Technical Report EL-97-13
July 1997

US Army Corps
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Waterways Experiment
Station

Value of Selected Mussel Beds in the Upper Mississippi River for *Lampsilis higginsi*

by Andrew C. Miller, Barry S. Payne

WES

Approved For Public Release; Distribution Is Unlimited

Prepared for Higgins' Eye Recovery Team, U.S. Fish and Wildlife Service
and U.S. Army Engineer District, St. Paul

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3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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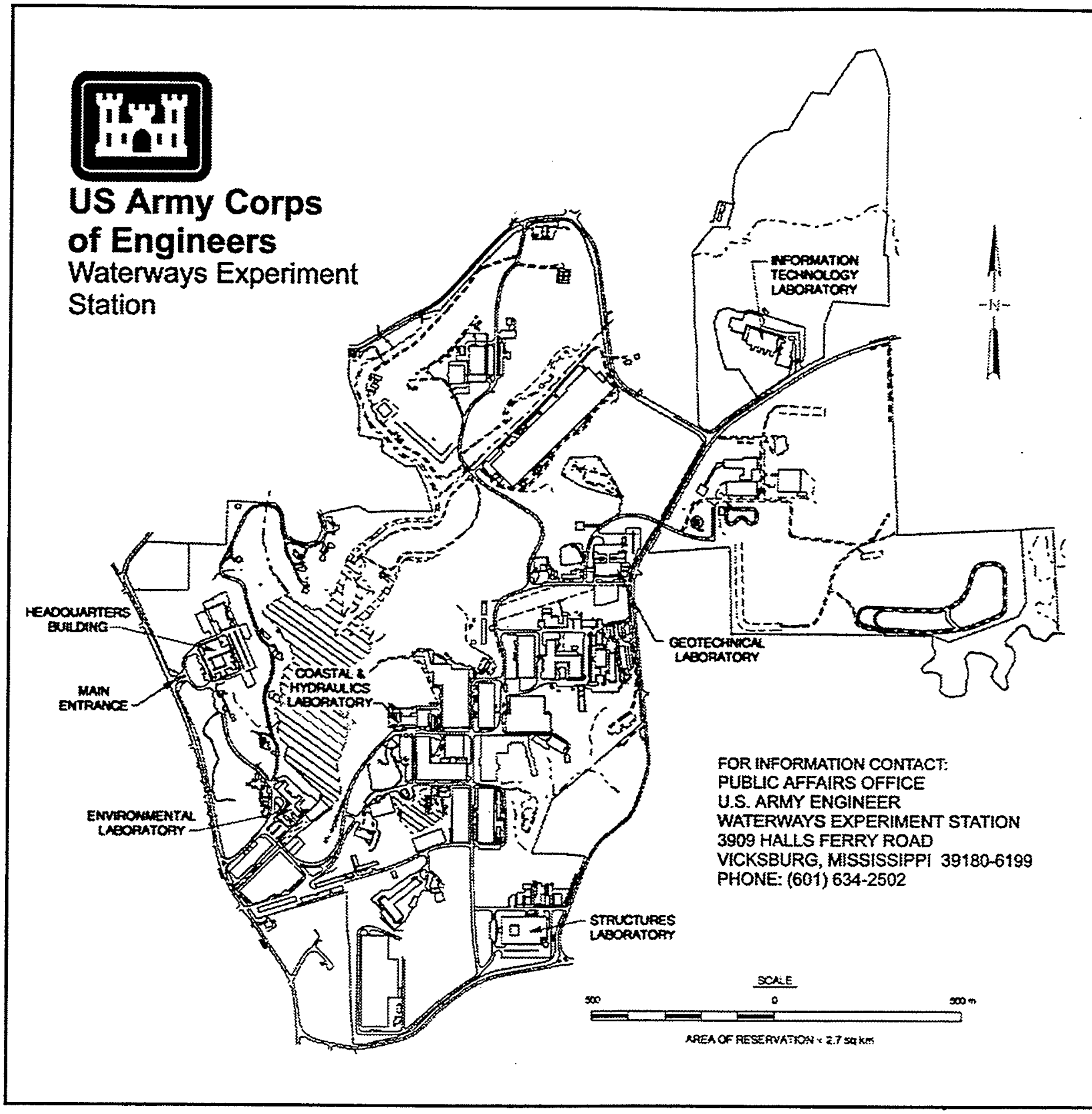

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Preface

Research described in this report was conducted by the U.S. Army Engineer Waterways Experiment Station (WES). Funds were provided by the Higgins' Eye Recovery Team, U.S. Fish and Wildlife Service (FWS), and the U.S. Army Engineer District, St. Paul. The purpose was to characterize native and nonnative bivalves at locations designated as essential for the endangered Higgins' eye mussel, *Lampsilis higginsi* (Lea). Information will be used by the personnel of the FWS and the U.S. Army Corps of Engineers to assist with managing aquatic resources in the upper Mississippi River.

This report was prepared by Drs. Andrew C. Miller and Barry S. Payne, Aquatic Ecology Branch (AEB), Ecological Research Division (ERD), Environmental Laboratory (EL), WES.

Divers for the study were Messrs. Larry Neill, Robert Warden, Rob James, and Johnny Buchannan, Tennessee Valley Authority. Assistance in the field was provided by Mr. Will Green and Dr. David Beckett, University of Southern Mississippi, and Mr. Rick Hart, North Dakota State University. Figures were prepared by Ms. Geralline Wilkerson, Jackson State University.

During the conduct of this study, Dr. John Harrison was Director, EL; Dr. Conrad J. Kirby was Chief, ERD; and Dr. Alfred F. Cofrancesco was Chief, AEB.

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
miles (U.S. nautical)	1.852	kilometers

1 Introduction

Background

In the early 1980s, the Higgins' Eye Recovery Team (1982) evaluated 16 localities in the upper Mississippi River (UMR) for the Higgins' eye mussel, *Lampsilis higginsi* (Lea 1857), listed as endangered (U.S. Fish and Wildlife Service 1991). The Team determined that sufficient information was available to list seven locations as essential for this species. An additional nine were considered to be of secondary importance, mainly because of a lack of information on these river reaches. Since the Higgins' Eye Recovery Plan was published in the early 1980s, many government and private organizations have funded additional research on freshwater mussels in the UMR. These studies, conducted to obtain information for environmental impact statements, assessments, and permit actions, have provided information not only on *L. higginsi* but other species as well. The purpose of this study was to obtain information on density, community composition, species diversity, species richness, and presence of *L. higginsi* at selected beds identified by the Higgins' Eye Recovery Team (1982).

Studies were conducted at the following mussel beds:

- Drew Chute, Pool 19, near River Mile (RM) 407, left descending bank (LDB).
- Sylvan Slough, Pool 15, near RM 485, LDB.
- Goetz Island, Pool 11, near RM 612, right descending bank (RDB).
- Lower East Channel, Pool 10, near RM 635.
- Harpers Slough, Pool 10, near RM 641, RDB.
- Whiskey Rock, Pool 9, near RM 656, RDB.

Detailed information on other beds known to support endangered mussels have been collected recently by various workers. Heath (1995) reported on a bed in the lower Wisconsin River, RM 45-50.1, and Hornbach et al. (1996)

described a mussel assemblage in the lower St. Croix River, Minnesota and Wisconsin. Davis and Hart (1995) reported on a survey of the tailwater of Lock and Dam 6 in Pool 7 of the UMR. Miller and Payne (1996a) conducted a mussel survey of natural substratum and wing dikes at McMillan Island, Pool 10 of the UMR. Cawley (1989) surveyed mussel populations at Sylvan Slough, Pool 15, the same bed that was examined during this survey.

Purpose and Scope

The purpose of this study was to conduct a detailed survey for freshwater mussels at six beds in the UMR designated as essential for *L. higginsi*. The investigation was designed to address four objectives:

a. Determine percent abundance and estimate total numbers of *L. higginsi* at each bed.

b. Determine the spatial distribution of *L. higginsi*.

c. Relate physical parameters (depth, water velocity, and sediment type) to presence of *L. higginsi*.

d. Determine if other species of native bivalves are found in association with *L. higginsi*.

2 Study Area and Methods

Study Area

Beds were located in the UMR between RM 407 in Pool 19 just south of Burlington, IA, to RM 657 in Pool 9, north of Prairie du Chien, WI (Figure 1). All were in the main stem of the river at historically known mussels beds considered to be important for *L. higginsi*. Location of the beds was taken from the Higgins' Eye Recovery Plan (Higgins' Eye Recovery Team 1982), published by the U.S. Fish and Wildlife Service. Following is a brief description of each bed.

Drew Chute, Pool 19, near RM 407, LDB

A total of 49 and 100 samples were taken at this location using qualitative and quantitative sampling methods, respectively (Figure 2, Table 1). The majority were along the LDB in water 3-4 m deep. Substratum consisted of approximately 31.5-percent silt and fine sand and 60-percent coarse-grained sediments greater than 34 mm diameter (Figure 3). For the most part, river bottom along the LDB was depositional, whereas the RDB was more erosional with sediments consisting mainly of fine- and coarse-grained sand. Water velocity during the study was moderate along the LDB, typically less than 1.0 ft/sec.[1] Higher water velocity was measured along the RDB toward the head of Otter Island. Two qualitative samples were taken from O'Connell Slough, which was much narrower, shallower, and less riverine than the main channel.

Sylvan Slough, Pool 15, near RM 485, LDB

Sylvan Slough is located along the LDB just downriver of the Iowa-Illinois Memorial Bridge (Figure 4). A total of 150 quantitative and 71 qualitative samples were taken. Water was shallow, typically 2-3 m deep, and the substratum consisted mainly of coarse-grained material (65.45 percent) with

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

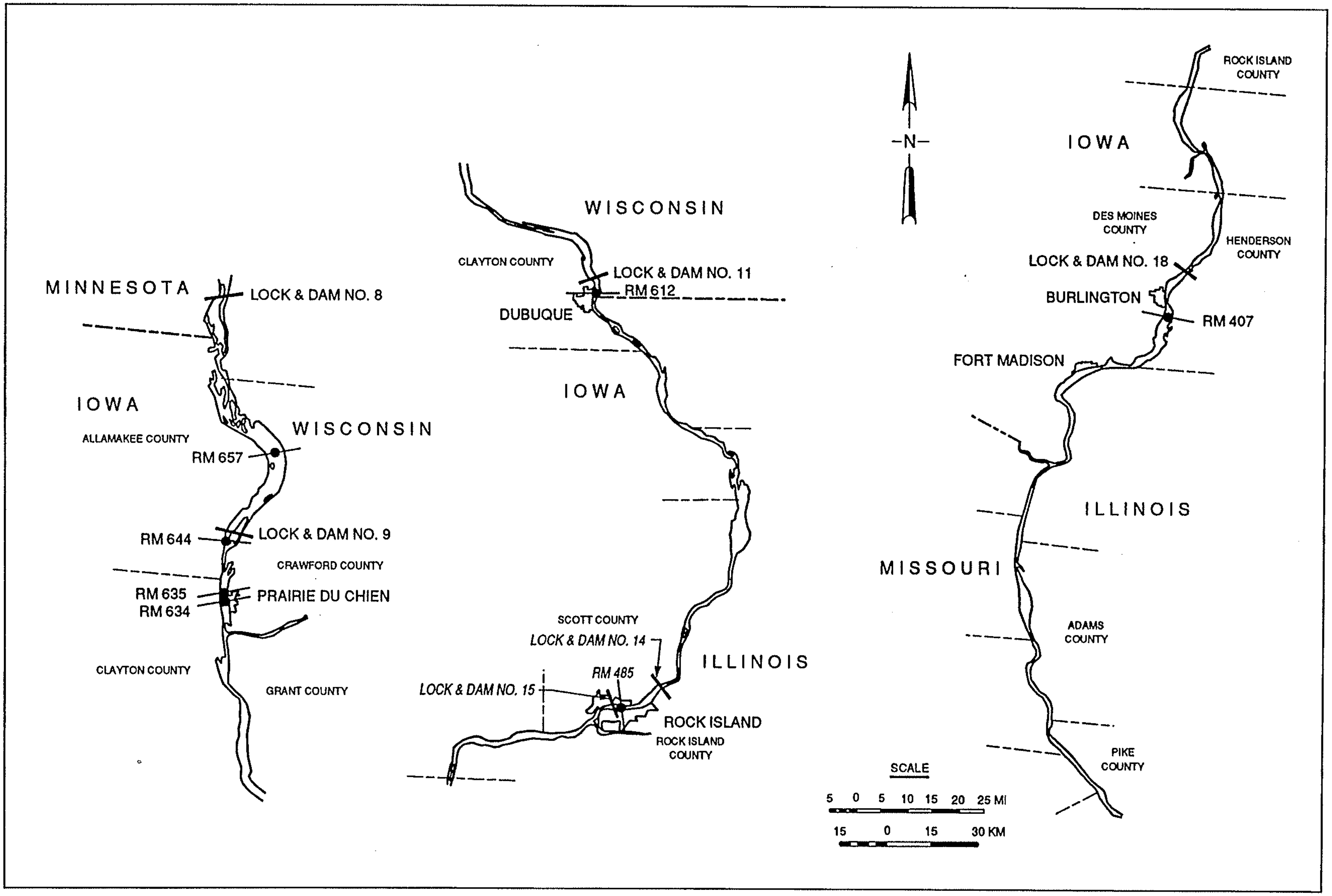

Figure 1. Areas surveyed for *L. higginsi* in UMR (Listed river miles represent center of mussel bed; samples were usually collected within several miles, or less, of this location)

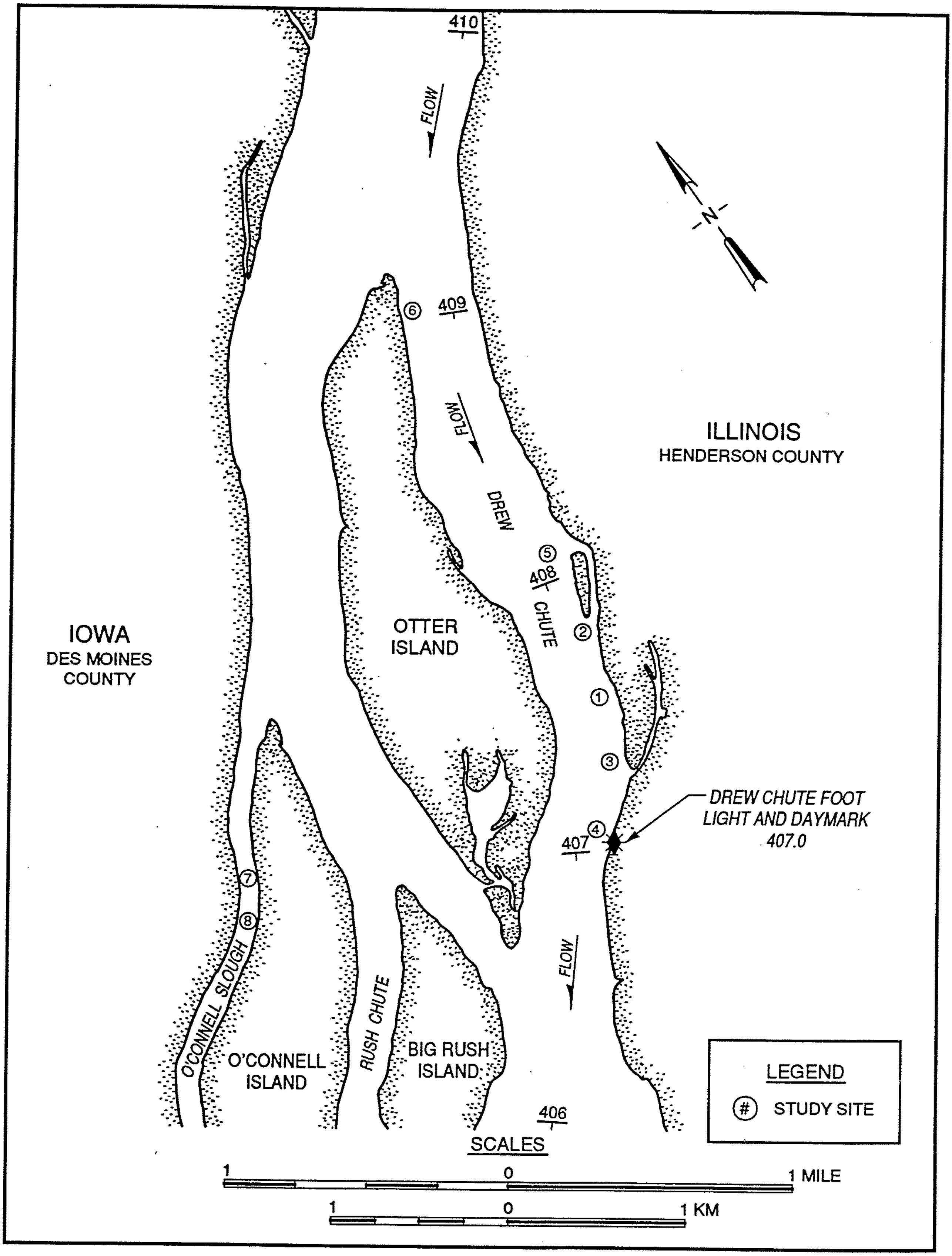

Figure 2. Collecting sites in Drew Chute, Pool 19

Table 1
Location and Type of Samples Collected at Six Locations in UMR, 1995

Description	River Bank	River Mile	Location No.	Qualitative Set No.	Qualitative No. of Samples	Qualitative Time min	Quantitative Set No.	Quantitative Type	Quantitative No. of Samples	Location Latitude	Location Longitude	Max Depth ft
11 Jul 95, Pool 19												
Drew Chute	LDB	407.5	1	1	12	102	1	Substrate	10	40 50.823	91 03.336	15
Drew Chute	LDB	407.7	2				2	Suction	10	40 50.806	91 03.327	18
Drew Chute	LDB	407.7	2				3	Suction	10	40 50.806	91 03.327	
Drew Chute	LDB	407.3	3	2	12	52	4	Suction	10	40 50.676	91 03.480	18
Drew Chute	LDB	407.3	3				5	Suction	10	40 50.676	91 03.480	
Drew Chute	LDB	407.3	3				6	Suction	10	40 50.676	91 03.480	
12 Jul 95, Pool 19												
Drew Chute	LDB	407.1	4	3	12	60	7	Suction	10	40 50.605	91 03.633	18
Drew Chute	LDB	407.1	4				8	Suction	10	40 50.605	91 03.633	
Drew Chute	LDB	408.2	5	4	7	67	9	Suction	10	40 51.559	91 02.851	15
Drew Chute	LDB	408.2					10	Suction	10	40 51.559	91 02.851	
Drew Chute	RDB	409.0	6	5	2	36				40 52.191	91 52.191	
O'Connell Sl.	RDB	407.2	7	6	2	35				40 51.215	91 04.800	10
O'Connell Sl.	CNT	406.9	8	7	2	30				41 51.043	91 05.267	8
Total for Bed					49				100			

(Sheet 1 of 4)

Note: LDB - Left Descending Bank; RDB - Right Descending Bank; CNT - Approximately in the Center of the Channel; Low E. Ch. - East Channel of the UMR near Prairie du Chien downriver of the bridge; Main Ch. - Main Channel of the UMR (RM 635.2) near Prairie du Chien; Sl - Slough. The time in minutes is usually the total for two divers at the site.

