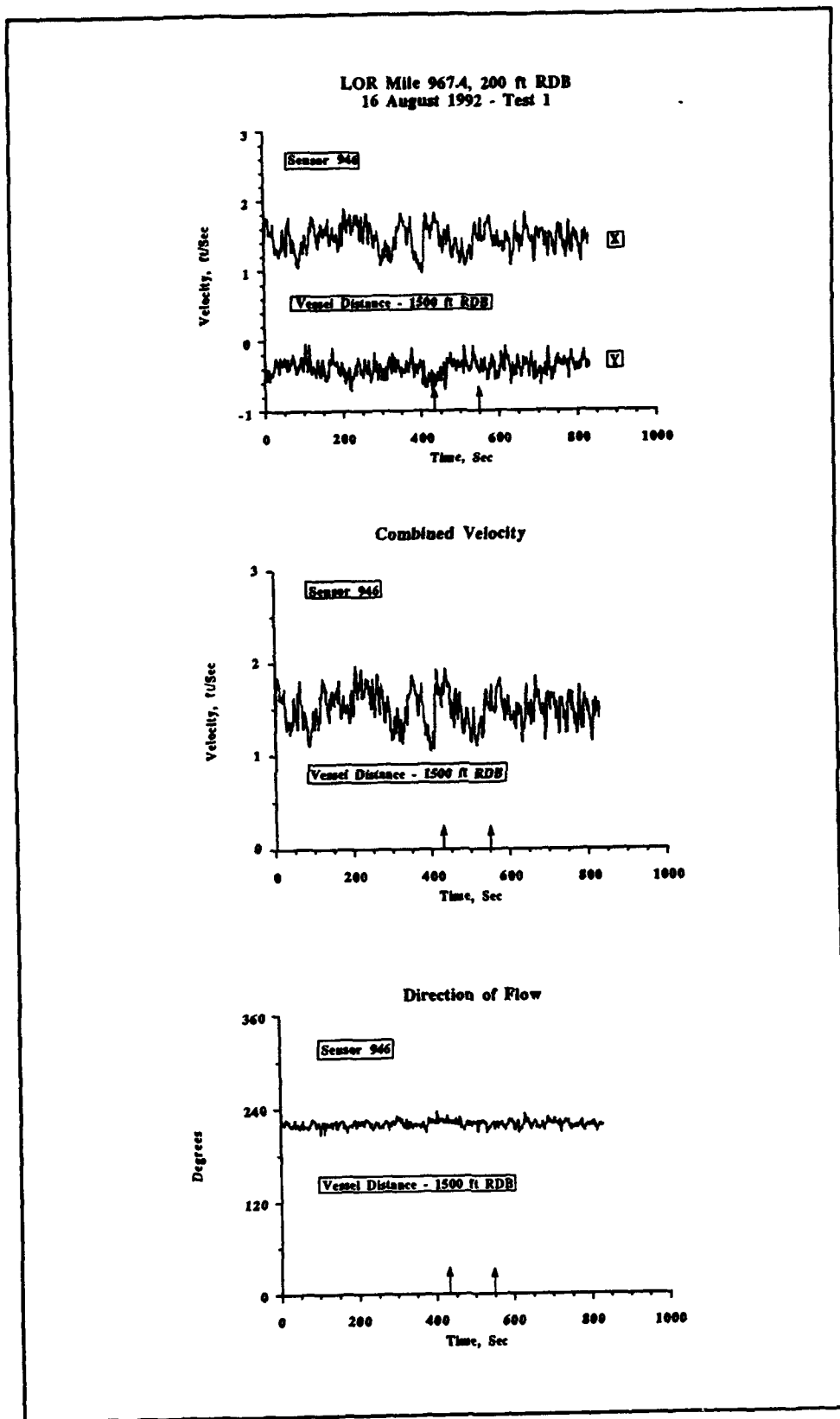


Figure D2. Test 1, LOR Mile 967.4, 200 ft RDB, 16 August 1992

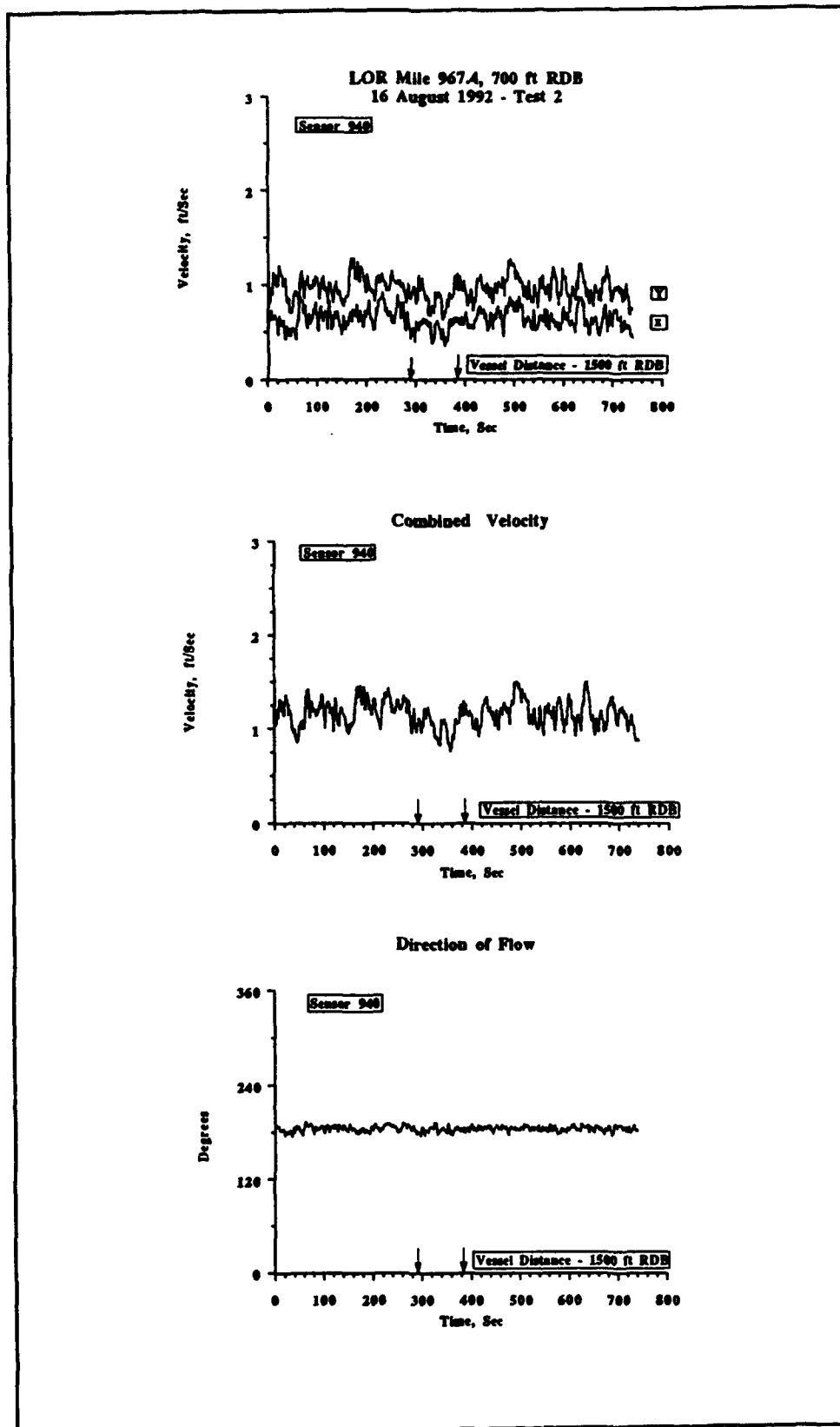


Figure D3. Test 2, LOR Mile 967.4, 700 ft RDB, 16 August 1992

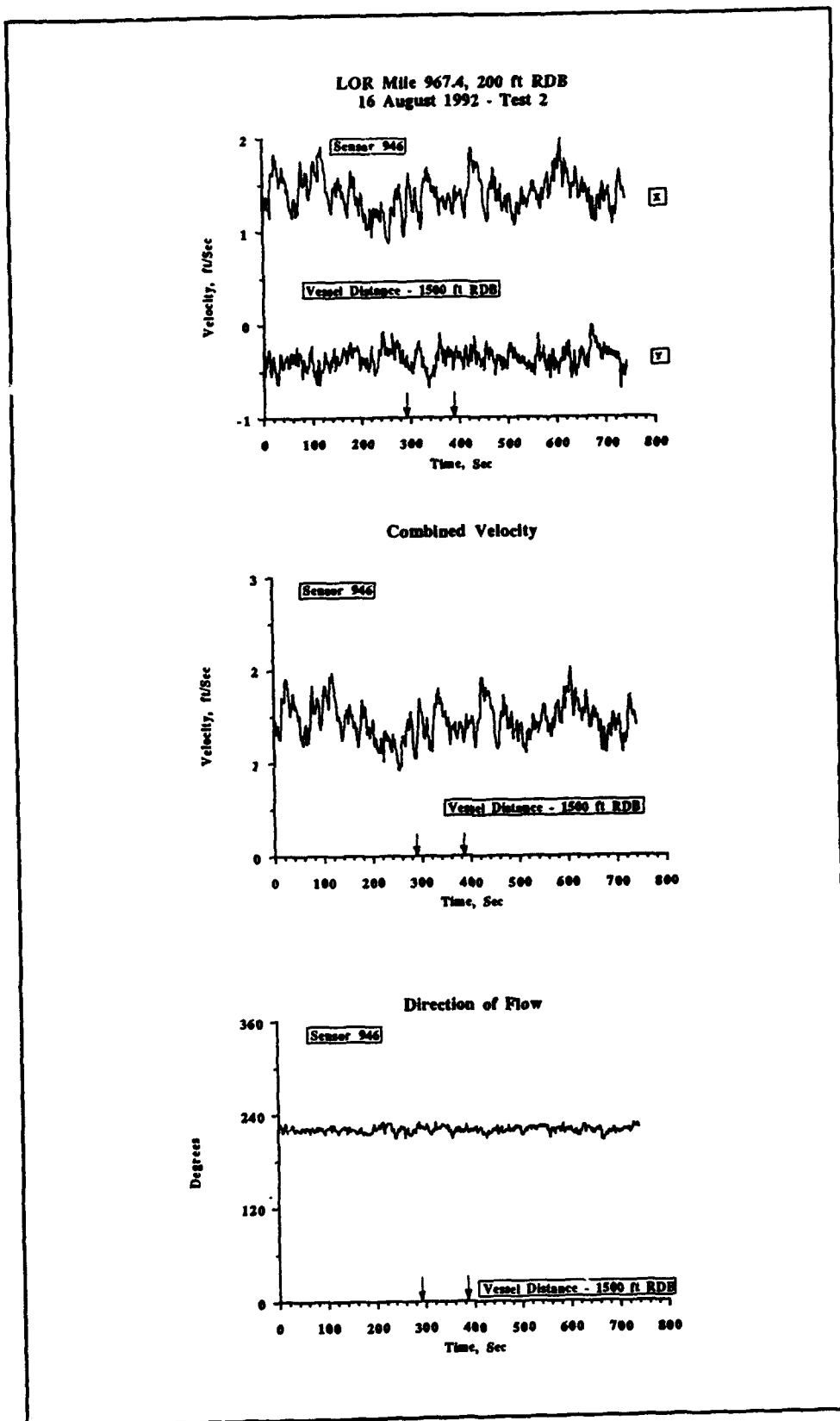


Figure D4. Test 2, LOR Mile 967.4, 200 ft RDB, 16 August 1992

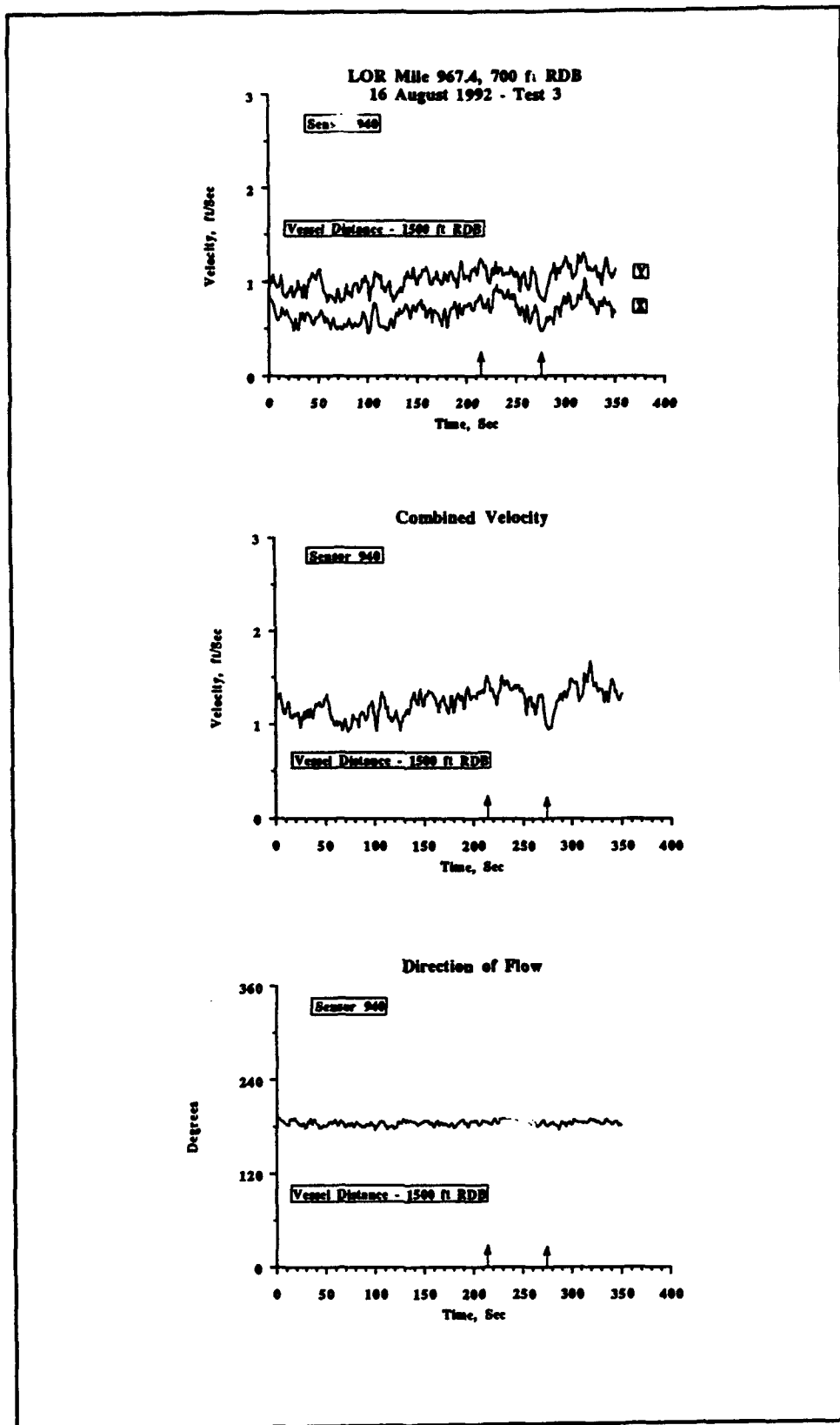


Figure D5. Test 3, LOR Mile 967.4, 700 ft RDB, 16 August 1992

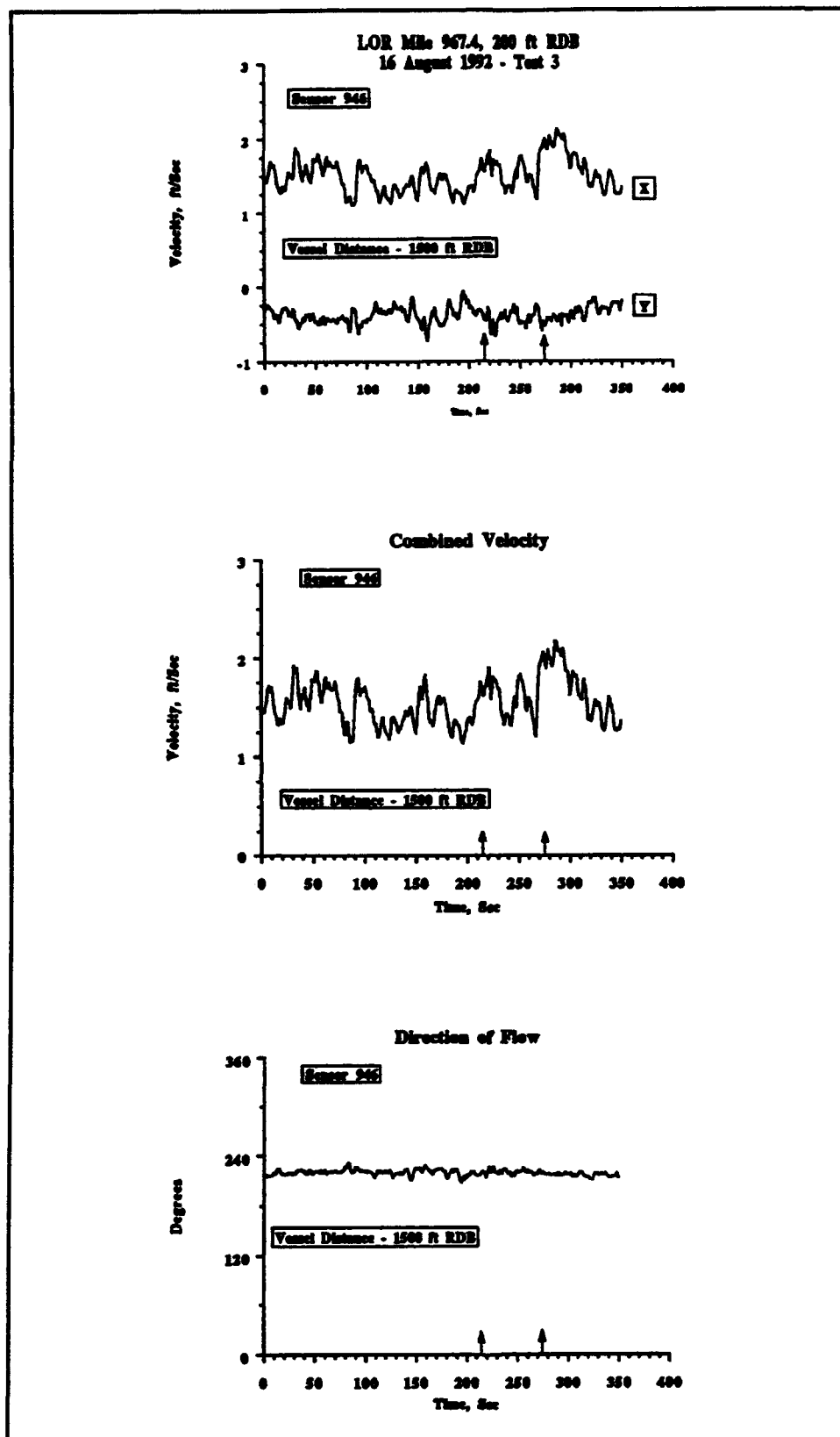


Figure D6. Test 3, LOR Mile 967.4, 200 ft RDB, 16 August 1992

