Mussel Habitat in the Richmond Island / Lock and Dam 6 Tailwater Area of Pool 7, Mississippi River, and its Importance for Recovery of the Federally Endangered Mussel, *Lampsilis higginsi*

Mike Davis and Rick Hart

November 1995

Ecological Services Section
Minnesota Department of Natural Resources
Lake City, MN 55041

Abstract

During September and October, 1995, a freshwater mussel survey was conducted in the Mississippi River within navigation pool 7 near Richmond Island at RM 714.2-712. Mussels were collected from thirty 0.25m² quadrats at each of four quantitative sampling sites. Divers also collected mussels at eight qualitative sampling sites. Two thousand one hundred sixteen mussels representing twenty-two species of unionids were collected using a combination of quantitative and qualitative sampling methods. Mussel densities ranged from 25-53/m². *Amblema plicata* and *Obliquaria reflexa* were the most abundant species. Mussels were found most often in sand substrates exposed to moderate current velocities. One live adult male and one live adult female *Lampsilis higginsi* were collected using qualitative methods. These individuals were found downstream of a wingdam in shifting sand substrate and high current velocities. Two recently consumed *Lampsilis higginsi* were collected from a muskrat midden pile. These individuals were females aged 5 and 7 years. Density of *Dreissena polymorpha* found at quantitative sites ranged from 5-84/m². *Dreissena polymorpha* were attached to 9-44% of the unionid mussels collected. Although few *Lampsilis higginsi* were found, mussel habitat in the Richmond Island area may be potentially important for *Lampsilis higginsi*. Evidence for this area's potential importance is supported by the presence of many other mussel species and its high mussel densities.

Acknowledgements

This study was conducted by personnel of Minnesota Department of Natural Resources Ecological Services Section, Lake City, MN office. Field assistance was provided by Becky Maxson, and Jenny Winkelman. Funding for this study was provided by the United States Fish and Wildlife Service. Equipment and logistical support was provided by the Minnesota Department of Natural Resources.

Table of Contents

List of Tables

List of Figures

Introduction

A Recovery Plan for *Lampsilis higginsi* was first written in 1982. In the plan, seven areas of "essential habitat" for this mussel species were identified. "Secondary habitats" were also discussed as sites for potentially increasing the abundance of *Lampsilis higginsi*. "Secondary habitats" are also areas that may be suitable for the reintroduction of *Lampsilis higginsi*.

In 1994, funds were made available for updating the Recovery Plan. As a result of interagency discussions for completing this update, it was determined that some of the funds should be used to investigate the mussel community of a potential secondary site and its present use by *Lampsilis higginsi*.

An area of the Mississippi River within navigation pool 7 and located along the right descending bank near Richmond Island (RM 714.2-712) was surveyed during September and October, 1995. The presence of *Lampsilis higginsi* in this area had been previously reported by biologists from the National Fisheries Research Station (Waller, NBS, pers. comm.).

Purpose

This study was conducted to assess the potential of the Richmond Island area to serve as recovery habitat for *Lampsilis higginsi*. Information collected during this survey was designed to:

1. Determine the composition of the mussel community at several sites within the general area.
2. Determine the population status of those species collected in adequate abundance for analysis.
3. Describe the distribution and abundance of *Lampsilis higginsi* in the area.
4. Relate mussel habitat conditions in the area to the potential recovery of a *Lampsilis higginsi* population.

Study Area

Richmond Island is located in pool 7 of the Upper Mississippi River near Trempealeau, Wisconsin (Fig. 1). The head of Richmond Island is located approximately 1.75 miles downstream of the US Army Corps of Engineers Lock and Dam 6. Qualitative and quantitative sampling sites were located on the Minnesota side of the Mississippi River from the upstream end of Richmond Island to the spillway of lock and dam 6. Sampling was conducted during the months of September and October, 1995 (Figs. 1 and 2).

Methods

All mussel sampling was conducted by divers using scuba equipment. Areas that were thought suitable for mussel sampling were investigated by divers during reconnaissance dives. During reconnaissance, divers qualitatively estimated mussel density, species composition, substrate composition, and current velocity. If mussel density seemed greater than about five mussels/m^2 the area was deemed suitable for intensive qualitative and quantitative mussel sampling.

Qualitative mussel samples were collected at seven sites near Richmond Island (Fig. 2, Table 1). Divers collected mussels by feel and placed them in nylon mesh bags. Divers collected every mussel encountered during the search. Where adequate mussel numbers were present, divers placed 20 live mussels into each of 10 bags. Preliminary results of the qualitative sampling aided in the determination and placement of quantitative sampling sites.

Quantitative samples were collected at four sites (Fig. 1, Table 2). At each of the sites, three subsites were chosen for sampling. At each of the three subsites, ten 0.25 m^2 quadrat samples were collected. Before quadrat

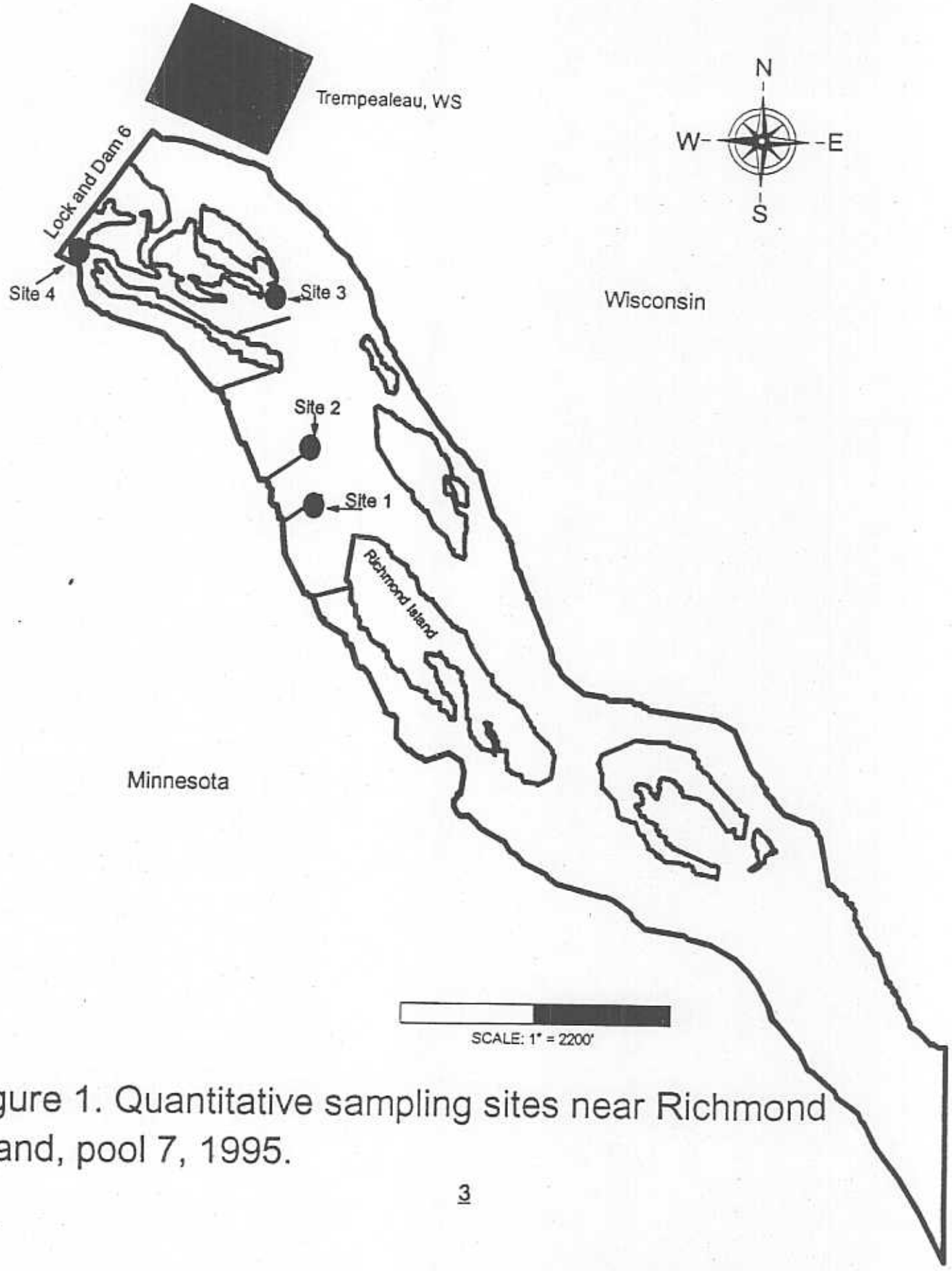

Figure 1. Quantitative sampling sites near Richmond Island, pool 7, 1995.

