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A SURVEY OF THE MUSSELS OF THE POMME DE TERRE AND CHIPPEWA RIVERS, MINNESOTA, 1990

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Pomme de Terre and Chippewa Rivers, Minnesota, 1990

by

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(ABSTRACT)

Nearly 60 species of freshwater mussels are endangered with another dozen species in decline that are harvested for their shell material and exported to Asia for the cultured pearl business. The causes for these declines vary from habitat destruction to industrial pollution. More recently, the invasion of the Zebra mussel (Dreissena polymorpha) has the potential to extirpate most of our native mussel fauna. These factors prompted the Minnesota Department of Natural Resources (MNDNR) to fund systematic mussel surveys in several rivers in Minnesota. The goals of the surveys were to gain information on the current status of Minnesota's mussel fauna and to better understand the natural history of these animals.

Mussels were examined and voucher specimens collected at 56 sites on the Pomme de Terre and Chippewa River systems. Twenty-four sites were surveyed in the Pomme de Terre River system and 32 in the Chippewa River system. Quantitative (density, shell dimensions, age) and qualitative (diversity, substrate type, and reproductive status) data were gathered using two methods. A grid method where 30 to 40 1/8 m^2 quadrats were sampled to a depth of 12 cm. This was followed by a random one hour timed search method that involved three people searching out prime mussel habitat and collecting all live or dead animals.

The number of live specimens collected in the Pomme de Terre River system was 1688 and 4090 in the Chippewa River system. Live mussel densities ranged from 0 to 4 mussels / m2 and averaged 0.8 mussels / m2 in the Pomme de Terre River system. Live mussel densities in the Chippewa River system ranged from 0 to 11.3 mussels / m2 and averaged 3.3 mussels / m2. Timed searches in the Pomme de Terre River produced densities ranging between 0 to 113 mussels / person / hour, the mean number of mussels found at each site was 19 mussels / person / hour. In the Chippewa River, timed search densities ranged from 0 to 167 mussels / person / hour, the mean number of mussels found at each site was 41. 3 mussels / person / hour.

Live mussel diversity at each site ranged between 1 and 11 in the Pomme de Terre River, the average being 4.0, with 14 live species observed in the drainage. Live mussel diversity in the Chippewa River ranged between 0 and 12 species, the average was 6.4, with 16 live species observed in the drainage. Including records of dead species, the number of species found in the Pomme de Terre River was 17 and in the Chippewa River was 21.

The mussel density in the Pomme de Terre River was low. We suspect habitat degradation and overharvest most responsible for the decline. In general, recruitment was poor for many species in both rivers. We suspect fluctuating flows have most severely affected recruitment. We recommend no harvest of shell material from either river until the populations show evidence of recruitment and have restored themselves, especially in the Pomme de Terre River.

Acknowledgements

This survey was funded by the Natural Heritage and Nongame Research Program of the Minnesota Department of Natural Resources. We would especially like to thank Lee Pfannmuller, MNDNR for giving us our start. John Schladweiler, MNDNR also provided financial support for two extra team members and personally assisted on several occasions. This report would not have been completed without the intellectual, moral, and lunchroom support of James C. Underhill. Dan Graf, our esteemed but younger colleague, proved to be an endless resource on systematics of freshwater molluscs. His sense of humor and devotion to the cause was both encouraging and refreshing. Professors McKinney and Jay Hatch also provided moral support throughout the writing of this report. We are very grateful to Susan Radke, Mark Hove, and James Underhill for critically reviewing this paper. We also wish to express our sincere gratitude to Arlene Fosdick of the Bell Museum. Last but not least, thanks to Rich Baker, MNDNR for having faith!

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Introduction

Nearly 60 species of freshwater mussels are endangered with another dozen species in decline that are harvested for their shell material and exported to Asia for the cultured pearl business. The causes for these declines vary from habitat destruction to industrial pollution. More recently, the invasion of the Zebra mussel (Dreissena polymorpha) has the potential to extirpate most of our native mussel fauna. These factors prompted the Minnesota Department of Natural Resources (MNDNR) to fund systematic mussel surveys in several rivers in Minnesota. The goals of the surveys were to gain information on the current status of Minnesota's mussel fauna and to better understand the natural history of these animals.

Freshwater mussels are worldwide in their distribution. Seven families occur in the superfamily Unionacea, with two native to North America, namely the Margaritiferidae and Unionidae (including Amblemidae and Lampsilidae of various authors) (Banarescu 1990). This study focused on the mussels of the family Unionidae (unionid) which is by far the largest family of freshwater mussels. Conversations with commercial clammers indicated mussels were once abundant in the Pomme de Terre and the Chippewa Rivers. Clammers claimed mussels were taken by the "truck-load" although it was difficult to determine precisely how many years' harvesting took place and exactly where mussels were collected. Specific objectives of this study were to determine the diversity, distribution, and abundance of mussels in the Pomme de Terre and Chippewa Rivers and to evaluate reproductive success at as many places as possible.

The Study Area

Pomme de Terre River

The Pomme de Terre River's origins are in lakes and ponds in the west-central Minnesota's lake region. It begins as a distinct stream from Stalker and Long lakes in southern Otter Tail County (Waters 1977). The river drains about 977 mi^2 of an elongated basin with the main stream meandering for about 100 miles. The valley is narrow and shallow in its upper reaches but becomes wider and deeper toward the mouth. The watershed is a hilly, poorly drained upland glacial till plain. River alluvium and outwash deposits of sand and gravel form terraces throughout most of the region. Precambrian crystalline rocks underlie the glacial till over most of the watershed except the southern part between Artichoke Lake and Appleton, where Cretaceous shales and sands overlie the Precambrian bedrock (MN Dept Cons. 1959). The primary use of the land is for agriculture. Trees and shrubs are common along the banks in many stretches but in others the vegetation has been stripped for the convenience of farming. Native vegetation on the floodplain likewise has been removed and the floodplain has been drained where it is possible to produce crops. The river is about 300 feet below the uplands at its mouth, and its average gradient is 3.4 feet per mile. The steepest gradient is near Appleton where in a stretch of 6 miles the fall is about 50 feet. Annual mean runoff is about 100 cfs with a maximum of more than 5000 cfs reported in 1952 (Waters 1977).

Chippewa River

The Chippewa River was historically one of the last wooded streams encountered by fur trappers, Native Americans, and early pioneers as they proceeded up the Minnesota River. Apparently, the Pomme de Terre was not significantly wooded (Moyer and Dale 1916). The woodlands along the Chippewa River were largely restricted to the south half of the watershed. Trees were common on the east side of the river and scattered on those bluffs which provided suitable protection from prairie fires. Since settlement times and the breaking of the prairie, woodlands have advanced along the rivers (Moyer and Dale 1916).

The Chippewa River's watershed lies just east of the Pomme de Terre. It drains approximately 2080 mi2, twice that of the Pomme de Terre (Waters 1977). It originates in lakes and ponds of southern Ottertail County and flows roughly 130 miles to its mouth in the Minnesota River (Waters 1977). The primary landuse is agricultural. In the upper part of the watershed, glacial drift covers Precambrian granitic rocks. In the lower basin, southward of Swift County, Cretaceous shale and sandstone lies between the glacial drift and the underlying granite (MN Dept. Cons. 1959). Erosion has removed most of the glacial drift in the southern area of the watershed along the Minnesota valley and granite outcrops are common. A poor drainage pattern also exists in the Chippewa watershed. The pebbly, clay glacial drift results in rapid runoff during periods of high precipitation and deficient streamflow during low rainfall. The Chippewa's average gradient is 4.5 feet per mile. The steepest gradient is near its headwaters in southern Ottertail County and near the confluence of the Little

Chippewa northeast of Hancock, MN. In the lower stretch of 57 miles, the river falls about 400 feet (MN Dept. Cons. 1959). Annual mean runoff is about 200 cfs with a maximum of more than 10,00 cfs reported in 1952 (Waters 1977). To alleviate some of the past flooding problems, a glacial river channel known as the Watson Sag was modified in 1958 by the Corps of Engineers. During periods of floods, high waters from the Chippewa are diverted through the Watson Sag to Lac Qui Parle Lake.

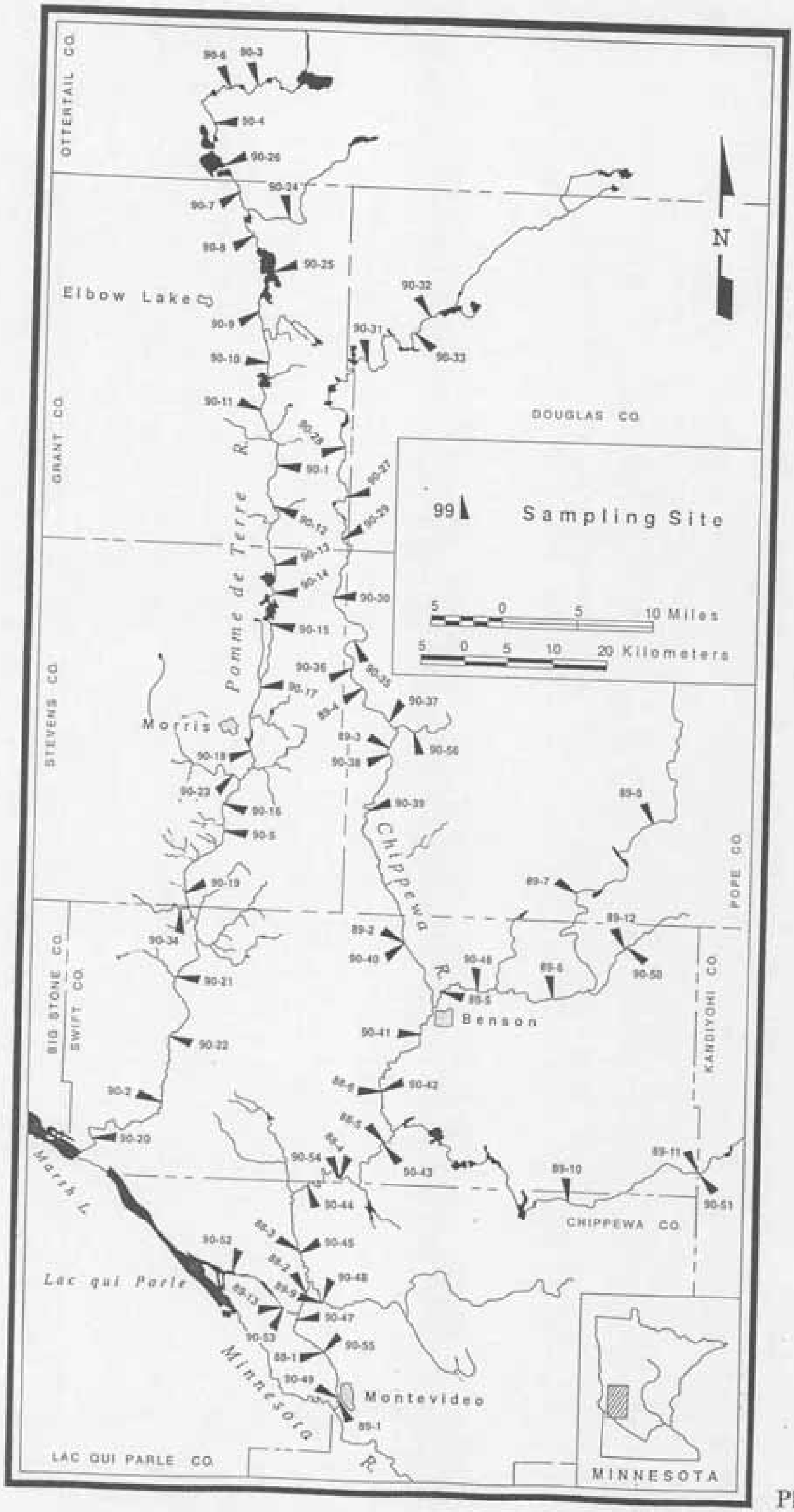
Previous Work

The only known surveys of freshwater mussels in the Pomme de Terre River and the Chippewa River are from John Schladweiler, MN DNR, who surveyed the Pomme de Terre River in 1985 and 1988, and Wayne Ostlie, Nature Conservancy, who surveyed the Chippewa River in 1988 and 1989. The best historical information on the condition and occurrence of mussels in both of these rivers came from local residents and landowners.

Materials and Methods

Mussels were examined and voucher specimens collected at 56 sites on the Pomme de Terre and Chippewa Rivers (Plate 1). We surveyed 24 sites in the main stem of the Pomme de Terre River, including the Pomme de Terre Lake, and 3 sites in tributaries to the Pomme de Terre River, Muddy, Pelican, and Drywood Creeks. We surveyed 22 sites in the main stem of the Chippewa River, 5 sites in tributaries to the Chippewa River, Dry Weather Creek, East Branch, Mud Creek, Shakopee Creek, and Little Chippewa River, and 2 sites on the Watson Sag diversion channel. The vouchers were deposited at the Bell Museum of Natural History, University of Minnesota. The distance between sites averaged 3.5 miles on the Pomme de Terre River and 4.3 miles on the Chippewa River.

Each site was examined by a combination of SCUBA, snorkeling, or wading. Two quantitative sampling techniques were used at each site. The first method consisted of establishing a starting point near the edge of the river and then establishing several rows of quadrats that resulted in a rectangular grid system having the starting point as a corner. Rows of quadrats were spaced 4 – 10 m apart. At each quadrat, a 25 X 25 cm steel frame was placed on the bottom and the substrate inside the frame was sampled for mussels to a depth of about 12 cm (wrist depth). This procedure was repeated once at each site resulting in a minimum quadrat sample of 1/8 m^2. The number of quadrats examined was determined at each site by the width of the river. In the upper reaches of the rivers, the number of quadrats ranged from 30 – 40. In the lower reaches, 60 quadrats were sampled except for site 90-17, 18, and 19 on the Pomme de Terre where 120, 80, and 80 quadrats were sampled, respectively.



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 1

Extra quadrats were sampled at these sites to determine if more quadrats added to the number of species found and to determine a reasonable number of quadrats given time constraints. After quadrats were examined, a timed search was conducted. This procedure involved three people independently searching as many habitats as possible for one hour. Searching prime mussel habitat was emphasized in the timed search. In addition, live mussels were collected, wherever possible, before collecting a dead shell. The reasoning was that we were most interested in the live mussel density at a site. Collecting a specimen and placing it in a collection bag takes time. Thus, to better use the one hour search time, a live animal was always picked up before picking up a nearby dead shell. Dead shells were collected when no live animals were observed.

Habitat information collected included the riverine type (pool, glide, run, or riffle), substrate particle size, depth, and water temperature. Substrate particle sizes are given in the standard Wentworth system (Wentworth 1922). Sizes finer than very coarse sand were determined by means of a grain-size pocket guide produced by geology students at Kent State University. Substrate preferences of each mussel collected in the grid sampling were noted. Due to the large numbers collected in the timed search, it proved nearly impossible to recall substrate preferences of all individuals. Water temperature was taken with a high-quality thermometer and was recorded to the nearest °F. The thermometer was normally immersed to a depth of about 10 cm at a shaded stretch of stream.

All live mussels were aged, sexed when possible and reproductive status noted, and measured to the nearest tenth of a millimeter using a caliper. Length was measured parallel to the hinge. Height was taken as the maximum distance perpendicular to the length. Width was measured perpendicular to the commisure. Age was determined by counting the external annuli. Because mussels sexually mature between 4 to 6 years of age, mussels less than 5 years are referred to as juveniles, except when information regarding the life history of a species indicates otherwise. For example, Amblema plicata can become sexually mature anywhere between 2 to 10 years (Stein 1973). Gravidity was determined by opening the shells with a pair of sharpened carpet pliers and then sampling marsupia for glochidia with a tiny glass pipette. All specimens were identified on site with the aid of a "mobile" reference collection provided by the Bell Museum. Each specimen observed was categorized as being in one of the following three conditions based on a set of specific criteria:

Live.

Recently Dead. The shell is not chalky. The nacre has some luster, the hinge ligament is still clinging to the shell, and the periostracum shows not much deterioration or peeling. Such shells probably represent individuals that have been dead less than 2 to 3 years.

Dead. The shell is chalky. The nacre has no luster, no body parts are clinging to the shell, and the periostracum is deteriorated and peeling or sometimes missing. These individuals have been dead probably more than 2 to 3 years and often cannot be distinguished from fossils several thousand years old.

Species diversity and density of live and dead mussels were tabulated at each site. Age and length data were plotted with age as the independent variable (Y) and length as the dependent variable (X). Growth curves were plotted assuming an exponentially growing function, Histograms were produced for those species where at least 20 live individuals per species / site were found. Histograms of length classes, were produced for each species by site to better determine recruitment and missing length classes.

Collecting sites were designated as either 88 - 1, 89 - 1, or 90 - 1, for collecting site 1 in 1988, 1989, or 1990, respectively (Plate 1). The most recent live, then dead, record of a species was always noted on the distribution maps. For example, Ostlie's records of each species from sites sampled in 1988 and 1989 are indicated where no record or sampling was done in 1990. Demographics of Ostlie's population data are discussed and comparisons are made with this study. Ostlie's data were collected using snorkel and wading techniques.

Nomenclature used is that of Turgeon et al. (1988) with several exceptions. The binomial Lampsilis cardium Rafinesque, 1820 has been synonymized with Lampsilis ovata Say, 1817 and Lampsilis ventricosa Barnes 1823 (Rafinesque 1820, Ortmann 1919, Ortmann and Walker 1922, Baker 1928) while others have argued that two species and possibly three species comprise the L. ovata complex (Cvancara 1963, Putnam 1971). The resurrection of the binomial L. cardium appears without justification in the recent literature (Turgeon et al. 1988, Cummings and Mayer 1992, Williams et al. 1993). Therefore, until a ruling has been made by the Bulletin on Zoological Nomenclature on the L. cardium, L. ovata, and L. ventricosa complex, we have maintained the binomial L. ventricosa for the type found in Minnesota (Ortmann and Walker 1922). Interestingly, we have never seen the distinct minnow-like mantle flap in gravid L. ventricosa females in Minnesota.

At the time of this study, the species Lampsilis siliquoidea was referred to as L. radiata luteola. Although we recognize L. siliquoidea as the preferred synonym and have used it in the text, the Plate and Figures were made using the prior subspecies name of L. r. luteola. In addition, Turgeon et al. (1988) have lumped the subspecies, Lampsilis teres teres and Lampsilis teres anodontoides into one species, Lampsilis teres. The type found at the time of this study was referred to as Lampsilis teres teres. Thus, this was the synonym used in the Plate and Figures. However, we have used the preferred synonym L. teres in the text. In addition, the mussel formerly referred to as Actinonaias ligamentina carinata has been elevated from subspecies to species, Actinonaias ligamentina. While we recognize the preferred species synonym and have used it in the text, the Plates and Figures were not revised. Turgeon et al. (1988) brought several other species of mussels down to the subspecies level. We have remained conservative by maintaining just the species names; they are Amblema plicata. Lasmigona complanata, and Quadrula pustulosa.