Table 1 (Continued)

Description	River Bank	River Mile	Location No.	Qualitative			Quantitative			Location		Max Depth ft
				Set No.	No. of Samples	Time min	Set No.	Type	No. of Samples	Latitude	Longitude	
13 Jul 95, Pool 15												
Sylvan Sl.	RDB	485.4	1	1	12	54	1	Substrate	10	41 30.672	90 31.092	11
Sylvan Sl.	RDB	485.6	2				2	Suction	10	41 30.775	90 30.997	6
Sylvan Sl.	RDB	485.6	2				3	Suction	10	41 30.775	90 30.997	6
Sylvan Sl.	CNT	485.9	3	2	12	88	4	Suction	10	41 30.793	90 30.747	6
Sylvan Sl.	CNT	485.9	3				5	Suction	10	41 30.793	90 30.747	6
Sylvan Sl.	LDB	485.9	4	3	12	86	6	Suction	10	41 30.796	90 30.176	6
Sylvan Sl.	LDB	485.9	4				7	Suction	10	41 30.796	90 30.176	8
14 Jul 95, Pool 15												
Sylvan Sl.	LDB	485.6	5	4	10	87	8	Suction	10	41 30.690	90 30.993	8
Sylvan Sl.	LDB	485.6	5				9	Suction	10	41 30.690	90 30.993	6
Sylvan Sl.	LDB	485.4	6	5	6	58	10	Suction	10	41 31.619	90 30.675	6
Sylvan Sl.	LDB	485.4	6				11	Suction	10	41 31.619	90 30.675	6
Sylvan Sl.	CNT	485.3	7	6	7	50	12	Suction	10	41 30.574	90 31.285	15
Sylvan Sl.	CNT	485.3	7				13	Suction	10	41 30.574	90 31.285	15
Sylvan Sl.	CNT	485.5	8	7	12	60	14	Suction	10	14 30.729	90 31.080	12
Sylvan Sl.	CNT	485.5	8				15	Suction	10	14 30.729	90 31.080	12
Total for Bed					71	483			150			

(Sheet 2 of 4)

Table 1 (Continued)

Description	River Bank	River Mile	Location No.	Qualitative Set No.	Qualitative No. of Samples	Qualitative Time min	Quantitative Set No.	Quantitative Type	Quantitative No. of Samples	Location Latitude	Location Longitude	Max Depth ft
15 Jul 95, Pool 11												
Goetz Island	RDB	612.6	1	1a	12	38				42 45.174	91 05.284	10
Goetz Island	RDB	612.6	1	1b	3							
Goetz Island	RDB	612.4	2	2	10	81	1	Suction	10	42 45.006	91 05.238	10
Goetz Island	RDB	612.5					2	Suction	10	42 45.006	91 05.238	10
Goetz Island	RDB	612.1	3	3	12	74	3	Bucket	10	42 44.713	91 04.999	17
Total for Bed					37	193			30			
16 Jul 95, Pool 9												
Whiskey Rock	RDB	657.9	1	1	12	102	1	Suction	10	43 19.466	91 07.737	10
Whiskey Rock	RDB	657.1	2	2	12	61	2	Bucket	10	43 19.020	91 06.951	13
Whiskey Rock	RDB	656.1	3	3	10	75	3	Suction	10	43 18.733	91 06.480	15
Whiskey Rock	RDB	656.1	3				4	Suction	10	43 18.733	91 06.480	15
Total for Bed					34	238			40			
17 Jul 95, Pool 10												
Low E. Ch.	LDB	634.5	1	1	12	67	1	Suction	10	43 02.288	91 09.247	8
Low E. Ch.	LDB						2	Suction	10	43 02.288	91 09.247	8
Low E. Ch.	RDB	633.8	2	2	12	60	3	Suction	10	43 02.069	91 09.408	10
Low E. Ch.	RDB						4	Suction	10	43 02.069	91 09.408	10

(Sheet 3 of 4)

Table 1 (Concluded)

Description	River Bank	River Mile	Location No.	Qualitative Set No.	Qualitative No. of Samples	Qualitative Time min	Quantitative Set No.	Quantitative Type	Quantitative No. of Samples	Location Latitude	Location Longitude	Max Depth ft
17 Jul 95, Pool 10 (Continued)												
Low E. Ch.	LDB	633.2	3	3	12	57	5	Suction	10	43 01.855	91 09.323	8
Low E. Ch.	LDB						6	Suction	10	43 01.855	91 09.323	8
Total for Bed					36	184			60			
18 Jul 95, Pool 10												
Harpers Sl.	RDB	644.2	1	1	12	126	1	Suction	10	43 09.986	91 10.646	18
Harpers Sl.	RDB	643.5	2	2	12	66	2	Suction	10	43 09.412	91 10.567	13
Harpers Sl.	RDB	640.2	3	3	9	60	3	Suction	10	43 06.838	91 10.755	15
Harpers Sl.	RDB	640.3	4	4	10	113	4	Suction	10	43 07.107	91 10.821	13
Total for Bed					43	365			40			
19 Jul 95, Pool 10, Main Channel												
Main Ch.	RDB	635.2	1	1	12	152	1	Suction	10	43 03.024	91 10.593	20
Total for Bed					12	152			10			
19 Jul, Pool 10, Lower East Channel												
Low E. Ch.	LDB	633.9	4	4	12	37	7	Suction	10	43 02.014	91 09.306	10
Low E. Ch.	LDB	633.9	4				8	Suction	10	43 02.014	91 09.306	10
Low E. Ch.	LDB	633.5	5	5	12	95	9	Suction	10	43 01.625	91 09.579	13
Low E. Ch.	LDB	633.5	5				10	Suction	7	43 01.625	91 09.579	13
Low E. Ch.	CNT	634.6	6	6	6	68	11	Suction	2	43 02.748	91 09.440	11
Total for Bed					30	200			39			
Grand Totals					312	1,815			469			

(Sheet 4 of 4)

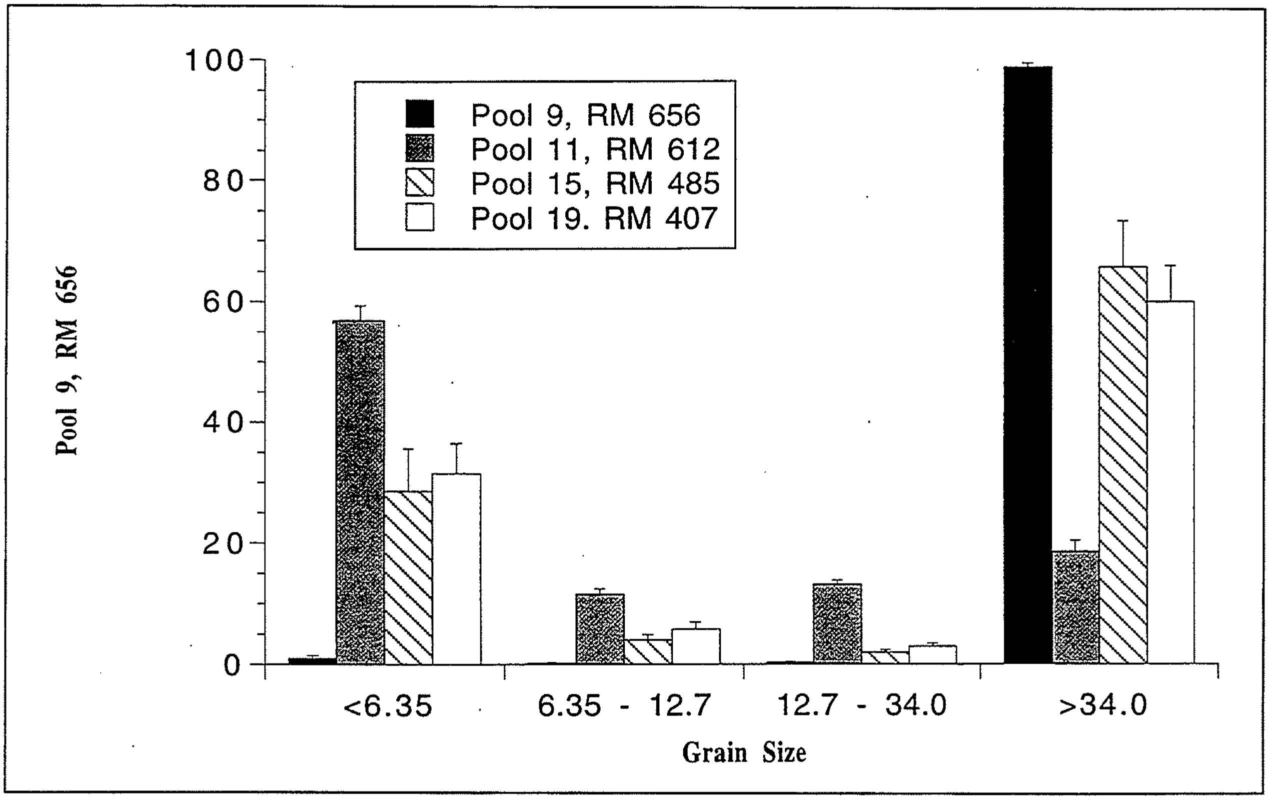

Figure 3. Grain-size distribution for four locations in UMR

28.6 percent of the particles less than 6.35 mm in diameter (Figure 3). In the main channel, the area was erosional; water velocity during the study period was approximately 1.0 ft/sec. Substratum consisted of cobble and coarse gravel.

Goetz Island, Pool 11, near RM 612, right descending bank (RDB)

Samples were taken at four sites along the RDB near RM 612 just downriver of Goetz Island (Figure 5). Thirty quantitative and thirty-seven qualitative samples were collected. Substratum along the most downriver portion of Goetz Island consisted mainly of fine-grained material (56.8 percent) with only 11.5-percent coarse-grained material greater than 24 mm in diameter (Figure 3). Further downriver substratum consisted of gravel and sand. Divers checked a series of sites along the LDB and RDB between RM 612.7 and 613 but did not find many mussels. In comparison to other mussel beds surveyed, this was a low-density bed.

Lower East Channel, Pool 10, near RM 635

Samples were taken on both sides of the East Channel south of the Highway 18 Bridge (Figure 6). Sixty quantitative and thirty-six qualitative samples

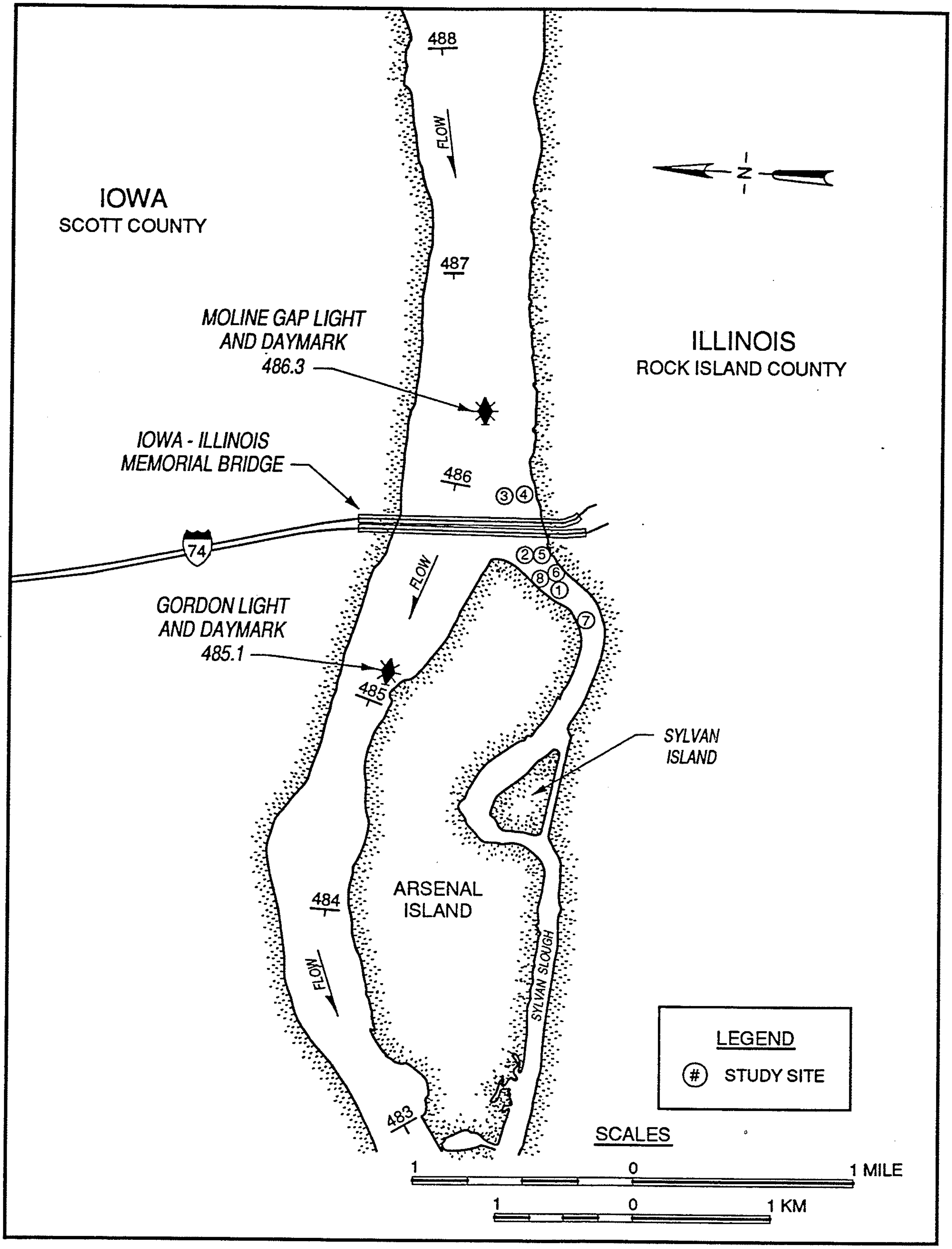

Figure 4. Collecting sites in Sylvan Slough, Pool 15

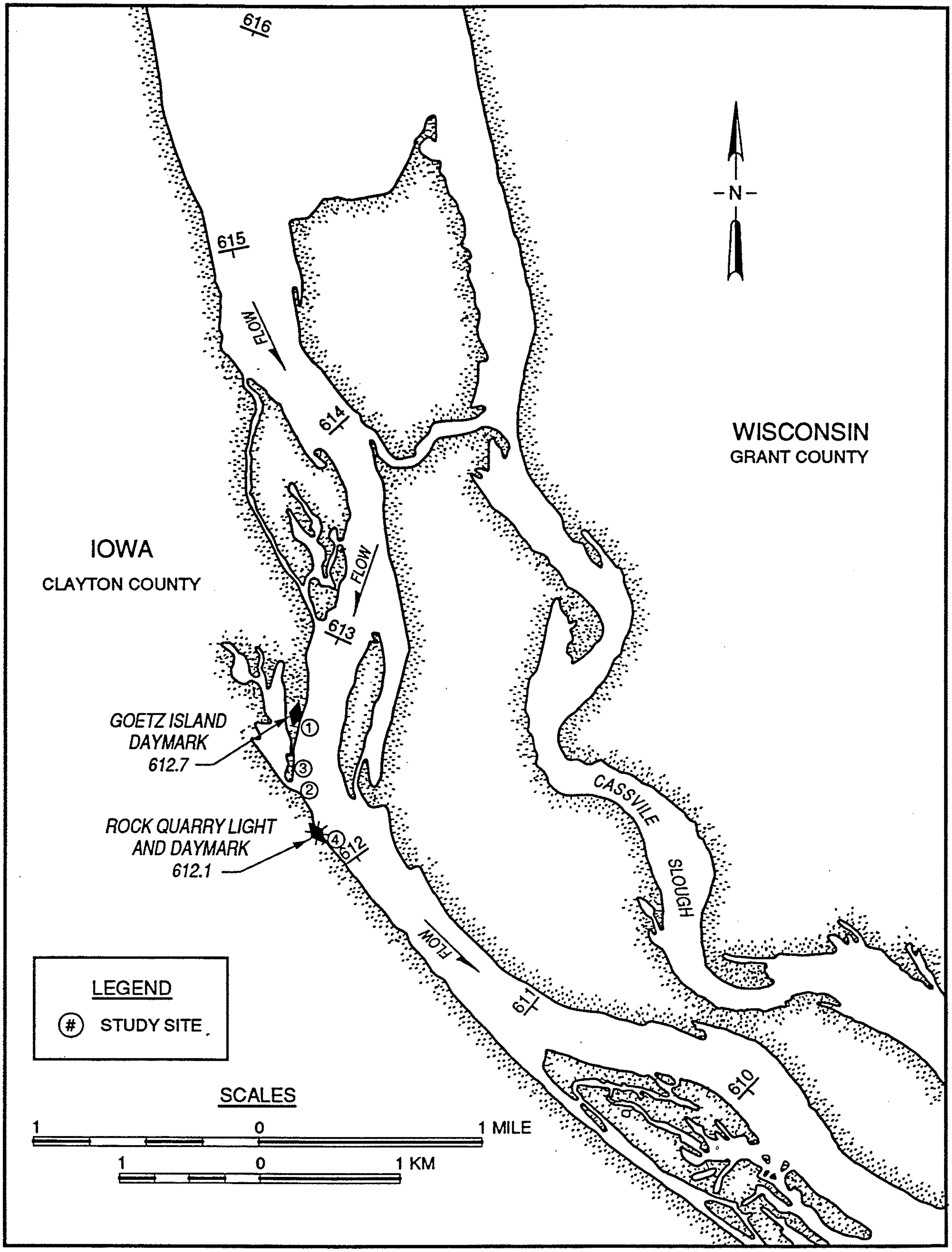

Figure 5. Collecting sites near Goetz Island, Pool 9

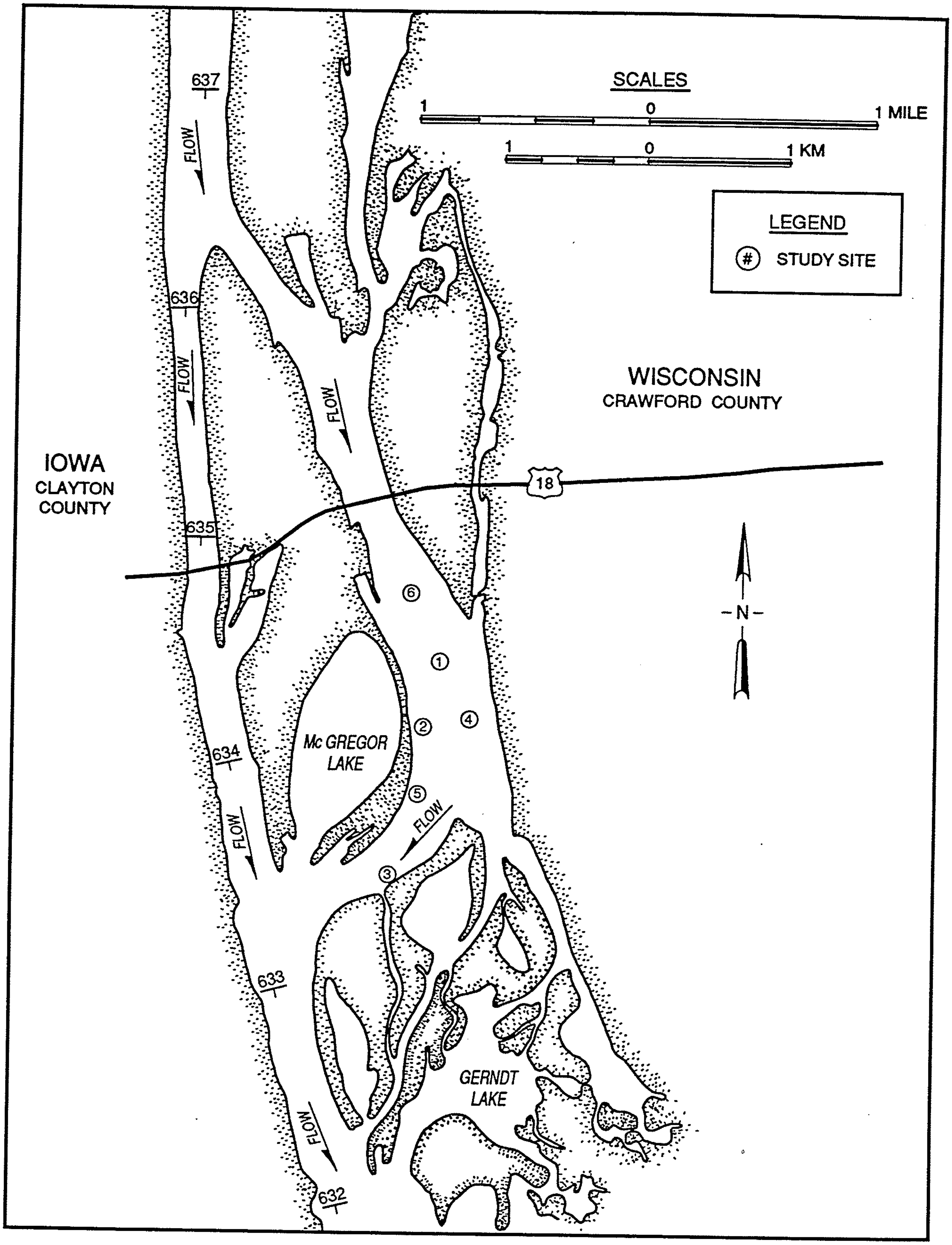

Figure 6. Collecting sites in East Channel, Pool 10 of UMR (One sample, consisting of 10 replicates, was taken at RM 635.2 on RDB

were taken on 17 July at this location. On 19 July, 36 qualitative and 42 quantitative samples were collected. The bed consisted mainly of fine sand and silt with less than 10-percent gravel or cobble. On 19 July, 12 qualitative and 10 quantitative samples were taken at one location along the RDB of the main channel near RM 635.2. Substratum at this location consisted mainly of coarse gravel and cobble.