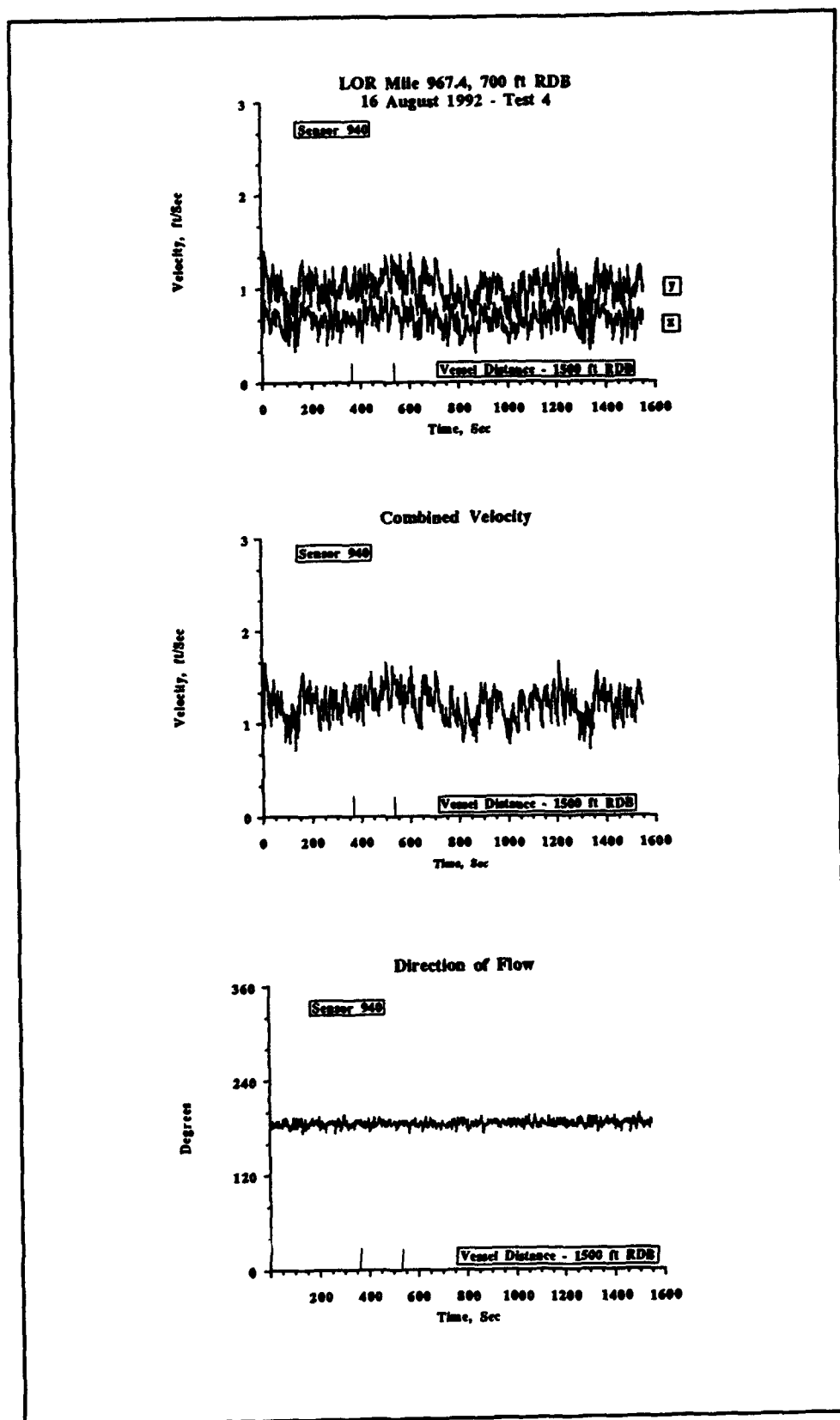


Figure D7. Test 4, LOP Mile 967.4, 700 ft RDB, 16 August 1992

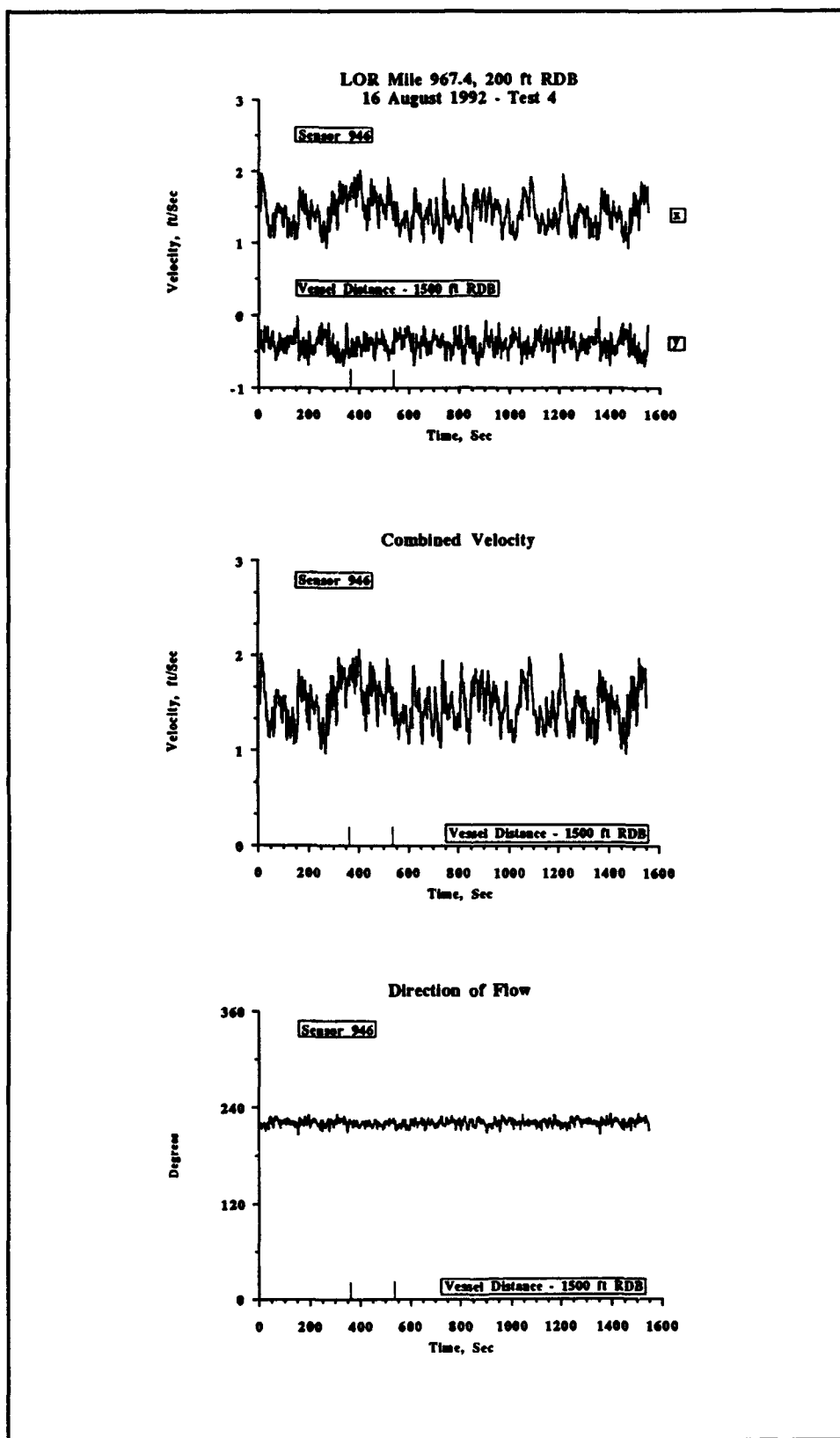


Figure D8. Test 4, LOR Mile 967.4, 200 ft RDB, 16 August 1992

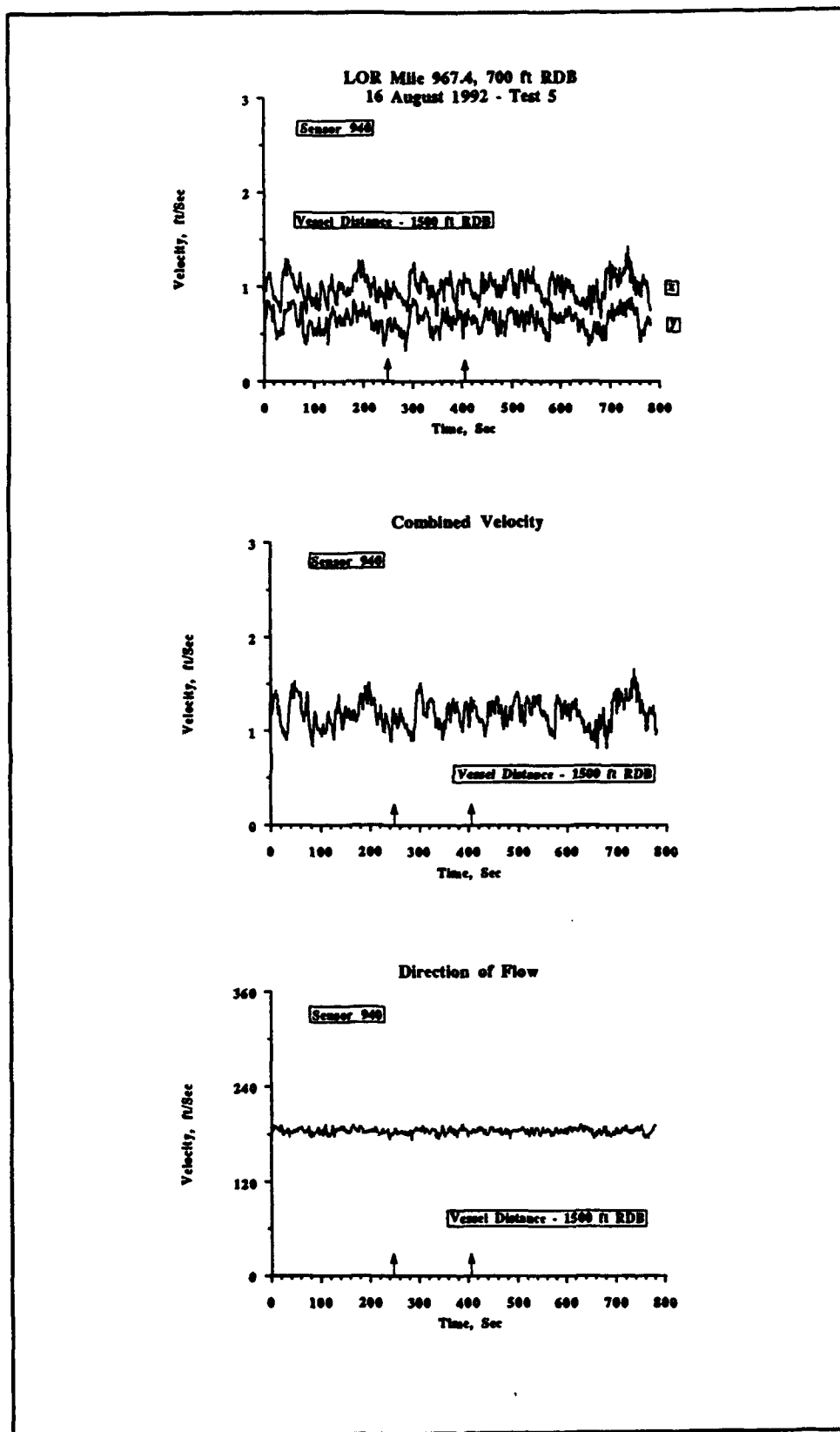


Figure D9. Test 5, LOR Mile 967.4, 700 ft RDB, 16 August 1992

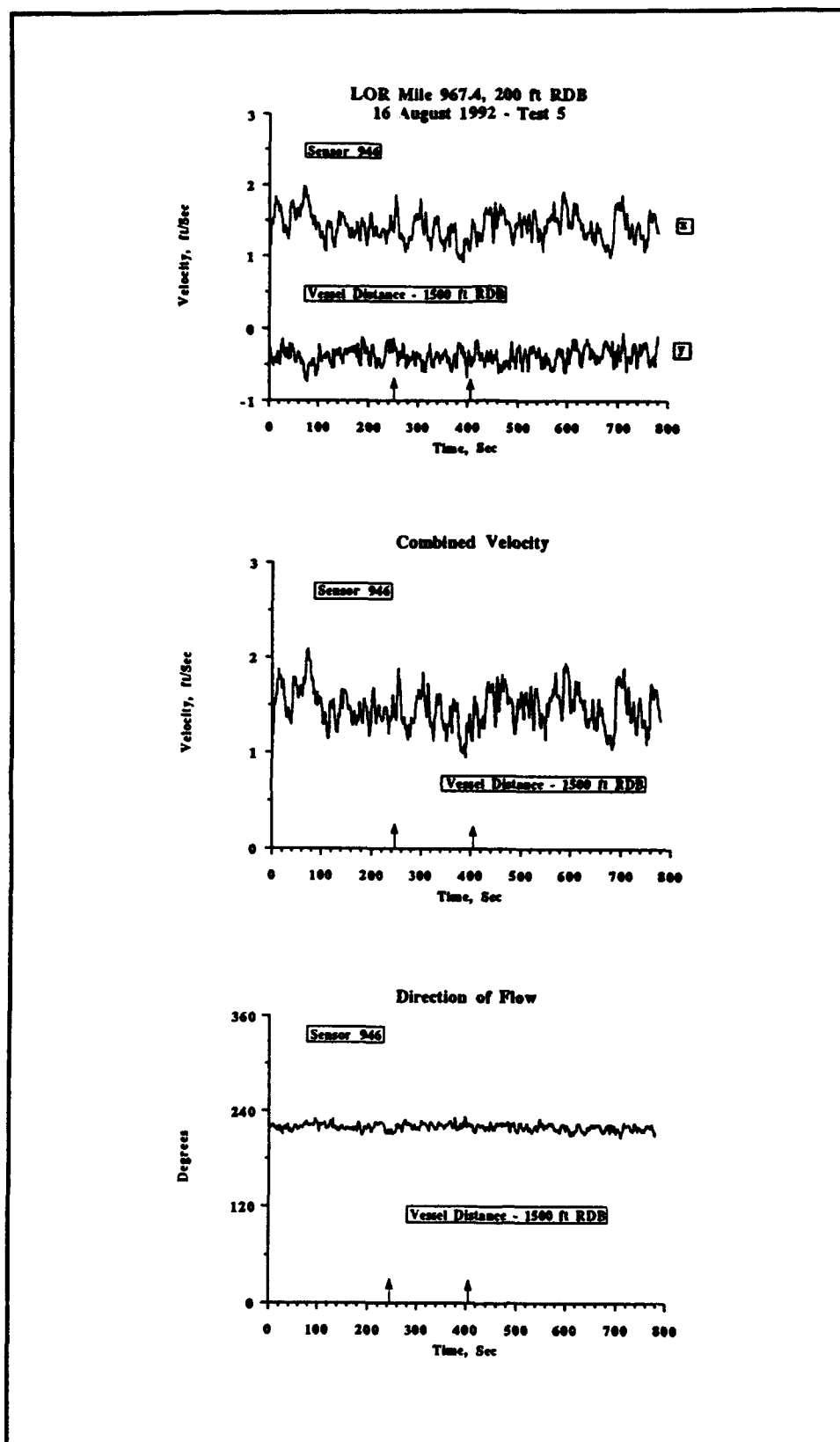


Figure D10. Test 5, LOR Mile 967.4, 200 ft RDB, 16 August 1992

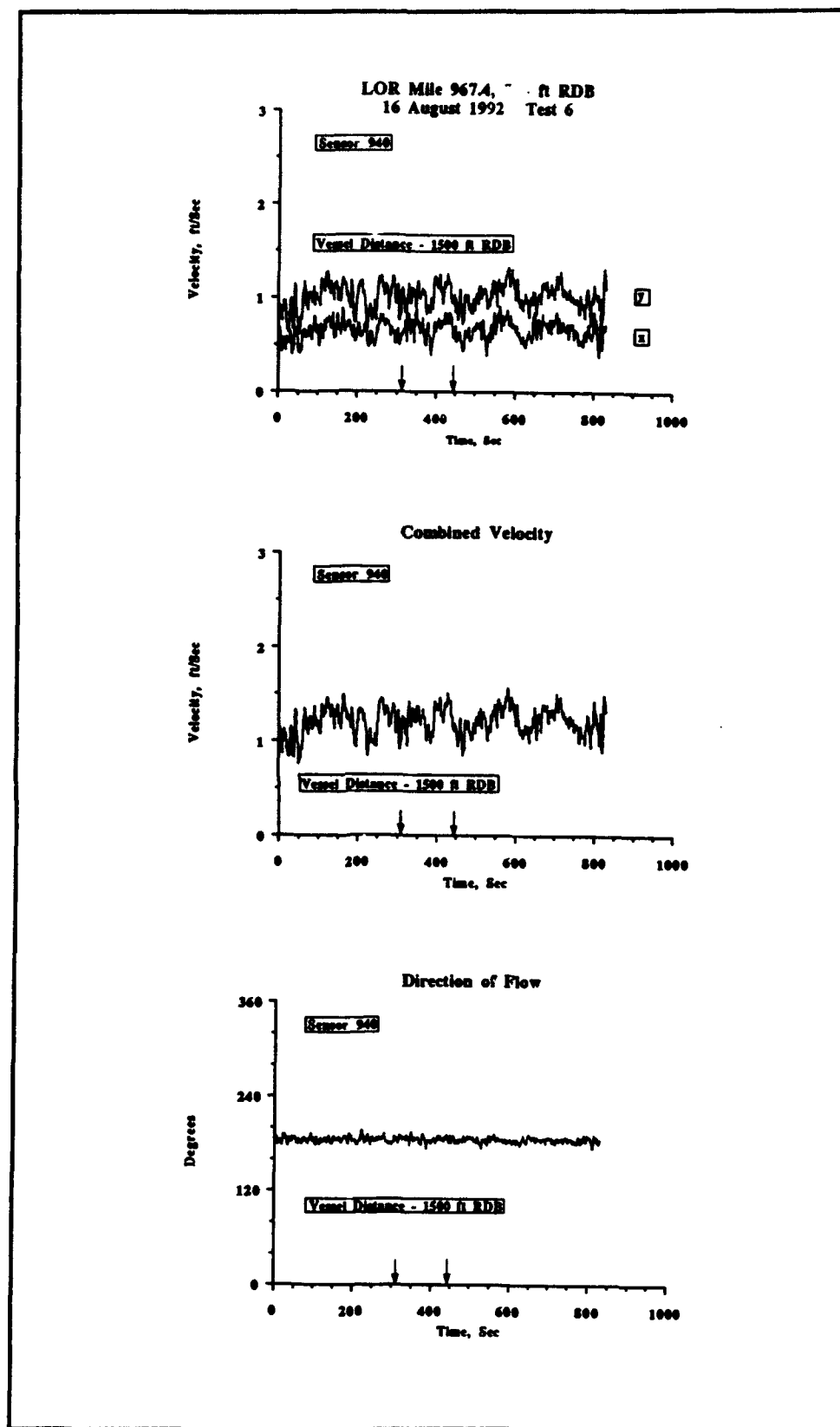


Figure D11. Test 6, LOR Mile 967.4, 700 ft RDB, 16 August 1992