In the case of the Anodontine types found in Minnesota, the changes to the genus Anodonta suggested by Hoeh (1990) were not convincing and so we have conserved the old nomenclature until further review by the Bulletin on Zoological

Nomenclature. Recent changes in the spelling of the specific for Anodontoides ferussacianus and Elliptio dilatata were made in the text but their respective distribution maps have not been corrected.

The status of each species in the Pomme de Terre and Chippewa Rivers have been described in the Species Accounts section of this paper. The terminology used was borrowed from Fuller (1978, 1980) and Williams et al (1993). They are:

Endangered. Any federally listed species that is in danger of extirpation throughout all or much of its range.

Jeopardized. Any species in danger of extirpation for any reason in the Pomme de Terre or Chippewa Rivers

Troubled. Any species whose range or abundance has been reduced, but still exhibits some evidence of reproduction in all or part of its range in either river.

Stable. A species whose distribution and abundance may be stable, or it may have declined in portions of its range but is not in need of immediate conservation management actions.

Rare. A species whose range was limited in the river.

Common. A species that was fairly widespread in the river, although not necessarily found in abundance.

RESULTS

Mussel Density

Pomme de Terre River

Live mussels were found at all sites throughout the Pomme de Terre River (Figure 1). The total number of live specimens collected was 1688 including specimens collected in the tributaries, and 1602 excluding the tributaries (Table 1). The number of live specimens collected was approximately two-thirds the number of dead (2358 with tributaries and 2179 without tributaries) specimens collected, indicating mussels were historically more abundant (Table 2).

Live mussel densities ranged from 0 to 4 mussels / m2 and averaged 0.8 mussels / m2 (Table 1, Figure 1). Timed searches produced densities ranging from 0 to 113 mussels / person / hour, the mean number of mussels found at each site was 19 / mussels / person / hour (Table 1, Figure 1). The greatest number were found at site 10, upstream of Barrett Lake, just north of Barrett, MN (Figure 1). Mean mussel densities then decreased downstream of Barret, MN, but remained fairly similar throughout the rest of the river. Of significance was the decrease in density downstream of the towns of Morris, MN and Fairfield, MN, and the significant increase near Appleton . The second greatest number of mussels was found near the mouth of the river, at Appleton, MN (Figure 1).

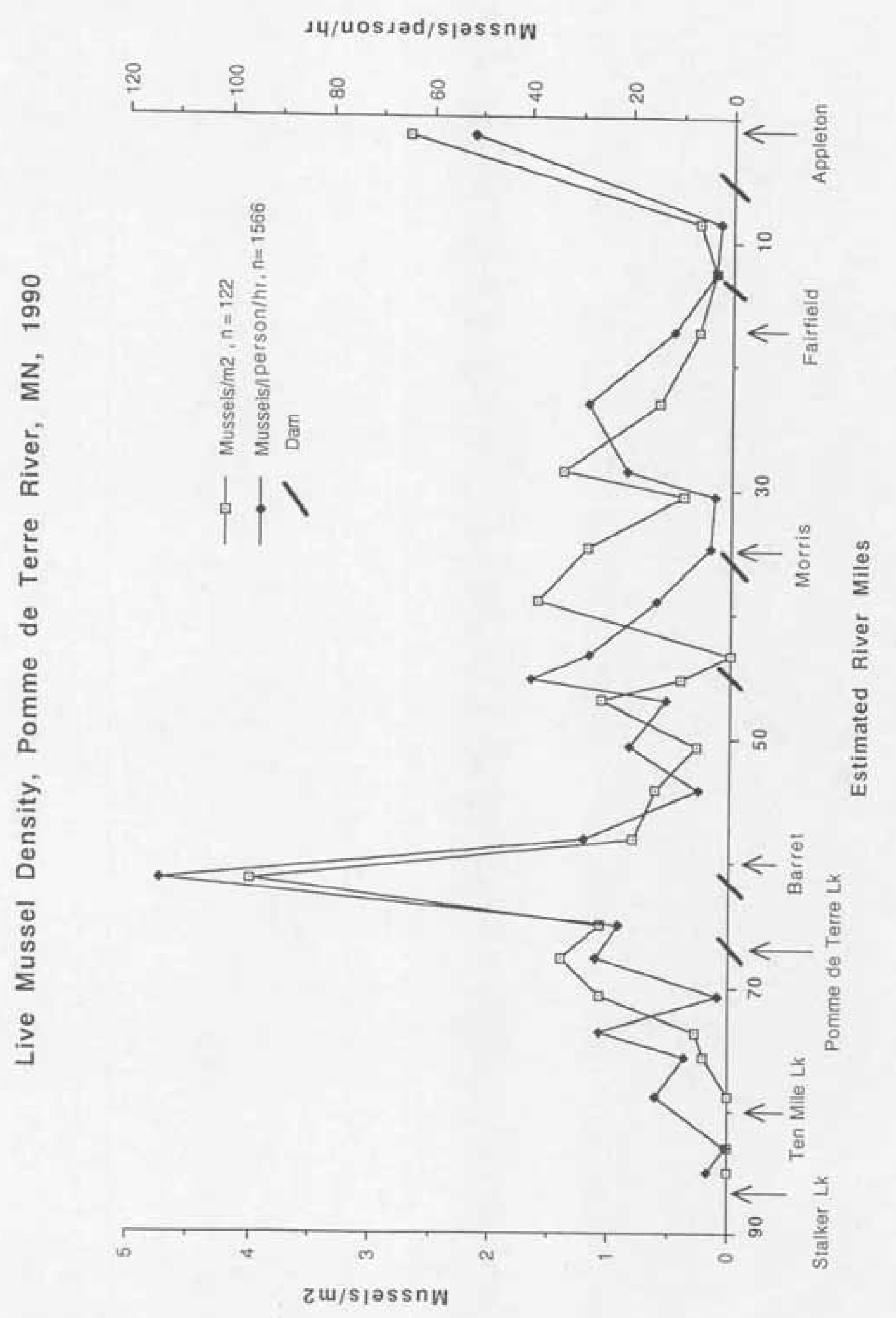

Live Mussel Density, Pomme de Terre River, MN, 1990
Mussels/m2 , n = 122
Mussels/person/hr, n= 1566
Dam
Mussels/person/hr
120
100
80
60
40
20
0
Mussels/m2
5
4
3
2
1
0
90
70
50
30
10
Estimated River Miles
Stalker Lk
Ten Mile Lk
Pomme de Terre Lk
Barret
Morris
Fairfield
Appleton

Figure 1

Table 1. Total, mean, and range (min - max) of live freshwater mussel densities, and live and dead species diversity in several rivers in Minnesota.

River	Total Live	Mussels per m^2	Mussels per person per hour	Species Live (Dead)	Species per Site
Cannon[1]	1344	0.6 (0 - 3.2)	not available	15	3.5 (1 - 11)
Zumbro[2]	1184	0.5 (0 - 8.0)	17.8 (0 - 11.4)	17	3.2 (1 - 9)
Minnesota[3]	1264	0.7 (0 - 8.4)	6.7 (0 - 94.3)	20 (27)	3.5 (0 - 9)
Pomme de Terre	1602	0.9 (0 - 4.0)	18.2 (0 - 113.3)	14 (17)	4.0 (1 - 11)
tributaries	86	0.1 (0 - 0.3)	9.4 (0 - 22.0)	3 (6)	2.3 (1 - 3)
	1688	0.8 (0 - 4.0)	19.3 (0 - 113.3)	14 (17)	3.8 (1 - 11)
Chippewa	2965	3.3 (0 - 11.3)	36.7 (0 - 167.0)	16 (21)	6.4 (0 - 12)
tributaries[4]	1010	3.0 (2 - 9.0)	79.0 (14.3 - 157.7)	8 (8)	6.5 (0 - 12)
Watson[5]	115	0.0	19.2 (14.3 - 24.0)	13 (14)	8.0 (6 - 10)
	4090	3.3 (0 - 11.3)	41.3 (0 - 167.0)	16 (21)	6.0 (0 - 12)

1 Davis (1988) data on pool habitats, excluding a typically high locality CAN4C.

2 Bright et al. 1989.

3 Bright et al. 1990.

4 Data from the Little Chippewa are not included since no live mussels were found.

5 Data includes the Watson Sag and the Watson Diversion Channel.

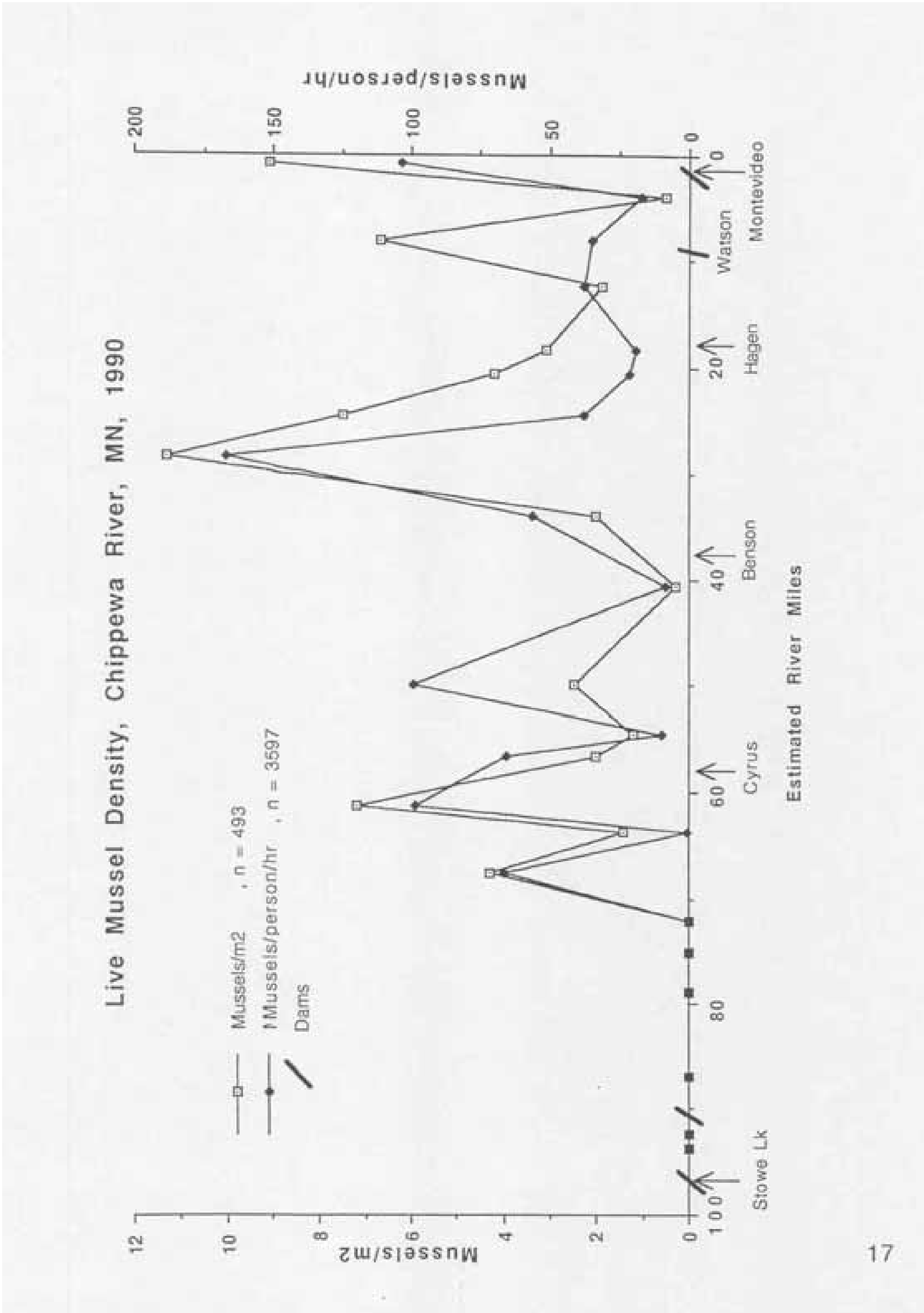
Table 2. Number of live and dead specimens collected of each species in the Pomme de Terre and Chippewa River systems in 1990 plus a record of live (L) and dead (D) species observed by Ostlie in 1988-1989. (data) = tributary or Watson Sag data only.

SPECIES	POMME DE TERRE RIVER		CHIPPEWA RIVER		
	Live	Dead	Live	Dead	Ostlie
Actinonaias ligamentina	0	20	0	43	D
Alasmidonta marginata	1	7	0	3	
Amblema plicata	95	103	896 (57)	115 (2)	L
Anodonta grandis grandis	442 (30)	579 (35)	276 (103)	400 (108)	L
Anodontoides ferussacianus	10 (4)	146 (73)	13 (10)	101 (51)	L
Elliptio dilatata	0	0	19 (1)	139	L
Fusconaia flava	144	205 (2)	237 (29)	185 (15)	L
Lampsilis siliquoidea	719 (52)	872 (59)	1708 (843)	1059 (302)	L
Lampsilis teres	0	0	0	1	
Lampsilis ventricosa	50	53	197 (8)	63 (1)	L
Lasmigona complanata	129	212 (8)	200 (10)	176 (3)	L
Lasmigona compressa	1	10	5 (2)	11 (4)	
Lasmigona costata	0	2	0	2	
Leptodea fragilis	6	4	174 (36)	118 (3)	L
Ligumia recta	11	10	56 (12)	13	L
Pleurobema sintoxia	0	1	0	0	
Potamilus alatus	2	0	24 (1)	8	L
Quadrula pustulosa	0	0	0	1	
Quadrula quadrula	0	0	10 (1)	0	
Strophitus undulatus	57	125 (2)	65 (3)	81 (5)	L
Toxolasma parvus	0	0	10 (9)	2 (1)	
Truncilla truncata	21	9	200	185 (5)	L
Total	1688 (86)	2358 (179)	4090 (1125)	2706 (500)	

Chippewa River

No live mussels were found in the upper 30 river miles of the Chippewa River where only dead specimens of 2 to 4 species were found (Figure 2). The number of live and dead specimens collected was 4090 and 2706, respectively (Tables 1 and 2). The number of dead shells (2205) collected in the main stem was similar to the number of live mussels collected (2965), indicating the abundance of live mussels in the main stem has been fairly stable (Table 2). However, the number of live mussels (1125) found in the tributaries was much greater than the number of dead (500) (Table 2). Recall that during a timed search live mussels are collected, wherever possible, before collecting a dead shell. Therefore, the abundance of live mussels collected over dead shells indicated that denser mussel beds were found in the tributaries than were seen in the main stem.

Live mussel densities in the Chippewa River system ranged from 0 to 11.3 mussels / m2 and averaged 3.3 mussels / m2 (Table 1, Figure 2). Timed searches revealed densities ranging from 0 to 167 mussels / person / hour, the mean number of mussels found at each site was 41.3 / mussels / person / hour (Table 1, Figure 2). The greatest number of live mussels (501) were collected during a timed search just downstream of Benson, MN, at site 90-42, approximate river mile 28.5 (Figure 2). Besides the upper six collecting sites, the lowest number of live mussels (26) collected (during a timed search) was upstream of Benson, MN, at site 90-40, approximate river mile 40.0 (Figure 2). In general, the mean number of mussels collected / m^2 were similar in the main stem and in the tributaries (grid sampling was not done in the Watson Sag and the Diversion channel). However, the mean number of mussels



Live Mussel Density, Chippewa River, MN, 1990
Musseis/m2 , n = 493
Mussels/person/hr , n = 3597
Dams
Mussels/m2
Mussels/person/hr
Estimated River Miles
Montevideo
Watson
Hagen
Benson
Cyrus
Stowe Lk
0
20
40
60
80
100
0
2
4
6
8
10
12
0
50
100
150
200
17

Figure 2

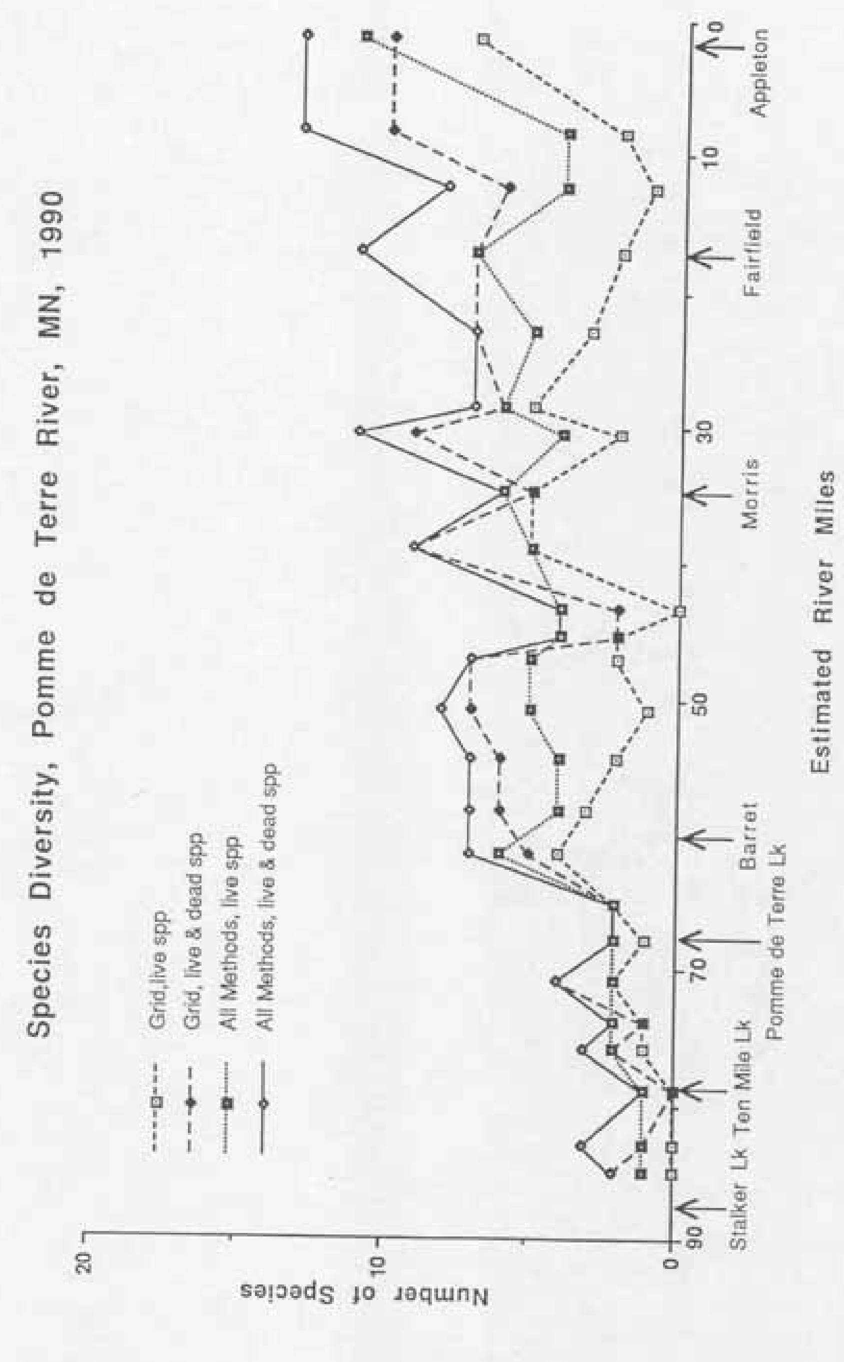
collected / person / hour in the tributaries (79) was twice that collected in the main stem (36.7), another indication that denser mussels beds were found in the tributaries (Table 1).