Harpers Slough, Pool 10, near RM 641, RDB

Two sites in the lower half of Harpers Slough and two sites immediately downriver of the slough along the RDB were searched for mussels on 18 July (Figure 7). A total of 43 qualitative and 40 quantitative samples were collected. Substratum in Harpers Slough consisted mainly of sand and silt stabilized with shells and was similar to that in the lower East Channel downriver. Sediments in the main channel immediately downriver of Harpers Slough consisted of sand and silt and stabilized with shells.

Whiskey Rock, Pool 9, near RM 656, RDB

On 17 July, 34 qualitative and 40 quantitative samples were taken along the RDB in Pool 9 near RM 656 (Figure 8, Table 1). Substratum consisted of less than 1-percent fine-grained sand and silt and over 98-percent coarse gravel and cobble greater than 23 mm in diameter (Figure 3). Water velocity was moderate, approximately 1.0 m/sec. This bed was similar to the one in Pool 11; mussels were scattered and overall densities were low.

Methods

All underwater work was accomplished by a dive crew equipped with surface-supplied air and communication equipment. Before intensive sampling was initiated, a diver conducted a preliminary reconnaissance of each site. He obtained qualitative information on substratum composition (i.e., relative percentages of sand and gravel), water velocity, and presence of mussels. Qualitative sampling was initiated if substratum appeared stable and if there was moderate to high mussel density (i.e., greater than three to five individuals/square meter).

Qualitative samples were obtained by two divers working simultaneously. Each diver worked for a specific length of time and retrieved live mussels by touch. Divers were instructed to obtain native mussels without bias to size or type and to exclude two small nonindigenous species, *Corbicula flůminea* and *Dreissena polymorpha*. Differentiation of these species was based upon touch. If these species were collected, they were later excluded.

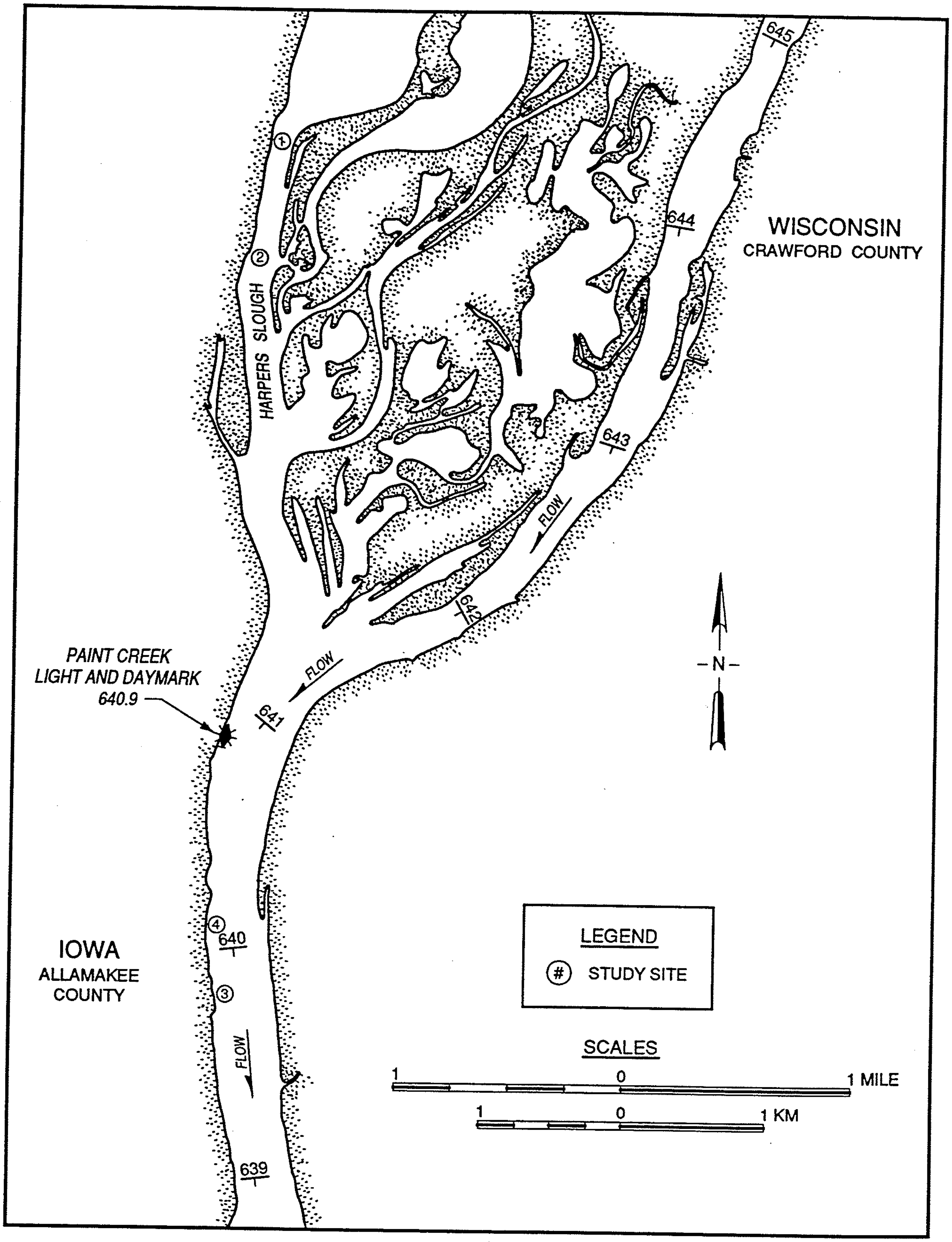

Figure 7. Collecting sites in Harpers Slough and immediately downriver, Pool 10

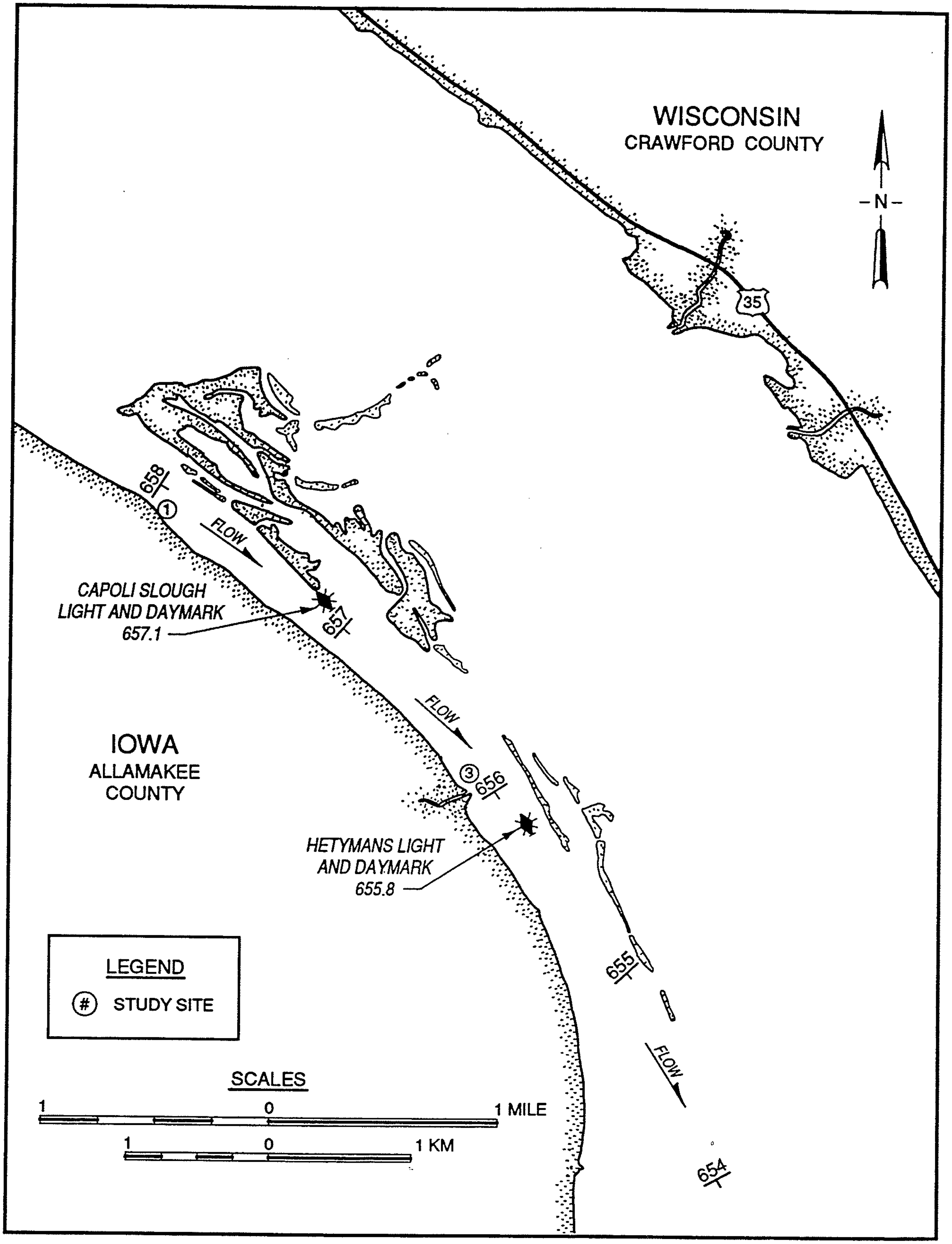

Figure 8. Collecting sites along RDB in Pool 9

Two methods for collecting quantitative samples were used. One method consisted of having a diver excavate all sand, gravel, and shells from within a 0.25-m^2 aluminum quadrat. Substratum was transferred to a 20-ℓ bucket, taken to shore, and sieved through a screen series with the finest apertures 6.4 mm. All live mussels removed from samples were placed in 4-ℓ zipper lock bags. Each bivalve was identified and total shell length measured to the nearest 0.1 mm with calipers.

In addition to the total substratum methods, quantitative samples were obtained with a suction pump. The suction pump was used to remove substratum from the 0.25-m^2 quadrat. This technique was used because it was fast and efficient, and previous sampling revealed that it provided results similar to total substratum methods. Sand and gravel were pumped to the boat where substratum was screened and picked for live mussels. Live mussels collected with the suction pump were bagged for later processing.

All live *L. higginsi* were aged, total shell length measured, and replaced in the substratum by hand.

Data from qualitative and quantitative collections 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. Mussels not needed for voucher were returned to the river. Methods for sampling mussels were based on techniques described in Isom and Gooch (1986); Kovalak, Dennis, and Bates (1986); Miller and Payne (1988); and Miller et al. (1994). Mussel identification was based on taxonomic keys and descriptive information in Murray and Leonard (1962); Parmalee (1967); Starrett (1971); and Burch (1975). Taxonomy was consistent with Williams et al. (1992).

Species diversity was determined with the following formula:

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

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 a personal computer.

3 Results

Condition of Bivalve Community at Each Mussel Bed

A total of 32 species of bivalves were collected at six mussel beds using qualitative methods (Table 2). This list includes two nonindigenous species, the Asian clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena polymorpha*. Using quantitative methods, 31 species were collected. Following is a brief description of community conditions at each bed.

Drew Chute, Pool 19, near RM 407, LDB

Using qualitative methods, 19 species of bivalves were collected at the mussel bed in Pool 19 (Appendix A, Table A1). The fauna was dominated by *Amblema p. plicata, Quadrula p. pustulosa, Obliquaria reflexa*, and *Obovaria olivaria*, which together comprised 58 percent of the collection. Eighteen species of bivalves were collected using quantitative methods. *Lampsilis higginsi* was not found at this location.

Although the total number of species collected using quantitative methods was slightly less than at the other beds surveyed, Shannon's species diversity index, 2.32, was high (Figure 9). Evidence of recent recruitment, as measured by the number of species with at least one individual less than 30-mm total shell length (SL) was greater than 50 percent (Figure 10). Slightly more than 12 percent of the native mussels were less than 30-mm total SL (Figure 10).

Sylvan Slough, Pool 15, near RM 485, LDB

A total of 24 species of native mussels were collected using quantitative methods at the bed in Sylvan Slough, Pool 15 of the UMR. The fauna was dominated by three species, *Quadrula p. pustulosa, Truncilla truncata,* and *A. p. plicata*, which together comprised approximately 50 percent of the community. Two uncommon species, *Plethobasus cyphyus* and *Cumberlandia monodonta*, which comprised 0.33 and 0.15 percent, respectively, of the community,

Table 2
List of Bivalves Collected at Six Mussel Beds in UMR Using Qualitative and Quantitative Methods, 1995

Species	Qualitative	Quantitative
Actinonaias ligamentina (Larmack)	X	X
Amblema p. plicata (Say)	X	X
Arcidens confragosus (Say)	X	X
Corbicula fluminea (Mueller)	X	X
Cumberlandia monodonta (Say)	X	X
Dreissena polymorpha (Pallas)	X	X
Ellipsaria lineolata (Rafinesque)	X	X
Elliptio dilatata (Rafinesque)	X	X
Fusconaia flava (Rafinesque)	X	X
Lampsilis cardium (Rafinesque)	X	X
Lampsilis higginsi (Lea)	X	X
Lampsilis siliquoidea (Barnes)	X	
Lampsilis teres (Rafinesque)	X	
Lasmigona c. complanata (Barnes)	X	X
Leptodea fragilis (Rafinesque)	X	X
Ligumia recta (Lamarck)	X	X
Megalonaias nervosa (Rafinesque)	X	X
Obliquaria reflexa Rafinesque	X	X
Obovaria olivaria (Rafinesque)	X	X
Plethobasus cyphyus Rafinesque	X	X
Pleurobema coccineum (Conrad)	X	X
Potamilus alatus (Say)	X	X
Potamilus ohiensis (Rafinesque)	X	X
Pyanodon grandis (Say)	X	X
Quadrula metanevra (Rafinesque)	X	X
Quadrula nodulata (Rafinesque)	X	X
Quadrula p. pustulosa (I. Lea)	X	X
Quadrula quadrula (Rafinesque)	X	X
Strophitus undulatus (Say)	X	X
Toxolasma parvus (Barnes)	X	X
Truncilla donaciformis (I. Lea)	X	X
Truncilla truncata Rafinesque	X	X
Utterbackia imbecillis Say	X	X
Total species	33	31
Total individuals	4,901	2,515
Total samples	321	467