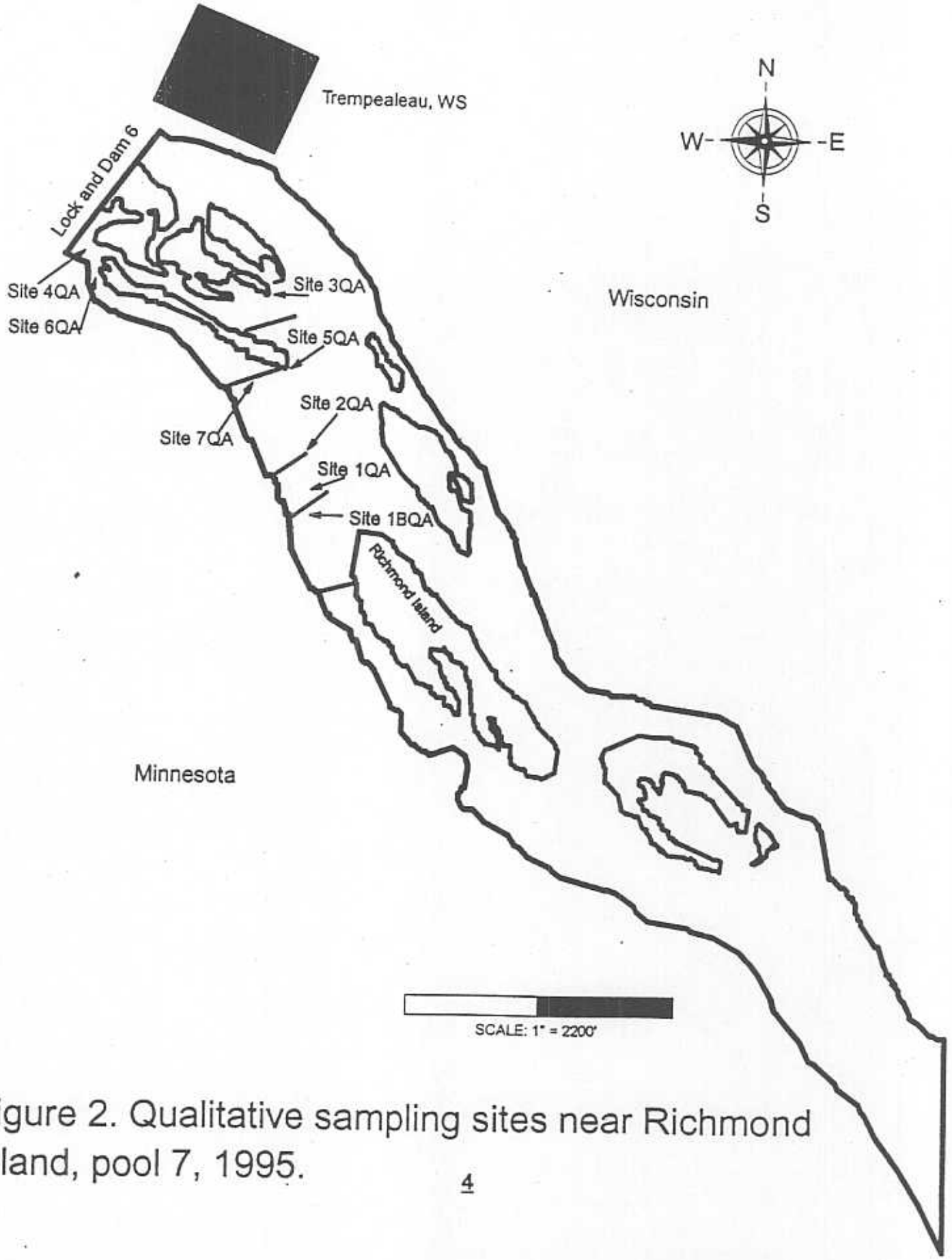

Figure 2. Qualitative sampling sites near Richmond Island, pool 7, 1995.

sampling was initiated at the subsites, water depth was recorded and divers noted substrate composition and current speed. Mussels were collected from within each of the quadrats with the use of a four inch diameter suction dredge. Substrate within each quadrat was pumped to the surface, sieved through a series of nested screens, and searched for live mussels (Miller and Payne 1995). All live mussels were removed from the screens and placed in labeled plastic bags. When sampling was completed at each site, all mussels were identified, their total length measured and finally, returned back into the substrate unharmed. All *Dreissena polymorpha* present were enumerated, attachment to mussels noted, removed from the sample and preserved for later analysis.

Several muskrat midden piles were investigated to determine if any mussel species not collected during sampling were present in the area. Muskrats are known to consume large numbers of mussels, including endangered mussel species (Neves and Odom 1989), and their midden piles are considered an excellent source for determining the presence of mussels in a particular stream reach (Kovalak, et.al., 1986) .

The qualitative and quantitative methods that were used for the collection of unionid mussels during this study were outlined in Miller and Payne (1995) and references contained therein. Mussel identifications were based on taxonomic descriptions found in Cummings and Mayer (1992).

Results

Mussel Community Characteristics

Quantitative sampling

One thousand twenty-five unionid mussels, representing 19 species, were collected at the four quantitative sampling sites (Table 3, 4). Mussel density ranged from 25.2 to 53.7 mussels/m^2 (Fig. 3). The federally endangered mussel species *Lampsilis higginsi* was not collected during quantitative sampling.

Site one

Quantitative sampling site one was located near a wing dam directly upstream of Richmond Island (Fig. 1, Table 2). Three subsites were sampled at site one, one upstream of the wingdam, one directly on the wingdam, and one downstream of the wing dam. Substrates at this site varied from rubble and sand on the wingdam, to gravel and shifting sand above and below it (Table 5). Water depth ranged from 1 - 1.5 meters with moderate to high current velocities (Table 2).

Two hundred thirty three unionid mussels from fourteen species were collected from quadrats. Mean unionid mussel density at this site was 31/m^2 . *Amblema plicata* and *Leptodea fragilis* dominated the mussel assemblage (Fig. 1, Table 4). Densities of zebra mussels, *Dreissena polymorpha,* (mean density, 83.7 /m^2), were much higher at this site than the other three sampling sites (Fig. 4). Twenty percent of the unionids present at site one were infested with *Dreissena polymorpha*, and an average of 0.31 *Dreissena polymorpha* were attached to each unionid mussel (Table 4).

Site two

Sampling site two was also located near a wing dam, with subsites located upstream, downstream, and at the offshore end of the structure (Fig.1, Table 2) . Substrates at this site were predominately stable sand, and silty-clay (Table 5). Current speed in this area was low to moderate, with water depths ranging from 1 - 5 meters (Table 2).

One hundred ninety four unionid mussels representing ten species were collected at site two. Density at site two averaged 25/m^2 (Fig. 3), and *Amblema plicata*, *Obliquaria reflexa*, and *Truncilla truncata* dominated the mussel assemblage (Table 4). *Dreissena polymorpha* densities were 19.2 /m^2, lower than at site one (Fig. 4), but 44% of the unionids present were infested, and 0.7 *Dreissena polymorpha* were attached to each unionid mussel (Table 4).

Site three

Site three was located on a sand bar (Fig. 1, Table 2) where *Lampsilis higginsi* had previously been found (Waller, NBS, pers. comm.). Stable sand and gravel substrates dominated the stream bottom in this area (Table 5). Water velocities were low in sampling depths that averaged about 1.5 meters (Table 2).

Unionid mussels collected from this site totaled one hundred ninety five individuals of nine species. Density of unionids averaged 26/m^2 with *Amblema plicata*, *Obliquaria reflexa*, and *Truncilla truncata* once again dominating the mussel assemblage (Fig. 3, Table 4). *Dreissena polymorpha* density averaged 4.8/m^2, lowest of all sites. Only 9% of unionids present had an average of 0.11 *Dreissena polymorpha* attached to their shells (Fig. 4, Table 4).

Site four

Site four was located in the tailwaters of lock and dam 6 (Table 2). Substrate at this site was dominated by sand, silt, and gravel (Table 5). Water velocities were low in depths ranging from 1.5 - 2 meters (Table 2).

This area contained the densest and most species rich assemblage of mussels out of the four sites sampled (Fig. 3, Table 4). Four hundred three unionid mussels representing sixteen species were collected from quadrats. *Amblema plicata* and *Obliquaria reflexa* once again dominated the mussel assemblage at this site. One specimen of *Ellipsaria lineolata*, a species proposed to be listed as threatened by the State of Minnesota, was collected at site four. Densities of unionid mussels averaged 53.7/m^2. *Dreissena polymorpha* density was 7.73/m^2 and only 12.9% of the unionids present were infested with an average of 0.14/unionid (Fig. 4, Table 4).

Qualitative sampling

Qualitative sampling at eight sites yielded one thousand ninety one unionid mussels of twenty species. *Amblema plicata* and *Obliquaria reflexa* were the dominant species at all of the qualitative sampling sites (Table 3, 6). The federally endangered mussel species *Lampsilis higginsi* was found only at sites 1QA and 1BQA (Fig. 2, Tables 1, 6), where two individuals, an adult male and an adult female, were collected. Substrates in the area where live *Lampsilis higginsi* were found were dominated by shifting sand in water depths of about 2 meters (Table 1).

Two freshly consumed *Lampsilis higginsi*, both females, were found while examining three large muskrat midden piles located on shore near qualitative site 5QA (Fig. 2, Table 1). By counting the annual growth rings we estimated them to be 5 and 7 years old. Since there was such a large and diverse middens pile on the waters edge, we erroneously assumed there to be a large and diverse mussel bed in this area. Qualitative sampling at this site

yielded only 26 individuals representing 5 species (Table 6).

Mussel Size Demography

Shell length analysis revealed ongoing recruitment for most of the common mussels species collected during quantitative sampling (figs. 5-11). A large, recent cohort of *Amblema plicata* is also evident in these data. Recruitment was also evident for *Dreissena polymorpha*.

Amblema plicata

Amblema plicata was the most abundant unionid species found at the Richmond Island mussel bed. Shell lengths for the 512 *amblema plicata* collected ranged from 10 - 138 mm. The population structure indicates strong cohorts centered at 16, 76, and 84mm (Fig. 5). Numerous age classes, and a high number of young individuals present in the population, indicates a regularly recruiting population.

Fusconaia flava

Shell lengths of the seventy *Fusconaia flava* collected near Richmond Island ranged from 10 - 86mm. All size classes were well represented, indicating that the *Fusconaia flava* population at the Richmond Island mussel bed is experiencing regular annual recruitment, in spite of low densities (Fig. 6, and Table 4).