Mussel Diversity

Pomme de Terre River

Live mussel diversity (as number of species) at each of the 24 sites ranged from 1 - 11, the average being 4.0, and the maximum in the river as a whole was 14. The average number of species found in the 3 tributaries was 2.3. (Table 1). The maximum number of species (live plus dead) found at a given site was 13, and in the river was 17 (Table 2, Figure 3).

The species composition of mussels were grouped into three stream reaches; fewer species occurred in the head waters than in the mid-sections, and the greatest number of species were found in the lower sections (Figures 3 and 4). However, at sites 90-14, 15, and 16, estimated river miles 42-46 and 30.5 near Morris MN, several species dropped out of the local fauna but were reappeared further downstream (Figures 3 and 4). If the river is considered as a whole, L. siliquoidea was the most common and abundant, followed by Anodonta grandis grandis (Figures 4 and 5). Lasmigona complanata and Fusconaia flava were common in the lower half of the river, and third and fourth in abundance. Amblema plicata was present in the lower 35 river miles and fifth in abundance (Figures 4 and 5). Six additional species were found at the mouth, namely, Alasmidonta marginata, Anodontoides ferussacianus, Lampsilis ventricosa, Leptodea fragilis, Ligumia recta, Potamilus alatus (Figure 4). However, each of these species was rare with the exception of Lampsilis ventricosa which was



Species Diversity, Pomme de Terre River, MN, 1990
Grid, live spp
Grid, live & dead spp
All Methods, live spp
All Methods, live & dead spp
Number of Species
20
10
0
90
70
50
30
10
0
Stalker Lk
Ten Mile Lk
Pomme de Terre Lk
Barret
Morris
Fairfield
Appleton
Estimated River Miles

Figure 3

Key to Species Abbreviations used in figures.

A. I. c.----------Actinonaias ligamentina carinata (Actinonaias ligamentina)

A. mar ---------Alasmidonta marginata

A. pli-----------Amblema plicata

A. g. g.---------Anodonta grandis grandis

A. fer-----------Anodontoides ferussacianus

E. dil-----------Elliptio dilatata

F. fla------------Fusconaia flava

L. r. l.-----------Lampsilis radiata luteola (Lampsilis siliquoidea)

L. ter -----------Lampsilis teres teres (Lampsilis teres)

L. ven ---------Lampsilis ventricosa

L. cpl-----------Lasmigona complanata

L. cpr-----------Lasmigona compressa

L. cos----------Lasmigona costata

L. fra----------Leptodea fragilis

L. rec-----------Ligumia recta

P. sin -----------Pleurobema sintoxia

P. ala-----------Potamilus alatus

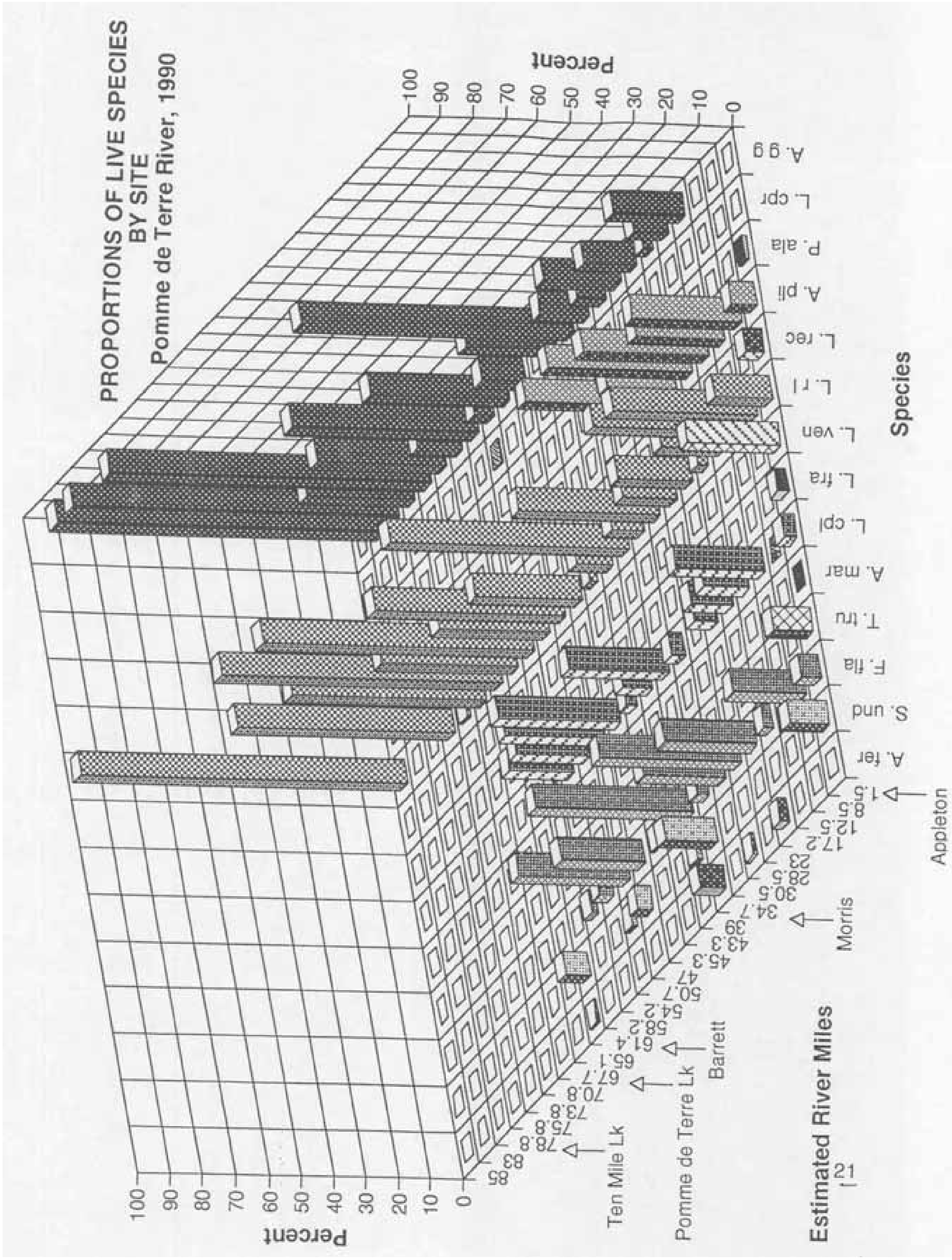
Q. pus--------- Quadrula pustulosa

Q. qua--------- Quadrula quadrula

S. und---------Strophitus undulatus

T. par -----------Toxolasma parvus

T. tru------------Truncilla truncata



PROPORTIONS OF LIVE SPECIES
BY SITE
Pomme de Terre River, 1990
Percent
0
10
20
30
40
50
60
70
80
90
100
Percent
Species
A. g g
L. cpr
P. ala
A. pli
L. rec
L. r l
L. ven
L. fra
L. cpl
A. mar
T. tru
F. fla
S. und
A. fer
Estimated River Miles
85
83
78.8
75.8
73.8
70.8
67.7
65.1
61.4
58.2
54.2
50.7
47
45.3
43.3
39
34.7
30.5
28.5
23
17.2
12.5
8.5
1.5
Ten Mile Lk
Pomme de Terre Lk
Barrett
Morris
Appleton

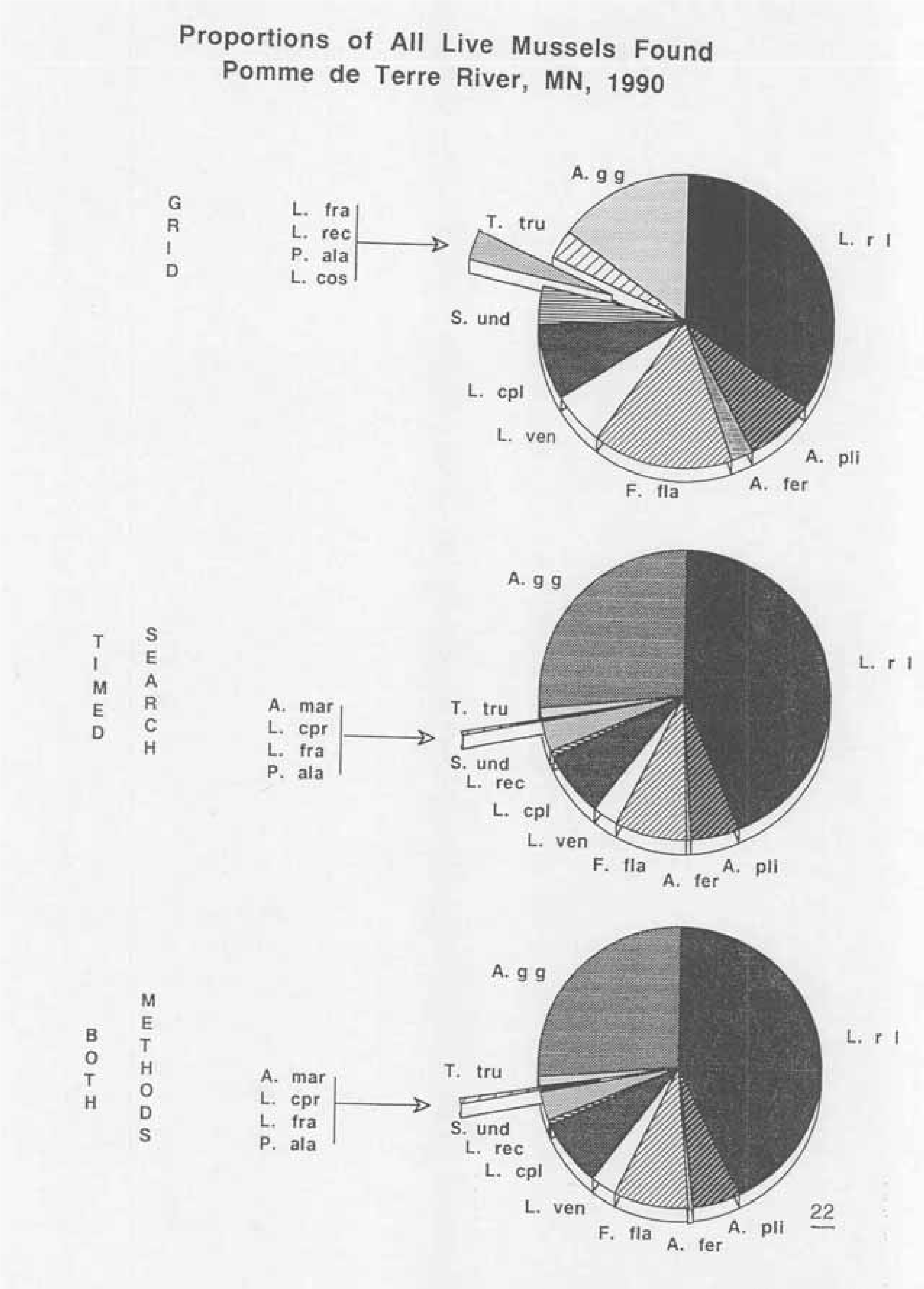

Proportions of All Live Mussels Found
Pomme de Terre River, MN, 1990
GRID
A. g g
L. r l
T. tru
L. fra
L. rec
P. ala
L. cos
S. und
L. cpl
L. ven
F. fla
A. fer
A. pli
TIMED SEARCH
A. g g
L. r l
T. tru
A. mar
L. cpr
L. fra
P. ala
S. und
L. rec
L. cpl
L. ven
F. fla
A. fer
A. pli
BOTH METHODS
A. g g
L. r l
T. tru
A. mar
L. cpr
L. fra
P. ala
S. und
L. rec
L. cpl
L. ven
F. fla
A. fer
A. pli
22

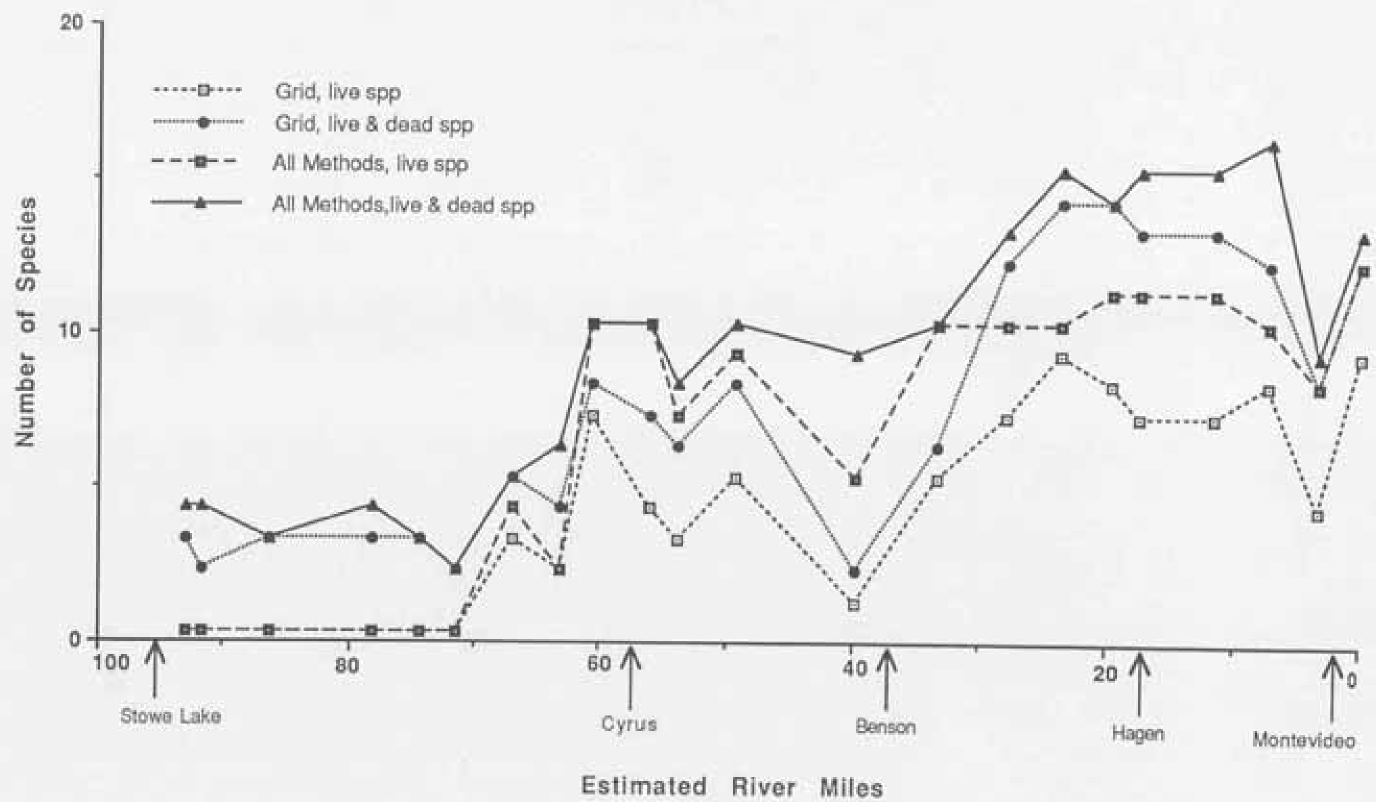
Figure 5

uncommon (14 individuals / person / hour) (Figure 5). Lasmigona compressa was also rare, found only at river mile 61.4 (Site 90-10) near Barrett, MN (Figure 4). Anodontoides ferussacianus and Strophitus undulatus occurred as far north as Barrett, MN down to the mouth (Figure 4). Both of these species were rare or uncommon. In all, approximately 8 of the 13 live species found were rare or uncommon (Figure 5). More detail on the status of each species is given in the Species Accounts section of this report.

Chippewa River

Live mussel diversity (as number of species) at each of the 22 sites ranged from 0 - 12, with an average of 6.4 species per site (Table 1, Figure 6). If the upstream sites where no live mussels were collected, are excluded, the average number of species found in the main stem of the Chippewa River was 8. The number of species found in the 5 tributaries ranged from 0 - 12; the average was 5.2. When the Little Chippewa River sample where zero live mussels were found, was excluded, the average number of species found in the 4 tributaries was 6.5 (Table 1). In the Watson Sag, the number of species ranged from 6 - 10; the average was 8.0 (Table 1). The maximum number of species (live plus dead specimens) found at a given site was 16 and in the river as a whole was 21 (Table 1, Figure 6). Ostlie found 13 live and 1 dead species in 1988 and 1989 (Table 2).

Species Diversity, Chippewa River, MN, 1990



24

Figure 6

The distribution and species composition of mussels were also grouped into three stream reaches; fewer species occurred in the head waters than in the middle and lower sections (Figures 6 and 7). Three additional species (Q. guadrula, E. dilatata, and P. alatus) were found in the lower section of the river near Hagen and Montevideo at river miles 18.3 (Site 90-44) and 0.8 (Site 9049) (Figure 7). If the river is considered as a whole it is apparent that L. siliquoidea was the most common and abundant species (Figure 8). It was the dominant species found in the middle section of the river whereas, Amblema plicata was dominant in the lower half, followed by A. g. grandis and Fusconaia flava which were fairly common (Figure 7). Approximately 8 of the 12 live species found were rare in the Chippewa River (Figure 8).

Mussel Distribution

The distribution of both live and dead specimens found during the 1990 season indicated that many mussels had formerly wider distributions within the Pomme de Terre and Chippewa Rivers. Some species are extirpated from both rivers; others have restricted distributions within each river (Plates 1-24). Further interpretation of each plate follows in the species accounts.