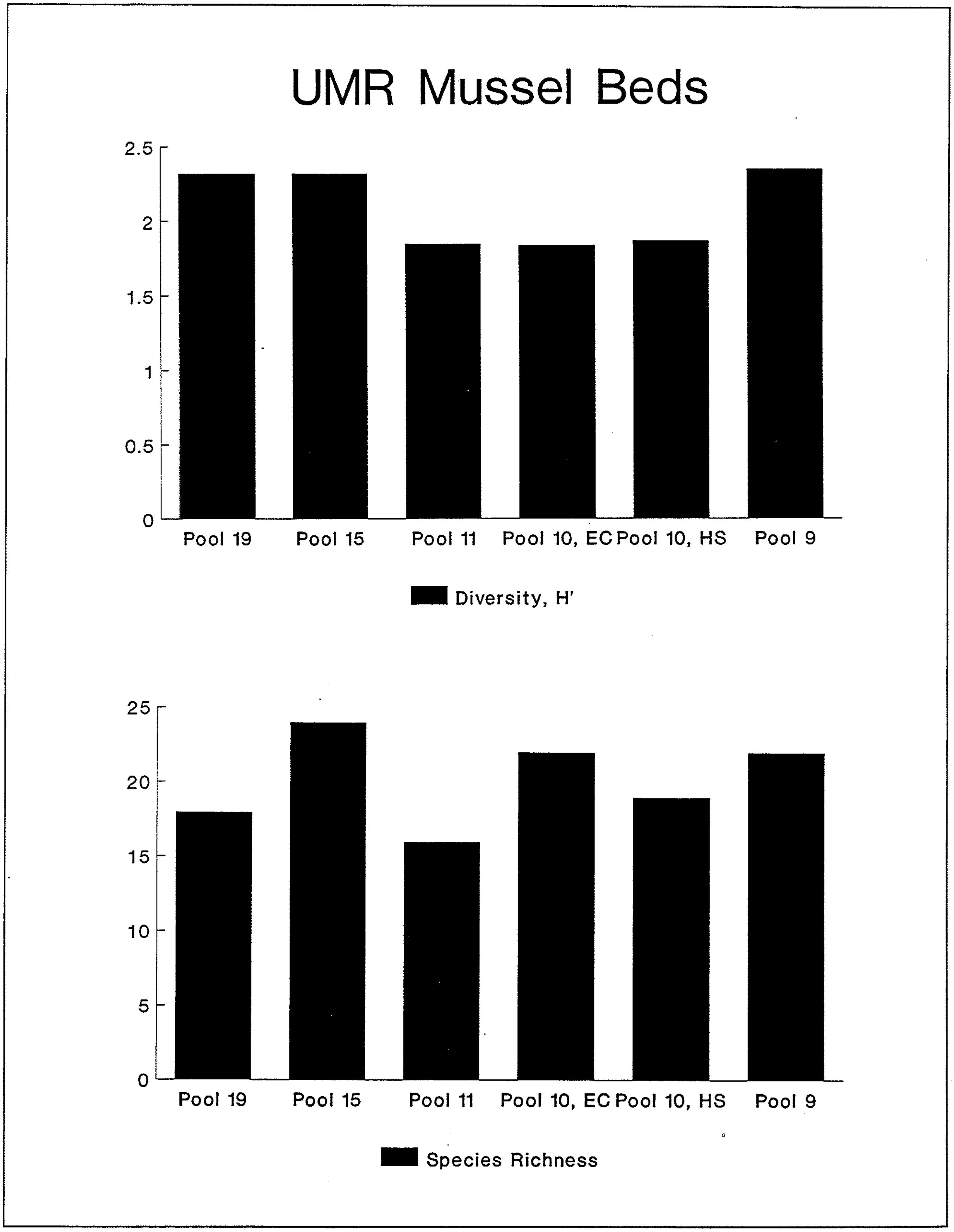

Figure 9. Species diversity (H') and richness at six locations in UMR

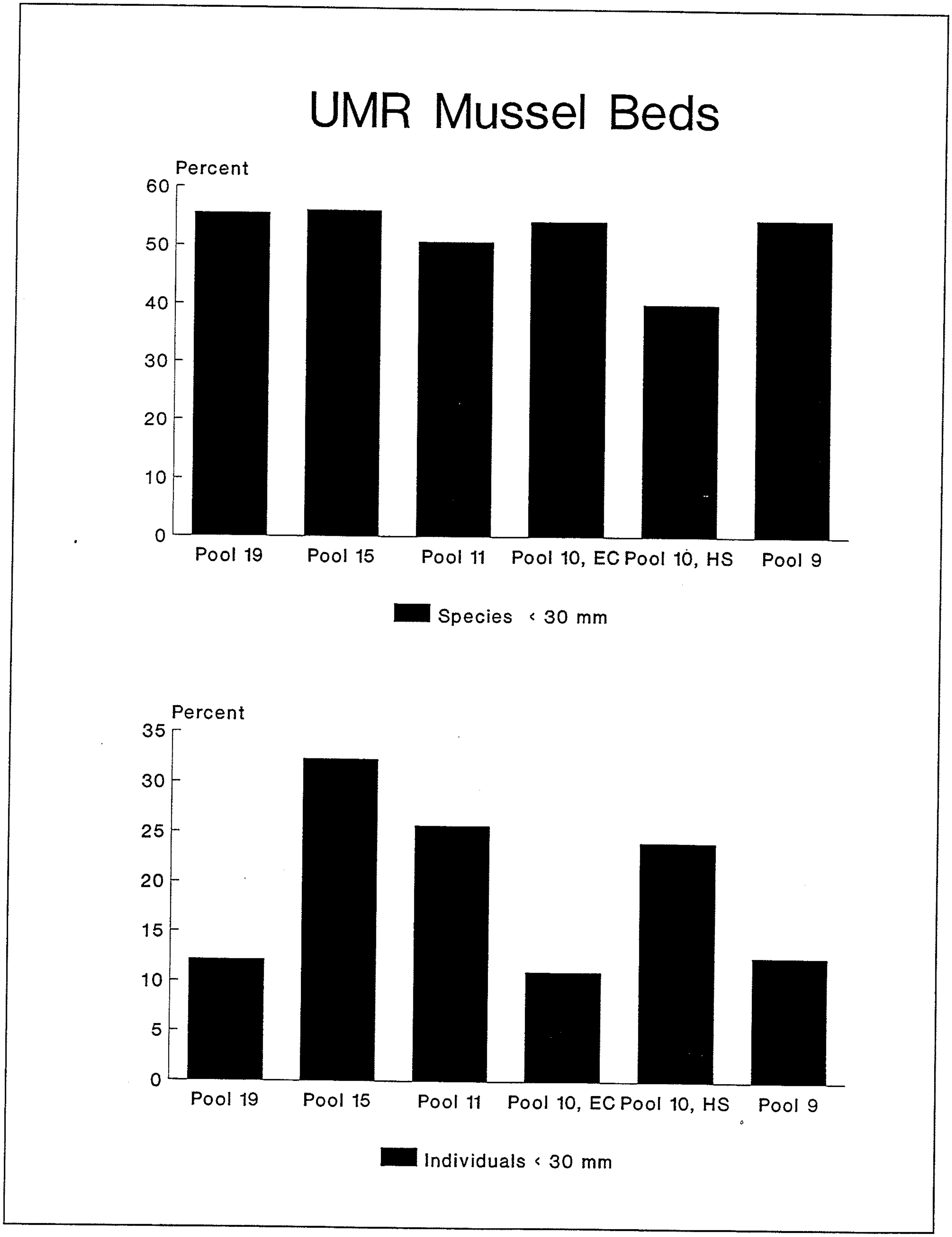

Figure 10. Percentage of species and individuals less than 30-mm total SL

were found only using qualitative collecting methods. Using qualitative methods, two *L. higginsi* were found (0.17 percent of the total collection).

Species diversity and richness were high at this bed, typically equal to or greater than values for these parameters at other beds surveyed. Evidence of recent recruitment, both in terms of total individuals and species less than 30-mm total shell length, was similar to or greater than values for these parameters at the other beds surveyed.

Goetz Island, Pool 11, near RM 612, RDB

Sixteen species of mussels were collected at this bed using quantitative methods. Three species, *A. p. plicata*, *T. truncata*, and *O. reflexa*, together comprised 65 percent of the collection. Because of the comparatively high dominance of three species, Shannon's diversity index was comparatively low, 1.85. Fifty percent of all species and twenty-six percent of all individuals collected were less than 30-mm total SL. Percent abundance of *L. higginsi* was low, 0.14 percent.

Lower East Channel, Pool 10, near RM 635

Twenty-two species of bivalves were collected in the lower East Channel using quantitative methods. The assemblage was strongly dominated by *A. p. plicata*, which comprised approximately 56 percent of the fauna. Each of the remaining species comprised less than 10 percent of the collection. Because of the strong dominance of the threeridge, Shannon's diversity index was low, 1.84. Eleven percent of the individuals and fifty-five percent of the species were less than 30-mm total SL. *Lampsilis higginsi* comprised 0.47 percent of the fauna taken using quantitative methods. This species was more abundant at this location than at any of the other beds surveyed.

Based upon qualitative samples, 1,029 individuals were collected and 23 species identified. Nearly 1 percent of the assemblage, 10 individuals, were *L. higginsi*. This species was more abundant at this location than any other mussel bed surveyed (Figure 11). The percentage of individuals and species less than 30-mm total SL was 11 and 54 percent, respectively, slightly less than at the other mussel beds (Figure 10).

Main channel of UMR, Pool 10, RM 635.2

Ten quantitative samples were taken in the main channel of the UMR. *Lampsilis higginsi* was not collected in the main channel using either quantitative or qualitative methods. The percentage of individuals and species less than 30-mm total SL was 31.6 and 46.7 percent, respectively, which was similar to that of the East Channel.

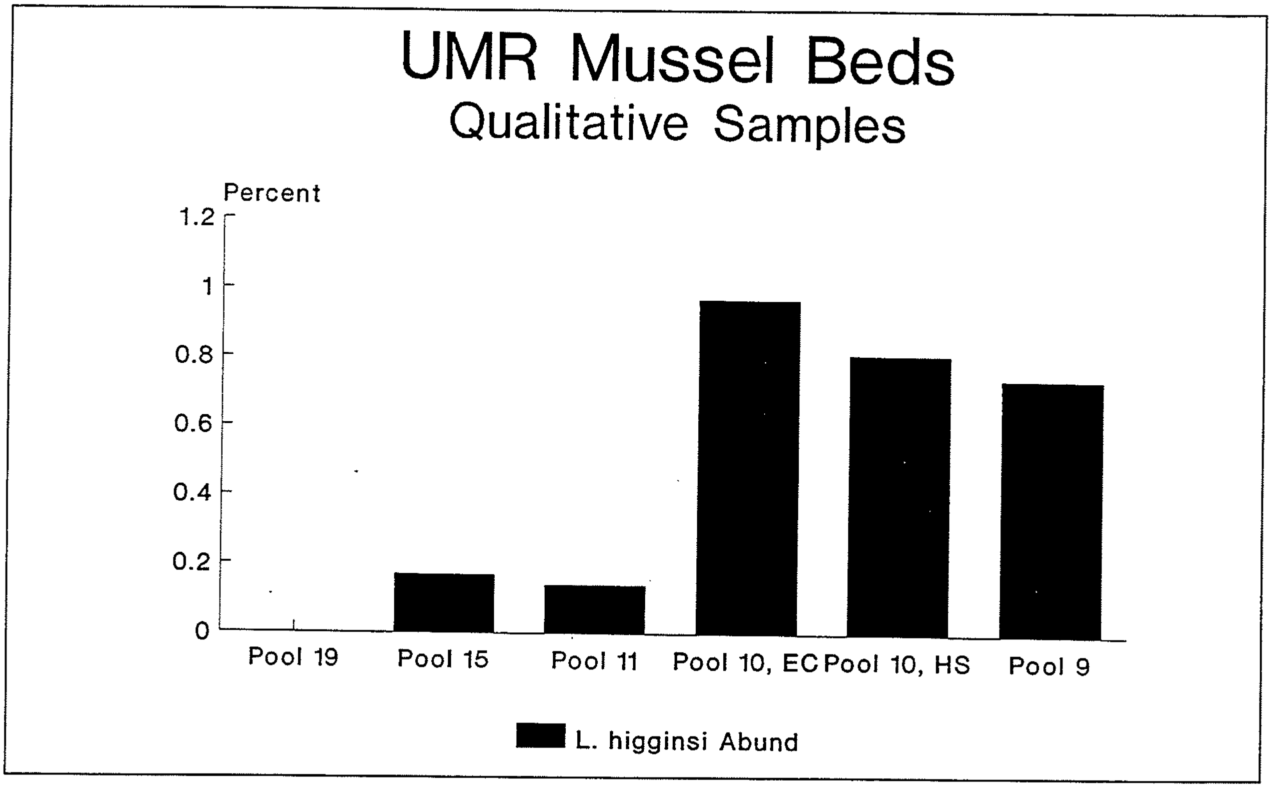

Figure 11. Percentage abundance of *L. higginsi* at six locations in UMR, 1995, based on qualitative sampling techniques

Harpers Slough, Pool 10, near RM 641, RDB

Harpers Slough is located along the RDB approximately 6 miles upriver of the East Channel. A total of 621 individuals were collected using qualitative methods; 0.81 percent were *L. higginsi*. Evidence of recent recruitment was high and similar to that at other sites in Pool 10; 24 and 40 percent of the individuals and species, respectively, were less than 30-mm total SL. Based upon community composition, presence of *L. higginsi*, and evidence of recent recruitment, the bivalve community in Harpers Slough and the East Channel near Prairie du Chien is similar.

Whiskey Rock, Pool 9, near RM 656, RDB

The bivalve community in Pool 9 exhibited high species diversity and richness. Using quantitative methods, 22 species were collected, and Shannon's index was 2.35. Abundance of *L. higginsi* based on qualitative methods was 0.27 and 0.74 percent using quantitative and qualitative methods, respectively (Appendix A, Figure 11). The abundance of *A. p. plicata* at this bed was only 29.6 percent, substantially less than at sites surveyed in Pool 10. A species that was relatively uncommon at other beds, *Elliptio dilatata*, comprised 18.8 percent of the community and was the second most abundant species. *Amblema p. plicata* reaches its highest dominance in fine-grained, slightly depositional substratum where water velocity is moderate to low.

Density of Indigenous and Nonindigenous Species

Density of native bivalves

Mean density of native bivalves at the seven locations studied ranged from 16.2 ± 1.3 (mean ± standard error) in Pool 9 to 37.6 ± 3.0 individuals/ square meter in Pool 15 (Table 3). Density data were used to estimate the total number of mussels, and *L. higginsi* when present, at these beds. Table 4 lists the total area suitable for mussels at each bed and an estimate of the total mussels and *L. higginsi* present. At locations where *L. higginsi* was only collected using qualitative methods, density estimates were obtained by applying percent abundance data from results of qualitative sampling. In the lower East Channel, it was estimated that nearly 170,000 *L. higginsi* (±127,057) were present. The total number of *L. higginsi* present at Sylvan Slough in Pool 15 was estimated at 8,000 (±15,105).

Table 3
Mean Density Data (number/square meter) for Freshwater Mussels Collected at Selected Mussel Beds in UMR, 1995

Mussel bed	N	Density	SE	Difference
Pool 19, RM 407.5	100	20.7	2.9	bc
Pool 15, RM 484.5	150	16.2	1.3	c
Pool 11, RM 612.1	30	33.7	7.7	a
Pool 10, RM 634, East Channel	97	17.56	1.5	bc
Pool 10, RM 635.2, Main Channel	10	29.2	3.5	ab
Pool 10, RM 644, Harpers Slough	40	26.2	3.0	abc
Pool 9, RM 657.9	40	37.6	3.0	a

Note: Means with similar letters are not significantly different at the 0.05 level (Duncan's test of the means).

Density of *Dreissena polymorpha*

Density estimates for the nonindigenous zebra mussel, *D. polymorpha,* appear in Table 5. These were obtained by adding the number of zebra mussels on the substratum with the number attached to native mussels in each 0.25-m^2 quadrat. Densities ranged from a low of 46.6 (±7.5) at the bed in Pool 15 to a high of 999.6 (±33.4) individuals/square meter in the main

Table 4
Estimated Size of Mussel Bed and Numbers of Mussels and *L. higginsi* Present

Location	Size, m^2	Total Mussel Density No. m^2	L. higginsi Density No. m^2	Total Mussels Present	*L. higginsi* Present
Pool 19, RM 407	655,300	20.7	0.00	13,564,710	0 ± 0
Pool 15, RM 486	287,500	16.2	0.03	4,657,500	7,918 ± 15,105
Pool 11, RM 612	120,600	33.7	0.05	4,064,220	5,690 ± 9,538
Pool 10, MC, RM 634	341,600	17.6	0.27	5,998,496	92,232 ± 27,567
Pool 10, EC, RM 634	884,100	29.2	0.08	25,815,720	70,728 ± 51,012
Pool 10, HS, RM 640	799,100	26.2	0.21	20,936,420	169,585 ± 127,057
Pool 9, RM 656	350,900	37.6	0.10	13,193,840	35,090 ± 34,630

Table 5
Mean Density Data (number/square meter) for *Dreissena polymorpha* Collected at Selected Mussel Beds in UMR, 1995

Mussel Bed	N	Den	SE	Difference
Pool 19, RM 407.5	100	49.0	13.1	d
Pool 15, RM 484.5	150	46.6	7.5	d
Pool 11, RM 612.1	30	176.9	52.8	cd
Pool 10, RM 634, East Channel	97	302.9	45.5	c
Pool 10, RM 635.2, Main Channel	10	999.6	33.4	a
Pool 10, RM 644, Harpers Slough	40	723.0	101.2	b
Pool 9, RM 657.9	40	107.6	27.8	d

Note: Means with similar letters are not significantly different at the 0.05 level (Duncan's test of the means).

channel of the UMR near Prairie du Chien, WI, in Pool 10. This overall mean does not include exceptionally high values found at Site 6 immediately downriver of the bridge on the east side of the river. At that location, two samples were collected; total zebra mussel densities were estimated at 10,328 in one and 6,852 in the other. At these densities, virtually every exposed shell or piece of gravel was covered with zebra mussels.

Size Demography of Common Species

Size demography of dominant populations of native mussels indicated relatively strong and consistent annual recruitment, with slight differences among species and sites. All populations from Pool 19 represented by at least 20 individuals included at least some recent recruits less than 30 mm long (Figure B1, Appendix B). The *Quadrula quadrula* population exemplified one in which individuals are relatively long lived and grow to large size (>80 mm) but still exhibit relatively consistent annual recruitment. Small-to-medium length mussels, ranging from 20 to 50 mm, comprised approximately half of this population. Pool 15 showed similar evidence of moderately strong recent recruitment (Figure B2). Over half of the *A. p. plicata* population in this pool was comprised of individuals less than 50 mm long and recent recruits less than 30 mm long present in all 10 species collected in sufficient abundance to warrant plotting of length-frequency histograms. Although only four species were collected in such abundance in Pool 11, all four populations included at least some individuals less than 30 mm long (Figure B3). Although the *A. p. plicata* population in Pool 10 varied somewhat from the main channel to the East Channel to Harper's Slough, all three locations supported ample recruitment of this species (Figures B4 to B6). Pool 9 populations of *A. p. plicata* and *Q. quadrula*, although dominated by large mussels, still showed strong recent recruitment (Figure B7).

Some interpool and intersite variation in size demography was apparent from comparisons of *A. p. plicata* samples; this was the only species collected in all pools. In addition, *T. truncata* was collected in all pools except Pool 9 in sufficient numbers to support demographic analysis. This species too showed noteworthy spatial variation in population size structure. *Amblema p. plicata* is representative of a species that grows to large adult size and has a life span of approximately 20 years. *Truncilla truncata* is a species that grows to small adult size and has a life span of approximately 5 years. In addition, size structure of populations of the nonindigenous zebra mussel, *Dreissena polymorpha*, was analyzed from samples in Pools 19, 15, 11, and 10 (Figure C1, Appendix C). Simple size structure characterized this mussel population at all locations. The mean size of the single cohort that heavily dominated or entirely comprised the population in each pool was slightly greater in Pools 10 and 11 than in Pools 15 and 19.

Amblema plicata plicata

The population in Pool 19 (RM 407) included individuals ranging from 22 to 106 mm long. Although the sample size was not especially large (n = 49), evidence of moderately consistent recruitment was strong. Mussels ranging from 64 to 78 mm were most abundant, comprising 35 percent of the population, probably indicating stronger than average recruitment in the year or years corresponding to this size range. However, no major gaps were noted in relative abundance of individuals ranging from 22 to 64 mm or from 78 to 106 mm, indicating moderately strong recruitment in most years.

The Pool 15 (RM 485) population included individuals ranging from 12 to 98 mm. There was not evidence of dominance of any particular size class. Recent recruitment has been strong; 12 of the 66 mussels collected were less than 24 mm long. As in Pool 19, there was no evidence of major gaps in the size-frequency distribution, with the possible exception of the lack of mussels from 24 to 30 mm long.

The Pool 11 (RM 612) sample of *A. p. plicata* included individuals ranging from 16 to 96 mm long. Mussels from 64 to 80 mm comprised 38 percent, and mussels from 40 to 58 mm comprised 39 percent of the population. The relative paucity of mussels of 58 to 64 mm long caused the overall population size structure to be slightly bimodal.

Although based on a small sample size (n = 24), similarly bimodality of general population size structure was evident in the main channel samples from Pool 10 (RM 635). No mussels were collected in the size range of 50 to 64 mm. More or less equally dominant groups of mussels ranged from 16 to 50 mm and 64 to 96 mm. Size structure in the lower East Channel of Pool 10 was slightly different, although evidence of overall bimodality was still present. Mussels ranging from 22 to 56 mm were slightly less abundant than mussels ranging from 58 to 98 mm. Peak abundances at 40 to 44 mm and 74 to 76 mm made the overall population size structure appear slightly bimodal. The Harper's Slough site in Pool 10 (RM 643) had even greater dominance of large mussels than the lower East Channel site. Mussels greater than 50 mm long comprised 84 percent of the population in Harper's Slough. Nevertheless, there was ample evidence of recent recruitment, as individuals ranged down to 8 mm long.

Truncilla truncata

The Pool 19 population included individuals ranging from 10 to 48 mm. Two and possible three cohorts were apparent in the population. The smallest was centered at approximately 27 mm and the largest at approximately 41 mm. In between these two cohorts was a possible third cohort centered at 35 mm. It is likely that these cohorts, running from smallest to largest, represented 1994, 1993, and 1992 recruitment.

The population in Pool 15 was dominated by a cohort centered at 21 mm. Mussels ranged from 10 to 48 mm long, but the low relative abundance of individuals greater than 30 mm long made cohort structure difficult to discern.

The Pool 11 population included individuals ranging from 12 to 50 mm. The smallest cohort, centered at 27 mm, probably represented 1994 recruitment. A second and less abundant cohort was centered at approximately 40 mm.

Populations in Pool 10 appeared to vary in size structure from the main channel to the East Channel to Harper's Slough, although none of the sites provided a large enough sample to support detailed analysis. Combined across the three sites, mussels ranged from 10 to 60 mm long.