Lampsilis cardium

Twenty-seven individuals of this species were collected during quantitative sampling. Shell lengths ranged from 14 - 146mm, with several cohorts not present (Fig. 7). Lack of cohorts may indicate irregular recruitment, or could be an artifact of sampling due to the small number

Lampsilis cardium that were collected.

Leptodea fragilis

Fifty five individuals of this species were collected. Shell lengths ranged from 18 - 130 mm. The population structure of this species appears to be bimodal with several cohorts missing, possibly indicating irregular recruitment. However, several size classes were well represented and a large number of young individuals (< 38mm) were present, suggesting a stable population (Fig. 8).

Obliquaria reflexa

This species was the second most abundant mussel at the Richmond Island mussel bed (Table 4). One hundred sixty three *Obliquaria reflexa* were collected during quantitative sampling. Shell lengths ranged from 10 - 74 mm. The population size structure for *Obliquaria reflexa* included a large cohort centered at 36mm (Fig. 9). All of the size classes were well represented indicating consistent annual recruitment.

Quadrula pustulosa

The size structure of the *Quadrula pustulosa* population at Richmond Island indicates regular annual recruitment. Shell lengths for the fifty two individuals collected ranged from 14 - 86mm. There was a large cohort centered at 64mm, with other size classes also well represented (Fig. 10).

Truncilla truncata

Most *Truncilla truncata* size classes were well represented, indicating both recent and consistent annual recruitment (Fig. 11). A total of one hundred eight individuals were collected, shell lengths ranged from 6 - 50mm.

Dreissena polymorpha

Three hundred four individuals of this exotic mussel species were collected from the Richmond Island study area. Shell lengths (figure 12) indicate recent recruits, as well as reproductive age adults. The size structure of *Dreissena polymorpha* indicates a healthy, recruiting population. Lengths of the largest individuals (35-40 mm) present suggests that they are probably three years old and therefore settled during the spring of 1993.

Discussion

Community

Species Richness

Twenty two unionid mussel species were collected live and one species as fresh dead shell from the study area (Table 1). Three species were collected using qualitative methods that were missing from quantitative samples. Conversely, two species were collected from quadrats that were not found during qualitative searches. Specimens of the zebra mussel, *Driesenia polymorpha*, were also collected.

Species richness in this area is indicative of a healthy mussel community when compared to other areas of the Mississippi River that have been studied over the past twenty years. Thiel (1981) reported only fifteen species during a survey of Pool seven and a total of thirty from all sampling in Pools 3-11. Miller (1987) reported twenty three species, including *Lampsilis higginsi* from Pool 7 during a reconnaissance of wing dam habitat about five miles downstream of Richmond Island. Miller and Payne (1995) reported twenty four species from Pool 10. Their study area is considered essential habitat for *Lampsilis higginsi* (USFWS,1982).

Species Associations

Lampsilis higginsi seemed to be found in the only area where *Obovaria olivaria* resided in significant numbers. Of the fifty six *Obovaria olivaria*, 89% were found in proximity to the two *Lampsilis higginsi* found during this study. This suggests that these two mussel species may share similar habitat requirements. Duncan and Thiel (1983) reported a similar relationship between these two species in their study of Pool 10.

Amblema plicata was the most abundant member of the mussel

community in all quantitative samples, and in six of the eight qualitative. *Obliquaria reflexa* was the most abundant in qualitative samples from two sites.

Many of the collected mussel species are common in the Mississippi at this latitude and were abundant in samples collected during this study. Most notable in abundance were *Amblema plicata* (threeridge), *Obliquaria reflexa* (threehorn wartyback), *Truncilla truncata* (deertoe), *Fusconaia flava* (pigtoe) and *Quadrula pustulosa* (pimpleback).

Of the species collected, thirteen comprised less than 1% of the 2,116 mussels collected from the study area. They include the federally endangered *Lampsilis higginsi* (Higgin's eye); *Anodonta grandis* (giant floater); *Anodonta imbecilis* (paper floater); *Elipsaria lineolata* (butterfly mussel), listed as endangered in neighboring Wisconsin and proposed for threatened status in Minnesota; *Lasmigona complanata* (white heelsplitter); *Ligumia recta* (black sandshell); *Megalonaias nervosa* (washboard), an important commercial species further downriver; *Pleurobema coccineum* (round pigtoe); *Potamilus alatus* (pink heelsplitter);*Quadrula quadrula* (mapleleaf); *Strophitus undulatus* (strange floater); *Toxolasma parvus* (lilliput); *Truncilla donaciformis* (fawnfoot);

Of these species, some, such as *Anodonta grandis* and *Anodonta imbecilis*, were probably not collected in abundance because they frequent other physical habitat types, such as slow moving water and soft substrates (Fuller, 1978), rather than because they are rare. Others, such as *Ligumia recta* and *Pleurobema coccineum*, are apparently becoming rarer in the Mississippi River over time (Thiel, 1981).

Density

Data from quantitative samples revealed densities ranging from over 53/m^2 to about 25/m^2 (table 4). These densities are typical of high quality

mussel beds in the Mississippi River (Miller and Payne, 1995).

Population Demography

Length frequency histograms for eight species indicate ongoing recruitment to their populations. This is a good indicator of population health (Miller and Payne, 1995), and of adequate habitat conditions in the area for maintaining at least some common mussel species. The health of other species is difficult to determine because they were collected in numbers too low to analyze. Other attributes of a healthy mussel population (Miller and Payne, 1995) require additional years of data collection to establish.

Finding two relatively young *Lampsilis higginsi* shells on a muskrat midden is an indication that even this uncommon species is still recruited to the study area at least occasionally.

Conclusion

In conclusion, the mussel habitat conditions in the study area clearly are good. Perhaps as good as anywhere else on the river. Reasons for *Lampsilis higginsi* remaining very uncommon in the area are probably due more to the changed hydrologic conditions in the Mississippi River than to any condition specific to the study area. Changes brought on by the river's management and re-engineering for navigation, and by massive changes in land cover and use within the basin, have affected the abundance and distribution of other mussel species requiring large floodplain rivers for habitat (Thiel, 1981; USFWS, 1982; Duncan and Thiel, 1983; Mueller, 1993.). That *Lampsilis higginsi* is found here at all may be due to the more naturally riverine character of the tailwater reaches of navigation pools.

Essential habitat for *Lampsilis higginsi* is surely the range of conditions

and variability once inherent to temperate zone large rivers such as the Mississippi. To the extent possible, restoring natural riverine conditions to the Mississippi seems to offer a sensible means for assuring the continued existence of and possible reoccupation of former range by *Lampsilis higginsi*.

References

Cummings, K.S., and C.A. Mayer. 1992. Field Guide to the Freshwater Mussels of the Midwest. Illinois Natural History Survey. Manual 5.

Duncan, Randall E., and P.A. Thiel. 1983. A Survey of the Mussel Densities in Pool 10 of the Upper Mississippi River. Technical Bulletin No. 139. Department of Natural Resources, Madison, Wisconsin.

Kovalak, W.P., S.D. Dennis, and J.M. Bates. 1986. Sampling Effort Required to Find Rare Species of Freshwater Mussels. Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems, ASTM STP 894, American Society for Testing and Materials, Philadelphia, 1986, pp.34-45

Miller, A.C., and B.S. Payne. 1995. The Importance of a Mussel Bed near McMillan Island, Pool 10 of the Upper Mississippi River, for *Lampsilis higginsi*. Technical Report EL-95-, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, Andrew C. 1987. Mussel Fauna Associated with Wing Dams, Mississippi River Mile 707.8 - 709.4. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Mueller, Lisa. 1993. Winged Mapleleaf Mussel and Higgins' Eye Pearly Mussel Freshwater Mussels Threatened with Extinction. Minnesota Department of Agriculture.

Neves, R.J., and M.C. Odom. 1989. Muskrat Predation on Endangered Freshwater Mussels in Virginia. Journal of Wildlife Management 53 (4):934-941.

USFWS. 1987. Higgens' Eye Mussel Recovery Plan.

Waller, Diane. 1995. Personal communication. National Biological Service, Onalaska, Wisconsin.

Table 1. Qualitative sampling site descriptions.

Site	Number of replicates	Sampling site description	Depth	Substrates
1QA	1	Same area as quantitative site 1	1-2 m	90% sand, 10% gravel
1BQA	10	Same area as quantitative site 1	1-2 m	70% sand, 30% rubble
2QA	3	Same area as quantitative site 2	1-5 m	80% sand, 10% silt, 10% gravel
3QA	12	Same area as quantitative site 3	1-2 m	90% sand, 10% gravel
4QA	10	Same area as quantitative site 4	1-2 m	80% sand, 20% gravel
5QA	1	Rm = 713.4, right descending bank near muskrat midden pile	1-3 m	90% sand, 10% gravel
6QA	1	Rm = 714.1, side channel area near lock and dam 6 spillway, right descending bank	1-2 m	80% sand, 10%silt, 10% gravel
7QA	1	Rm = 713.4, side channel area, right descending bank	1-3 m	80% sand, 20% gravel

Table 2. Quantitative sampling site descriptions.