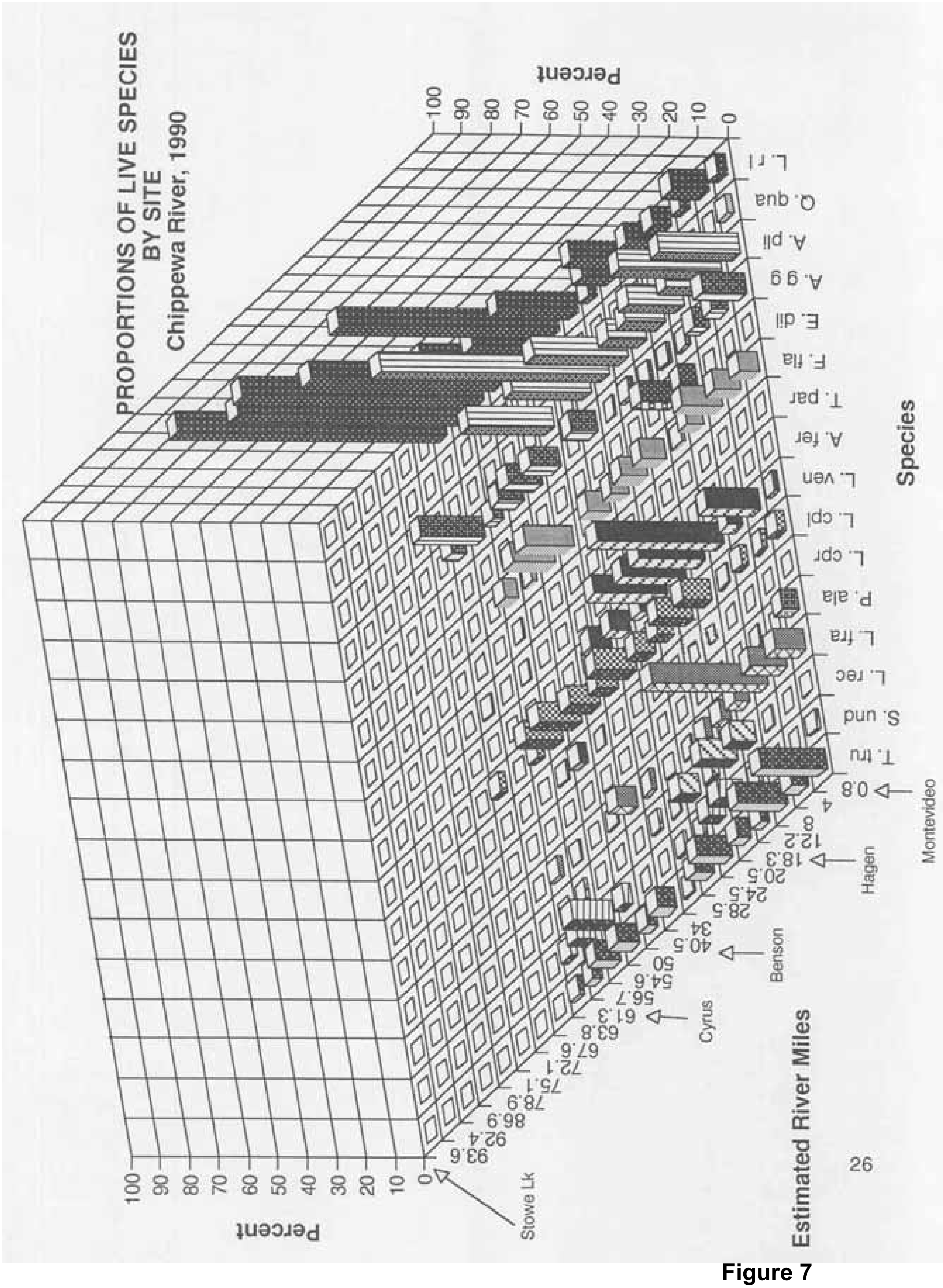
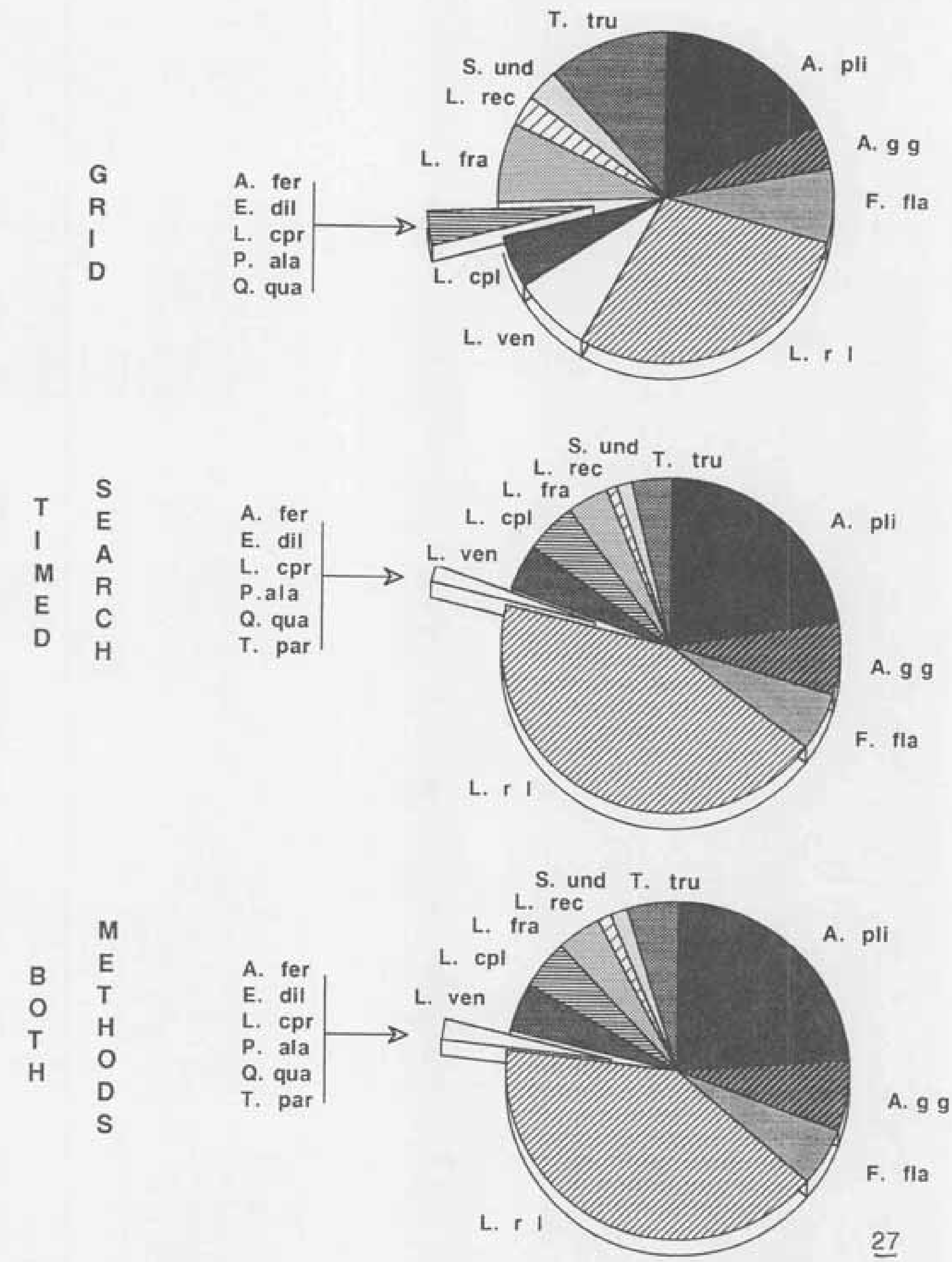

PROPORTIONS OF LIVE SPECIES
BY SITE
Chippewa River, 1990
Percent
0 10 20 30 40 50 60 70 80 90 100
Species
L. r l
Q. qua
A. pli
A. g g
E. dil
F. fla
T. par
A. fer
L. ven
L. cpl
L. cpr
P. ala
L. fra
L. rec
S. und
T. tru
Estimated River Miles
0 93.6 92.4 86.9 78.9 75.1 72.1 67.6 63.8 61.3 56.7 54.6 50 40.5 34 28.5 24.5 20.5 18.3 12.2 8 4 0.8
Stowe Lk
Cyrus
Benson
Hagen
Montevideo
26

Figure 7

Proportions of Live Mussels Found
Chippewa River, MN, 1990



27

Figure 8

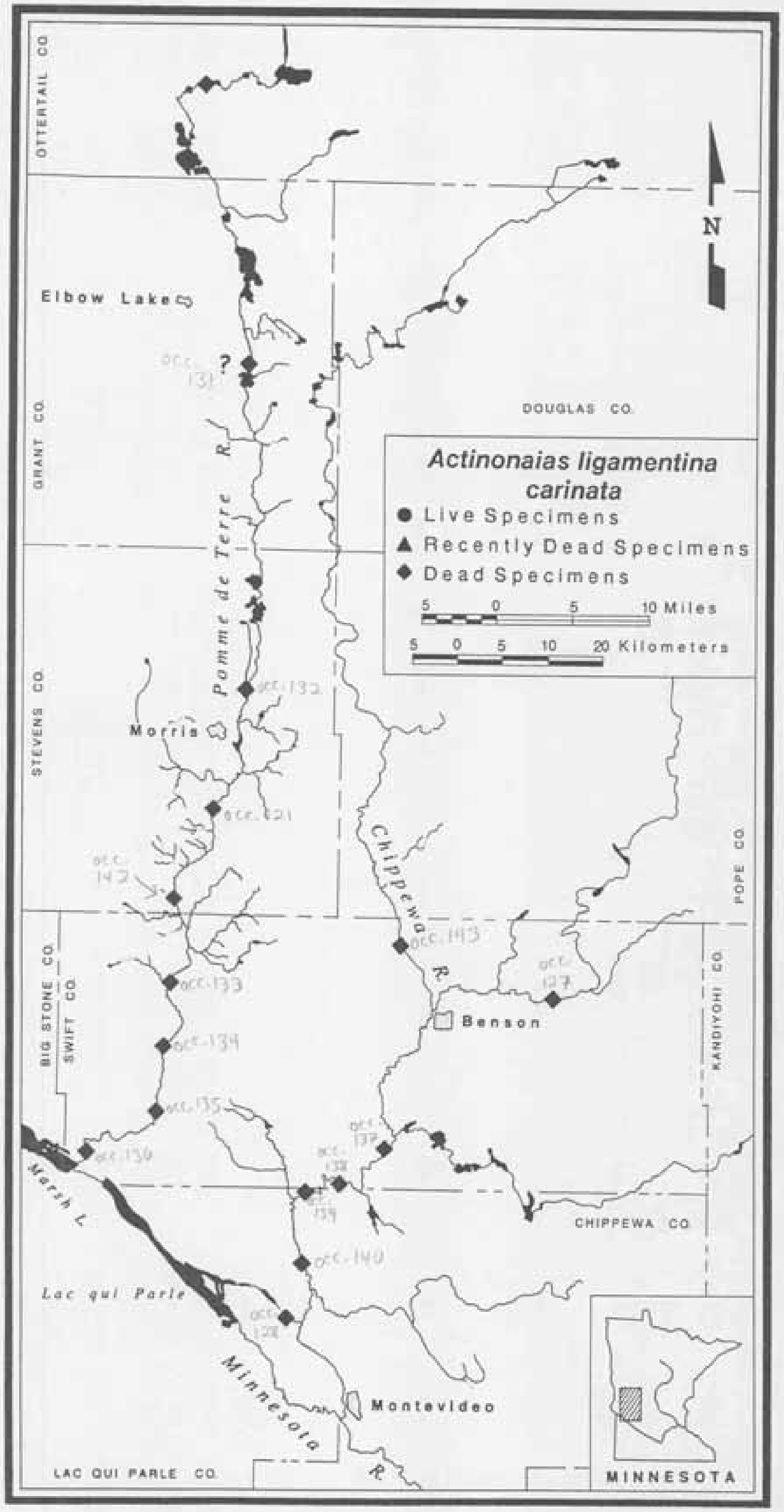
Species Accounts

Reproductive Status and Substrate Preferences

Actinonaias ligamentina (A. l. carinata) (mucket)

No live specimens of A. ligamentina were found in the Pomme de Terre and Chippewa Rivers during this study (Plate 2). Dead shells were common, indicating that it was formerly widespread throughout both rivers. One questionable dead specimen was found in the Pomme de Terre above Barrett Lake, Grant County. Otherwise, dead A. ligamentina was observed in the middle and lower portions of the Pomme de Terre River and only in the lower portion of the Chippewa River.

Nine of the Mucket's twelve fish hosts occur in the Pomme de Terre River and six fish hosts occur in the Chippewa River (Fuller, 1974, James Underhill, pers. comm.). Therefore, fish host availability was not limiting A. ligamentina's distribution. The condition of shells indicated that this species had not been alive in either river for at least 3 years and possibly longer. Lusterless nacre, deteriorated periostracum, and chalky shells make them indistinguishable from shells several thousand years old. Nachtrieb (1908) reported that of the commercial species, A. ligamentina was second to A. plicata in abundance in the Minnesota River. Dawley (1947) considered A. ligamentina " ..widely distributed in medium and large rivers [in Minnesota], but not present in large numbers." Regardless of whether it was abundant or just "widely distributed . . but not in . . . large numbers" something, such as overharvest, caused a



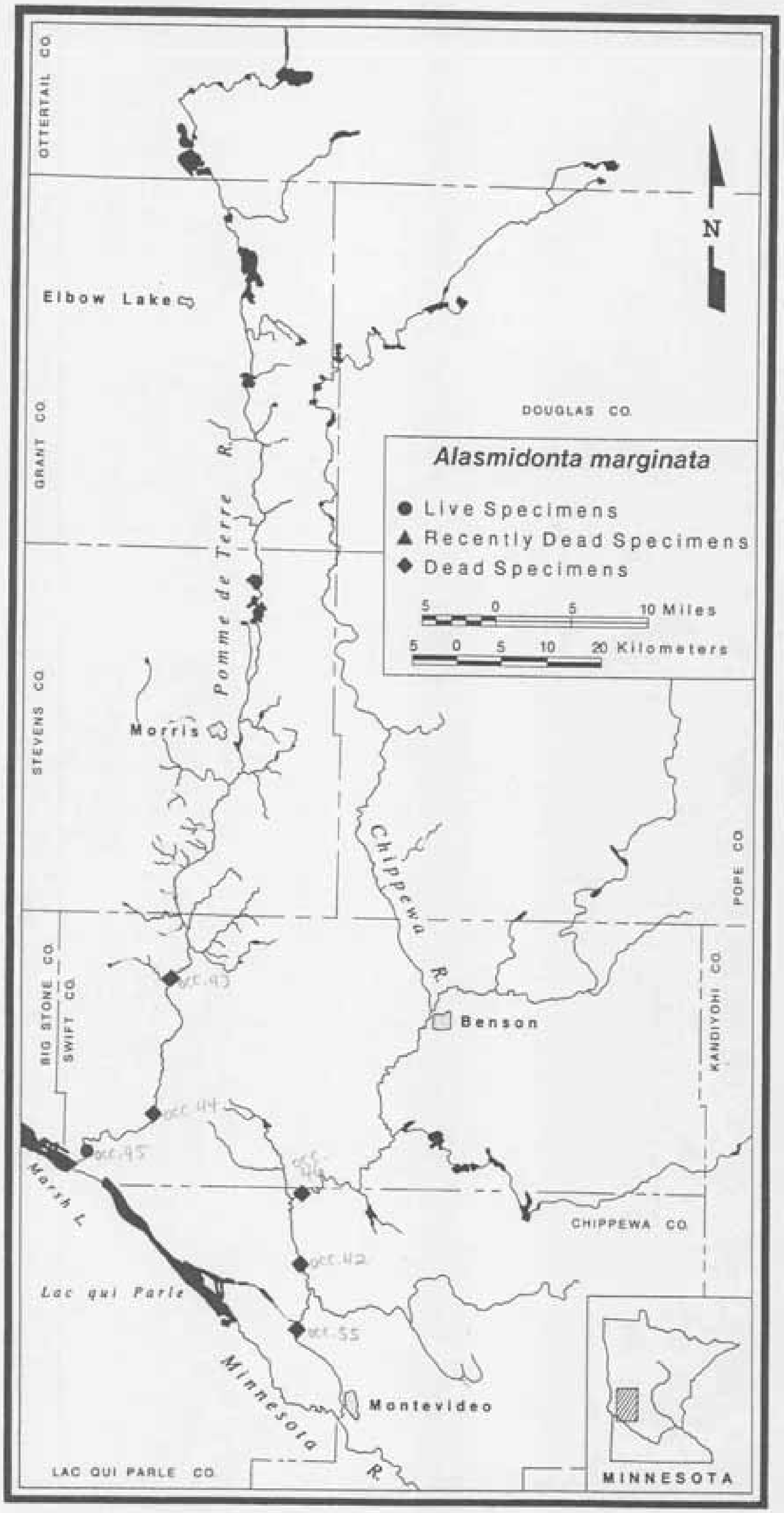
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 2

decline in abundance to a point that they were not able to recover. Recent surveys have reported that A. ligamentina are extirpated in the Minnesota River, and are in serious trouble in the Cannon and the Zumbro Rivers (Davis 1988, Bright et al. 1989, 1990). They are apparently extirpated in the Pomme de Terre and Chippewa Rivers.

Alasmidonta marginata (Elktoe)

Only one live individual and three dead shells were found in the Pomme de Terre River at site 90-20, below the dam at Appleton, MN and near the confluence with the Minnesota River (Plate 3, Bright et al. 1994). The live individual was found in sandy granules (Figure 9). No live specimens were found in the Chippewa River (Plate 3). Based on the presence of dead shells, A. marginata occurred only in the lower portions of both rivers. Four of its five known fish hosts occur in the Pomme de Terre River and at least three of its fish hosts occur in the Chippewa River (Fuller 1974, Bell Museum Collections). One such fish host, Ambloplites rupestris (rock bass), is considered ubiquitous throughout Minnesota's lakes and streams (James Underhill, pers. comm:). Therefore, it is unlikely that fish host distribution is limiting this species in both rivers. Dawley (1947) considered A. marginata as "not common, but found in both small and large rivers in Minnesota." However, A. marginata is so rare in the Pomme de Terre River at the present time that it is in risk of extirpation, and it is apparently extirpated in the Chippewa River.