Dreissena polymorpha

Individuals in Pool 19 ranged from 8 to 24 mm long and had a mean length of approximately 14 mm. The population consisted of a single cohort. Presumably these individuals represented 1994 recruitment.

The population in Pool 15 was slightly different from that in Pool 19. Individuals ranged in length from 8 to 32 mm. Two cohorts were evident. A small cohort, by far the most abundant in the population, had a mean length of 14 mm. A large cohort had a mean length of 29 mm. These cohorts probably represented 1994 and 1993 year classes.

In Pool 11 nearly all mussels were of the 1994 cohort, ranging in length from 10 to 28 mm (mean equaled 16 mm). A few individuals greater than 30 mm long probably represented the 1993 year class.

Multiple sites were sampled in Pool 10. Although mean length of the 1994 cohort varied among sites, all sites showed simple demography with only one cohort. Mean length of this cohort varied from approximately 16 mm at Site 2-1 to 19 mm at Site 11-1.

4 Discussion

Community and Population Characteristics

Typically, the total number of species known to inhabit a bed exceeds the total number collected during a single survey. Previously collected species have either been extirpated or else are so uncommon that they are often missed. If a species comprised only 0.01 percent of the fauna, one thousand or more individuals might have to be collected before one individual was collected. Heath (1995) collected 1,329 live mussels from a bed in the lower Wisconsin River and identified 24 taxa, which was less than the 32 taxa known from the site.

Total unionid species richness ranged from 16 to 24 at the beds in the UMR surveyed in 1995; a total of 30 species were collected. In the East Channel of the UMR, approximately 30 species of mussels have been collected, although, typically, 20-25 are collected each year (Miller and Payne 1996b). At the bed near McMillan Island, 22 species of unionids were collected (Miller and Payne 1996a). Typically, *L. higginsi* is found in beds with moderate to high species richness. Conditions suitable for common to abundant species must also be suitable for *L. higginsi*.

Total species richness at these beds is actually slightly greater than at other mussel beds in large rivers. At a bed in the lower Ohio River near Olmsted, IL, 23 species of freshwater mussels were identified during a single survey. In a survey of the lower Tennessee River, Miller, Payne, and Tippit (1992) collected 4,768 individuals and identified 23 species.

In comparison with other large-river mussel beds, the range in total unionid density (17.6-37.6) can be considered moderate. At an inshore and offshore site in the lower Tennessee River sampled in 1986 (32 quantitative samples were collected at each), total mussel density was 187.7 and 79.7 individuals/square meter, respectively (Way, Miller, and Payne 1989). In a survey of the UMR conducted in 1988, Miller et al. (1990) reported that total mussel density ranged from 5.2 to 333.2 individuals/square meter at 16 sites (10 quantitative samples were taken at each). At half of the sites, total density was greater than 50 individuals/square meter, and at four sites it was greater than 100 individuals/square meter. As an example of a low-density bed where *L. higginsi* was found, Heath (1995) reported that density in the lower Wisconsin River in 1988 was 2.5 individuals/square meter.

The number of individuals less than 30-mm total shell length provides an estimate of recent recruitment. Individuals of this size are 3 or less years old, and their presence indicates that conditions were appropriate for successful recent reproduction. The overall percentage of indigenous individuals (excluding *C. fluminea* and *D. polymorpha)* ranged from 11.0 to 32.3 percent; overall, this value was 20 percent. At the bed studied by Heath (1995), the percentage of mussels less than 30 mm was substantially less, 1.4 and 6.2 percent in 1995 and 1988, respectively.

Presence of *L. higginsi*

The range in abundances for this species at these beds, from 0.17 to 0.97 percent (Table A1), can be considered moderate to high when compared with results from other locations. For example, in the lower Wisconsin river, Heath (1995) reported that this species comprised 0.21 and 0.08 percent in 1988 and 1995, respectively. In the main channel of the UMR, due west of the East Channel, the abundance of *L. higginsi* ranged from 0 to 1.72 percent based on samples collected from 1988 to 1994 (Miller and Payne 1996b). In the East Channel, *L. higginsi* percentages have remained stable for years. Havlik and Marking (1981) reported that this species comprised approximately 0.5 percent of the dead shell found in dredged material, which included material that could have been many tens of years old. Hornbach et al. (1996) collected 2,625 mussels in the lower St. Croix River; 0.21 percent were *L. higginsi*. Davis and Hart (1995) collected just over 200 mussels at two sites in the Lock and Dam 6 tailwater. *Lampsilis higginsi* comprised 0.47 and 0.50 percent of the fauna at these two sites.

When present, the estimated total density of *L. higginsi* was low, (between 0.03 and 0.27 individuals/square meter, Table 4). However, given the size of these beds, the total numbers of *L. higginsi* present can be surprisingly high. For example, the total number of this species present at the bed in Harpers Slough was estimated at nearly 170,000. The standard error about this value, ±127,057 gives an indication of the uncertainty of making these estimates. The least number of *L. higginsi* present was estimated at 5,690 individuals (±9,538) at the bed at Pool 11. In comparison, at a comparatively small mussel bed in the lower Wisconsin River, Heath (1995) estimated that total population of this species was 2,273.

Presence of *Dreissena polymorpha*

The first report of *Dreissena polymorpha* in North America was from Lake St. Clair in June 1988 (Hebert, Muncaster, and Mackie 1989). By late summer 1989, zebra mussels had spread downstream into the Detroit River, Lake Erie, Niagara River, and western Lake Ontario (Griffiths, Kovalak, and Schloesser 1989). By late September 1990, zebra mussels had spread through Lake Ontario and down the St. Lawrence River to Massena, NY. In June 1991, biologists from the Illinois Natural History Survey found adult zebra mussels at Illinois River Miles 50, 60, and 110 (Moore 1991; Sparks and Marsden 1991).

By early January 1993, zebra mussels had spread throughout most of the inland waterway system. They probably reached upriver sites on hulls of commercial navigation vessels (Keevin, Yarbrough, and Miller 1992). They were found in the lower Mississippi River as far south as Vicksburg, MS, and in the UMR near St. Paul, MN (*Dreissena polymorpha* Information Review 1992). There is every reason to believe that this species will continue to spread throughout North America where suitable habitat exists (Strayer 1990).

Based on quantitative sampling at these beds, mean density of *D. polymorpha* ranged from 49 to just under 1,000 individuals/square meter (Table 5). Zebra mussel densities were greater than densities of native mussels (compare Tables 3 and 5). Two samples from one site in the lower East Channel had densities of 10,328 and 6,852, respectively. These values were nearly 600 times the density of native mussels. In the main channel of the UMR in Pool 10, *D. polymorpha* density was 34 times greater than native mussels. A nonindigenous species usually achieves high densities after initial introduction; then numbers decline rapidly as resources diminish and parasites and predators become more abundant. Unlike the case of *C. fluminea*-unionid interactions, which are not always adverse (Miller and Payne 1994), zebra mussels are likely to have negative localized effects on native mussels. It is possible that numbers of *D. polymorpha* will increase in this reach of the UMR and will ultimately have adverse effect on native mussels including *L. higginsi*. Adverse effects will probably be felt quickly and then are likely to decline. Future success of mussel stocks in this reach of the UMR will depend on how well native mussels survive the infestation.

Suitability of These Mussel Beds for *L. higginsi*

This research was designed to provide information on the ecology of *L. higginsi* in the UMR. The following is a brief summary of major findings.

Relation of physical parameters (depth, water velocity, and sediment type) to presence of *L. higginsi*

Heath (1995) found no relationship between substrate particle size and total mussel density at a bed in the lower Wisconsin River. Davis and Hart (1995) found two live *L. higginsi* in an area dominated by shifting sand where depths were approximately 2 m. Hornbach et al. (1996) evaluated the effects of substratum conditions and water velocity on mussels in the lower St. Croix River. Areas inhabited by the endangered winged mapleleaf mussel, *Quadrula fragosa*, were evaluated. It was concluded that *Q. fragosa* did not have requirements different from other mussels in the community, although it did occur in shallower areas with lower bottom-current velocity as compared with other species.

Miller and Payne (1996a) concluded that suitable sediments at McMillan Island for *L. higginsi* consisted mainly of small to medium-sized particles, <6.35 mm (90 percent), small gravel, with lesser amounts of large particles, 6.35-12.7 mm (2 percent), medium gravel, 12.7-34.0 mm (5 percent), and large gravel, >34.0 mm (2 percent). Holland-Bartels (1990) and Strayer (1993) reported that predictive models relating presence of mussel species with habitat variables have low confidence. When all beds surveyed in 1995 are considered, density of *L. higginsi* and grain-size distribution were unrelated (Figure 12).

Multiple factors are responsible for determining the exact location where a unionid species will be found. A suitably infected fish must be at an area with appropriate velocity, depth, and substratum conditions when glochidea is released. A specific microhabitat will not necessarily be suitable during all hydrologic conditions. A mussel community, comprised of multiple species and cohorts, exists because suitable hydrologic conditions are present over various seasons and years.

Spatial distribution of *L. higginsi*

Habitat was considered suitable for *L. higginsi* at these beds if water was greater than 1.0 m deep at low flow and substratum was free of plants and woody material and consisted of stable, gravelly sand. Areas with moderate to high velocity (greater than 1.5 ft/sec) were not suitable. Much of the substratum along the RDB and LDB upriver of RM 613 at the Goetz Island site was unstable and not suitable for this species.

An examination of mussel distribution maps prepared by the Higgins' Eye Recovery Team (1982) suggests that some beds have distinctive boundaries. However, these designations on maps should not be taken too literally. Beds do not end abruptly but densities gradually diminish. Based on work in Pool 10, it is likely that virtually any area in Pool 10 with suitably stable substratum and moderate flow supports some *L. higginsi*.

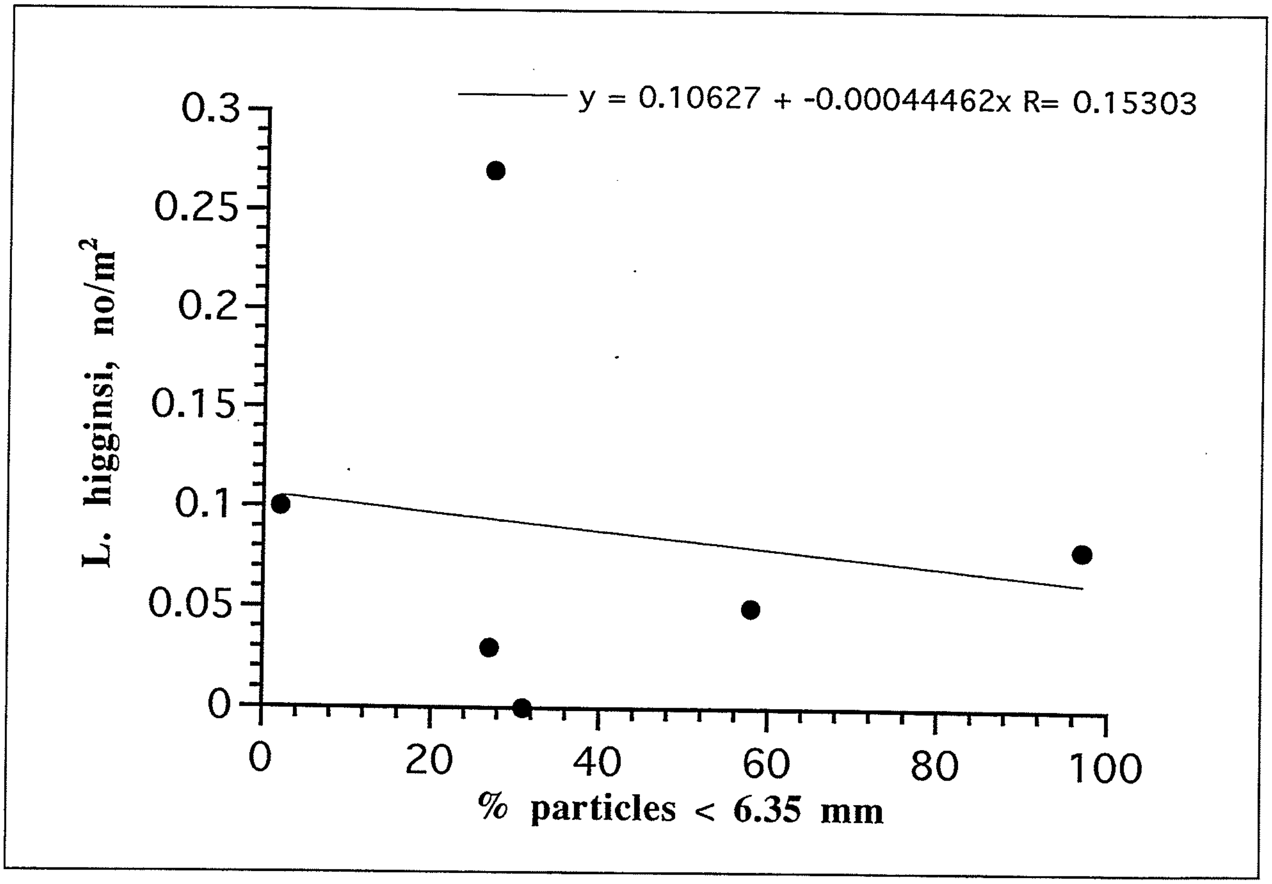

Figure 12. Relationship between grain size and density of *L. higginsi* at six locations in UMR

Percent abundance and numerical density estimate for *L. higginsi* in project area

Lampsilis higginsi was most abundant at mussel beds in Pool 10 of the UMR. Although Figure 11 illustrates a poor relationship between grain-size distribution and *L. higginsi* abundance, it is apparent that this species tends to be found in areas with reduced current velocity and fine-grained sediments. However, it is also likely that a dense reproductive stock of mussels in suitable habitat will produce high numbers of offspring that colonize areas that are marginally suitable. High numbers of *L. higginsi* in the main channel in Pool 10 could be the result of this. *Lampsilis higginsi* is found throughout Pool 10, and in some areas at least it is more abundant than it is in the East Channel. At RM 619.0 near McMillan island, this species comprised 1.3 percent of the fauna. Total unionid density near McMillan Island was 9.2 individuals/square meter, which was substantially less than in the East Channel (Miller and Payne 1996a).

Accurate estimates of standing crop with low-density populations require many quantitative samples. The total number of samples required to estimate the mean (plus or minus a certain acceptable error) with 95-percent confidence limits can be estimated (Green 1979). An estimate of the total standing crop of *L. higginsi* at the beds surveyed ranged from slightly less than 6,000 to nearly 170,000.

Relationship of other species of native bivalves to *L. higginsi*

Jaccard's Association Index (Ludwig and Reynolds 1988) was calculated for all mussels collected using quantitative methods at sites in the lower East Channel. This index considers each pair of species in the total collection and considers four possibilities: both species present, both species absent, only species "A" present, and only species "B" present. Since the index ignores the case when both species are absent, there are no spurious correlations between zero values that can occur with a Pearson Product-Moment Correlation. Jaccard's index for each species-by-species comparison was tested for significance using the chi square frequency test and appears in Table 6.

Significant relationship ($p < 0.05$), based on the chi square analysis, was found for 59 species-to-species comparisons for quantitative data collected in the East Channel of the UMR taken with quantitative methods (Table 6). *Amblema p. plicata* showed a significant positive relationship with *Fusconaia flava, Quadrula nodulata, Q. quadrula, Lasmigonia complanata, Actinonaias ligamentina, Lampsilis cardium*, and *L. higginsi*. *Lampsilis higginsi* showed a significant positive relationship with *Ligumia recta, A. p. plicata, Q. nodulata, Q. quadrula, Lasmigonia complanata*, and *L. cardium* and a negative relationship with *A. ligamentina*. In a study at McMillan Island (Miller and Payne 1996a), *A. p. plicata* was positively associated with 15 out of 10 species. *Lampsilis higginsi* was associated with *Potamilus alatus, Lasmigonia complanata, Pyganodon grandis, Strophitus undulatus*, and *Elliptio dilatata*.

Regardless of the appeal of these indices, it must be remembered that mussel species are relatively nonmotile, and their location is governed to a large extent by local hydrologic conditions and fish behavior at the time glochidea are released from the host. There is no attraction among various species; since relationships occurred regardless of age, it is likely that local hydrologic conditions structured species relationships.

Recommendation on Value of These Mussel Beds for *L. higginsi*

Based on the results of this survey and criteria stated by members of the original Higgins' Eye Recovery Team (1982), all of these beds surveyed have value and could be considered as essential for *L. higginsi*. This recommendation applies to shallow-to-moderately deep areas with firm gravelly sand substratum. Although not specifically studied during this survey, this recommendation would also apply to wing dams that are not buried in sand and silt

Table 6
Jaccard's Association Index for Native Mussels Collected Using Qualitative Methods in Lower East Channel of UMR Near Prairie du Chien, WI, 1995

	AP	FF	QN	QP	QQ	MN	LC	AL	EL	LD	LH	LF	PA	PO	TD	TT	OR	PR	UI	LR	OO	AC
AP	1.00	0.31	0.24	0.20	0.18	0.25	0.17	0.17	0.20	0.10	0.18	0.05	0.12	0.11	0.07	0.10	0.05	0.21	0.14	0.24	0.00	0.14
FF		1.00	0.10	0.12	0.24	0.14	0.16	0.16	0.27	0.09	0.24	0.10	0.18	0.24	0.13	0.15	0.11	0.20	0.25	0.22	0.05	0.19
QN			1.00	0.19	0.11	0.14	0.16	0.10	0.12	0.09	0.24	0.00	0.18	0.11	0.06	0.10	0.17	0.06	0.04	0.16	0.00	0.04
QP				1.00	0.20	0.63	0.19	0.27	0.33	0.17	0.20	0.12	0.13	0.06	0.08	0.11	0.06	0.07	0.05	0.12	0.06	0.10
QQ					1.00	0.15	0.40	0.24	0.20	0.15	0.18	0.24	0.12	0.11	0.23	0.16	0.11	0.13	0.09	0.11	0.05	0.09
MN						1.00	0.14	0.33	0.44	0.20	0.15	0.14	0.08	0.07	0.10	0.13	0.07	0.09	0.06	0.14	0.07	0.12
LC							1.00	0.10	0.27	0.26	0.17	0.16	0.11	0.11	0.13	0.21	0.31	0.13	0.14	0.10	0.11	0.09
AL								1.00	0.19	0.14	0.05	0.10	0.05	0.11	0.13	0.15	0.05	0.06	0.04	0.10	0.05	0.04
EL									1.00	0.31	0.20	0.19	0.13	0.13	0.17	0.25	0.13	0.15	0.16	0.19	0.06	0.16
LD										1.00	0.21	0.20	0.29	0.15	0.19	0.32	0.28	0.11	0.23	0.09	0.10	0.08
LH											1.00	0.11	0.27	0.33	0.23	0.16	0.25	0.21	0.14	0.17	0.05	-0.20
LF												1.00	0.18	0.17	0.13	0.15	0.17	0.13	0.14	0.10	0.17	0.14
PA													1.00	0.36	0.25	0.24	0.36	0.23	0.28	0.18	0.12	0.10
PO														1.00	0.33	0.29	0.25	0.31	0.20	0.11	0.05	0.20
TD															1.00	0.39	0.33	0.44	0.25	0.21	0.14	0.25
TT																1.00	0.38	0.27	0.37	0.15	0.16	0.18
OR																	1.00	0.21	0.26	0.17	0.25	0.14
PR																		1.00	0.50	0.39	0.21	0.40
UI																			1.00	0.32	0.20	0.33
LR																				1.00	0.17	0.32
OO																					1.00	0.20
AC																						1.00

Note: Underlined numbers are significant (an association between species exists) based on a chi square frequency test. The index of overall association = 5.3, and the W statistic = 511.9.

and stable areas immediately downriver of wing dams. The recommendation would not apply to deep water associated with the main navigation channel, since few *L. higginsi* are in these areas.