Site	Subsite	Location	Number of replicates	Depth	Velocity
1	1A	Rm = 713.1, on top of wingdam, upstream of Richmond Island	10	1 m	high
	1B	Rm = 713.1, downstream of wing dam	10	1.5 m	moderate
	1C	Rm = 713.1, upstream of wing dam	10	1 m	moderate
2	2A	Rm = 713.3, downstream of wing dam	10	2 m	moderate
	2B	Rm = 713.3, upstream of wing dam	10	3 m	moderate
	2C	Rm = 713.3, offshore edge of wing dam in scour hole	10	5 m	low
3	3A	Rm = 713.6, sand bar on the right descending bank	10	1.5 m	low
	3B	Rm = 713.6, sand bar on the right descending bank	10	1.5 m	low
	3C	Rm = 713.6, sand bar on the right descending bank	10	1.5 m	low
4	4A	Rm = 714.2, spillway of lock and dam 6	10	1.5 m	low
	4B	Rm = 714.2, spillway of lock and dam 6	10	2 m	low
	4C	Rm = 714.2, spillway of lock and dam 6	10	1.5 m	low
Total number of replicates =			120		

Table 3. Species collected using quantitative and qualitative methods near Richmond Island, pool 7, 1995.

Species	Sampling Method	
	Quantitative	Qualitative
Anodonta grandis	X	X
Anodonta imbecillis	X	
Amblema plicata	X	X
* *Ellipsaria lineolata*	X	
Fusconaia flava	X	X
Lampsilis cardium	X	X
* *Lampsilis higginsi*		X
Lasmigona complanata	X	X
Leptodea fragilis	X	X
* *Ligumia recta*	X	X
* *Megalonaias nervosa*	X	X
* *Obovaria olivaria*	X	X
Obliquaria reflexa	X	X
* *Pleurobema coccineum*	X	X
Potamilus alatus	X	X
Potamilus ohiensis	X	X
Quadrula pustulosa	X	X
Quadrula quadrula	X	X
Strophitus undulatus		X
Toxolasma parvus		X
* *Tritogonia verrucosa*	Fresh dead	
Truncilla donaciformis	X	X
Truncilla truncata	X	X
Total species	19	20

Table 4. Quantitative sampling species list and summary statistics for mussels collected near Richmond Island, pool 7, 1995.

	Number of individuals (percent species composition in parenthesis)			
Species	Site 1	Site 2	Site 3	Site 4
Anodonta grandis	0 (0)	0 (0)	1 (0.5)	2 (0.5)
Anodonta imbecillis	1 (0.43)	0 (0)	0 (0)	3 (0.7)
Amblema plicata	80 (34.3)	83 (42.8)	136 (69.7)	213 (52.9)
Ellipsaria lineolata	0 (0)	0 (0)	0 (0)	1 (0.2)
Fusconaia flava	34 (14.6)	8 (4.1)	9 (4.6)	19 (4.7)
Lampsilis cardium	17 (7.3)	4 (2.1)	3 (1.5)	3 (0.7)
Lasmigona complanata	0 (0)	0 (0)	0 (0)	1 (0.2)
Leptodea fragilis	42 (18.0)	1 (0.5)	8 (4.1)	4 (1.0)
Ligumia recta	1 (0.43)	0 (0)	0 (0)	1 (0.2)
Megalonaias nervosa	1 (0.43)	0 (0)	0 (0)	0 (0)
Obovaria olivaria	2 (0.86)	3 (1.5)	0 (0)	0 (0)
Obliquaria reflexa	30 (12.9)	45 (23.2)	16 (8.2)	72 (17.9)
Pleurobema coccineum	0 (0)	1 (0.5)	0 (0)	2 (0.5)
Potamilus alatus	0 (0)	0 (0)	0 (0)	1 (0.2)
Potamilus ohiensis	5 (2.1)	0 (0)	4 (2.1)	1 (0.2)
Quadrula pustulosa	10 (4.3)	14 (7.2)	4 (2.1)	24 (5.9)
Quadrula quadrula	1 (0.43)	0 (0)	0 (0)	0 (0)

Table 4. Continued

Species	Sites			
	Site 1	Site 2	Site 3	Site 4
Truncilla donaciformis	2 (0.86)	2 (1)	0 (0)	2 (0.5)
Truncilla truncata	7 (3.0)	33 (17)	14 (7.2)	54 (13.4)
Tritogonia verrucosa	0 (0)	0 (0)	1 fresh dead shell	0 (0)
Number of subsites	3	3	3	3
Number of 0.25 m^2 quadrats sampled	30	30	30	30
Total number of individuals	233	194	195	403
Total number of species	14	10	9	16
Mean unionid density (m^2)	31.07	25.2	26.0	53.7
Standard deviation	24.76	18.8	10.54	25.47
Mean *D. polymorpha* density (m^2)	83.73	19.2	4.8	7.73
Mean number of *D. polymorpha* / unionid	0.31	0.70	0.11	0.14
% infestation of unionids by *D. polymorpha*	20	44	8.7	12.9

Table 5. Quantitative sampling sites substrate compositions.

Site	Subsite	Substrate composition
1	1A	90% rubble, 10% sand
	1B	90% sand, 10% gravel
	1C	70% sand, 30% rubble
2	2A	80% sand, 10% silty clay, 10% detritus
	2B	90% gravel, 10% sand
	2C	80% sand, 10% silty clay, 10% detritus
3	3A	90% sand, 10% gravel
	3B	90% sand, 10% gravel
	3C	90% sand, 10% gravel
4	4A	90% sand, 10% gravel
	4B	70% sand, 30% silt
	4C	90% sand, 10% gravel

Table 6. Qualitative species list for mussels collected near Richmond Island, pool 7, 1995.

	Number of individuals (percent species composition in parenthesis)							
	Site							
Species	1QA	1BQA	2QA	3QA	4QA	5QA	6QA	7QA
Anodonta grandis	0 (0)	0 (0)	0 (0)	8 (2.6)	1 (0.48)	0 (0)	1 (4.3)	0 (0)
Amblema plicata	58 (27.1)	82 (37.8)	31 (40.8)	251 (83.4)	110 (52.6)	21 (80.8)	12 (52.2)	15 (57.7)
Fusconaia flava	3 (1.4)	1 (0.5)	1 (1.3)	8 (2.6)	9 (4.3)	2 (7.7)	2 (8.7)	3 (11.5)
Lampsilis cardium	11 (5.1)	4 (1.8)	2 (2.6)	5 (1.7)	3 (1.4)	0 (0)	0 (0)	0 (0)
Lampsilis higginsi	1 (0.47)	1 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Lasmigona complanata	2 (0.9)	0 (0)	2 (2.6)	7 (2.3)	1 (0.48)	0 (0)	0 (0)	0 (0)
Leptodea fragilis	1 (0.47)	0 (0)	0 (0)	0 (0)	3 (1.4)	0 (0)	0 (0)	0 (0)
Ligumia recta	0 (0)	0 (0)	1 (1.3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Megalonaias nervosa	0 (0)	0 (0)	0 (0)	1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
Obovaria olivaria EOR #46	35 (16.4)	15 (6.9)	0 (0)	1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
Obliquaria reflexa	73 (34.1)	85 (39.2)	28 (36.8)	11 (3.7)	41 (19.6)	1 (3.8)	2 (8.7)	3 (11.5)
Pleurobema coccineum	0 (0)	1 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Potamilus alatus	0 (0)	0 (0)	0 (0)	4 (1.3)	1 (0.48)	1 (3.8)	1 (4.3)	0 (0)
Potamilus ohiensis	6 (2.8)	1 (0.5)	0 (0)	2 (0.7)	2 (0.96)	0 (0)	0 (0)	1 (3.8)
Quadrula pustulosa	23 (10.7)	25 (11.5)	3 (3.9)	2 (0.7)	17 (8.1)	1 (3.8)	2 (8.7)	3 (11.5)
Quadrula quadrula	0 (0)	2 (0.9)	2 (2.6)	1 (0.3)	1 (0.48)	0 (0)	0 (0)	0 (0)

Table 6. Continued

	Sites							
	1QA	1BQA	2QA	3QA	4QA	5QA	6QA	7QA
Strophitus undulatus	0 (0)	0 (0)	1 (1.3)	0 (0)	1 (0.48)	0 (0)	0 (0)	0 (0)
Toxolasma parvus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.8)
Truncilla donaciformis	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.96)	0 (0)	0 (0)	0 (0)
Truncilla truncata	1 (0.47)	0 (0)	5 (6.6)	0 (0)	16 (7.66)	0 (0)	3 (13.0)	0 (0)
Total number of individuals	214	217	76	301	208	26	23	26
Total number of species	11	10	10	12	14	5	7	6