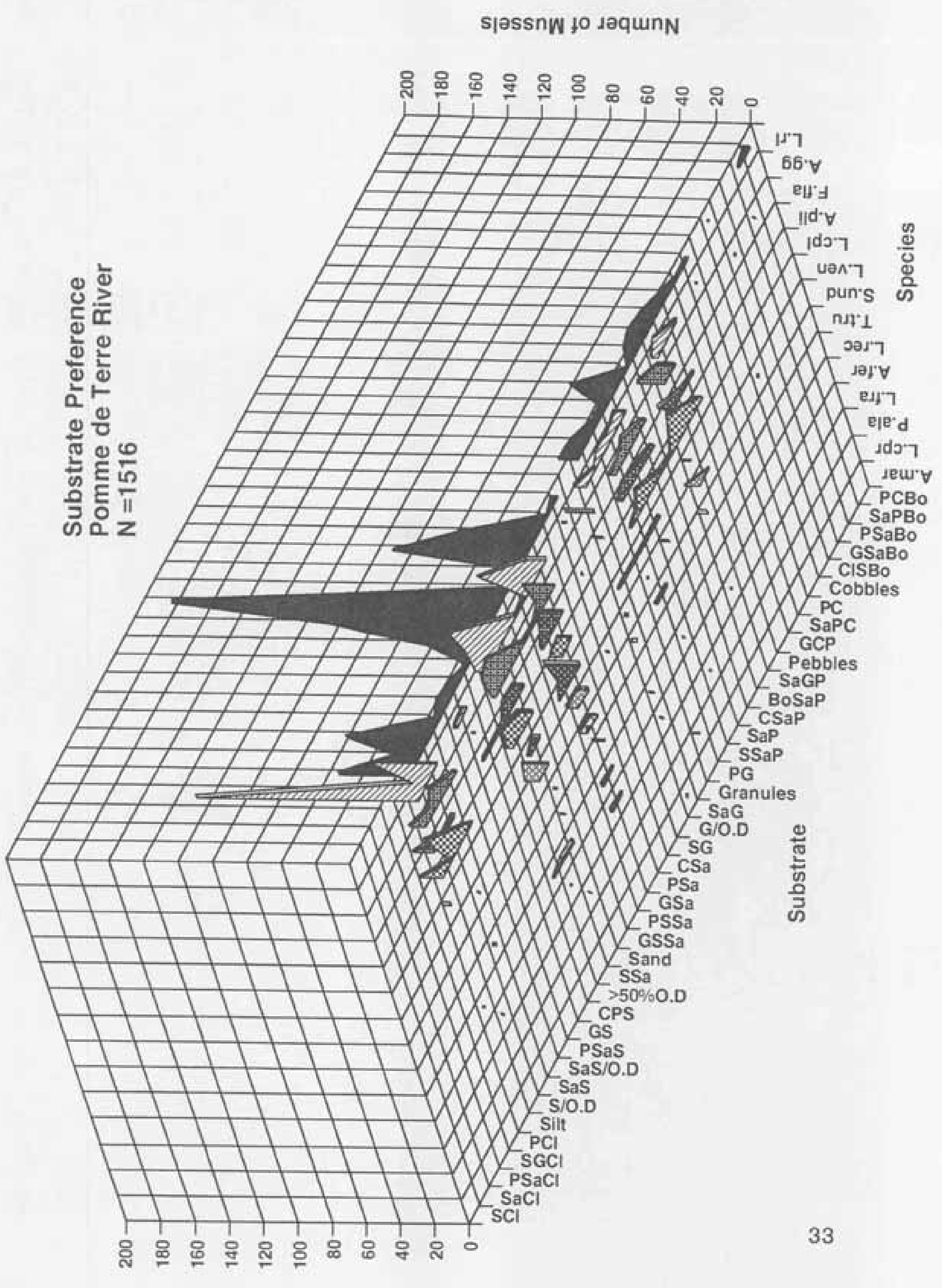


Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 3

Key to the substrate abbreviations used in figures 9 and 13, Pomme de Terre and Chippewa River, 1990.
listed in ascending order - fine material to coarse material

SCI=SILTY CLAY
SaCL=SANDY CLAY
PSaCI=PEBBLY SANDY CLAY
SGCI=SILTY GRANULAR CLAY
PCI=PEBBLY CLAY
SILT
S/O.D.=SILT w/ <50% ORGANIC DETRITUS
SaS=SANDY SILT
SaS/O.D.=SANDY SILT w/ <50% ORGANIC DETRITUS
PSaS=PEBBLY SANDY SILT
GS=GRANULAR SILT
CPS=COBBLY PEBBLY SILT
>50%O.D.=>50% ORGANIC DETRITUS
SSa=SILTY SAND
SAN D
GSSa=GRANULAR SILTY SAND
PSSa=PEBBLY SILTY SAND
GSa=GRANULAR SAND
PSa=PEBBLY SAND
CSa=COBBLY SAND
SG=SILTY GRANULES
G/O.D.=GRANULES w/ <50% ORGANIC DETRITUS
SaG=SANDY GRANULES
GRANULES
PG=PEBBLY GRANULES
SSaP=SILTY SANDY PEBBLES
SaP=SANDY PEBBLES
CSaP=COBBLY SANDY PEBBLES
BoSaP=BOULDER SANDY PEBBLES
SaGP=SANDY GRANULAR PEBBLES
PEBBLES
GCP=GRANULAR COBBLY PEBBLES
SaPC=SANDY PEBBLY COBBLES
PC=PEBBLY COBBLES
COBBLES
CISBo=CLAY SILTY BOULDERS
GSaBo=GRANULAR SANDY BOULDERS
PSaBo=PEBBLY SANDY BOULDERS
SaPBo=SANDY PEBBLY BOULDERS
PCBo=PEBBLY COBBLY BOULDERS


Substrate Preference
Pomme de Terre River
N =1516
Number of Mussels
0
20
40
60
80
100
120
140
160
180
200
Species
L.rl
A.gg
F.fla
A.pli
L.cpl
L.ven
S.und
T.tru
L.rec
A.fer
L.fra
P.ala
L.cpr
A.mar
Substrate
PCBo
SaPBo
PSaBo
GSaBo
ClSBo
Cobbles
PC
SaPC
GCP
Pebbles
SaGP
BoSaP
CSaP
SaP
SSaP
PG
Granules
SaG
G/O.D
SG
CSa
PSa
GSa
PSSa
GSSa
Sand
SSa
>50%O.D
CPS
GS
PSaS
SaS/O.D
SaS
S/O.D
Silt
PCl
SGCl
PSaCl
SaCl
SCl

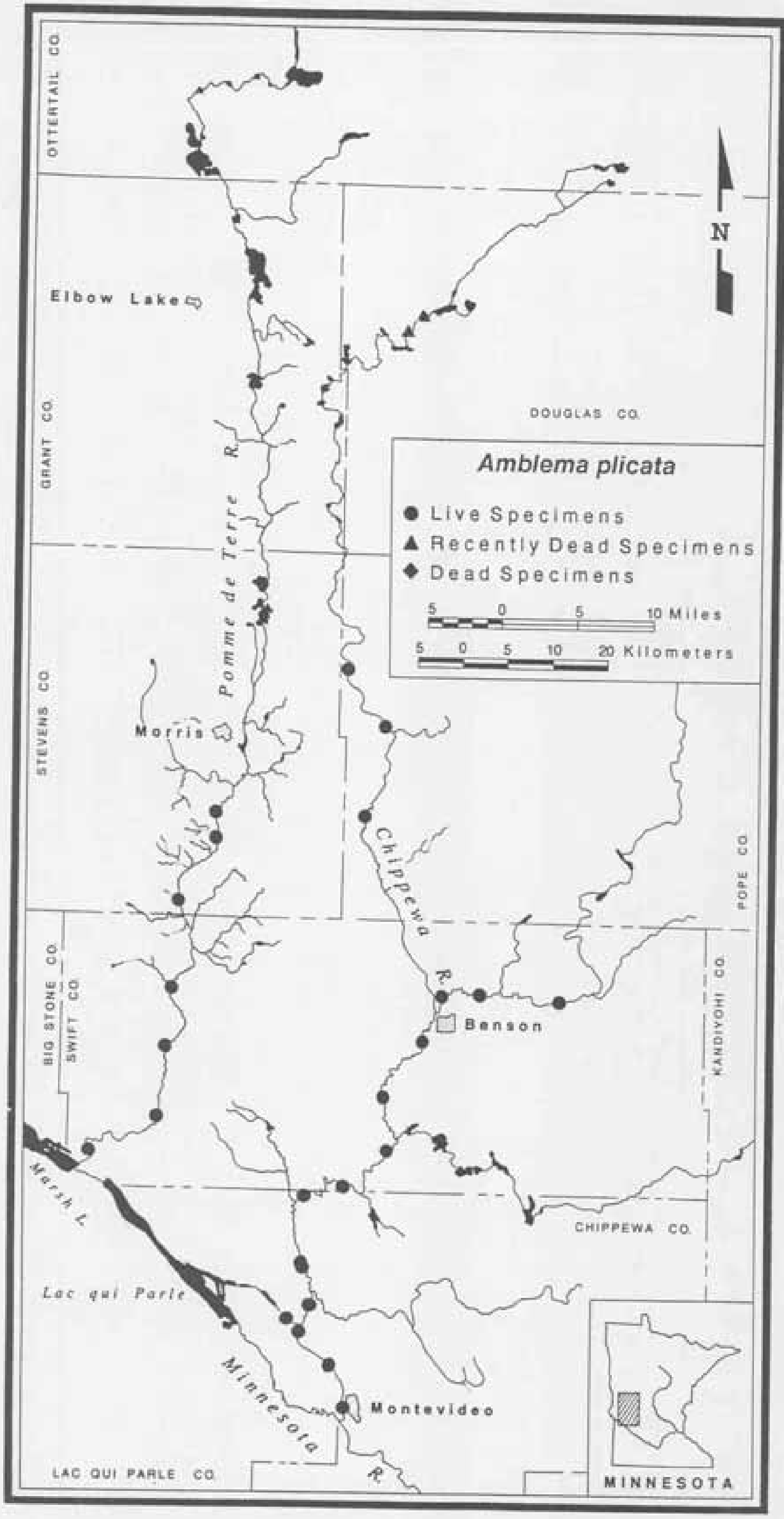
33

Figure 9

Amblema plicata (threeridge)

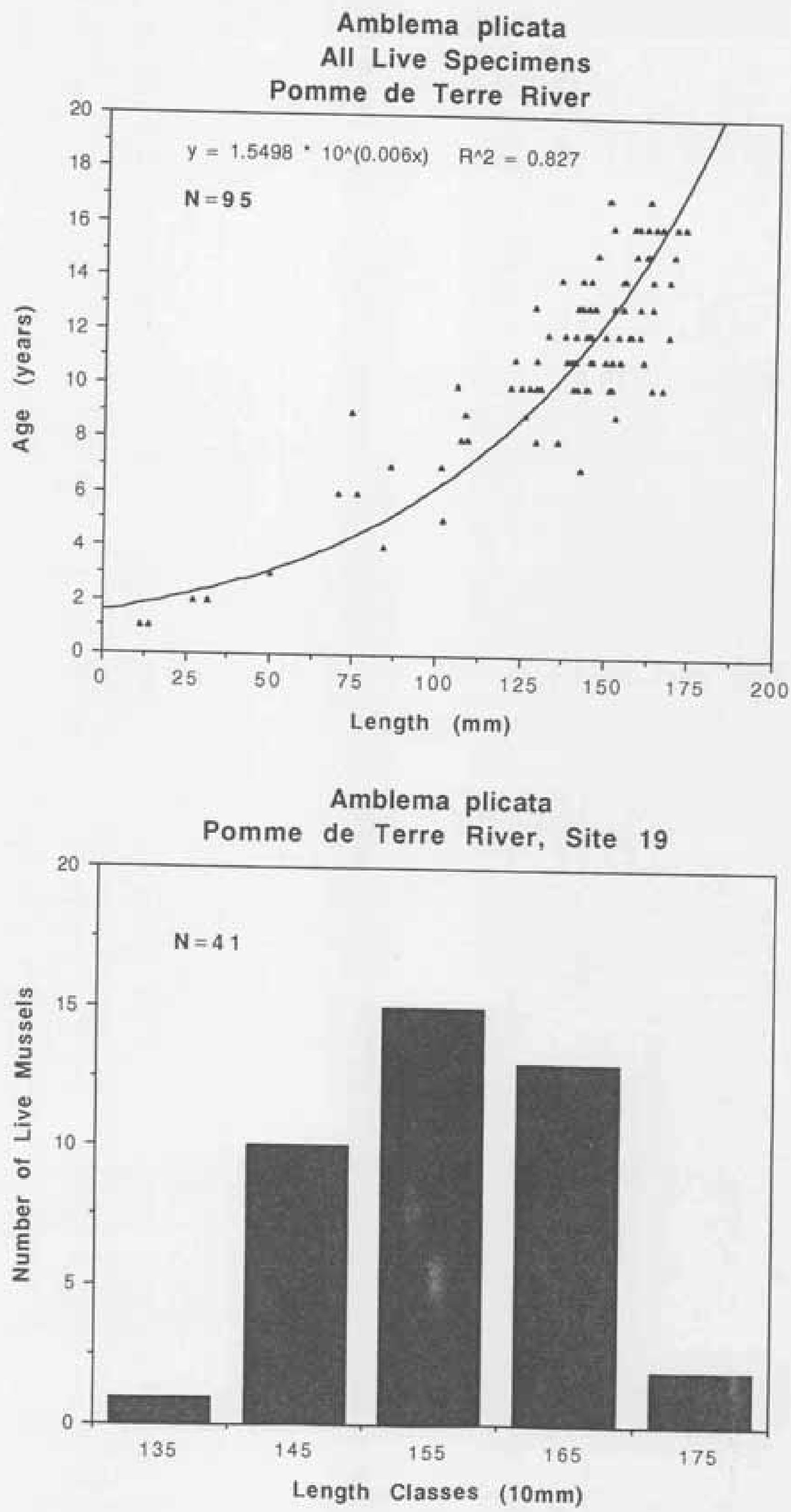
A. plicata was widely distributed in both small and large streams in Minnesota (Dawley 1947). It can still be found in abundance in some places (Bright et al 1990). However, in the Pomme de Terre River, it was rarely found in abundance. A total of 95 individuals were collected from seven sites downstream of Morris, MN (Plate 4, Figures 4 and 5). Since fish hosts for A. plicata are known to occur above Morris, MN, it is likely that A. plicata has never occurred in the upper portions of the Pomme de Terre River. A. plicata was found in a variety of sediment types from very fine (silt) to coarse (cobbles and pebbles) (Figure 9). Typically, we would not expect heavy shelled mussels inhabiting fine sediments. However, because of eroded stream banks and sedimentation problems seen in the Pomme de Terre River, that A. plicata was found in silt may be the result of available habitat rather than preference.

Stein (1973) reports that reproduction begins when A. plicata is 57 to 83 mm long, at an age from 2 to 10 years, and continues throughout the individual's life span. Stein (1973) also reports that the length at which a specimen becomes mature is more consistent than the age of maturity. Several juveniles, individuals < 83 mm in shell length, were found at sites 90-5, 90-20, 21, and 22, indicating some recruitment had taken place (Figure 10). However, juveniles less than 3 years-old, or recruits from 1988 and 1989, were frequently missing from several sampling sites (Figure 10). Fluctuating flows in the Pomme de Terre probably affected survival and hindered recruitment (Figures 11 and 12). The only site where more than 25 live individuals were collected



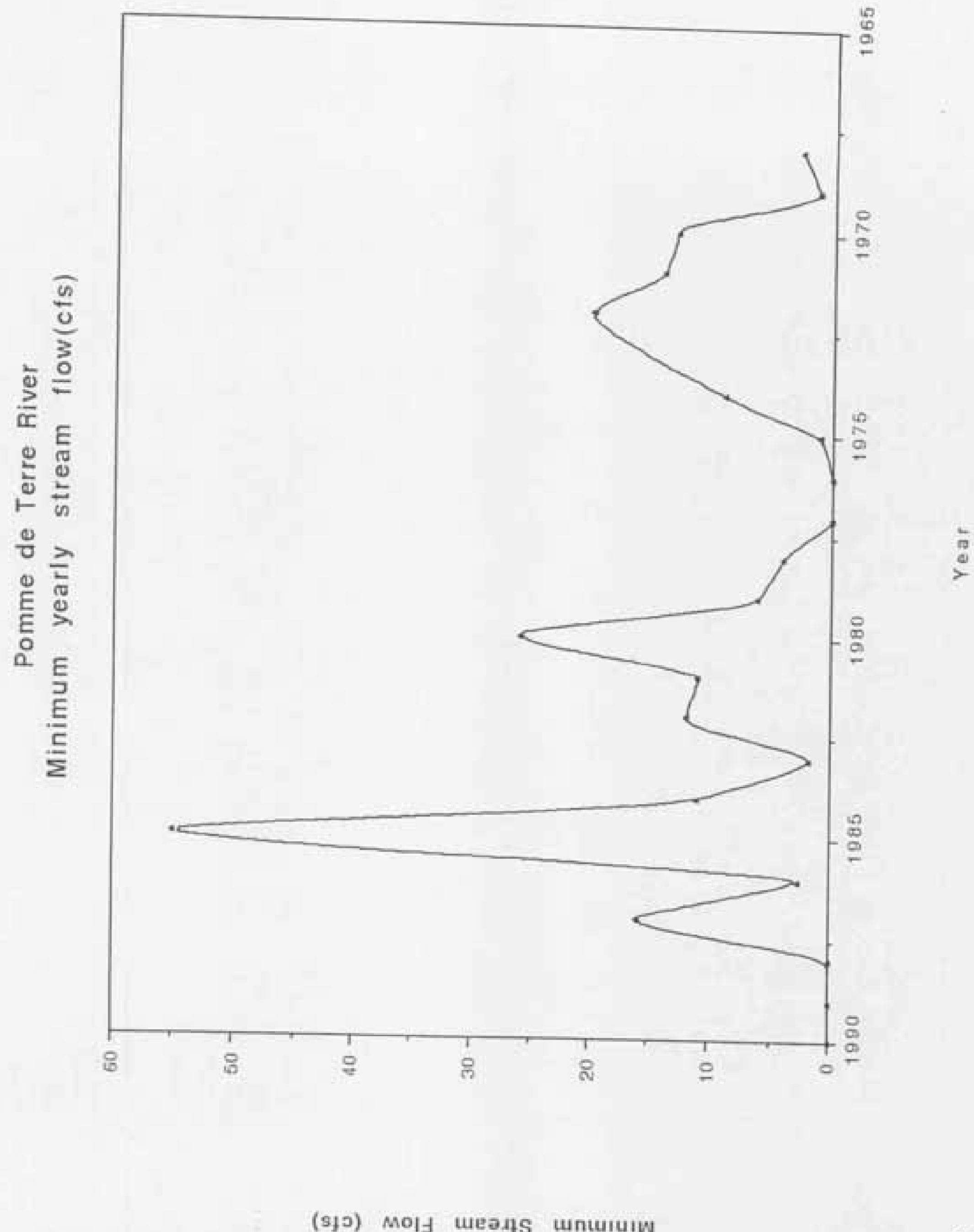
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 4


Amblema plicata
All Live Specimens
Pomme de Terre River
y = 1.5498 * 10^(0.006x)   R^2 = 0.827
N=95
Age (years)
Length (mm)
Amblema plicata
Pomme de Terre River, Site 19
N=41
Number of Live Mussels
Length Classes (10mm)
135
145
155
165
175

36

Figure 10



Pomme de Terre River
Minimum yearly stream flow(cfs)
Year
Minimum Stream Flow (cfs)
1965
1970
1975
1980
1985
1990
0
10
20
30
40
50
60

37

Figure 11.