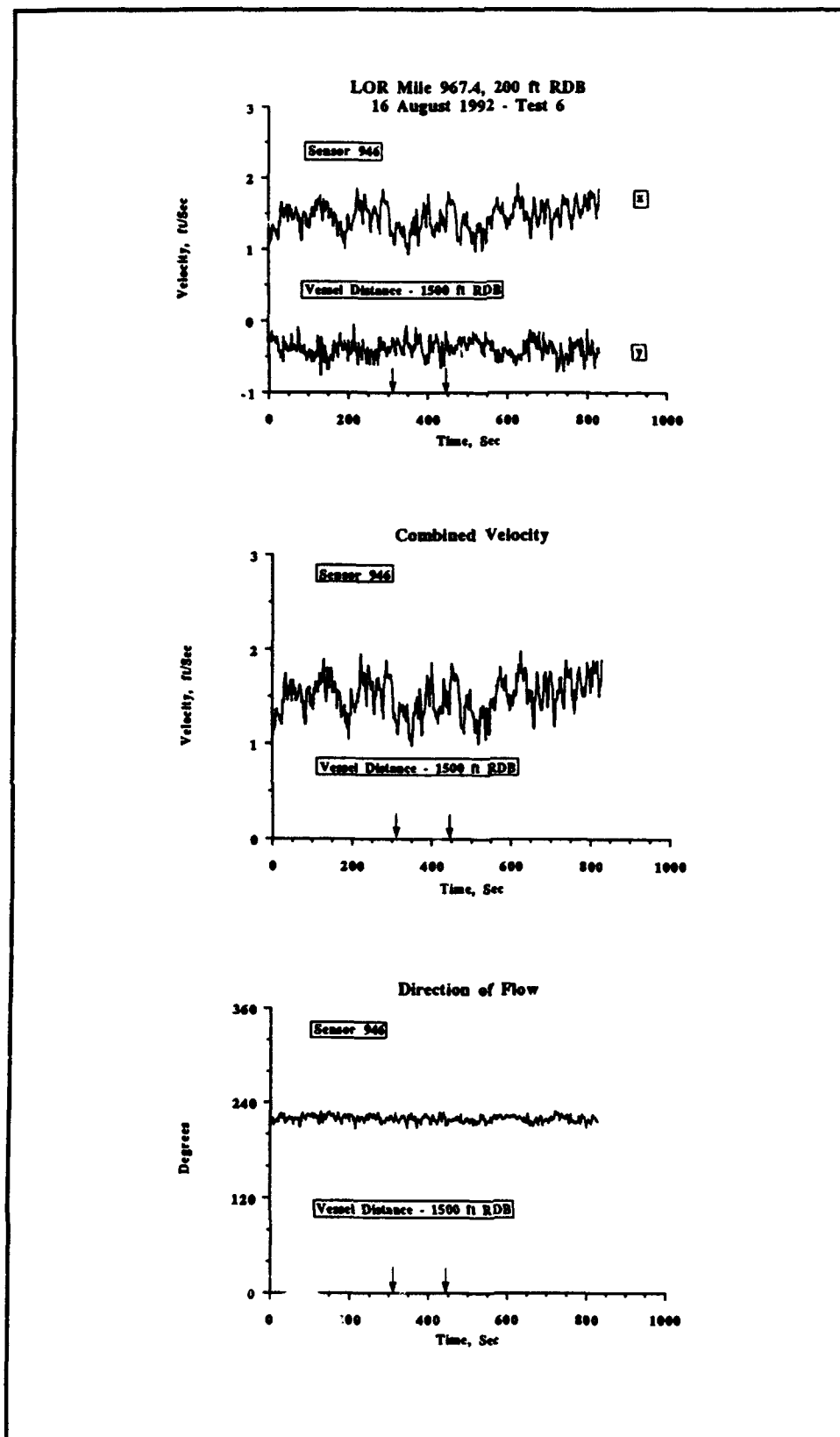


Figure D12. Test 6, LOR Mile 967.4, 200 ft RDB, 16 August 1992

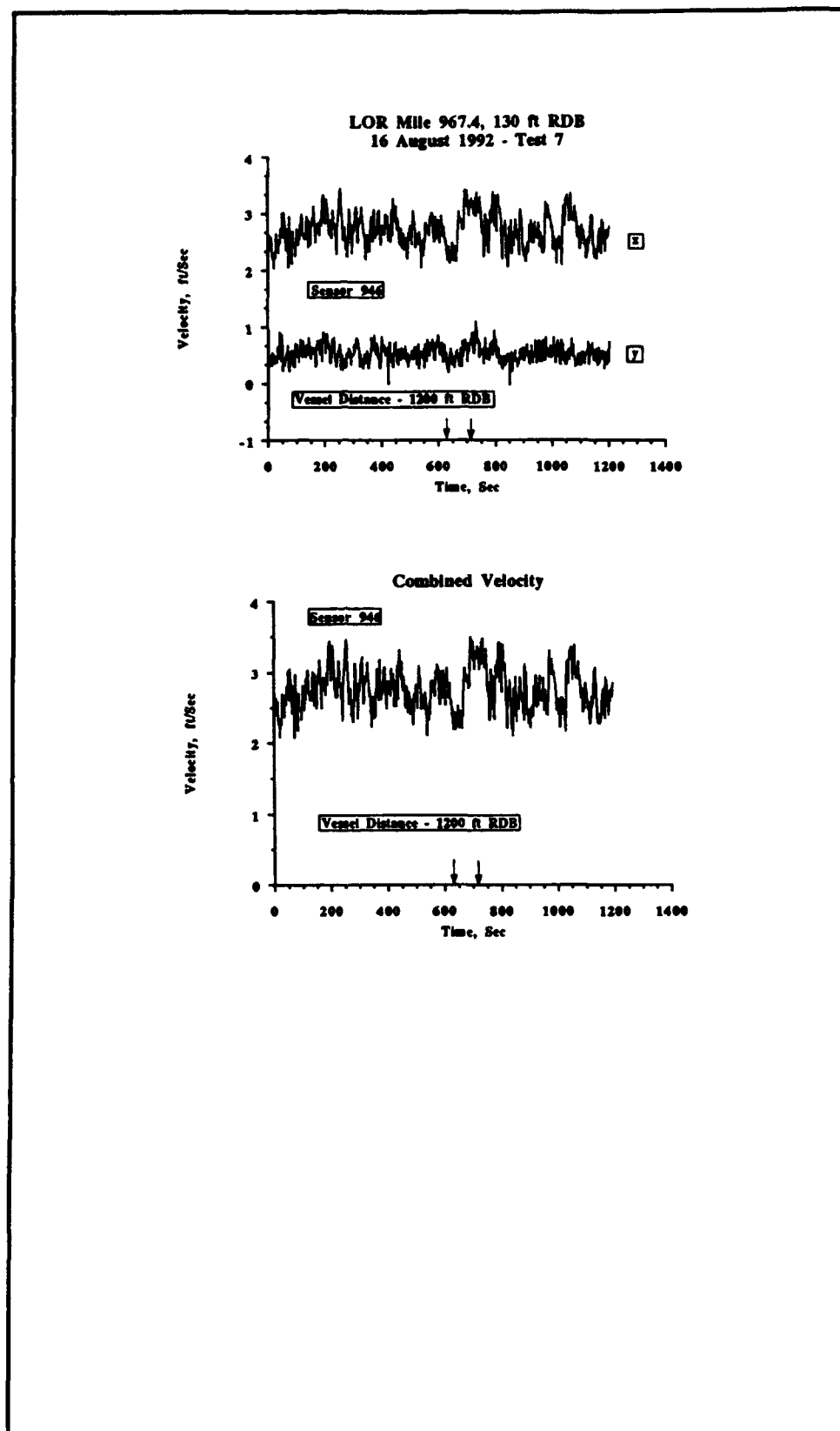


Figure D13. Test 7, LOR Mile 967.4, 130 ft RDB, 16 August 1992

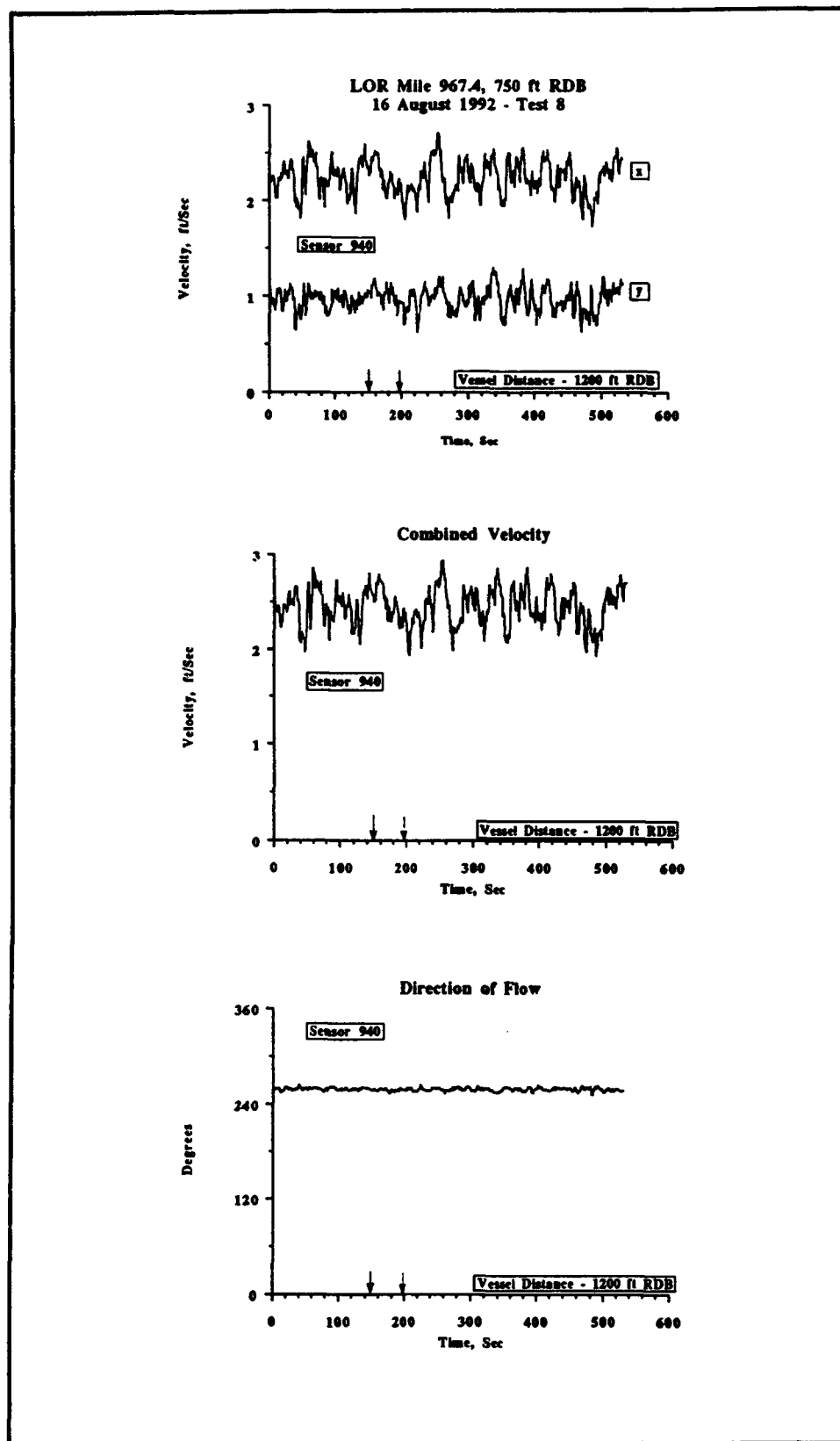


Figure D14. Test 8, LOR Mile 967.4, 750 ft RDB, 16 August 1992

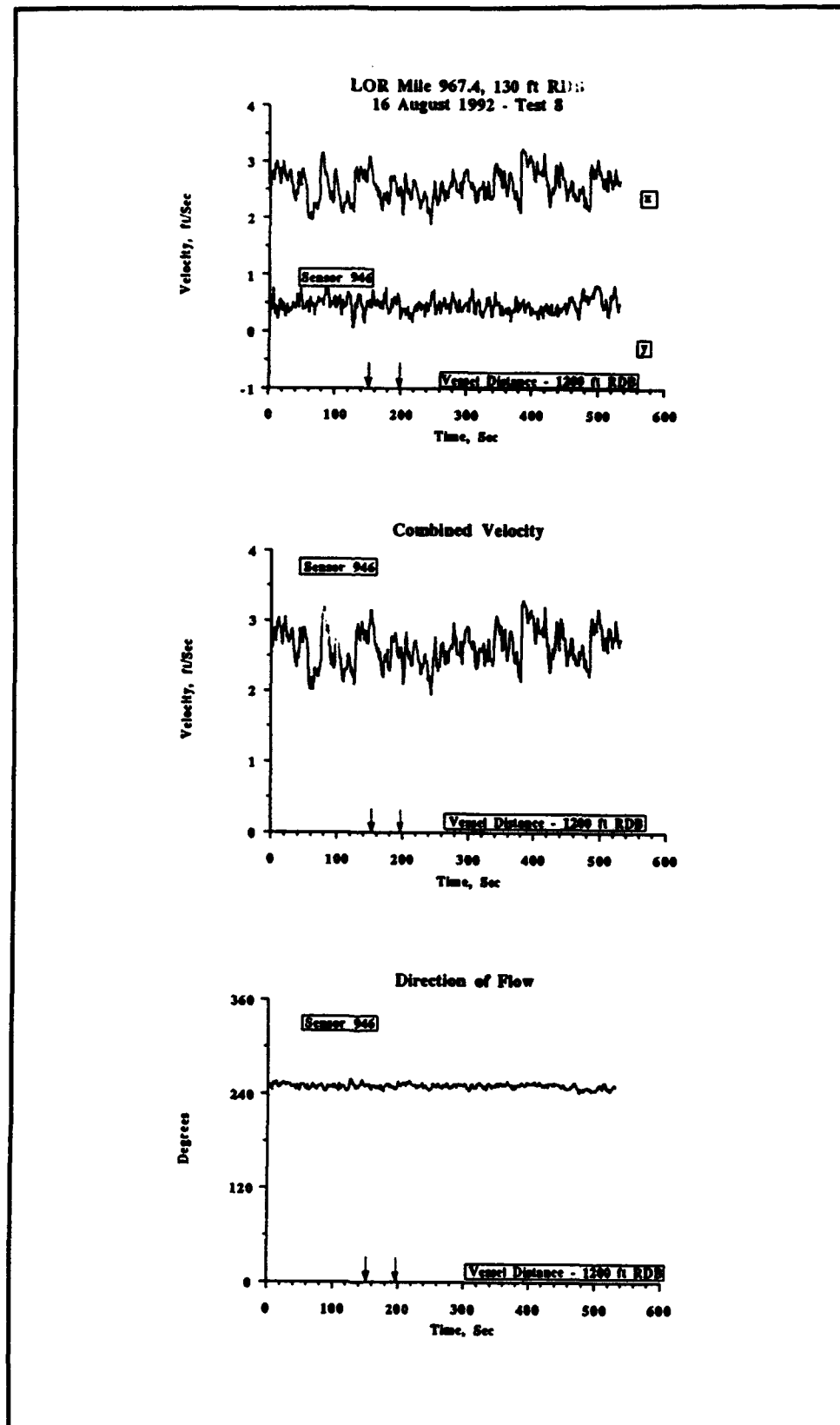


Figure D15. Test 8, LOR Mile 967.4, 130 ft RDB, 16 August 1992

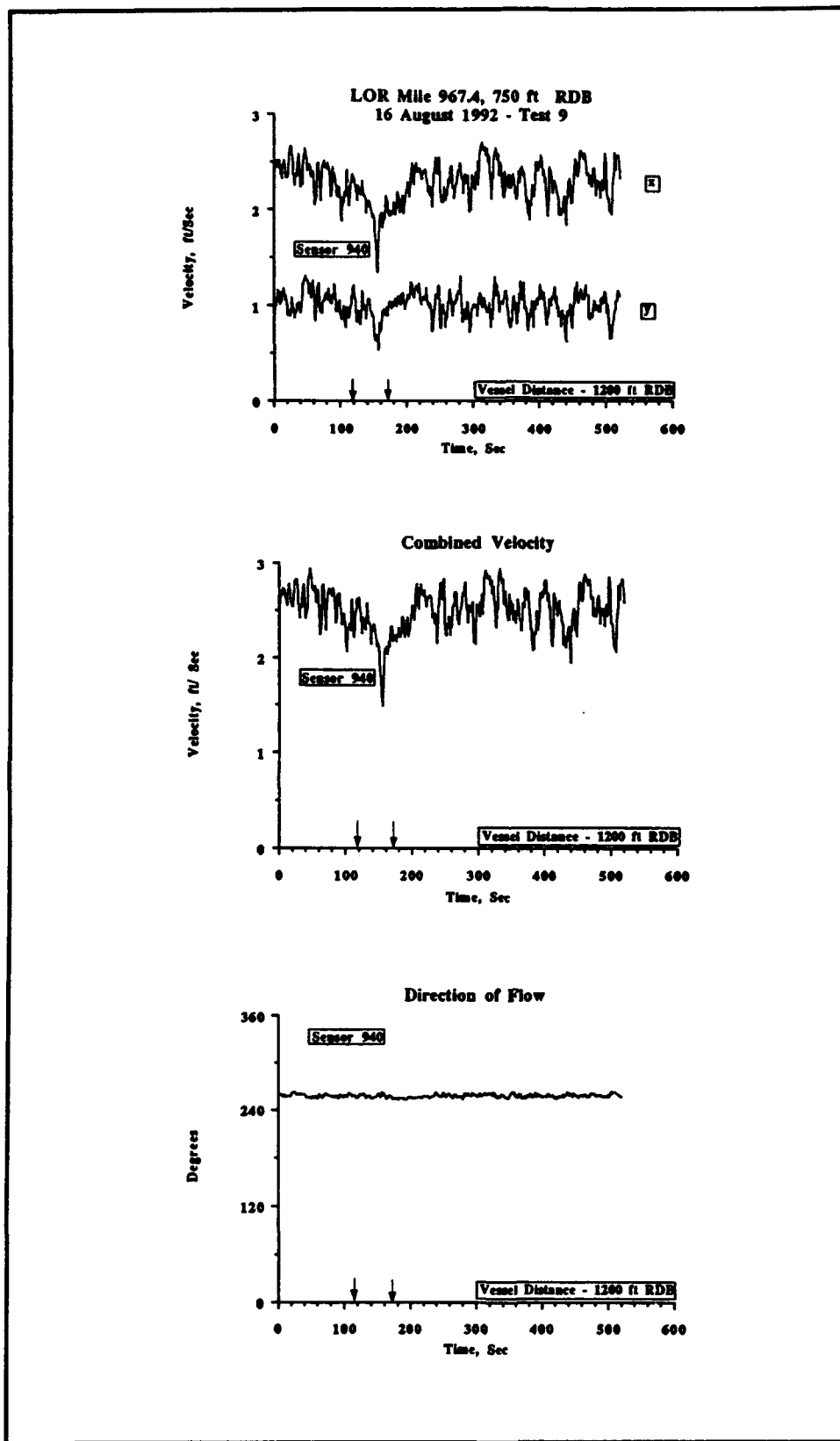


Figure D16. Test 9, LOR Mile 967.4, 750 ft RDB, 16 August 1992