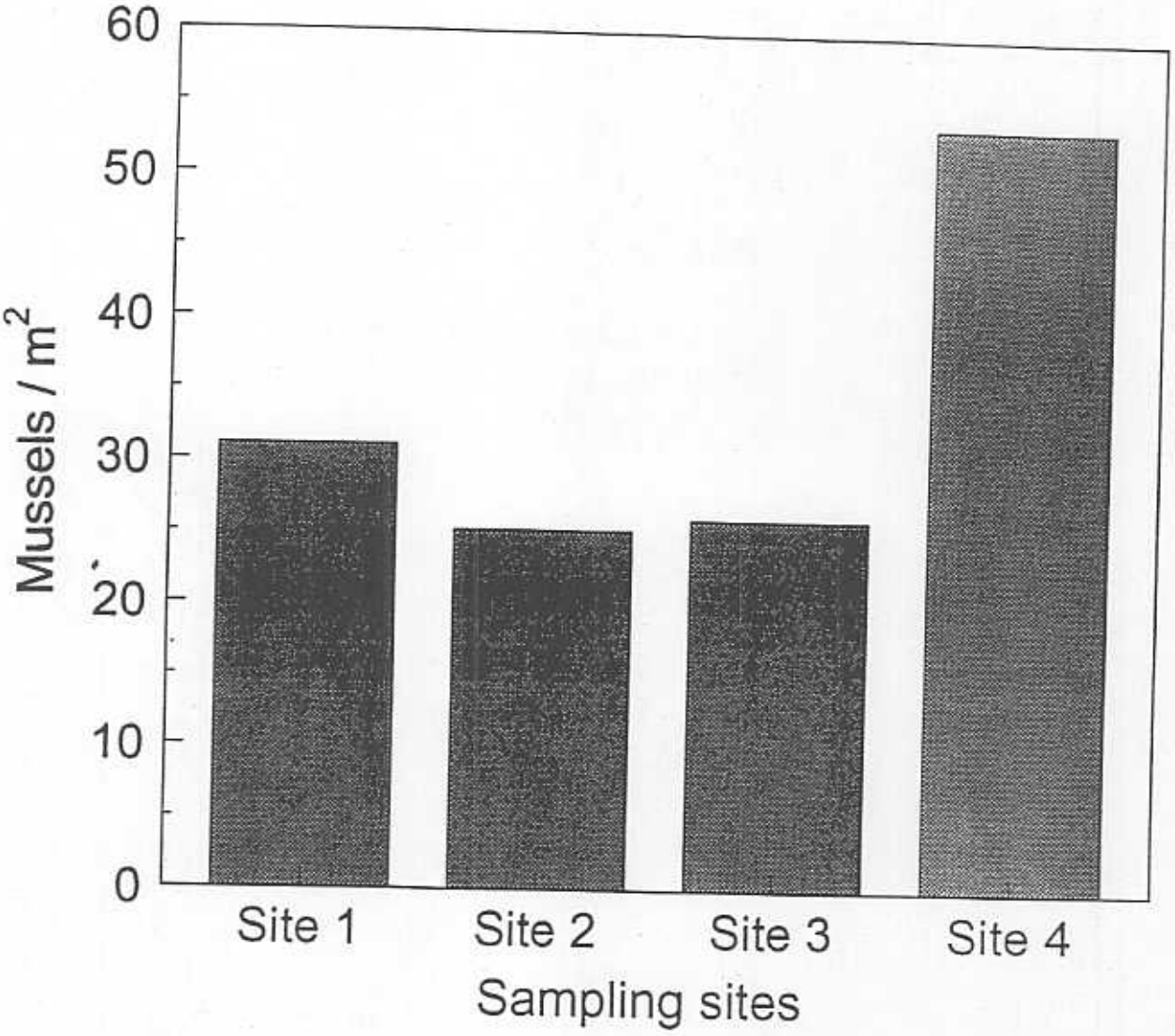

Figure 3. Quantitative sampling sites unionid mussel densities near Richmond Island, pool 7, 1995.

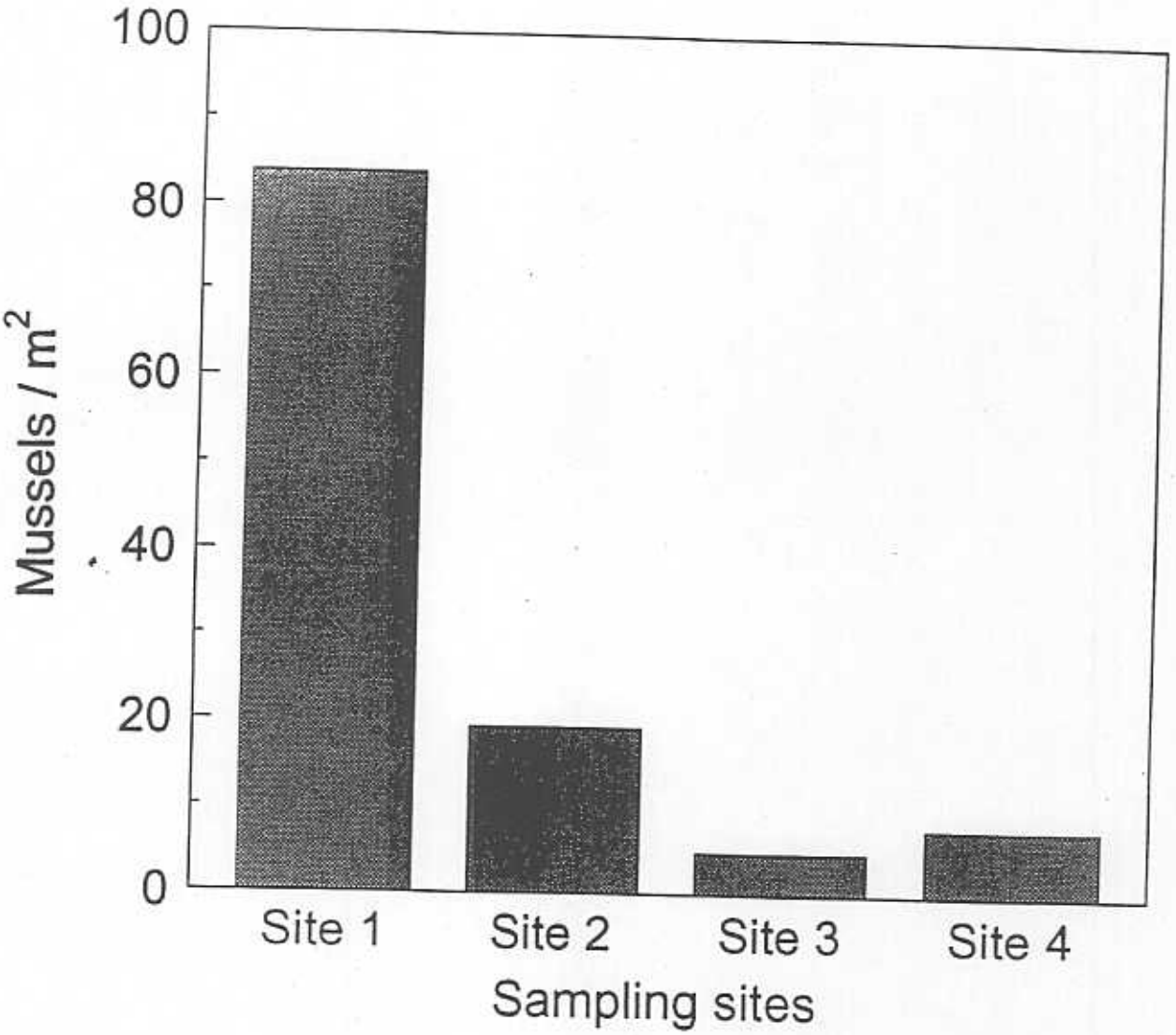

Figure 4. Quantitative sampling sites *Dreissena polymorpha* densities near Richmond Island, pool 7, 1995.

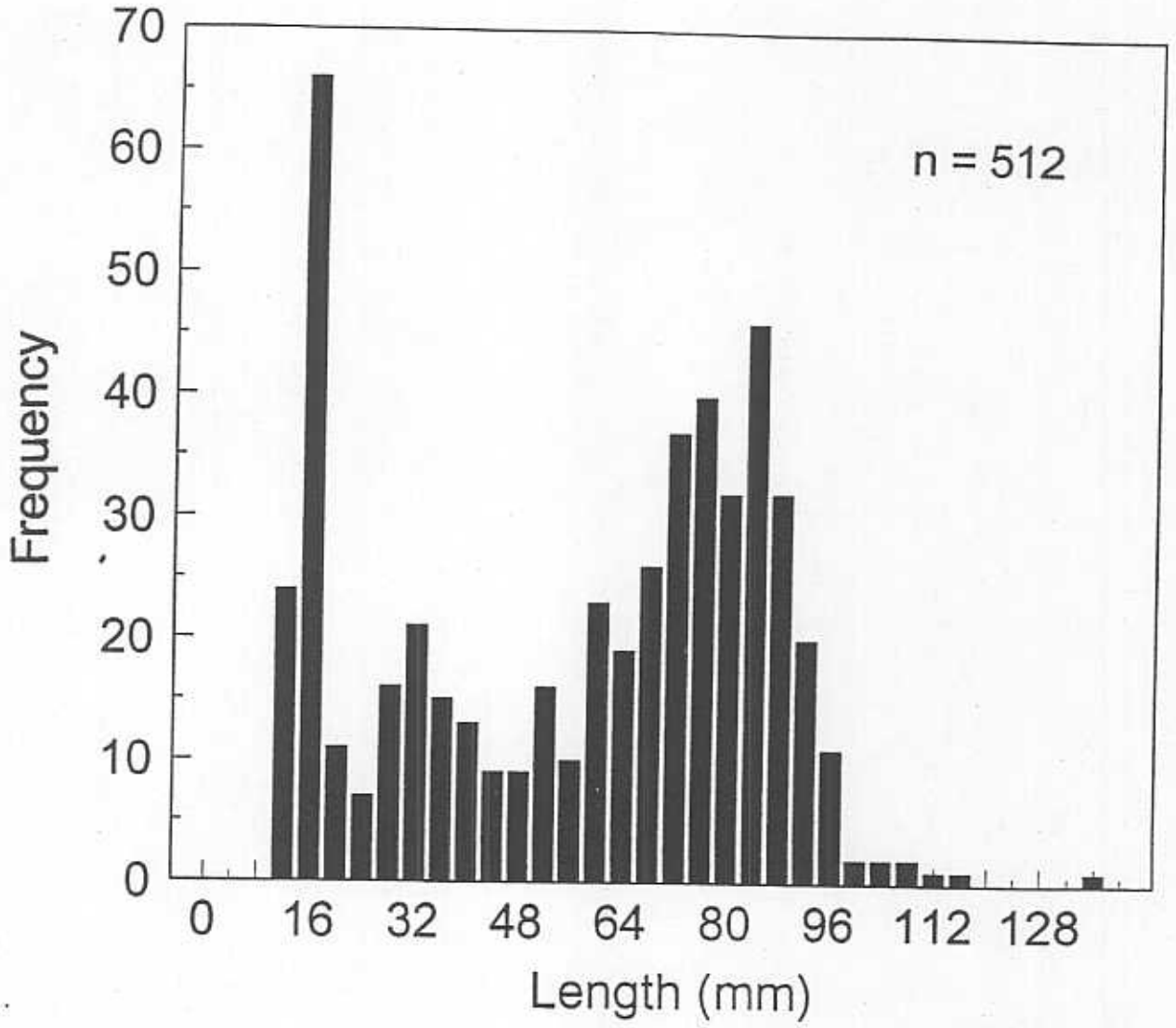

Figure 5. Length-frequency histogram for *Amblema plicata* near Richmond Island, pool 7, 1995.