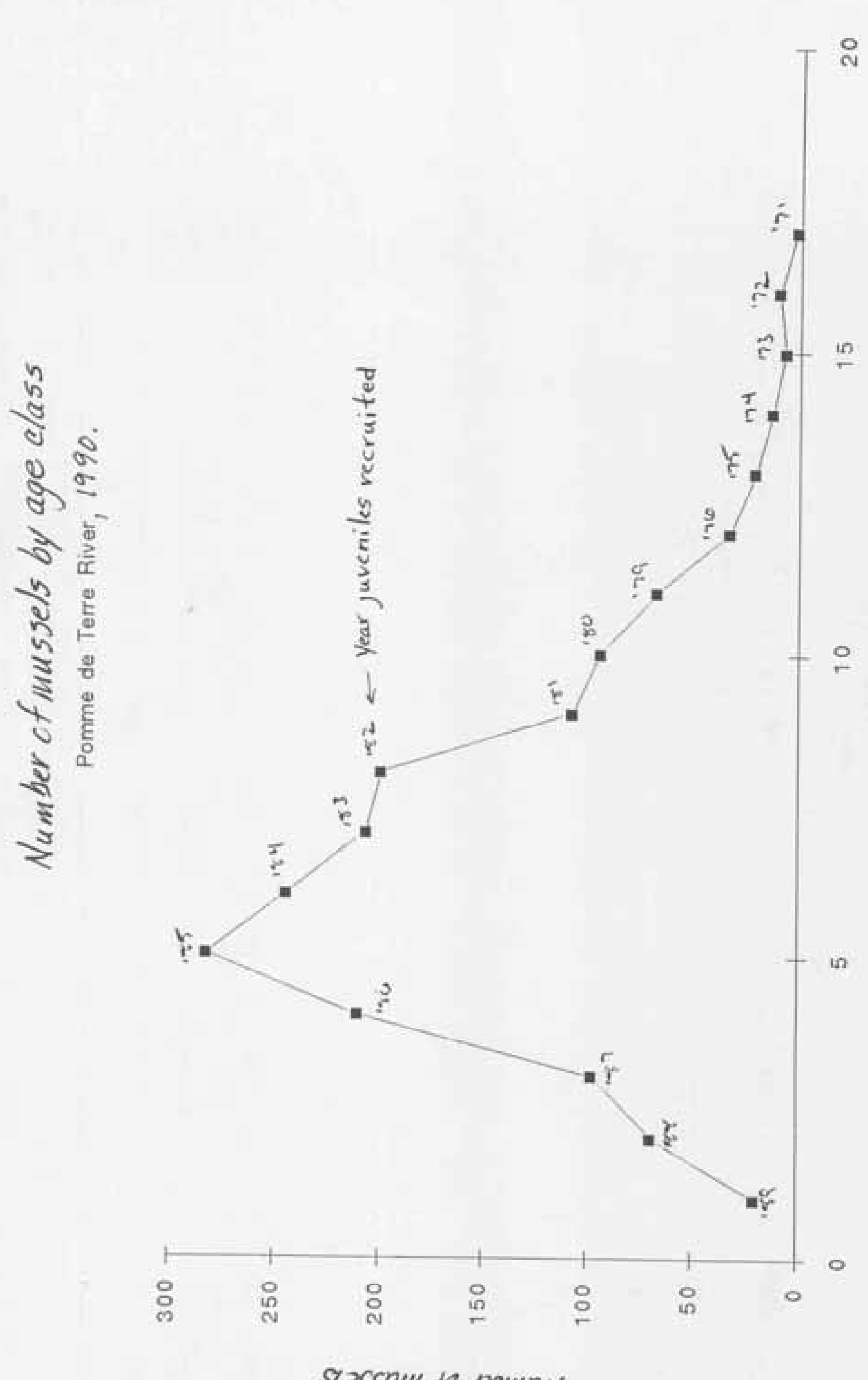

Number of mussels by age class
Pomme de Terre River, 1990.
'82 ← Year juveniles recruited
Number of mussels
Age (years)
0
50
100
150
200
250
300
0
5
10
15
20

Figure 12.

was site 90-19, near the Stevens and Swift county line. Based on shell lengths, sexually mature individuals were present for reproduction, although little evidence of recruitment was found at site 90-19 (Figure 10). A. plicata seems to be holding on in the lower Pomme de Terre River. However, the numbers are so low, we consider it in trouble and thus, it should not be harvested.

A. plicata occurred only in the middle and lower portions of the Chippewa River (Plate 4). A. plicata was much more abundant in the Chippewa River than in the Pomme de Terre River. It was a major component of the mussel fauna, second only to Lampsilis siliquoidea in abundance (Figures 7 and 8). A total of 895 live specimens was collected at 18 sites, 3 of which were on the East Branch (Table 2, Plate 4). Site 90 - 42 had the greatest abundance (457) of live A. plicata. Substrate types preferred by A. plicata in the Chippewa River were pebbles, cobbles, and sand, with a few individuals found in finer sediments such as silt, in combination with larger sized sediments (Figure 13). No differences in distribution were found between 1988 and 1990 (Plate 4).

Recruitment was evident at most of the sites, with juveniles less than 85 mm in length present at all sites (Figure 14a-e). However, several populations in the Chippewa River were missing some length classes. When compared with the age/length regressions, individuals from the missing length classes would have been between 2 and 10 years of age and over 20 years of age (Figure 14a). Therefore, they would have been recruited in 1987 to 1977 and in 1968. Minimum yearly stream flows in the Chippewa River reflected drought and low flow conditions in 1988, 1977, 1976, and 1968 (Figure 15). Thus, it was not surprising that several year classes were missing (Figure 16).

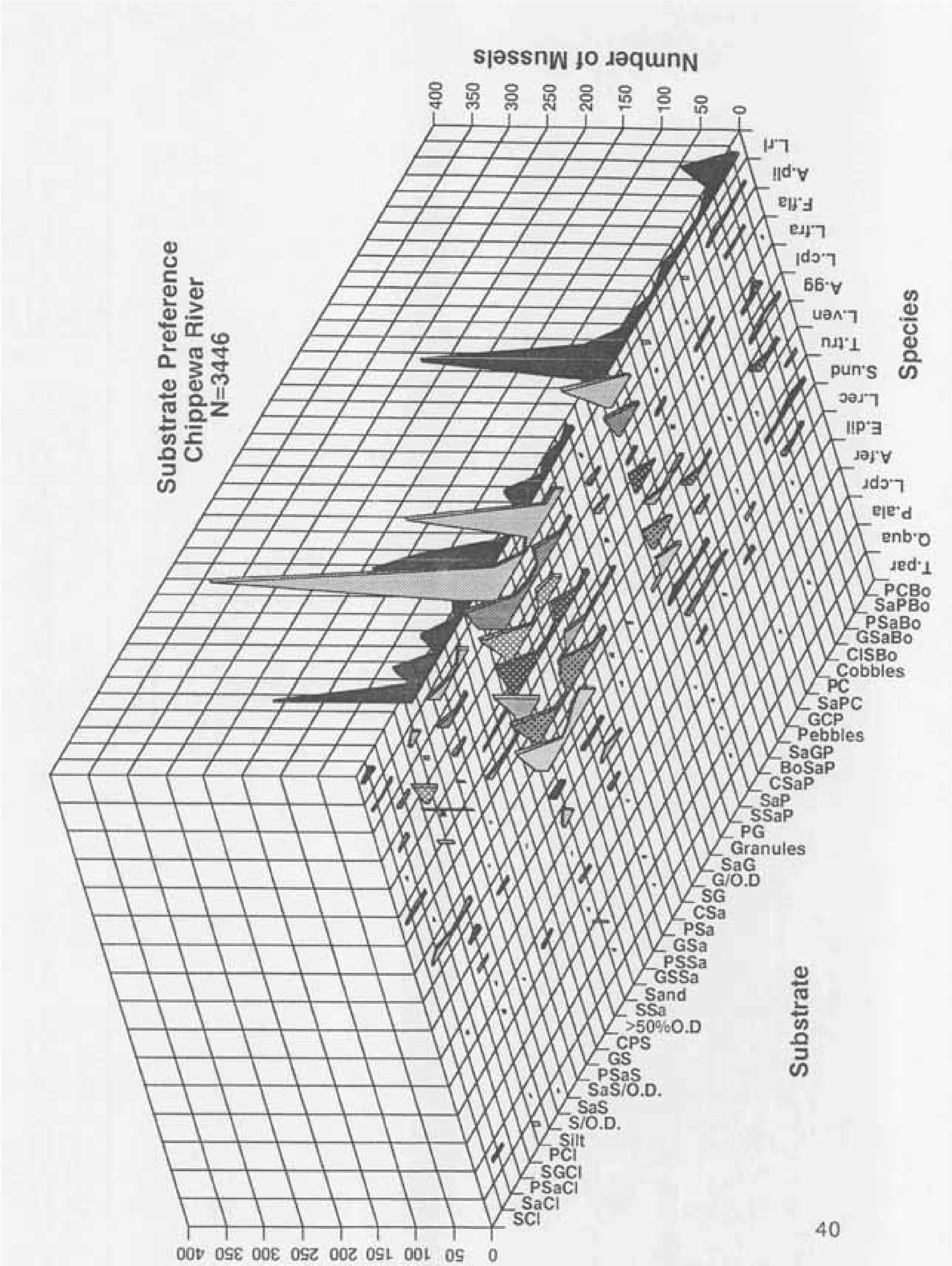
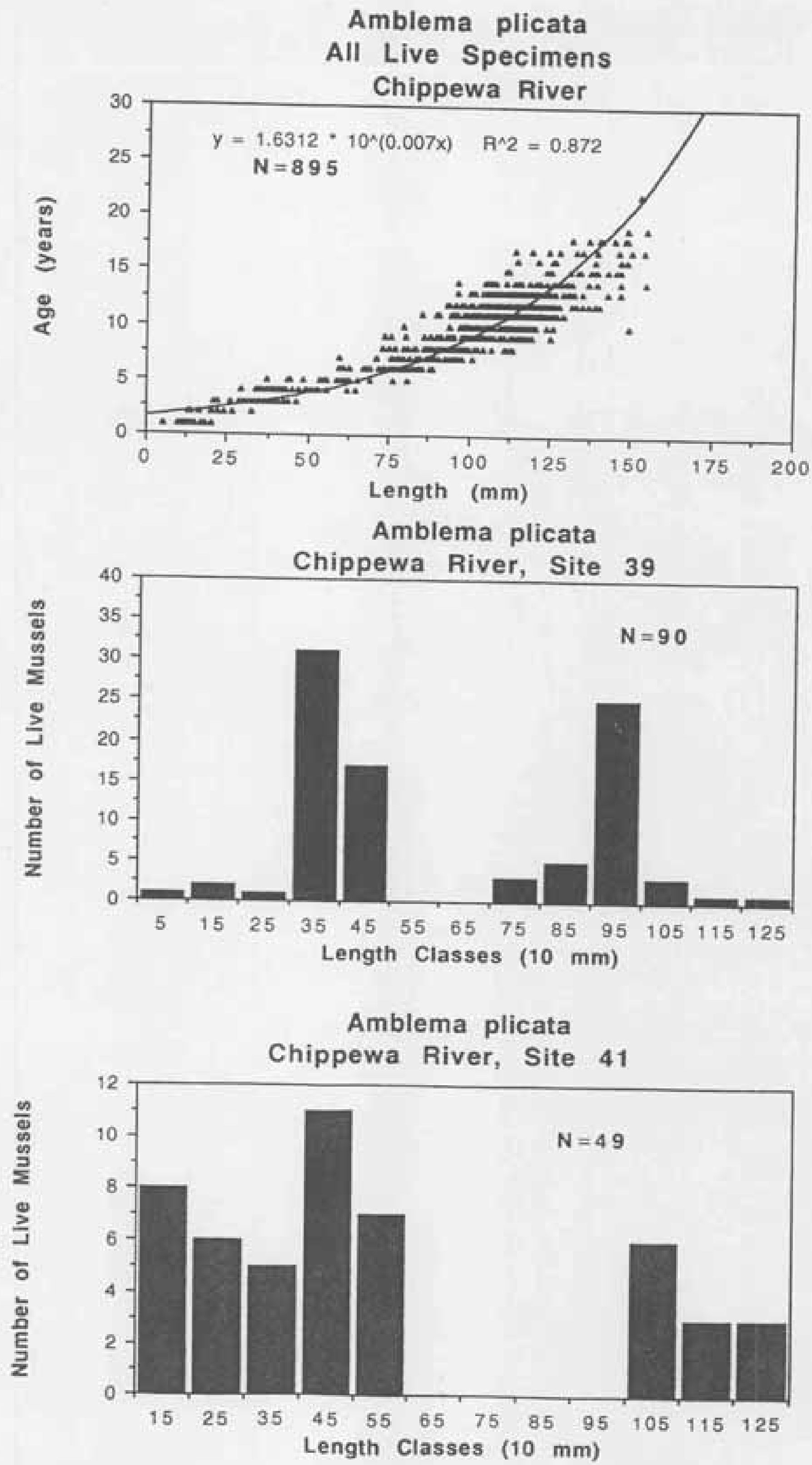
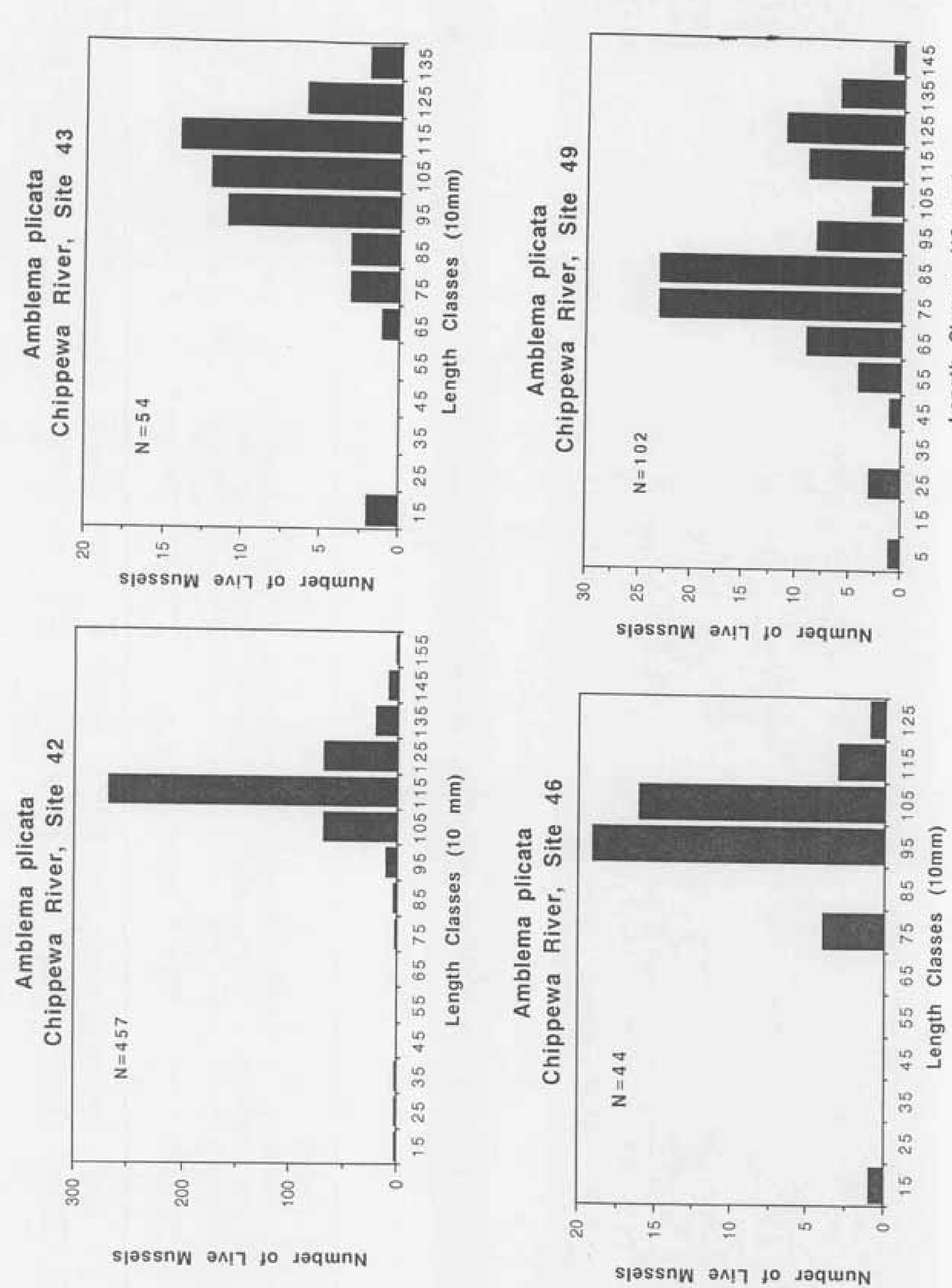

Substrate Preference
Chippewa River
N=3446
Number of Musssels
Number of Mussels
Species
Substrate
40