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Appendix A
Summary of Qualitative and Quantitative Data on Fresh-water Bivalves Collected at Six Locations in the Upper Mississippi River, 1995

Table A1
Percent Abundance of Freshwater Mussels Collected in UMR Using Qualitative Methods, 1995

Species	Pool 19	Pool 15	Pool 11	Pool 10 MC	Pool 10 EC	Pool 10 HS	Pool 9	Total
A. p. plicata	11.62	17.92	37.55	56.42	70.07	69.73	29.65	40.09
Q. p. pustulosa	17.59	25.02	2.13	0.56	1.94	0.81	3.50	9.53
O. reflexa	15.50	7.88	18.63	1.12	3.21	1.45	3.50	7.94
Q. quadrula	7.60	8.92	2.42	5.59	7.29	2.90	11.97	6.92
T. truncata	4.62	4.07	10.53	10.61	2.82	9.82	6.63	6.06
F. flava	3.73	3.12	14.79	3.35	5.44	2.42	1.66	5.12
E. lineolata	7.90	8.57	1.56	0.00	0.10	0.16	0.18	3.39
Q. metanevra	7.30	8.83	0.71	0.00	0.58	0.00	0.00	3.31
M. nervosa	0.60	5.80	0.14	2.79	0.68	2.09	7.92	2.86
E. dilatata	0.00	0.00	0.14	3.35	0.19	0.81	18.78	2.37
O. olivaria	13.41	0.00	1.85	0.56	0.39	0.00	0.37	2.24
L. cardium	4.02	1.73	4.13	1.68	1.17	0.97	2.03	2.20
L. fragilis	3.28	0.78	0.43	6.15	1.07	4.35	4.24	2.16
L. recta	0.15	0.87	1.28	2.79	0.39	0.48	3.31	1.02
Q. nodulata	0.15	1.21	0.71	0.00	1.26	0.00	1.10	0.80
P. grandis	0.00	2.25	0.28	0.56	0.00	0.16	0.55	0.67
A. confragosus	0.30	1.21	0.00	1.12	0.97	0.32	0.37	0.65
S. undulatus	0.75	0.17	0.43	2.23	0.19	1.93	0.18	0.59
L. higginsi	0.00	0.17	0.14	0.00	0.97	0.81	0.74	0.45
L. complanata	0.00	0.43	0.57	0.00	0.68	0.32	0.55	0.43
P. alatus	0.15	0.35	0.57	0.00	0.10	0.16	0.18	0.24
T. donaciformis	0.15	0.09	0.71	1.12	0.00	0.00	0.00	0.18
P. coccineum	0.00	0.00	0.00	0.00	0.19	0.00	1.66	0.22
A. ligamentina	1.19	0.00	0.00	0.00	0.10	0.00	0.00	0.18
U. imbecillis	0.00	0.00	0.00	0.00	0.19	0.16	0.92	0.16
P. ohiensis	0.00	0.17	0.14	0.00	0.00	0.00	0.00	0.06
L. teres	0.00	0.09	0.14	0.00	0.00	0.00	0.00	0.04
C. monodonta	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.04
P. cyphyus	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.04
L. r. radiata	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.02
Total individuals	671	1,155	703	179	1,029	621	543	4,901
Total species	19	24	23	16	23	20	22	30

Note: MC = Main channel; EC = East channel; HS = Harpers Slough.

Table A2
Percent Occurrence of Freshwater Mussels Collected in UMR Using Qualitative Methods, 1995

Species	Pool 19	Pool 15	Pool 11	Pool 10 MC	Pool 10 EC	Pool 10 HS	Pool 9	Total
A. p. plicata	81.40	82.86	77.08	100.00	98.48	83.33	91.18	86.60
Q. quadrula	58.14	64.29	29.17	58.33	60.61	31.25	64.71	52.34
T. truncata	46.51	40.00	54.17	83.33	34.85	64.58	52.94	48.60
O. reflexa	74.42	61.43	62.50	16.67	34.85	16.67	29.41	46.11
Q. p. pustulosa	81.40	91.43	22.92	8.33	24.24	10.42	41.18	45.48
F. flava	34.88	25.71	58.33	33.33	57.58	25.00	23.53	38.32
M. nervosa	9.30	52.86	2.08	33.33	10.61	14.58	58.82	24.92
E. lineolata	62.79	65.71	8.33	0.00	1.52	2.08	2.94	24.92
L. cardium	37.21	27.14	20.83	25.00	16.67	8.33	29.41	22.74
L. fragilis	13.95	11.43	6.25	50.00	12.12	35.42	38.24	19.00
Q. metanevra	60.47	31.43	10.42	0.00	7.58	0.00	0.00	18.07
O. olivaria	69.77	0.00	18.75	8.33	6.06	0.00	5.88	14.33
L. recta	2.33	14.29	8.33	25.00	6.06	6.25	41.18	12.15
E. dilatata	0.00	0.00	2.08	41.67	3.03	8.33	70.59	11.21
Q. nodulata	2.33	12.86	8.33	0.00	18.18	0.00	17.65	9.97
A. confragosus	4.65	15.71	0.00	16.67	15.15	4.17	5.88	9.03
S. undulatus	11.63	2.86	6.25	25.00	3.03	14.58	2.94	7.17
P. grandis	0.00	22.86	2.08	8.33	0.00	2.08	8.82	6.85
L. higginsi	0.00	2.86	2.08	0.00	15.15	8.33	11.76	6.54
L. complanata	0.00	7.14	6.25	0.00	10.61	4.17	5.88	5.92
A. ligamentina	18.60	0.00	0.00	0.00	1.52	0.00	0.00	2.80
P. alatus	2.33	4.29	4.17	0.00	1.52	2.08	2.94	2.80
T. donaciformis	2.33	1.43	10.42	16.67	0.00	0.00	0.00	2.80
P. coccineum	0.00	0.00	0.00	0.00	3.03	0.00	20.59	2.80
U. imbecillis	0.00	0.00	0.00	0.00	3.03	2.08	11.76	2.18
P. ohiensis	0.00	2.86	2.08	0.00	0.00	0.00	0.00	0.93
P. cyphyus	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.62
C. monodonta	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.62
L. teres	0.00	1.43	2.08	0.00	0.00	0.00	0.00	0.62
L. r. radiata	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.31
Total samples	43	70	48	12	66	48	34	321

Table A3
Percent Species Abundance of Freshwater Mussels Collected in UMR Using Quantitative Methods, 1995

Species	Pool 19	Pool 15	Pool 11	Pool 10 HS	Pool 10 MC	Pool 10 EC	Pool 9	Total
A. p. plicata	9.46	10.87	26.88	43.89	36.99	56.10	30.05	26.92
T. truncata	12.36	10.54	37.15	12.60	24.66	5.87	13.30	13.84
Q. pustulosa	20.27	28.67	3.16	1.15	1.37	2.58	2.13	12.33
O. reflexa	18.53	6.75	11.46	6.11	2.74	3.29	2.93	8.31
L. fragilis	2.32	4.61	1.98	16.03	12.33	5.16	11.70	6.44
Q. quadrula	8.49	3.13	2.77	1.91	1.37	6.57	7.45	5.25
T. donaciformis	1.54	9.23	1.19	7.25	5.48	1.88	1.33	4.10
E. lineolata	5.41	8.24	2.37	0.38	2.74	0.23	0.27	3.54
Q. metanevra	3.09	9.23	1.19	0.00	0.00	0.00	0.27	3.02
F. flava	2.51	0.33	6.72	0.76	1.37	6.34	0.27	2.50
O. olivaria	9.85	0.00	2.77	0.00	0.00	0.70	0.27	2.47
M. nervosa	0.58	3.13	0.00	0.38	2.74	0.94	3.72	1.71
L. cardium	3.86	0.66	0.40	0.76	1.37	2.35	2.13	1.83
E. dilatata	0.00	0.00	0.40	0.76	2.74	0.00	9.04	1.55
L. recta	0.00	0.82	0.79	1.15	1.37	0.94	4.52	1.27
U. imbecillis	0.00	0.99	0.00	4.58	1.37	0.94	3.19	1.39
P. alatus	0.00	0.49	0.40	0.38	0.00	1.64	2.66	0.87
P. grandis	0.39	0.16	0.00	0.76	1.37	0.00	2.39	0.60
Q. nodulata	0.39	0.66	0.00	0.00	0.00	0.70	0.00	0.36
P. coccineum	0.00	0.00	0.40	0.38	0.00	0.47	1.33	0.36
A. confragosus	0.19	0.33	0.00	0.38	0.00	0.94	0.00	0.32
P. ohiensis	0.00	0.16	0.00	0.00	0.00	0.94	0.53	0.28
A. ligamentina	0.58	0.16	0.00	0.00	0.00	0.47	0.00	0.24
L. complanata	0.19	0.16	0.00	0.00	0.00	0.47	0.27	0.20
L. higginsi	0.00	0.00	0.00	0.00	0.00	0.47	0.27	0.12
P. cyphus	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.08
S. undulatus	0.00	0.16	0.00	0.38	0.00	0.00	0.00	0.08
C. monodonta	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.04
Total individuals	518	607	253	262	73	426	376	2,515
Total species	18	24	16	19	15	22	22	28
Total individuals <30 mm	12.16	32.29	25.69	24.05	31.61	11.03	12.53	20.05
Total species <30 mm	55.55	56.00	50.00	40.00	46.67	54.17	54.54	77.42
Species diversity	2.32	2.32	1.85	1.87	1.93	1.84	2.35	2.48
Menhenicks Index	0.79	0.97	1.01	1.17	1.76	1.06	1.13	0.56
Evenness	0.79	0.69	0.62	0.56	0.64	0.38	0.64	0.63

Table A4
Percent Occurrence of Freshwater Mussels Collected in UMR Using Quantitative Methods, 1995

Species	Pool 19	Pool 15	Pool 11	Pool 10 HS	Pool 10 MC	Pool 10 EC	Pool 9	Total
A. p. plicata	26.00	29.33	46.67	67.50	90.00	75.26	80.00	48.18
T. truncata	30.00	26.00	46.67	50.00	90.00	21.65	60.00	33.62
Q. pustulosa	46.00	52.00	16.67	7.50	10.00	11.34	17.50	32.33
O. reflexa	48.00	21.33	60.00	32.50	10.00	12.37	20.00	28.27
L. fragilis	7.00	15.33	16.67	62.50	60.00	17.53	45.00	21.63
Q. quadrula	26.00	9.33	16.67	10.00	10.00	25.77	47.50	20.13
T. donaciformis	7.00	24.67	10.00	30.00	20.00	7.22	7.50	15.20
E. lineolata	16.00	22.00	16.67	2.50	20.00	1.03	2.50	12.63
Q. metanevra	13.00	20.67	6.67	0.00	0.00	0.00	2.50	10.06
F. flava	7.00	1.33	33.33	5.00	10.00	21.65	2.50	9.42
O. olivaria	35.00	0.00	16.67	0.00	0.00	3.09	2.50	9.42
M. nervosa	3.00	10.00	0.00	2.50	10.00	4.12	25.00	7.28
L. cardium	17.00	4.67	3.33	5.00	10.00	10.31	17.50	9.64
E. dilatata	0.00	0.00	3.33	5.00	20.00	0.00	47.50	5.14
L. recta	0.00	3.33	6.67	7.50	10.00	4.12	30.00	5.78
U. imbecillis	0.00	1.33	0.00	22.50	10.00	4.12	17.50	4.93
P. alatus	0.00	2.00	3.33	2.50	0.00	7.22	22.50	4.50
P. grandis	2.00	0.67	0.00	5.00	10.00	0.00	20.00	3.00
Q. nodulata	2.00	2.67	0.00	0.00	0.00	3.09	0.00	1.93
P. coccineum	0.00	0.00	3.33	2.50	0.00	2.06	12.50	1.93
A. confragosus	1.00	1.33	0.00	2.50	0.00	4.12	0.00	1.71
P. ohiensis	0.00	0.67	0.00	0.00	0.00	4.12	2.50	1.28
A. ligamentina	3.00	0.67	0.00	0.00	0.00	2.06	0.00	1.28
L. complanata	1.00	0.67	0.00	0.00	0.00	2.06	2.50	1.07
L. higginsi	0.00	0.00	0.00	0.00	0.00	2.06	2.50	0.64
P. cyphus	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.21
S. undulatus	0.00	0.67	0.00	2.50	0.00	0.00	0.00	0.43
C. monodonta	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.21
Total samples	100	150	30	40	10	97	40	467

Table A5
Total Density of Freshwater Mussels at Selected Mussel Beds in UMR, 1995

Pool 19, RM 407.5				
Site	**N**	**Den**	**SE**	**STD**
1	10	85.6	12.7	40.05
2	10	12.4	2.3	7.167
3	10	32.0	6.8	21.66
4	10	12.0	2.7	8.4327
5	10	15.6	7.5	23.585
6	10	10.4	2.6	8.26
7	10	20.0	6.0	19.13
8	10	12.0	2.2	7.055
9	10	3.2	1.3	4.131
10	10	4.0	0.8	2.667
Pool 15, RM 484.5				
Site	**N**	**Den**	**SE**	**STD**
1	10	20.0	3.8	12.07
2	10	17.2	2.5	8.011
3	10	10.0	2.3	7.363
4	10	28.0	4.1	13.0639
5	10	45.6	4.9	15.57
6	10	37.6	3.0	9.4657
7	10	42.4	2.0	6.31
8	10	7.2	1.4	4.54
9	10	7.6	2.0	6.38
10	10	4.8	1.6	4.917
11	10	3.6	1.3	3.977
12	10	4.0	1.2	3.77
13	10	2.8	0.9	2.699
14	10	4.8	1.0	3.155
15	10	7.2	1.0	3.155

(Continued)

Table A5 (Concluded)				
Pool 11, RM 612.1				
Site	N	Den	SE	STD
1	10	4.8	2.2	7
2	10	6.8	0.9	2.699
3	10	89.6	6.4	20.32
Pool 10, RM 634, East Channel				
Site	N	Den	SE	STD
1	10	13.2	2.5	7.78
2	10	24.0	3.8	11.92
3	10	8.0	2.5	8
4	10	8.4	2.4	7.647
5	10	40.0	6.9	21.908
6	10	26.0	4.2	13.23
7	10	10.0	2.2	6.86
8	10	6.4	2.7	8.68
9	10	15.2	2.8	8.804
10	7	27.4	4.9	12.946
Pool 10 RM 635.2, Main Channel				
Site	N	Den	SE	STD
1	10	29.2	3.5	11.16
Pool 10, RM 644, Harpers Slough				
Site	N	Den	SE	STD
1	10	33.4	3.2	10.01
2	10	45.6	5.3	16.67
3	10	5.6	1.9	6.022
4	10	20.0	3.5	11.15
Pool 9, RM 657.9				
Site	N	Den	SE	STD
1	10	78.8	12.4	39.28
2	10	15.6	6.2	19.454
3	10	10.8	1.8	5.67
4	10	45.2	5.6	17.69

Table A6
Total Density of *Dreissena polymorpha* at Selected Mussel Beds in UMR, 1995

Site	N	Den	SE	STD
Pool 19, RM 407.5				
1	10	347.2	83.3	263.4
2	10	11.6	3.6	11.4
3	10	10.4	3.2	10.2
4	10	10.0	3.7	11.8
5	10	5.6	2.1	6.6
6	10	11.2	5.2	16.3
7	10	68.4	22.0	69.6
8	10	24.4	7.3	23.1
9	10	0.0	0.0	0.0
10	10	1.2	0.9	2.7
Pool 15, RM 484.5				
Site	**N**	**Den**	**SE**	**STD**
1	10	168.8	81.5	257.8
2	10	24.0	7.4	23.3
3	10	14.8	5.5	17.3
4	10	72.4	14.2	44.8
5	10	145.2	19.3	61.0
6	10	81.6	10.3	32.7
7	10	158.4	17.6	55.6
8	10	9.6	2.2	6.9
9	10	2.8	1.2	3.8
10	10	2.8	2.4	7.6
11	10	7.6	3.8	12.1
12	10	1.2	0.9	2.7
13	10	2.8	1.6	5.0
14	10	4.0	1.6	5.0
15	10	3.2	2.0	6.2

(Continued)

Table A6 (Concluded)				
Pool 11, RM 612.1				
Site	N	Den	SE	STD
1	10	2.8	1.6	5.0
2	10	2.8	1.0	3.3
3	10	525.2	91.7	289.9
Pool 10, RM 634, East Channel				
Site	N	Den	SE	STD
1	10	87.6	21.0	66.4
2	10	250.8	86.9	274.8
3	10	29.2	12.0	38.0
4	10	30.0	14.1	44.5
5	10	707.2	125.6	397.1
6	10	670.4	135.6	428.8
7	10	5.6	2.4	7.6
8	10	5.2	2.5	7.8
9	10	269.0	69.4	219.5
10	7	1,261.1	208.1	550.6
Pool 10 RM 635.2, Main Channel				
Site	N	Den	SE	STD
1	10	999.6	33.4	105.6
Pool 10, RM 644, Harpers Slough				
Site	N	Den	SE	STD
1	10	2,068.0	186.2	588.7
2	10	1,272.0	123.5	390.7
3	10	40.0	4.3	13.7
4	10	564.4	87.9	278.1
Pool 9, RM 657.9				
Site	N	Den	SE	STD
1	10	373.0	50.4	159.4
2	10	4.4	1.9	6.1
3	10	2.8	1.0	3.3
4	10	50.0	15.1	47.9

Appendix B
Size Demography of Dominant Mussels at Study Sites in the Upper Mississippi River, 1995