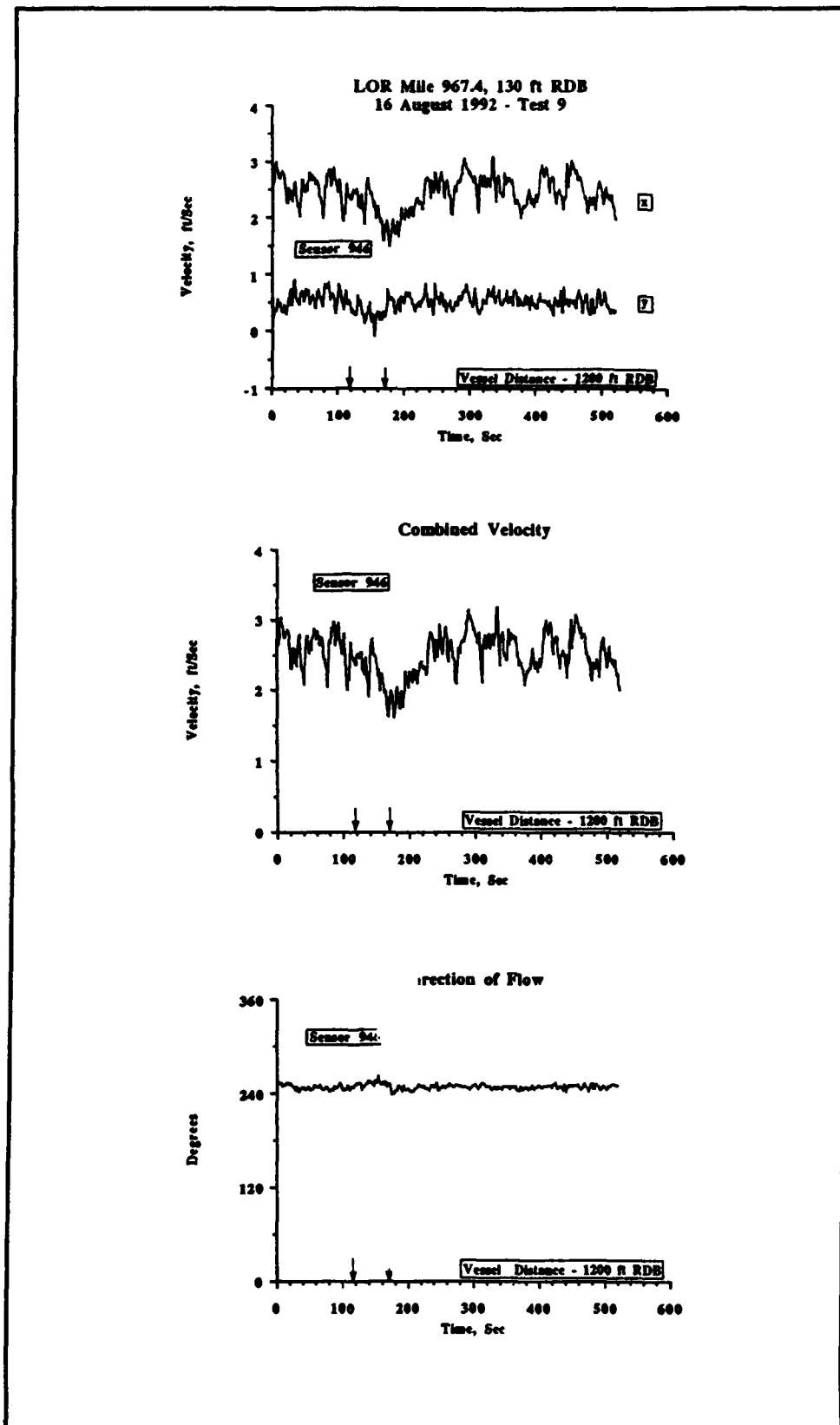


Figure D17. Test 9, LOR Mile 967.4, 130 ft RDB, 16 August 1992

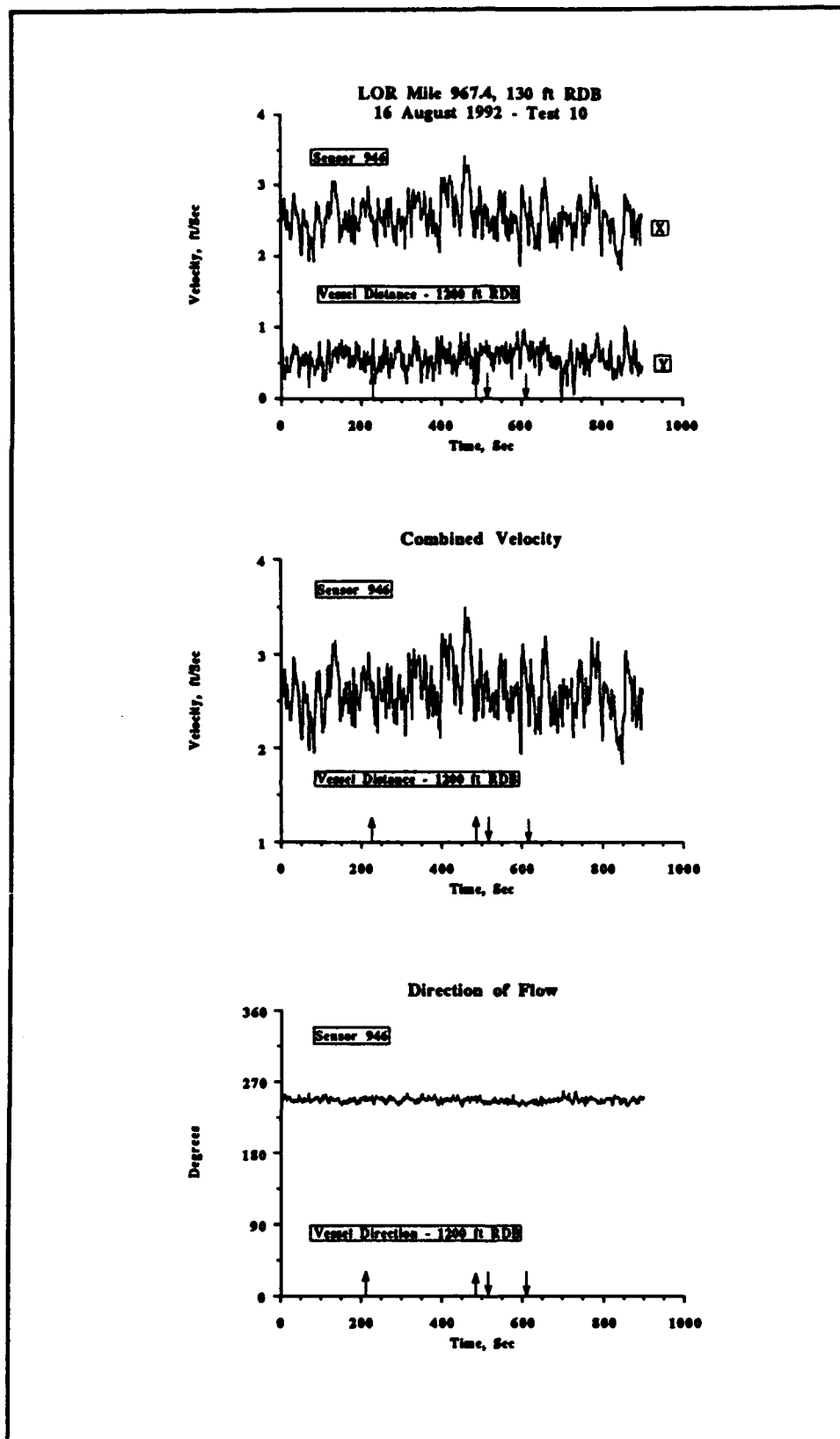


Figure D18. Test 10, LOR Mile 967.4, 130 ft RDB, 16 August 1992

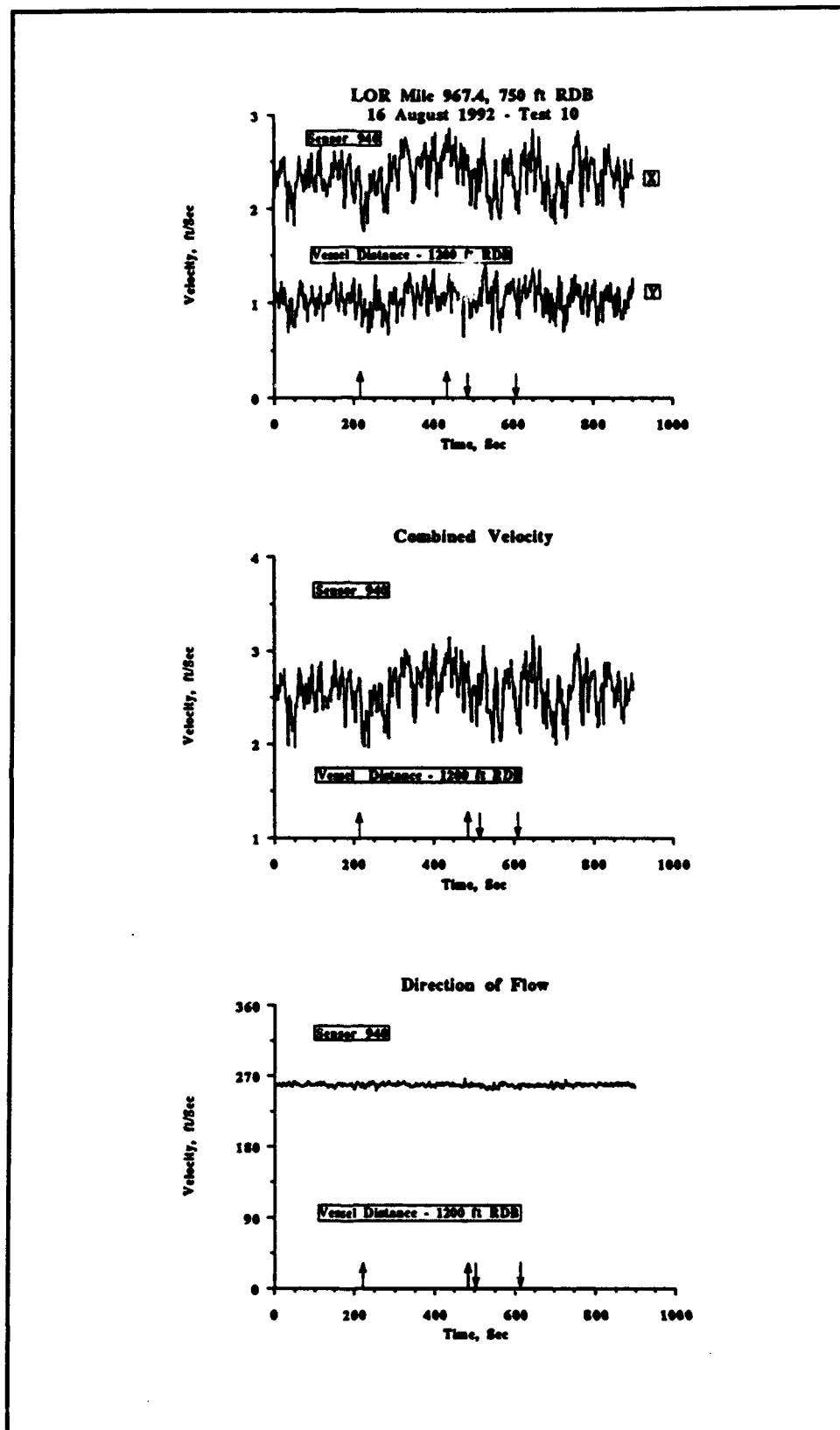


Figure D19. Test 10, LOR Mile 967.4, 750 ft RDB 16 August 1992

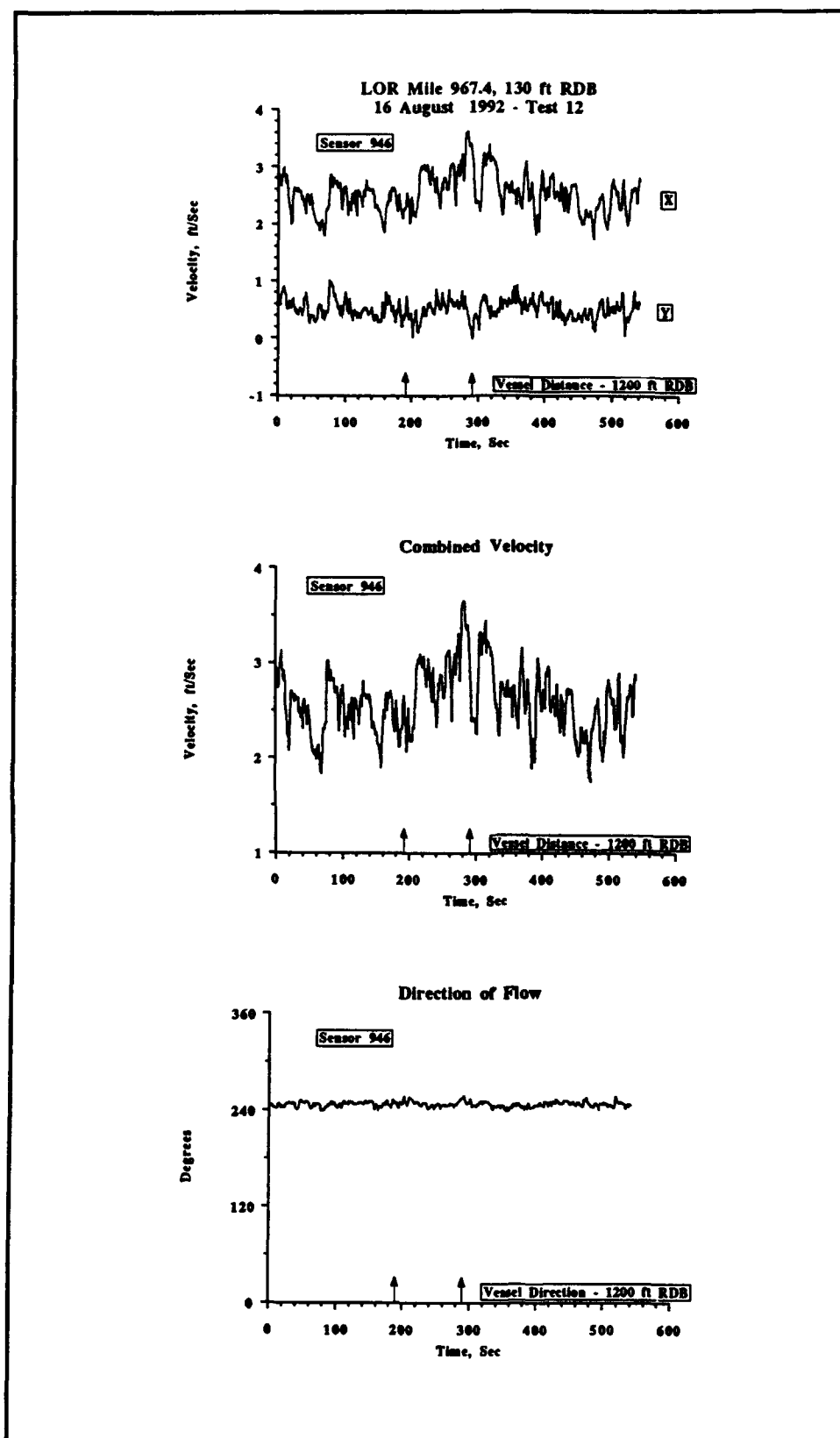


Figure D20. Test 12, LOR Mile 967.4, 130 ft RDB, 16 August 1992

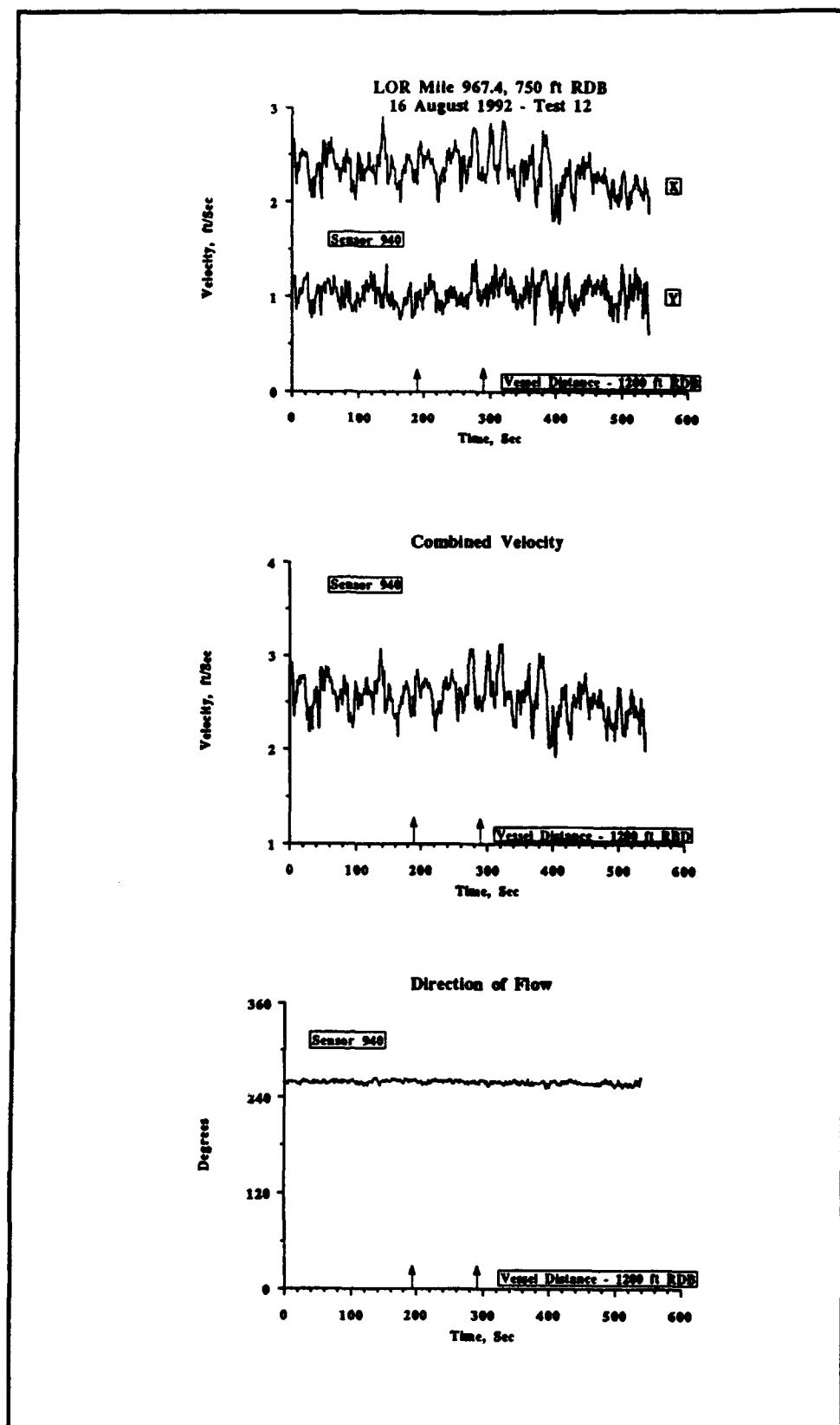


Figure D21. Test 12, LOR Mile 967.4, 750 ft RDB, 16 August 1992