figure 13



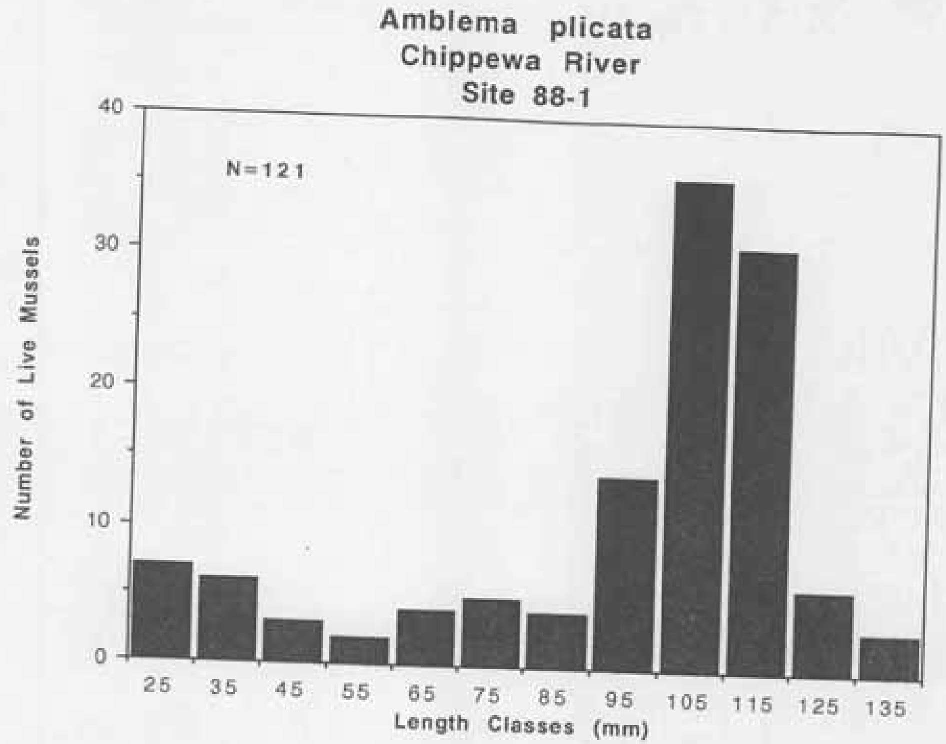
41

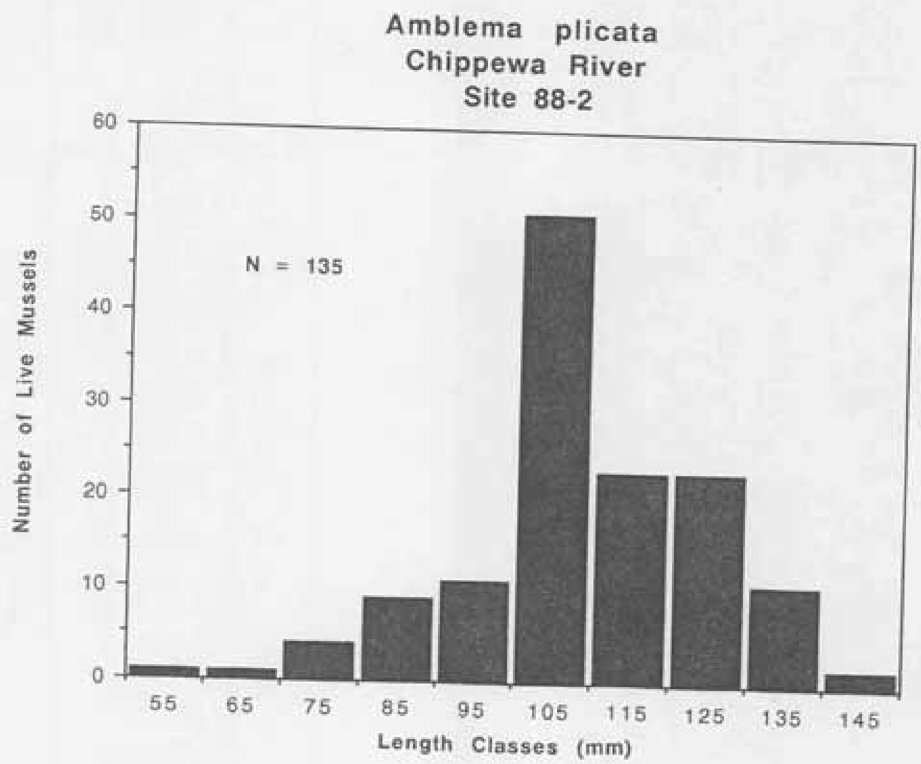
Figure 14a



42

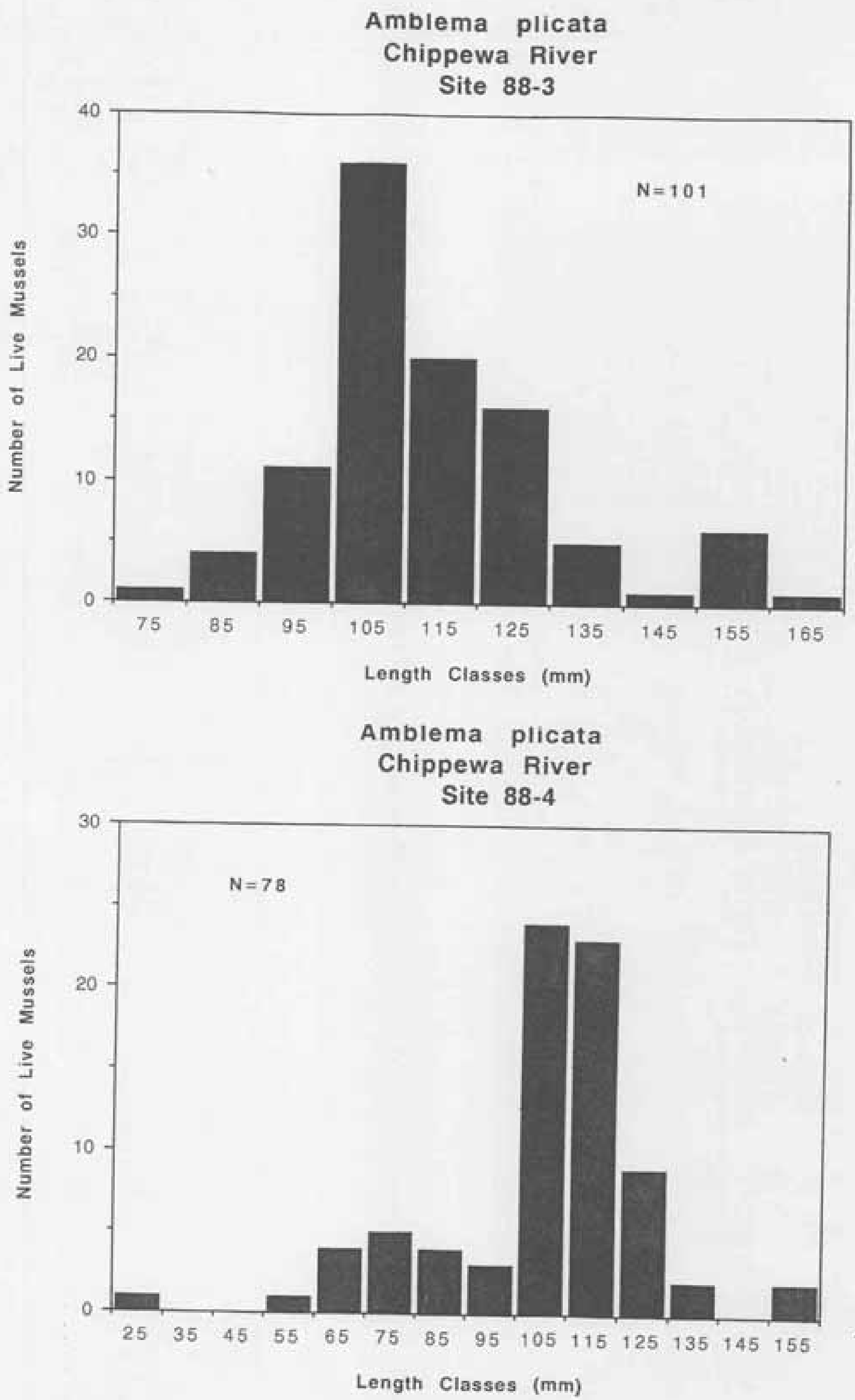
Figure 14b.





43

Figure 14c



44

Figure 14d

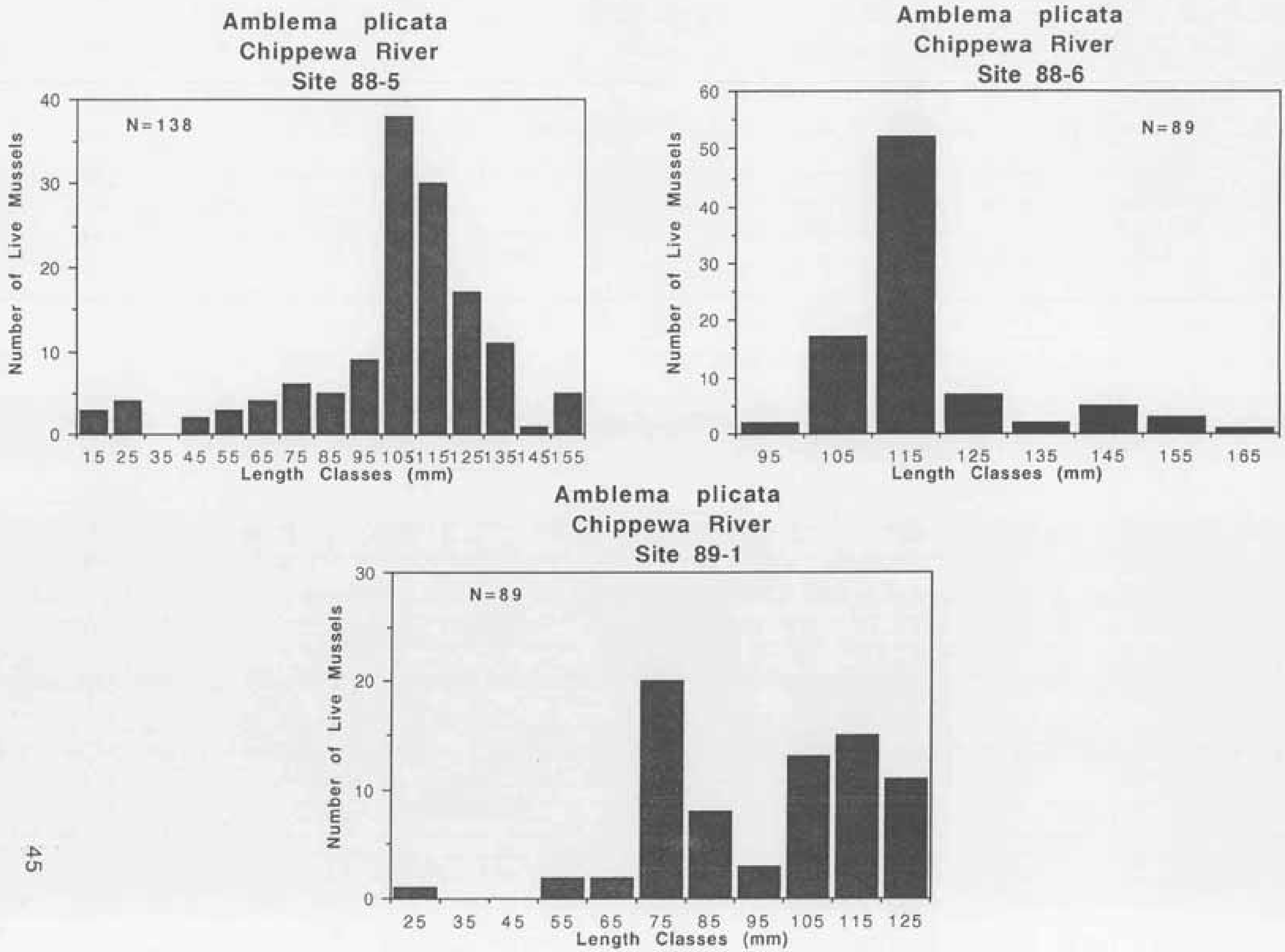

Amblema plicata
Chippewa River
Site 88-5
N=138
Number of Live Mussels
0
10
20
30
40
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155
Length Classes (mm)
Amblema plicata
Chippewa River
Site 88-6
N=89
Number of Live Mussels
0
10
20
30
40
50
60
95 105 115 125 135 145 155 165
Length Classes (mm)
Amblema plicata
Chippewa River
Site 89-1
N=89
Number of Live Mussels
0
10
20
30
25 35 45 55 65 75 85 95 105 115 125
Length Classes (mm)

Figure 14e

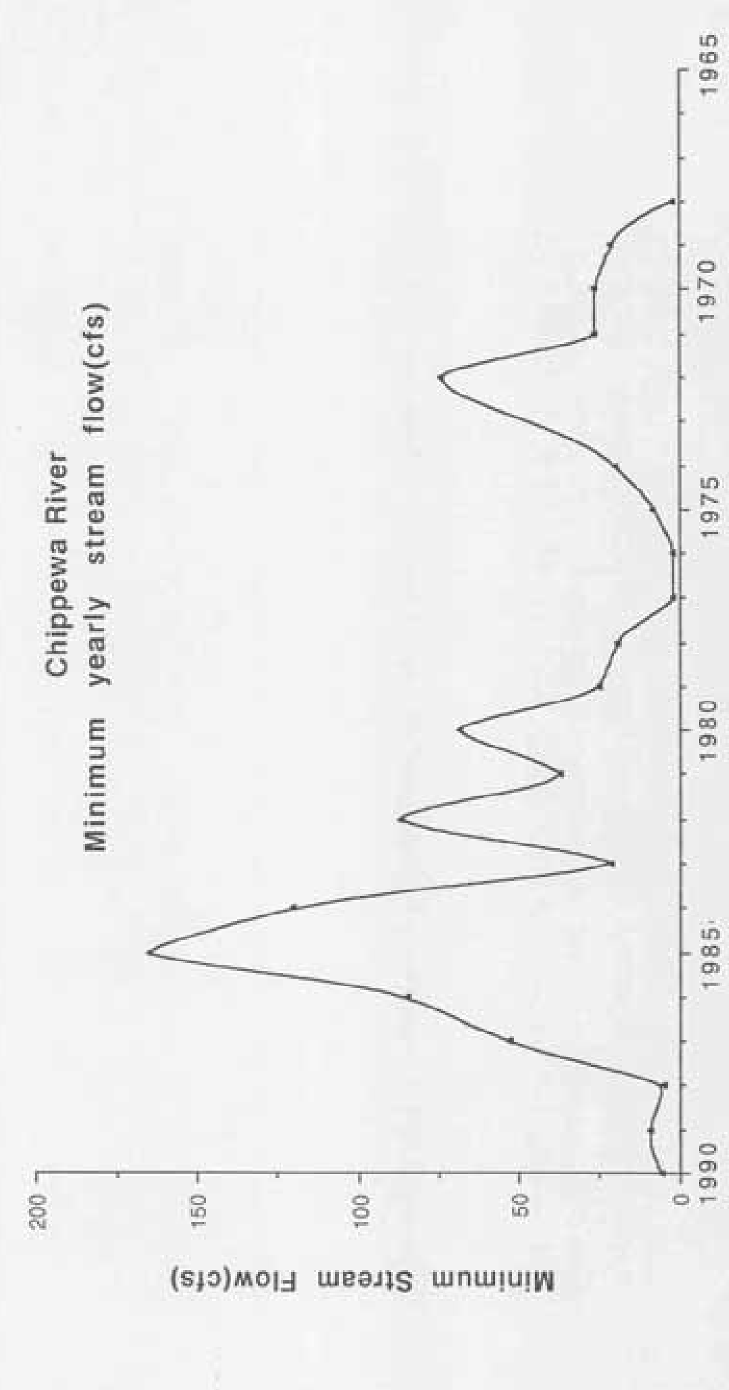

Chippewa River
Minimum yearly stream flow(cfs)
Minimum Stream Flow(cfs)
0
50
100
150
200
1990
1985
1980
1975
1970
1965
Calendar Year

Figure 15

However, the very young (1 to 4 years of age) were present at some sites. They were found in deep pools at sites 90-41, and 90-49 (Bright et al. 1994). In contrast to the rest of the river, a unimodal age/length class distribution was observed at site 90-49, near the mouth of the Chippewa River, indicating low flows in the last 15 years had not affected survival in this part of the river (Figure 14b). Ostlie found representation of all length classes from 15 mm to 165 mm at several sites in 1988 and 1989 with the larger length classes representing individuals over 20 years of age also missing (Figure 14c-e). In general, A.plicata was common and appeared stable in the Chippewa River. However, sufficient flow is required to ensure recruitment of juveniles.

Anodonta grandis grandis (giant floater)

The giant floater was one of the most widespread mussels in the Pomme de Terre River (Plate 5). A total of 442 live individuals was collected in the Pomme de Terre River (Table 2). A. g. grandis was a major component of the mussel fauna in the Pomme de Terre River although it was found in abundance (over 50 live) only at sites 90-7 and 90-14 (Figures 4 & 5). A. g. grandis preferred finer sediments such as sand and silt, but was also found in pebbles and a few in cobbles (Figure 10). Recruitment was evident at many sites (Figure 17a). However, the majority of A. grandis mussels were within 4 to 10 years of age and length classes from 55 mm to 75 mm or 2 to 3 year old, were frequently missing (Figure 17a & b). We suspect low flows in 1988 and 1989 and the droughts in 1976 and 1977 affected the survival of large segments of the

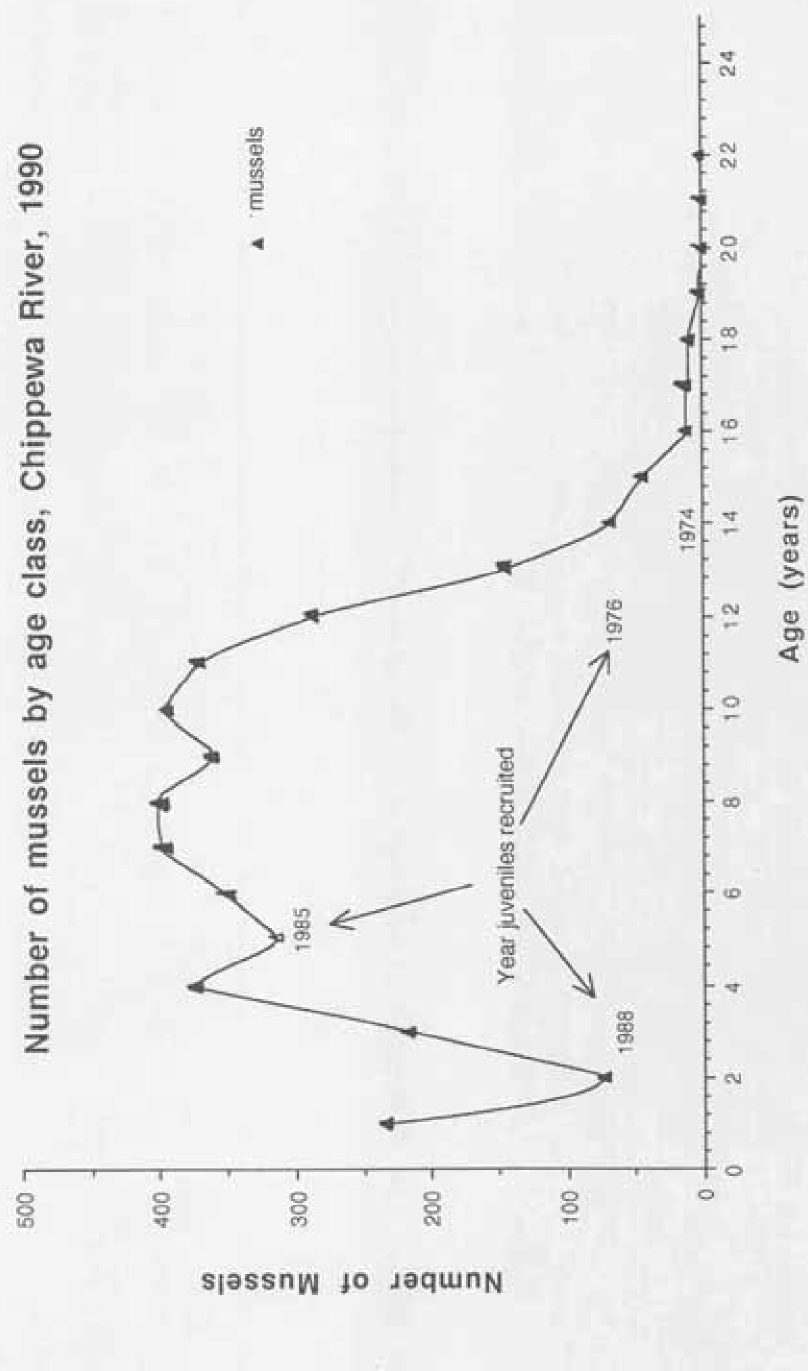
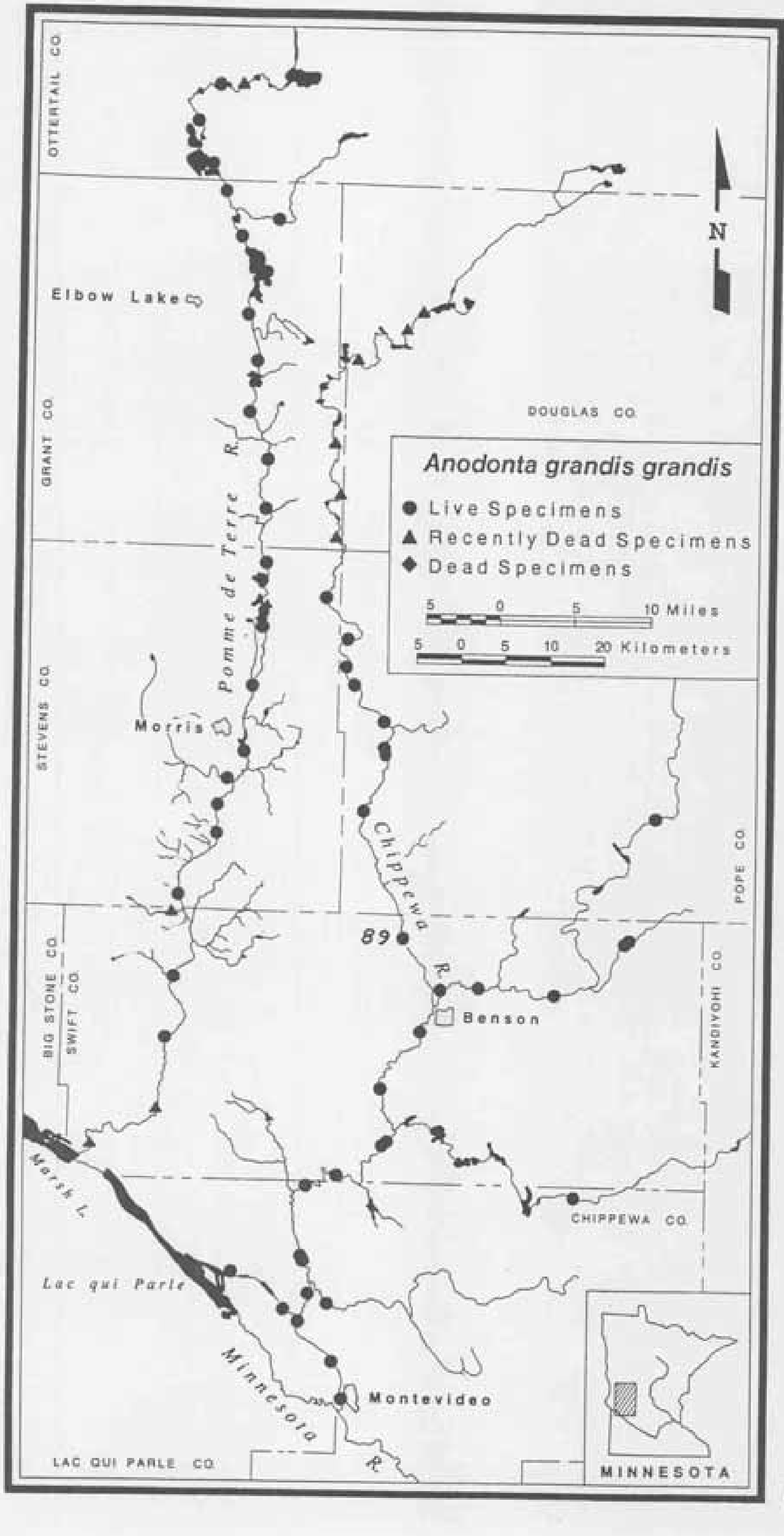
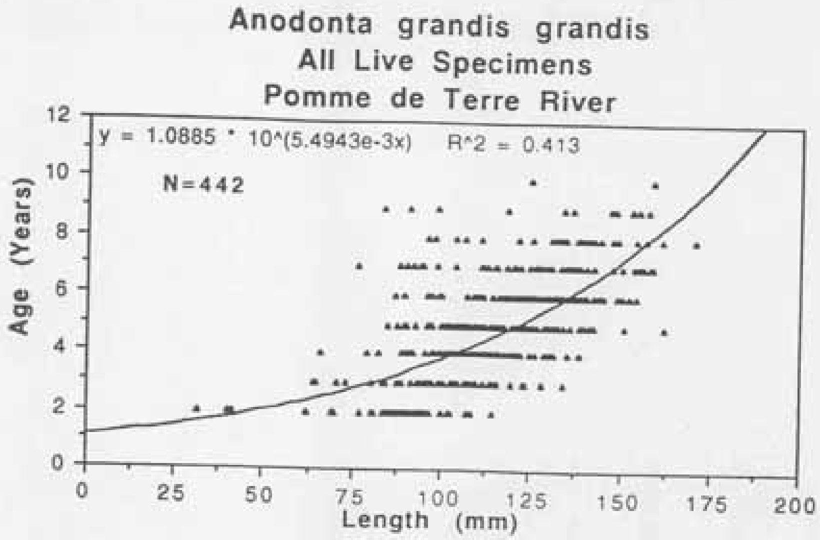