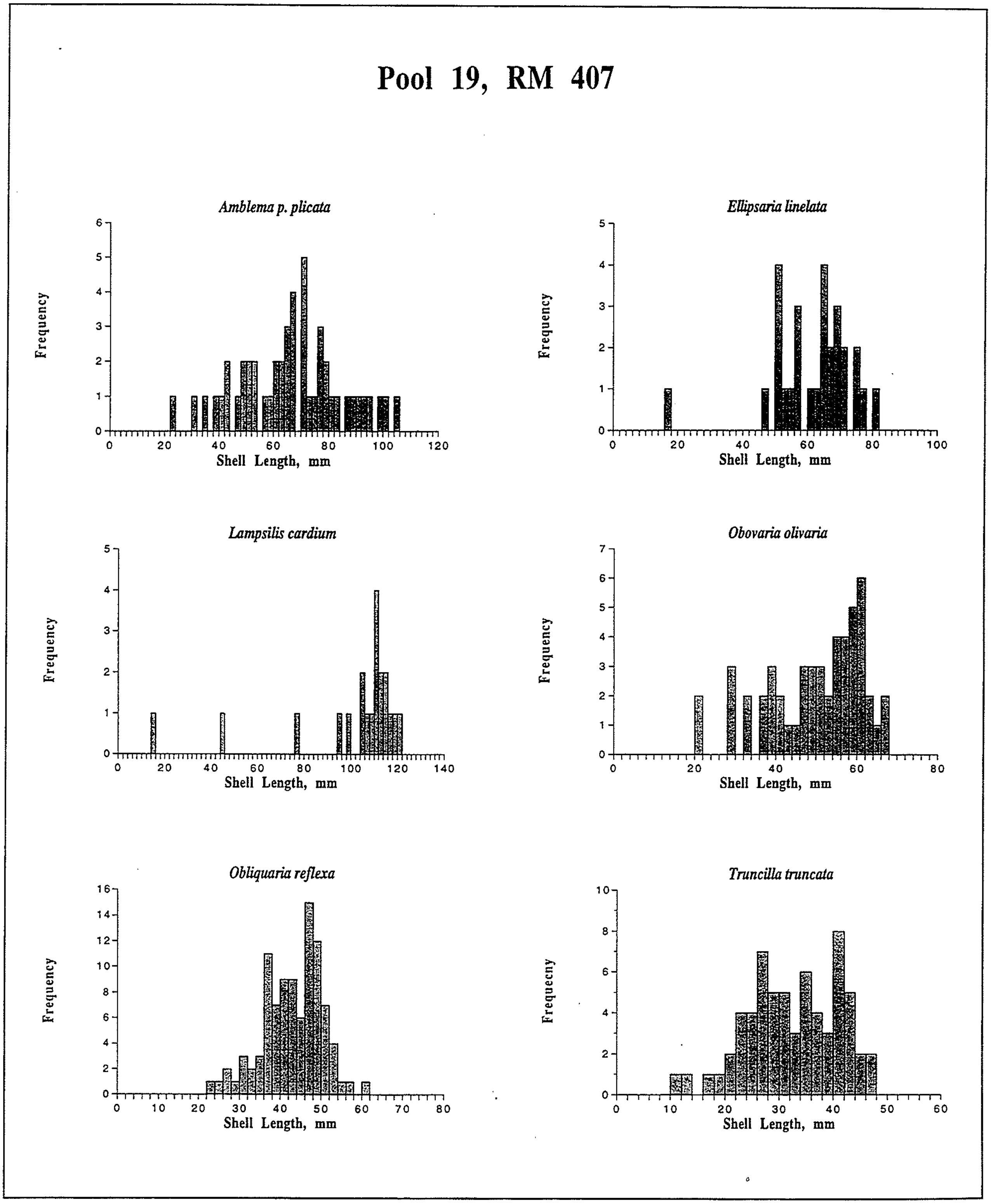
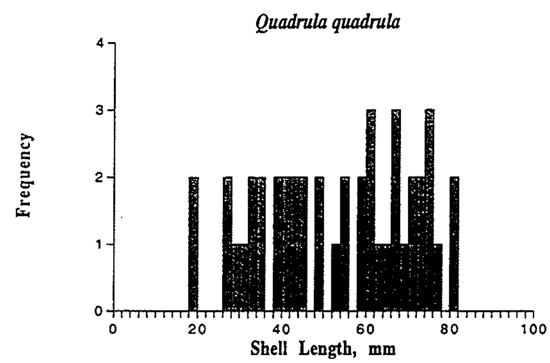
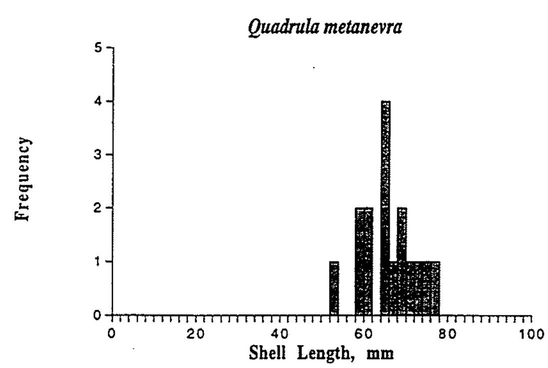


Figure B1. Size demography, Pool 19, RM 407 (Continued)

Pool 19, RM 407





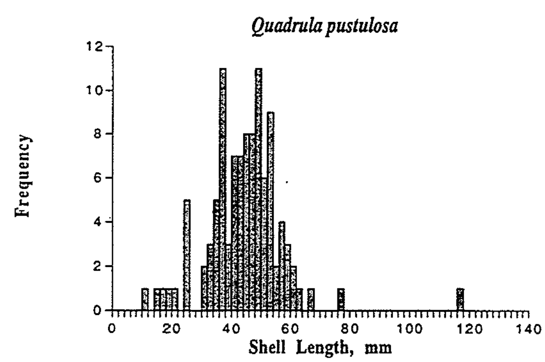


Figure B1. (Concluded)

Pool 15, RM 485

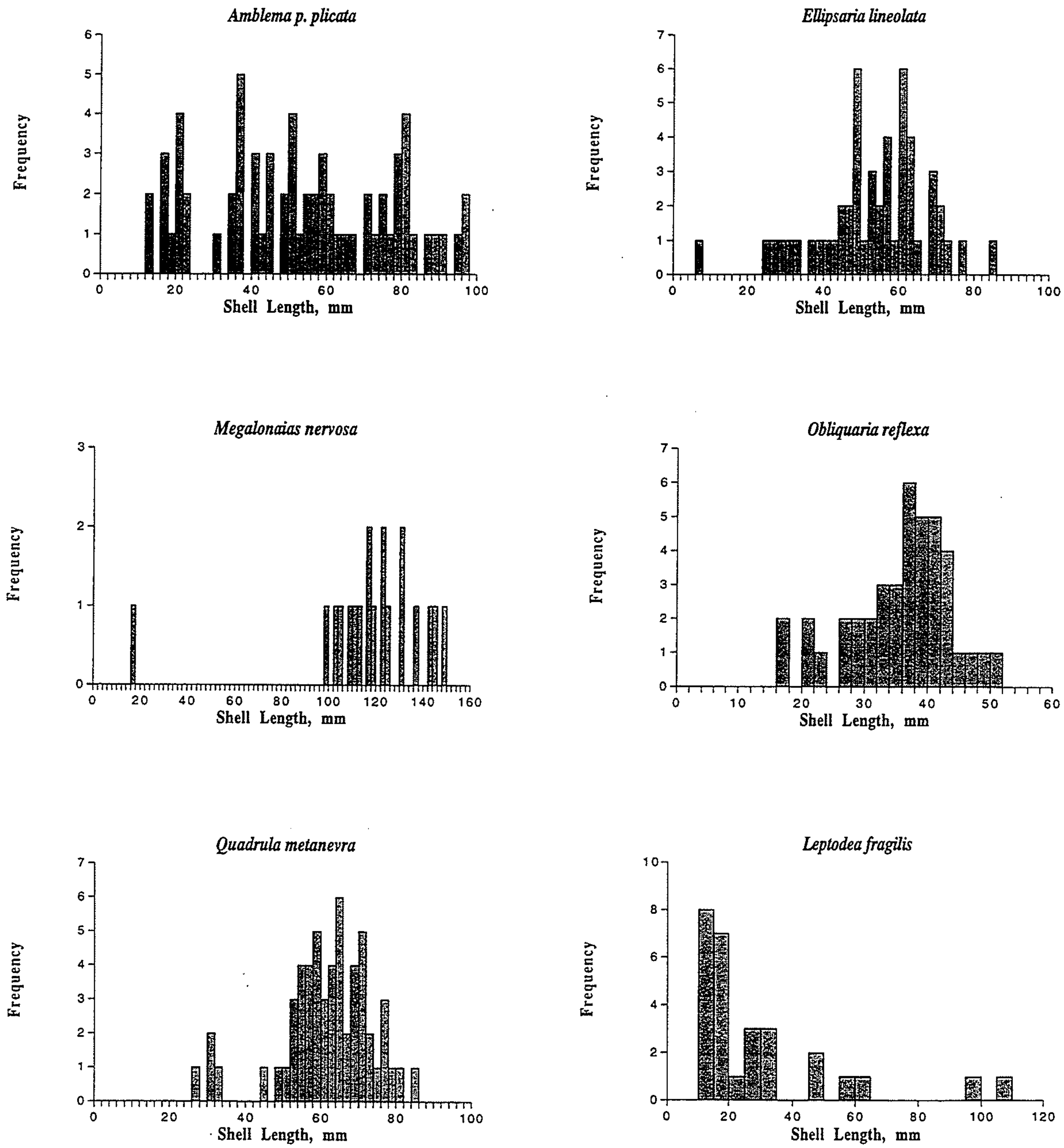


Figure B2. Size demography, Pool 15, RM 485 (Continued)

Pool 15, RM 485

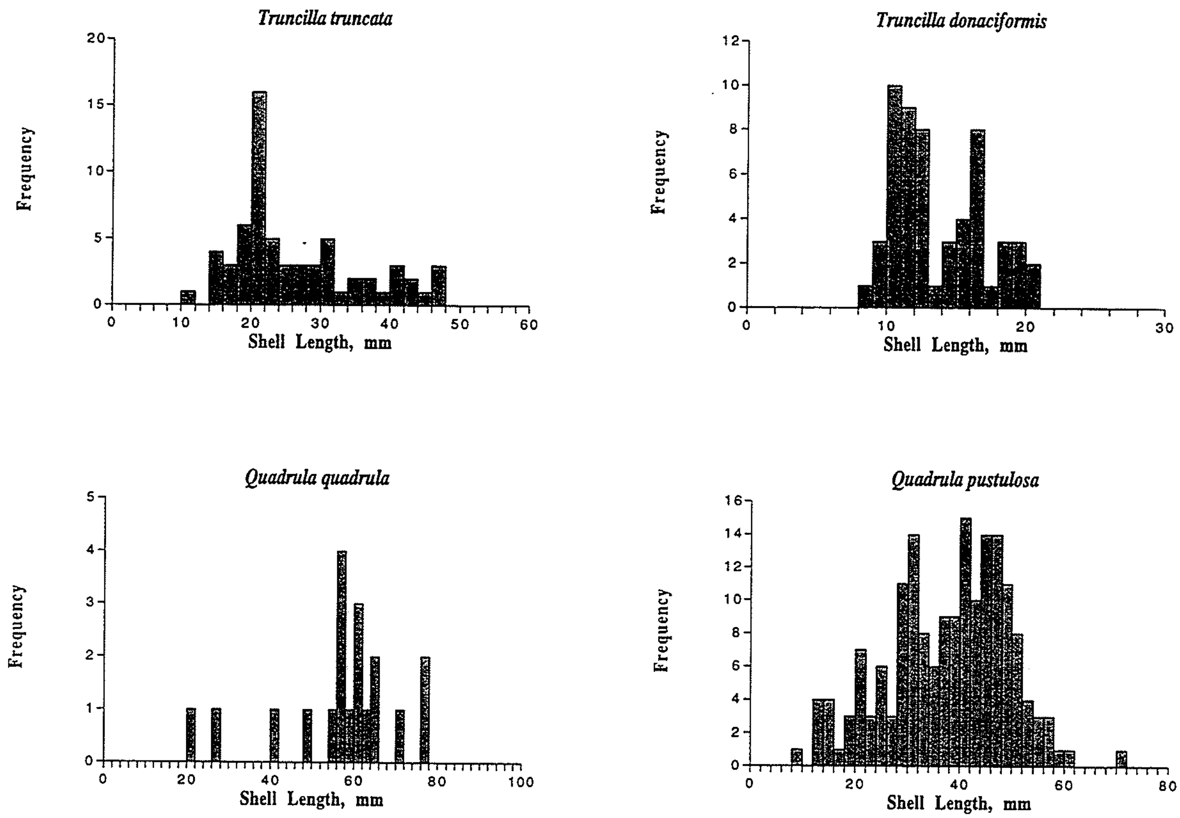


Figure B2. (Concluded)

Pool 11, RM 612

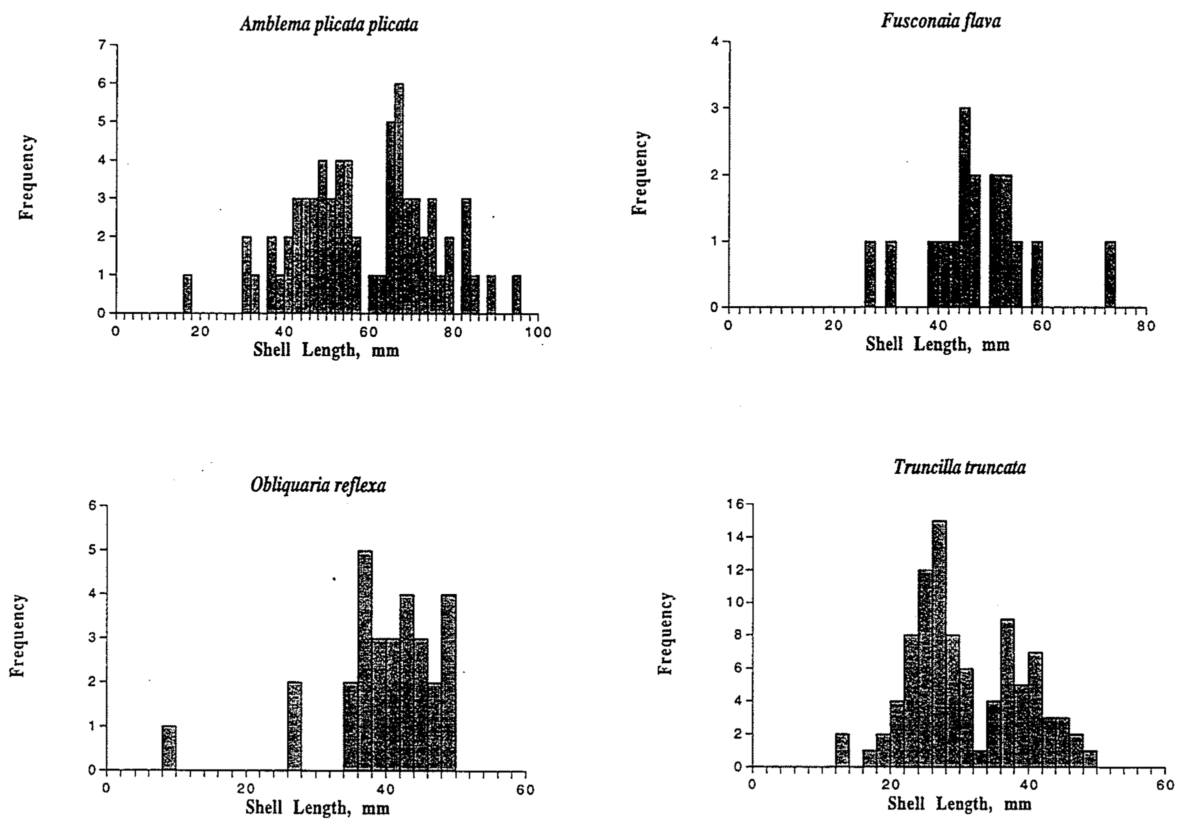
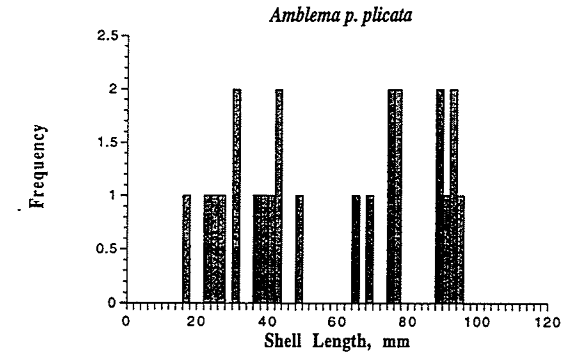