Appendix E

Analysis of Habitat Conditions for Freshwater Mussels at an Area To Be Immediately Affected by the Olmsted Lock and Dam Project, October 1-3, 1991

Introduction

In 1987, Dr. James B. Sickel, Murray State University, found the endangered fat pocket book mussel, *Potamilus capax* (Green, 1832), in the channel of the Ohio River between Cumberland Island Towhead and the Kentucky shore. The U.S. Fish and Wildlife Service determined that similar habitat could occur at and immediately downriver of the proposed Olmsted Locks and Dam Project. They then requested that a qualitative survey be undertaken to determine the presence and community composition of mussels in the project area. The U.S. Army Engineer District, Louisville, requested that the U.S. Army Engineer Waterways Experiment Station survey this area of the proposed Olmsted Locks and Dam Project in October 1991 for freshwater mussels and *P. capax*.

Site and Methods

The area that will be impacted by construction and operation of the project is located on the lower Ohio River between Illinois and Kentucky (Ohio River Mile 964.4) (Figure E1). At each of 18 sites within the project area, a qualitative search was made to evaluate the presence, composition, and habitat conditions for existing mussels. Each qualitative search consisted of having two or three divers completely work the area within the range of a 100-ft-long "umbilicus" (compressed air and communications line) that attached each diver to the dive boat. Searches averaged approximately 50 diving min per site. A total of 890 diving min were