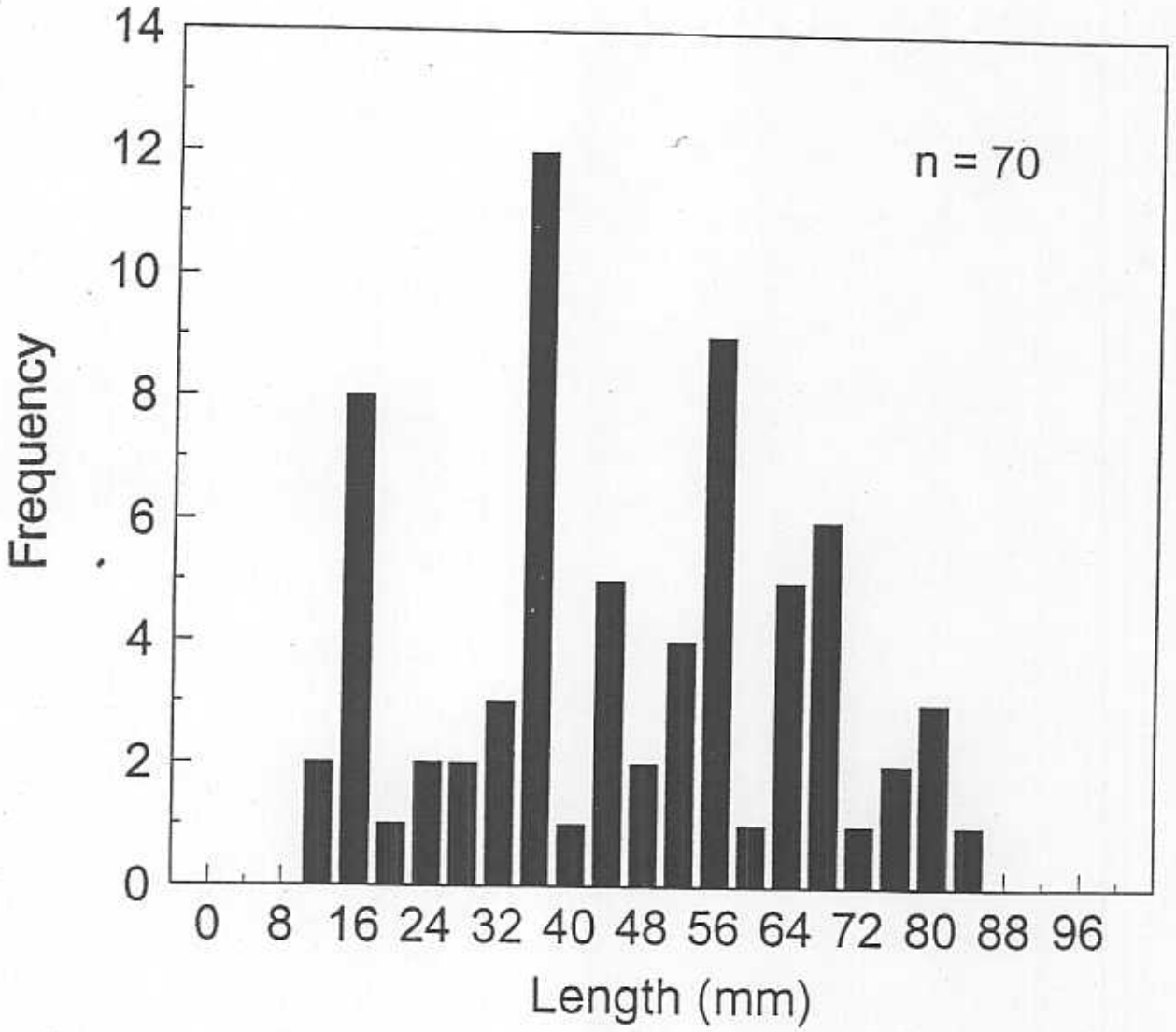

Figure 6. Length-frequency histogram for *Fusconaia flava* near Richmond Island, pool 7, 1995.

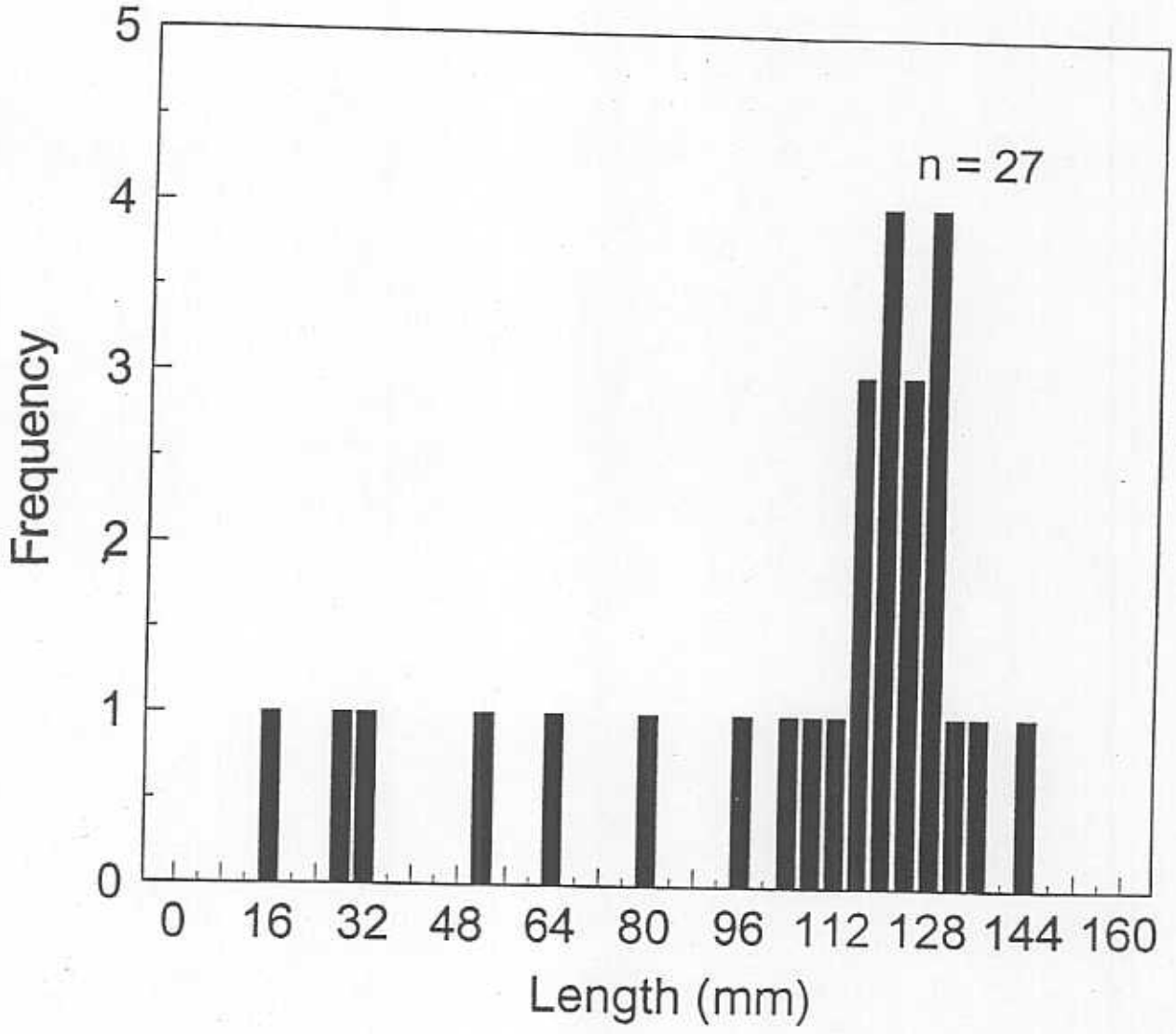

Figure 7. Length-frequency histogram for *Lampsilis cardium* near Richmond Island, pool 7, 1995.