Figure B3. Size demography, Pool 11, RM 612

Pool 10, RM 635
Main Channel



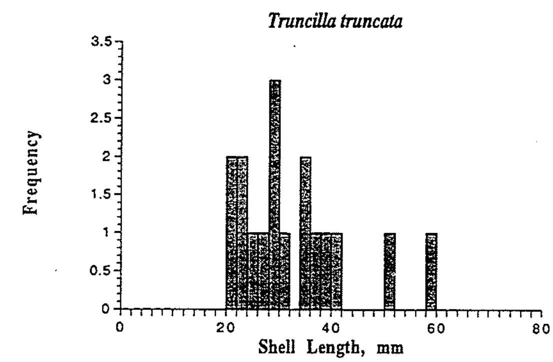


Figure B4. Size demography, Main Channel, Pool 10, RM 635

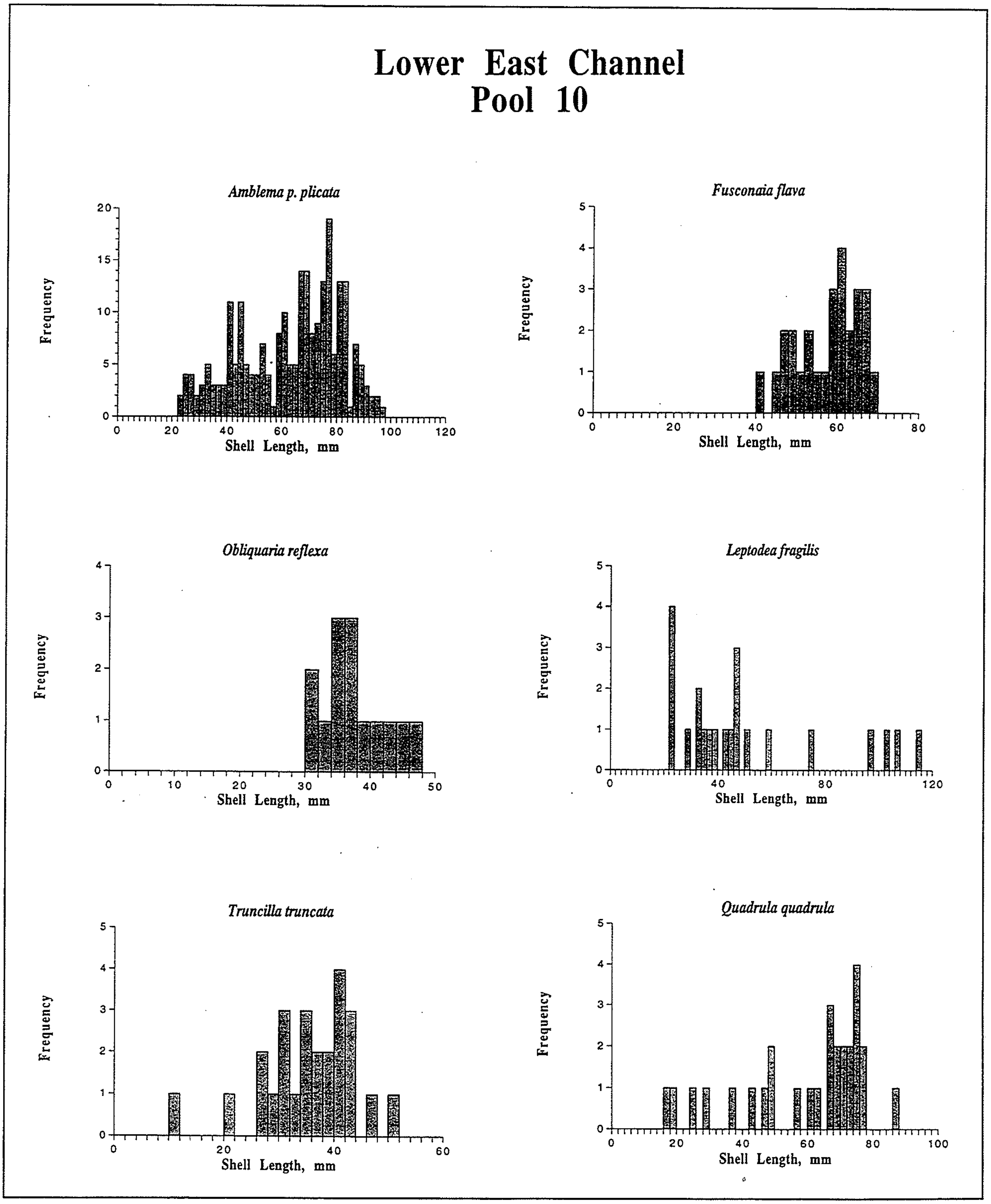


Figure B5. Size demography, Lower East Channel, Pool 10

Pool 10 Harpers Slough
RM 643

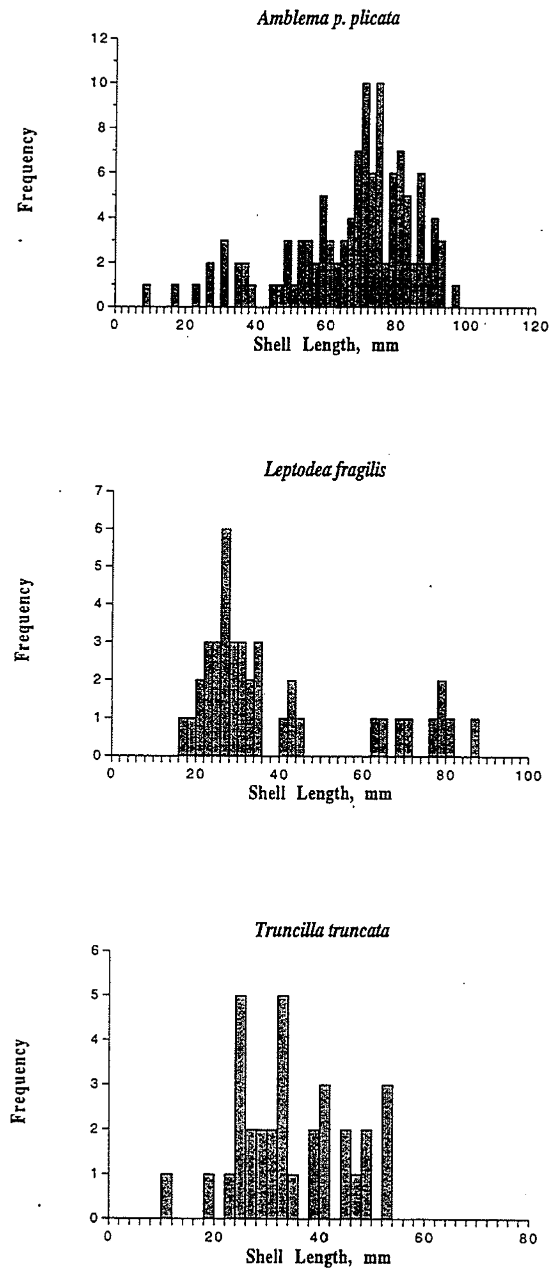


Figure B6. Size demography, Harpers Slough, Pool 10, RM 643

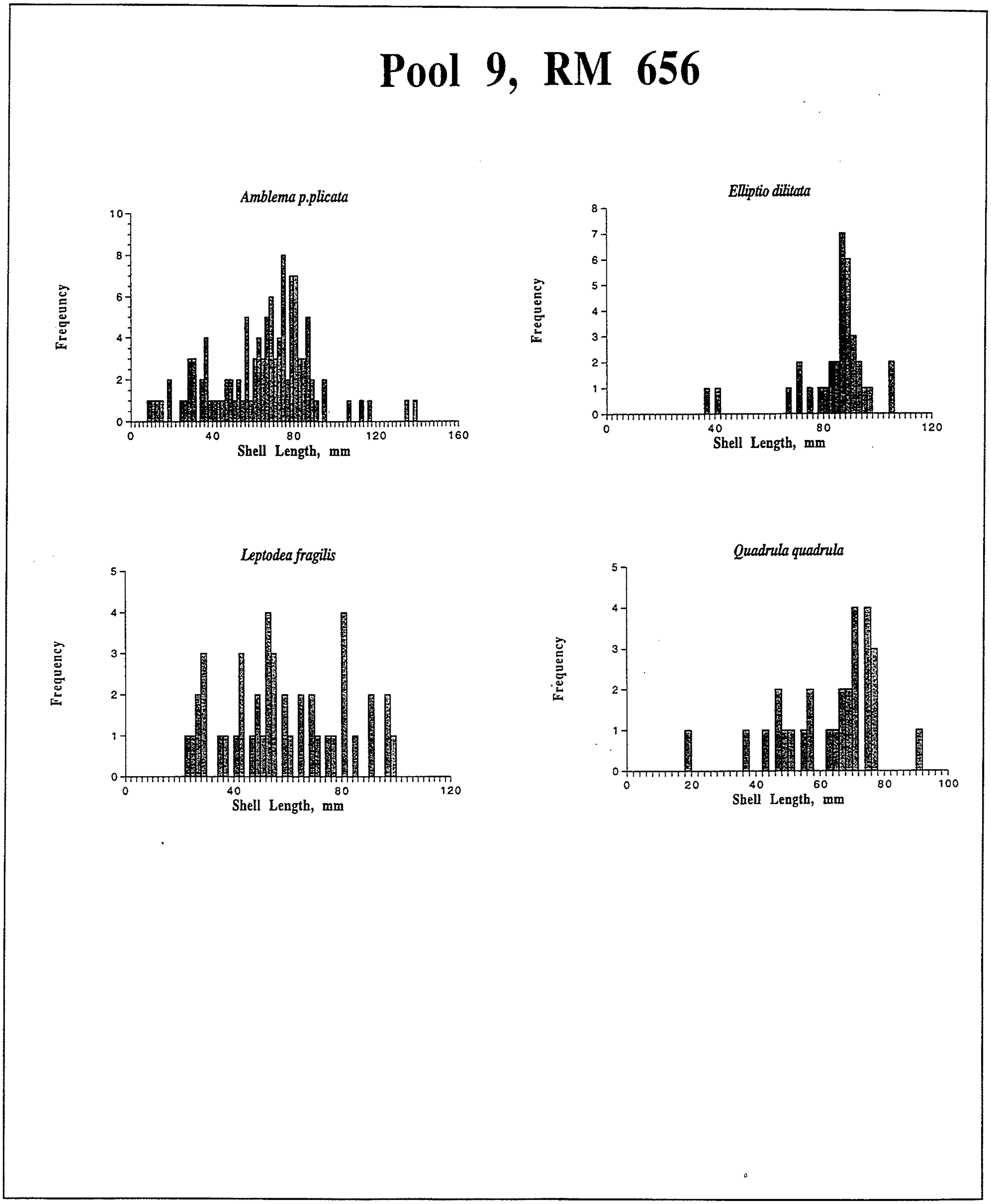


Figure B7. Size demography, Pool 9, RM 656

Appendix C
Size Demography of *Dreissena polymorpha* at Study Sites in the Upper Mississippi River, 1995

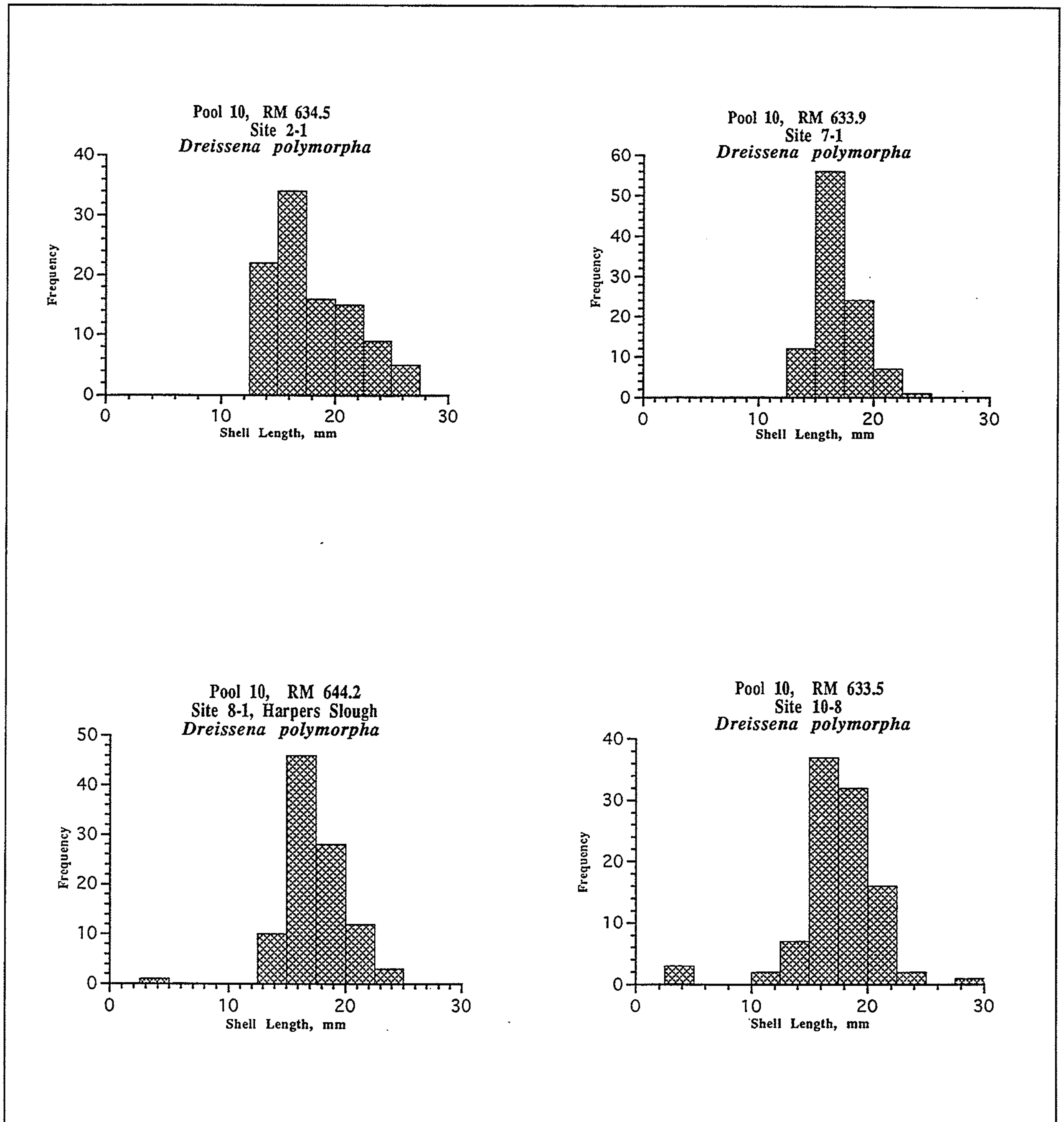


Figure C1. Size demography, *Dreissena polymorpha*, UMR, 1995 (Sheet 1 of 3)

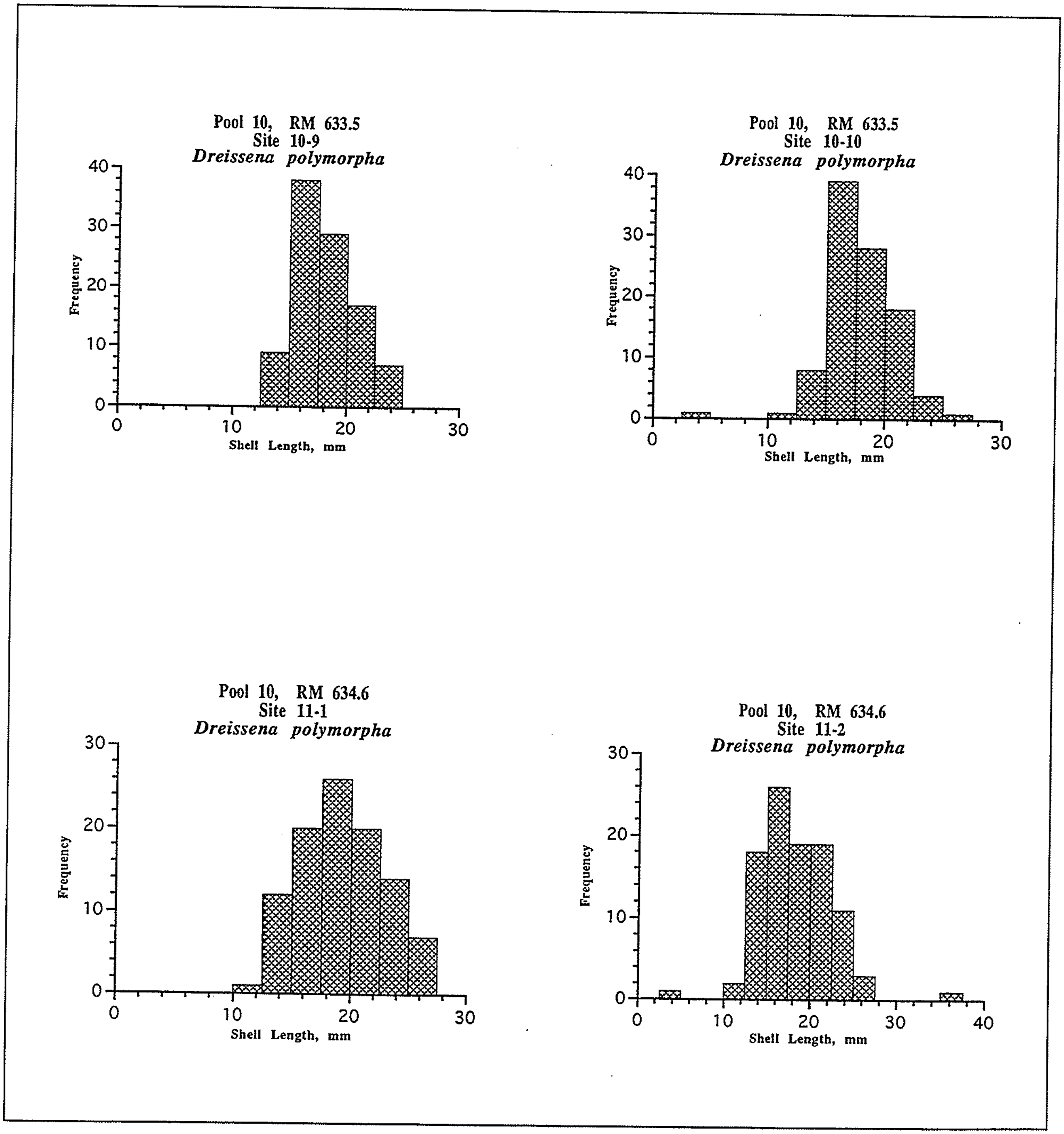


Figure C1. (Sheet 2 of 3)

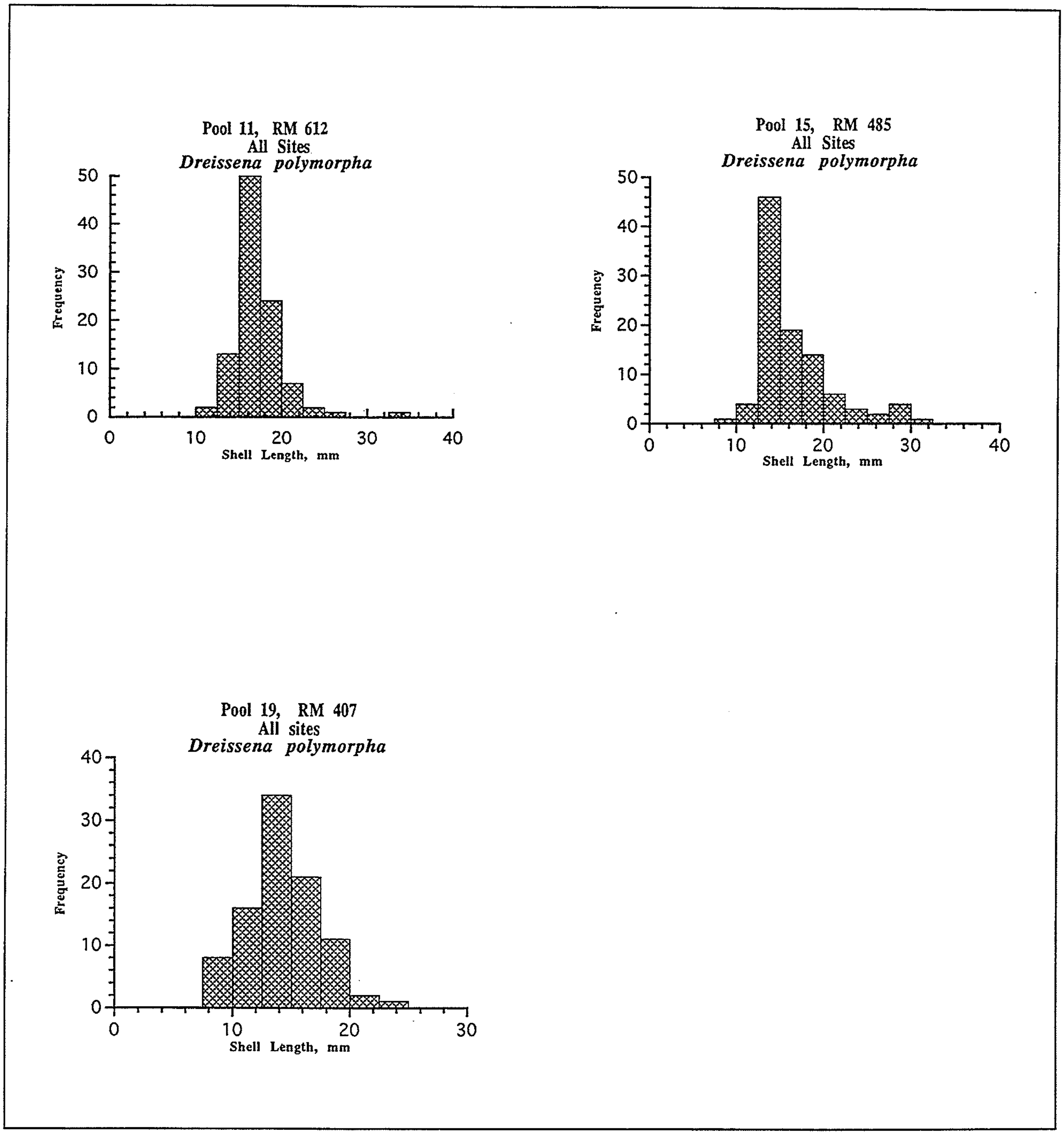


Figure C1. (Sheet 3 of 3)

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13. ABSTRACT *(Maximum 200 words)*

Bivalve surveys were conducted at six locations in the upper Mississippi River at beds designated as essential habitat for the endangered mussel *Lampsilis higginsi* (Lea). Mussel beds were located at Drew Chute, Pool 19, near River Mile (RM) 407, left descending bank (LDB); Sylvan Slough, Pool 15, near RM 485, LDB; Goetz Island, Pool 11, near RM 612, right descending bank (RDB); lower East Channel, Pool 10, near RM 635; Harpers Slough, Pool 10, near RM 641, RDB; and Whiskey Rock, Pool 9, near RM 656, RDB. All of these beds were characterized by moderate to high densities of native mussels (17.6 ± 1.5 to 37.6 ± 3.0 (± Standard Error) and species richness 16-24, 30 species overall). Evidence of recent recruitment (number of individuals and species less than 30-mm total shell length) was 11.3 to 32.3 percent of individuals present and 40.0 to 56.0 percent of species present. At the majority of sites, mean numbers of the nonindigenous zebra mussel, *Dreissena polymorpha*, ranged from 49 to just under 1,000 individuals/square meter. At two sites in Pool 10 immediately downriver of the Highway 18 Bridge, total zebra mussel density was 10,328 and 6,852 individuals/square meter.

(Continued)

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Mean density of *L. higginsi* ranged from 0.3 to 0.27 individual/square meter and was present at all beds surveyed except the bed in Pool 19. Although relatively uncommon (less than 1 percent of the fauna), total numbers of this species present ranged from 5,690 ± 9,538 to 169,585 ± 127,057 at the bed in Pool 10 and the lower East Channel, respectively. Based upon Jaccard's Index, presence of *L. higginsi* was correlated with certain species, although there does not appear to be a specific causative factor present to explain these relationships. Typically, *L. higginsi* is found in water greater than 1 m deep with velocities between 0.5 and 1.0 m/sec during moderate flow in the summer. It is less common in the channel than in shallow areas near shore and less common in scoured substratum, areas of shifting sand, or high sediment deposition. All of the beds surveyed, with the exception of the one in Pool 19, are important for *L. higginsi* and should be considered essential for this species.