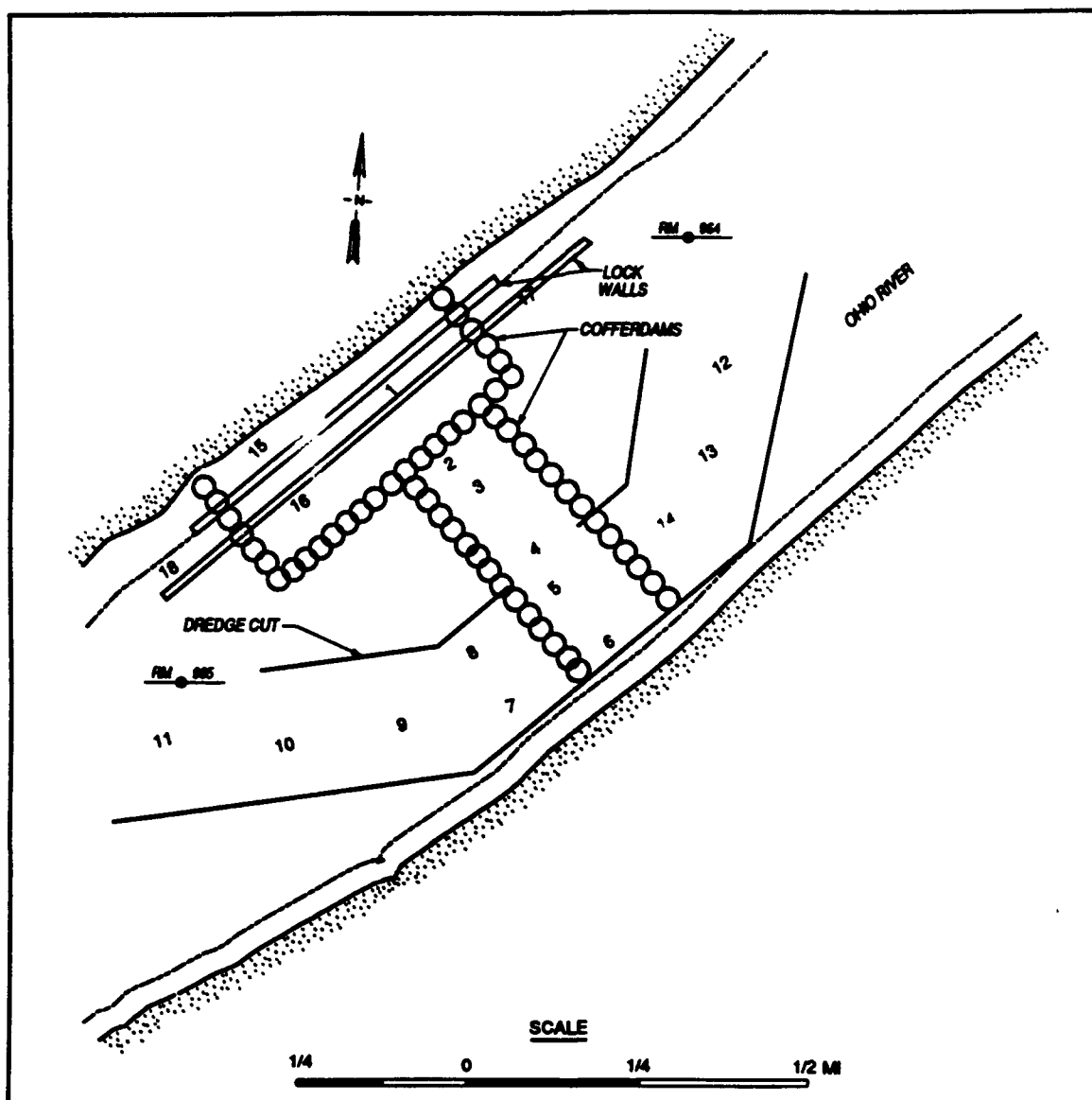


Figure E1.

spent at all 18 sites combined. This survey was completed on 1-3 October 1991.

Divers were instructed to feel the bottom for live mussels and place each mussel into mesh bags. Bags were returned to the surface, identified, and their shell lengths were measured to the nearest 0.1 mm using dial calipers. Using bottom to surface communications equipment, divers described substrate conditions as they surveyed each site.

For comparative purposes, a single qualitative search was made at Ohio River Mile 967, right descending bank, in a historically prominent and dense bed of mussels. In addition, two sets of 10 quantitative substrate samples were obtained at sites closely adjacent to the qualitatively search

area. The quantitative samples were sieved, and all live mussels were removed. This technique enabled an accurate estimation of mussel density.

Results

A total of 36 mussels representing 12 species were obtained from qualitative searches of the 18 sites located throughout the proposed construction site (Tables E1 and E2). Total diving time expended was 890 min. The average rate of return was only 2.4 mussels per diving hour. Few mussels were large, old adults. Only 13 of the 36 individuals were greater than 50 mm in length (Table E3). Two specimens of *Lampsilis ovata*, a species morphologically very similar to *Potamilus capax*, were obtained along the left descending bank (Kentucky side of river). These two individuals were young and small, measuring only 38.7 and 31.7 mm in shell length. The low density and the predominance of small, young mussels indicate that this location is not suitably stable to sustain mussel populations.

Substrate conditions indicate that the right descending bank (Illinois side of river) appears to be too scoured for establishment of unionids (Sites 1, 2, and 15-18, Table E1). The left descending bank (Kentucky side of river) is more depositional, with fine sand at most sites and silt or mud on top of sand at some sites (Sites 3-14, Table E1). Divers described sand waves along the bottom on the left descending bank with 1- to 2-in. crests spaced at approximately 12-in. intervals. The presence of these sand waves, like the very low density and dominance of young, small mussels, indicates lack of sufficient stability to sustain mussel populations.

In comparison, in a single hour, qualitative searching of the historically prominent mussel bed at River Mile 967 yielded a total of 194 mussels and 14 species (Table E4). The 80-fold lower rate of return of mussels from qualitative searches at the site of the Olmsted Locks and Dam Project site versus that at River Mile 967 indicates the comparatively low habitat value for unionids at the proposed construction site. The mussel bed sampled at River Mile 967 occurs among a stable shoal comprised of cobble, shells, gravel, sand, and mud. The 20 quantitative samples taken at this location provided a density estimate of 55 mussels per square meter.

Conclusions

The mussel fauna at the Olmsted Locks and Dam Project site is of very low density and is dominated by young, small mussels. Substrate does not appear to be sufficiently stable to support mussels. It is highly unlikely that this area provides suitable habitat for the endangered species *Potamilus capax*.

Table E1
Description of Diving Time, Mussel Catch, and Substrate
Characteristics at 18 Sites Located in the Proposed Area for the
New Olmsted Lock and Dam and Approach Channels, October 1991

Dive No.	No. of Minutes ¹	No. of Mussels	Species	Substrate Conditions
1	60	1	1	Coarse sand over fine gravel and over hard clay
2	60	5	2	Sand covered by woody debris and fine pebbles; lots of caddisflies
3	45	1	1	Sand
4	60	2	2	Sand and hard clay
5	75	0	0	Sand with some silt on top
6	60	0	0	Fine sand
7	45	0	0	Fine sand
8	25	3	2	Sand with some silt
9	50	2	2	Fine sand
10	40	1	1	Fine sand
11	40	4	3	Sand with a few rocks
12	40	3	3	Sand with a 1- to 2-in. layer of flocculent mud on top
13	50	6	4	Sand with a 1- to 2-in. layer of flocculent mud on top
14	50	2	2	Sand with a 1- to 2-in. layer of silt on top
15	50	1	1	Rocks on hard clay; lots of large woody debris
16	50	2	2	Coarse sand
17	50	2	2	Fine gravel; with lots of caddisflies
18	40	0	0	Fine gravel and shell debris

¹ This is the cumulative minutes of all divers at a site.

Table E2
Relative Abundance of Unionid Species Among 36 Individuals
Collected from All 18 Sites in the Area of the Proposed Olmsted
Lock and Dam and Approach Channe's, October 1991

Species	No. of Individuals
<i>Quadrula nodulata</i>	7
<i>Truncilla donaciformis</i>	5
<i>Potamilus alatus</i>	5
<i>Leptodea fragilis</i>	5
<i>Fusconaia ebena</i>	3
<i>Obliquaria reflexa</i>	3
<i>Anodonta imbecillis</i>	2
<i>Lampsilis ovata</i>	2
<i>Quadrula quadrula</i>	1
<i>Quadrula p. pustulosa</i>	1
<i>Ellipsaria lineolata</i>	1
<i>Ambleria p. plicata</i>	1

Table E3
Shell Length Records for Individual Mussels Obtained from
Qualitative Searches of 18 Sites in the Olmsted Locks and Dam
Project Area, October 1991

Species	Shell Length (mm) of Each
<i>Quadrula nodulata</i>	66.0, 67.7, 57.9, 47.2, 40.7, 36.6, 31.4
<i>Truncilla donaciformis</i>	21.7, 20.2, 19.5, 15.9, 14.4
<i>Potamilius alatus</i>	76.1, 68.1, 56.9, 59.4, 41.5
<i>Leptodea fragilis</i>	57.4, 44.1, 39.5, 39.3, 31.2
<i>Fusconaia ebena</i>	66.5, 63.4, 69.4
<i>Obliquaria reflexa</i> *	30.0, 28.1, 29.4
<i>Anodonta imbecillis</i>	41.9, 28.6
<i>Lampsilis ovata</i>	38.2, 31.7
<i>Quadrula quadrula</i>	63.9
<i>Quadrula pustulosa</i>	36.5
<i>Ellipsaria lineolata</i>	52.1
<i>Ambelma p. plicata</i>	36.3

Table E4
Relative Abundance of Species Among 194 Unionids Obtained in a
Qualitative Search of a Historically Prominent Mussel Bed at Ohio
River Mile 967, October 1991

Species	No. of Individuals
<i>Fusconaia ebena</i>	124
<i>Quadrula p. pustulosa</i>	16
<i>Quadrula metanevra</i>	18
<i>Obovaria olivaria</i>	8
<i>Ellipsaria lineolata</i>	12
<i>Amblema p. plicata</i>	5
<i>Quadrula quadrula</i>	3
<i>Pleurobema cordatum</i>	2
<i>Truncilla donaciformis</i>	1
<i>Quadrula nodulata</i>	1
<i>Ligumia recta</i>	1
<i>Plethobasus cyphus</i>	1
<i>Elliptio crassidens</i>	1
<i>Tritogonia verrucosa</i>	1

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13. ABSTRACT (Maximum 200 words) A survey to assess community characteristics, density, population demography of dominant species, and the likelihood of finding endangered species of freshwater mussels (Unionidae) was conducted in the lower Ohio River near Olmsted, IL. Data will be used to analyze impacts of construction and operation of a new lock and dam at River Mile (RM) 964.4 on the Ohio River. Species diversity (2.36) and evenness (0.80) were higher upriver than downriver of Lock and Dam 53 (1.55 and 0.51 at three farshore sites at RM 967). Based on quantitative samples taken upriver of the lock, five species individually comprised more than 10 percent of the community. These species and their percent abundance were as follows: <i>Fusconaia ebena</i> (21 percent), <i>Truncilla donaciformis</i> (16 percent), <i>Quadrula pustulosa</i> (12 percent), <i>T. truncata</i> (12 percent), and <i>Obliquaria reflexa</i> (10 percent). <i>Fusconaia ebena</i> and <i>M. nervosa</i> comprised a greater fraction of the community downriver than upriver of Lock and Dam 53. <i>Quadrula pustulosa</i> , <i>Q. quadrula</i> , <i>Q. metanevra</i> , and <i>O. reflexa</i> had greater relative abundance upriver than downriver of Lock and Dam 53. Density of native unionids (15.0 to 105.2 individuals/square meter) and <i>Corbicula fluminea</i> (229.4 to 653.8 individuals/square meter) varied significantly among nearshore, midshore, and farshore sites downriver of Lock and Dam 53. Biomass density differences were not nearly as clear (i.e., they were significant at the 0.1 (Continued)					
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but not 0.05 level) nor as substantial. The endangered species *Plethobasus cooperianus* was obtained in qualitative samples upriver of Lock and Dam 53 in 1992, but was not obtained in either quantitative samples (both beds) or qualitative samples downriver of Lock and Dam 53. Overall, the size structure of the *F. ebena* population downriver of Lock and Dam 53 indicated two major cohorts: very recent recruits (presumably 1991) centered at 8 to 20 mm in length and a cohort of moderately large and old mussels centered at 60 to 70 mm in length.

Drought, natural patterns of recruitment, and species introductions are natural factors that potentially affect native mussels in the lower Ohio River. Effects of construction and operation of the Olmsted Lock and Dam project can best be monitored by regularly monitoring density, diversity, and size demography of dominant native mussel populations in the lower Ohio River.