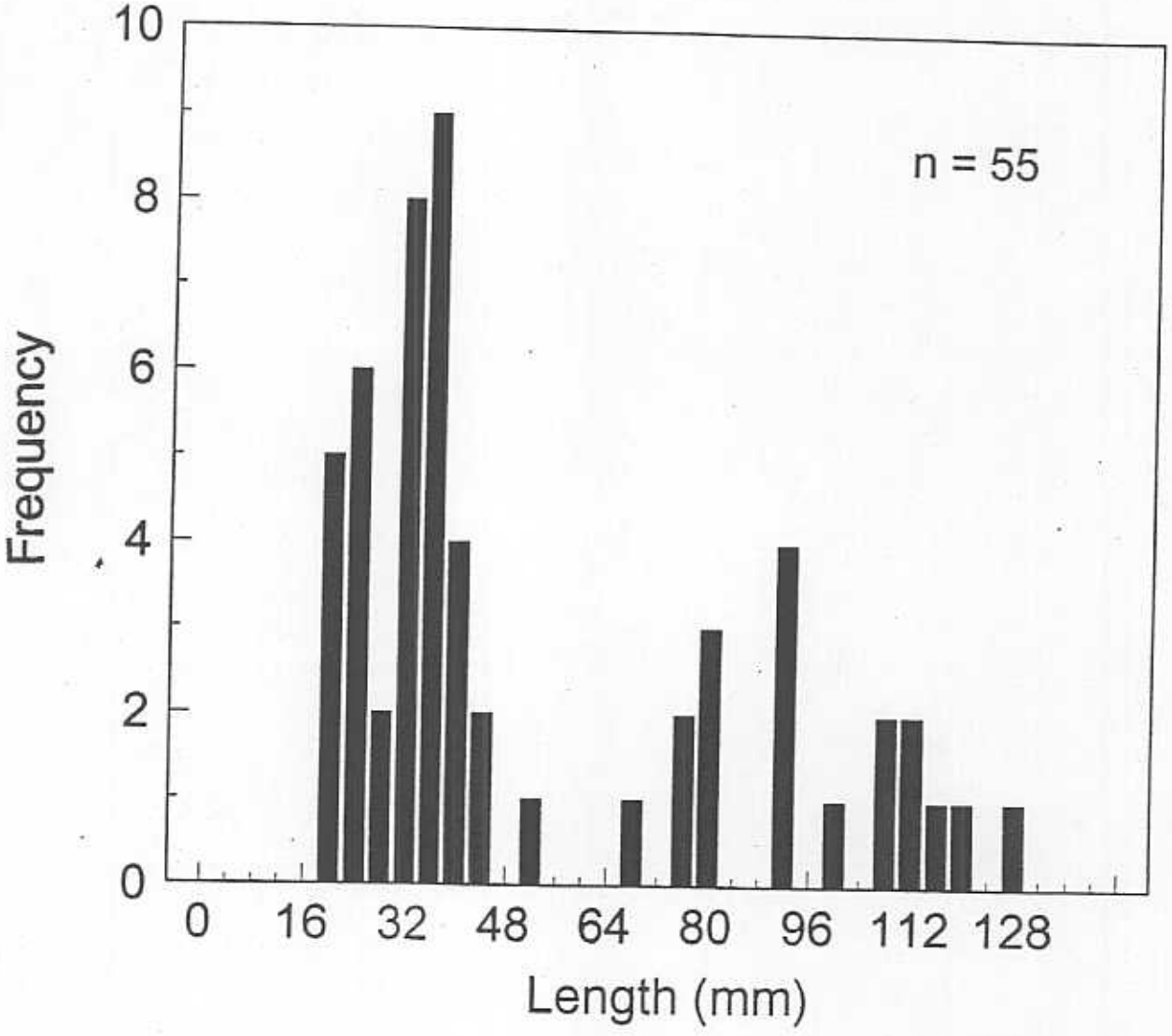

Figure 8. Length-frequency histogram for *Leptodea fragilis* near Richmond Island, pool 7, 1995.

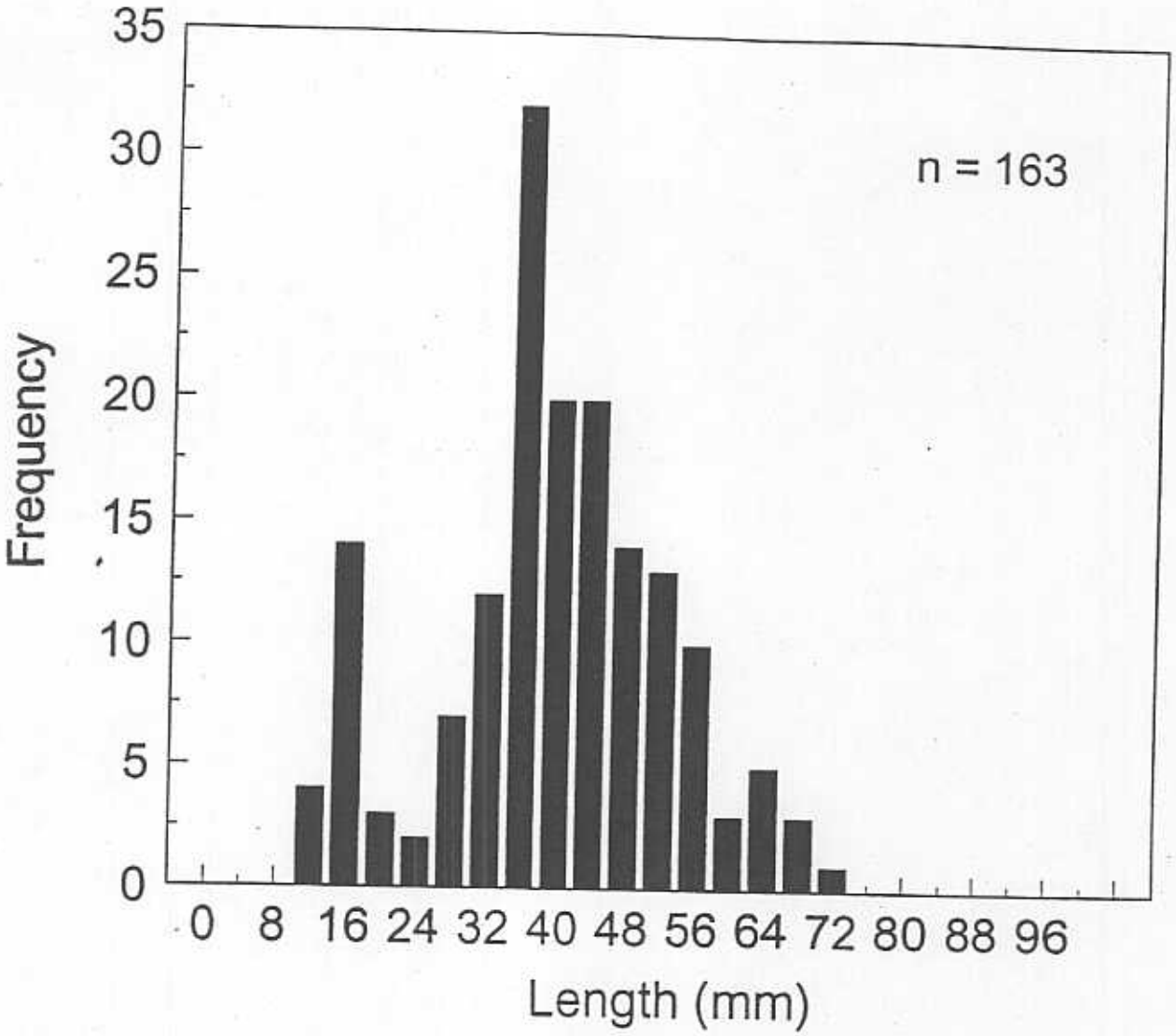

Figure 9. Length-frequency histogram for *Obliquaria reflexa* near Richmond Island, pool 7, 1995.

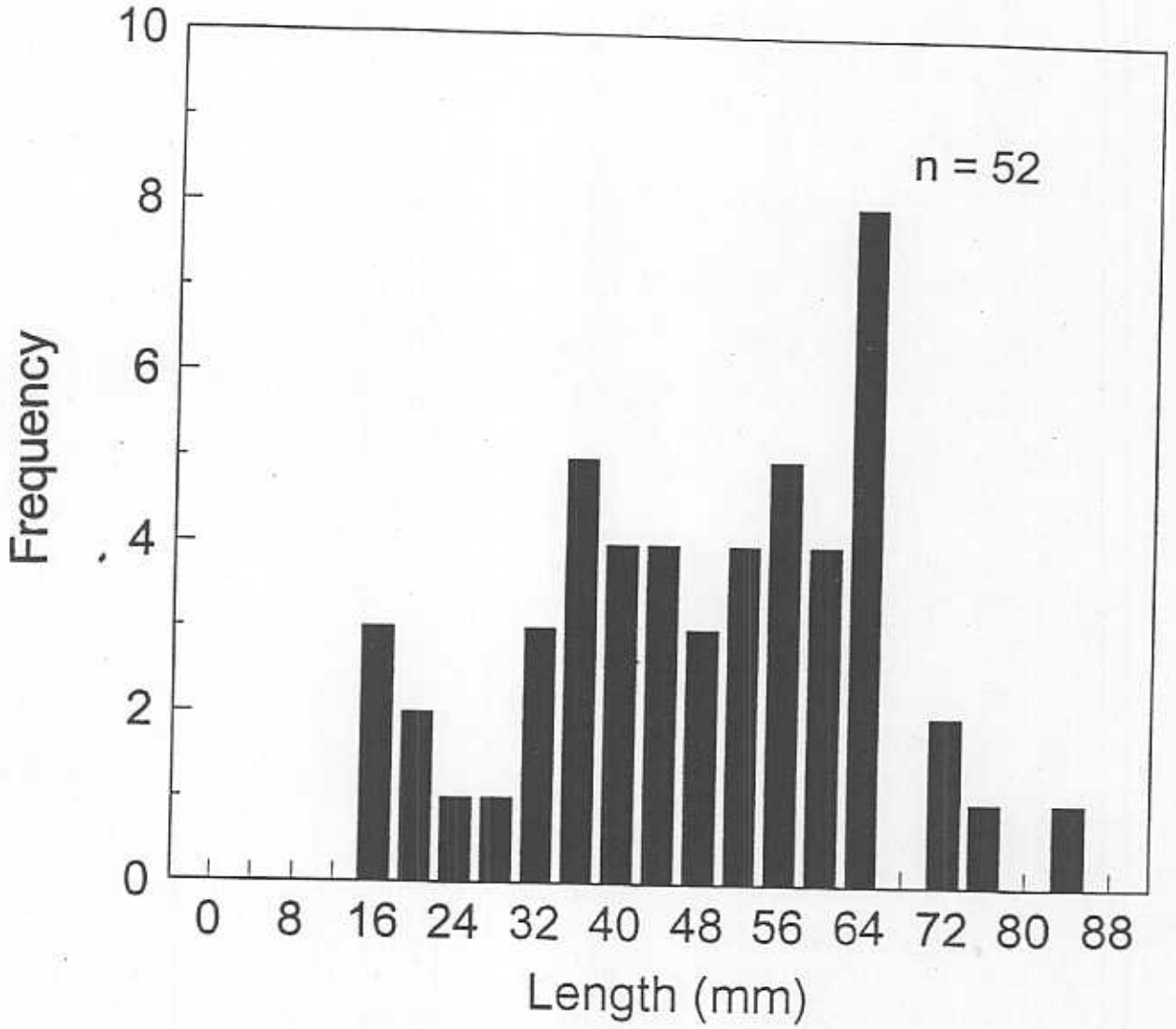

Figure 10. Length-frequency histogram for *Quadrula pustulosa* near Richmond Island, pool 7, 1995.

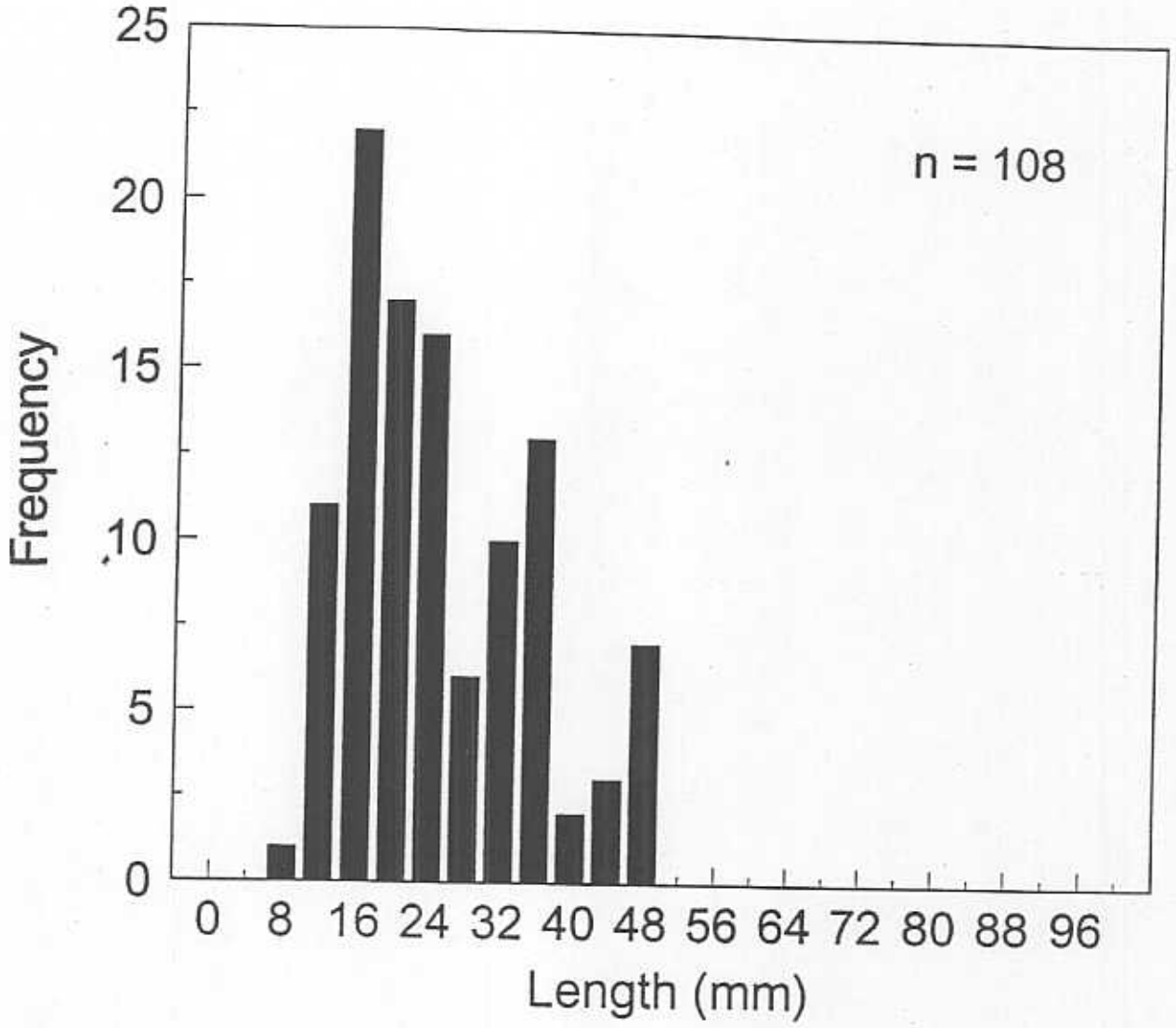

Figure 11. Length-frequency histogram for *Truncilla truncata* near Richmond Island, pool 7, 1995.

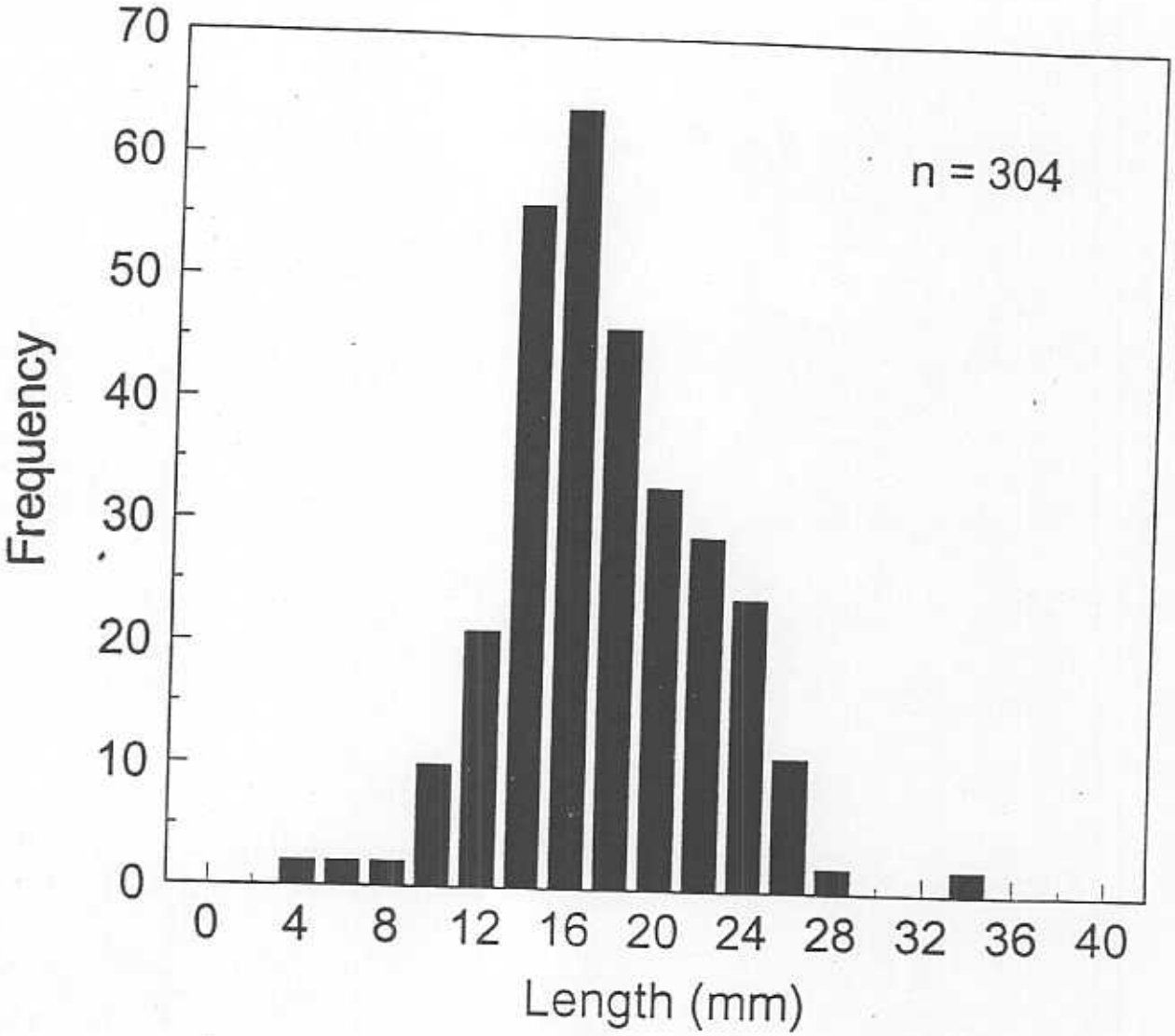

Figure 12. Length-frequency histogram for *Dreissena polymorpha* near Richmond Island, pool 7, 1995.