Number of mussels by age class, Chippewa River, 1990
mussels
Number of Mussels
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Age (years)
1988
1985
1976
1974
Year juveniles recruited

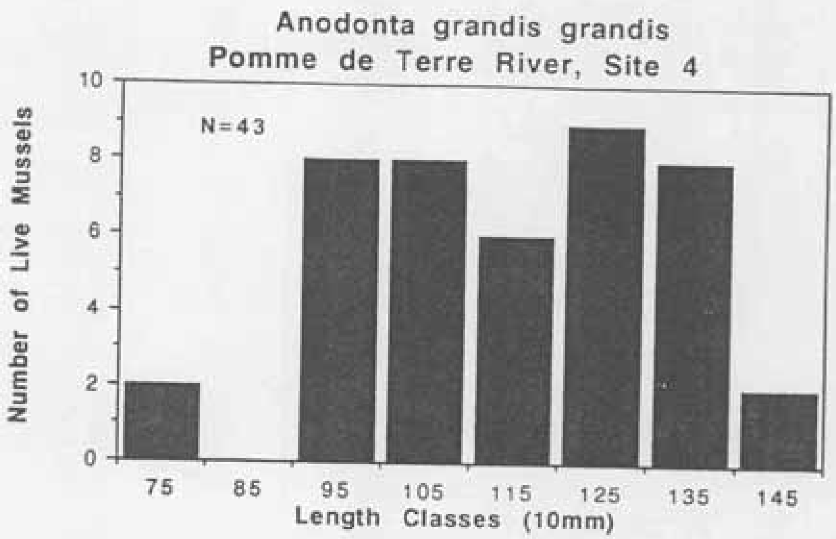
Figure 16

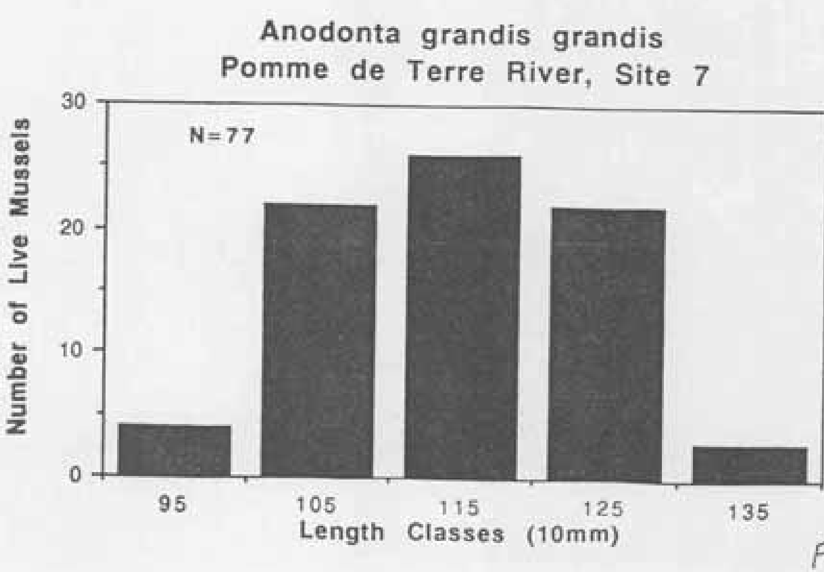


Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 5

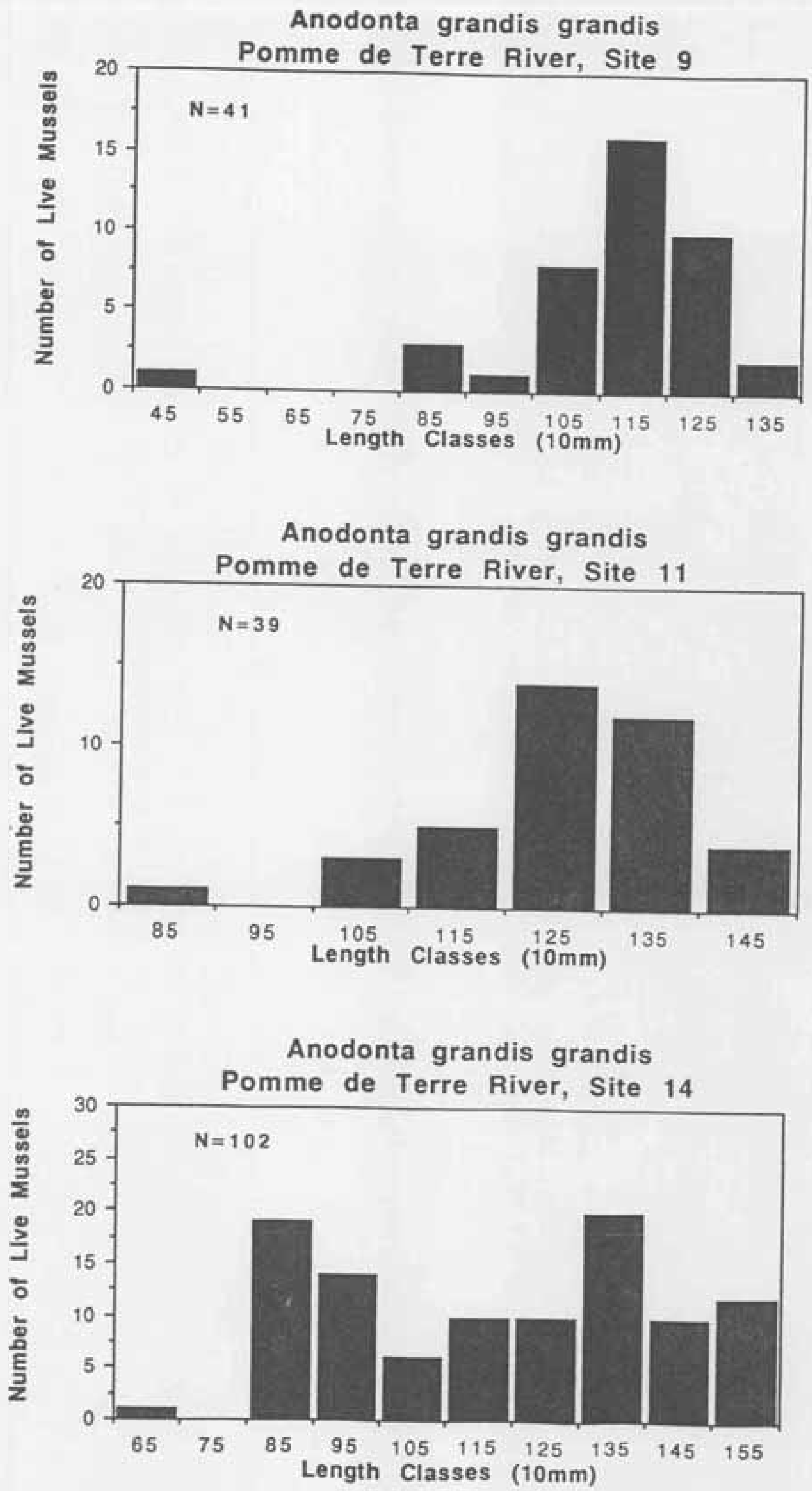






50

Figure 17a



51

Figure 17b

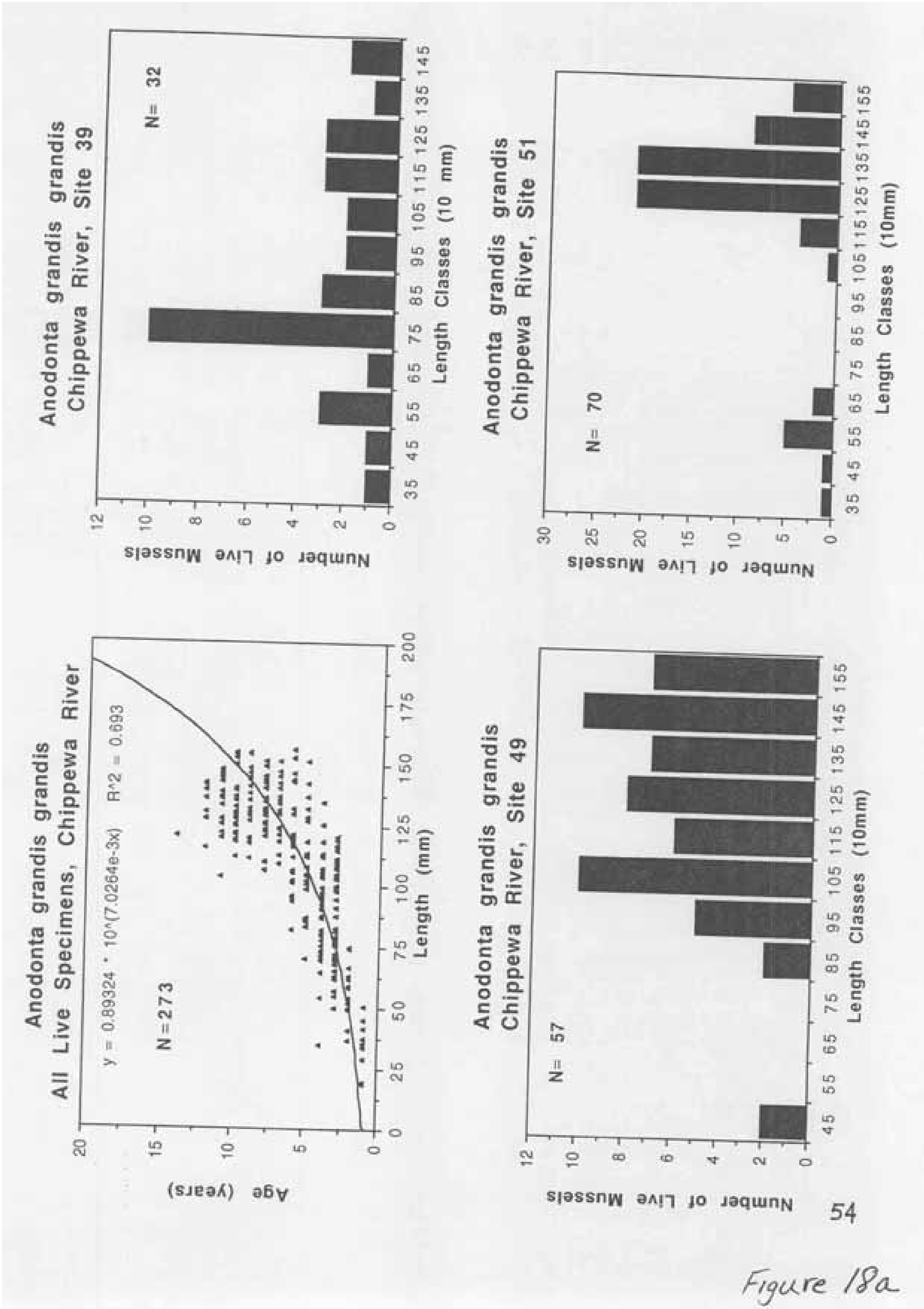
populations. In the Pomme de Terre River, A. grandis was generally found in pools and slower moving areas of the river (Bright et al. 1994). Despite missing age/length classes at some of the sites, A. g. grandis appeared stable in the Pomme de Terre River. However, it is imperative that in-stream flows be high enough to allow recruitment over the next few years.

In the Chippewa River, a total of 274 A. grandis were collected (Table 2). Although prevalent throughout the river, A. g. grandis was found in abundance (over 50 live individuals) only at sites 90-51 and 90-49 (Figure 7). A. g. grandis comprised a significant portion of the mussel fauna in the Chippewa River but was not as great a component as it was in the Pomme de Terre River (Figures 5 and 8). Mussel harvest was apparently minimal on the Chippewa River in comparison to the Pomme de Terre River. Therefore, commercially sought after species were more abundant in the Chippewa River and non-commercial species such as A. g. grandis, did not encompass as large of a proportion of the mussel fauna in the Chippewa River. In addition, sedimentation was a greater problem in the Pomme de Terre River than it was in the Chippewa River. Thus, species intolerant of sedimentation may comprise a greater portion of the mussel fauna in the Chippewa River than in the Pomme de Terre River. A. g, randis preferred finer sediments, such as sand and silt, but was also found in fine sediments with pebbles and cobbles in the Chippewa River (Figure 13). A. g. grandis was generally found in pools and slower moving areas of the river (Bright et al. 1994). No major differences in distribution were found between 1988 and 1990 (Plate 5).

Recruitment was evident at many sites (Figure 18a-b). However, length classes from 55 mm to 95 mm, estimated at 1 to 3 years old, were missing at some sites in 1990. Yet, in 1989 mussels 65 to 95 mm in length were present (Figure 18a-b). In 1990, the majority of A. g. grandis mussels were within 4 to 12 years of age. Again, we suspect low flows in 1988 and 1989 negatively affected recruitment and the droughts in 1977 and 1976 caused near decimation of the would be older generations (Figures 15 and 16). In general, A. g. grandis was common and appeared stable in the Chippewa River.

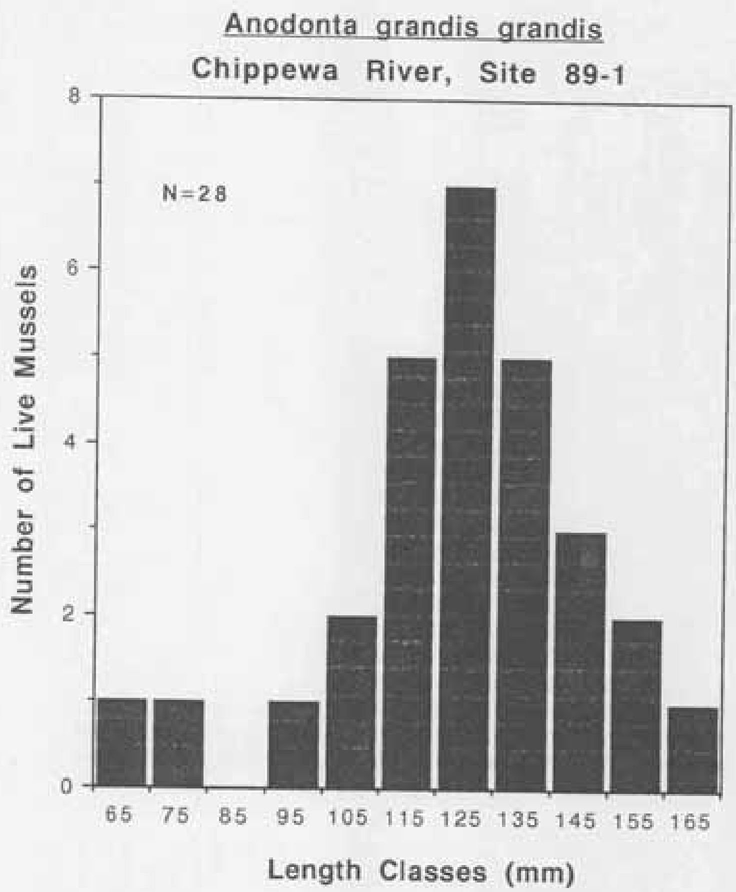
Anodontoides ferussacianus (cylindrical papershell)

A. ferussacianus is primarily confined to small and medium-sized streams in Minnesota (Dawley 1947; Bright et al. 1989, 1990). A. ferussacianus was found live sporadically from the headwaters to the mouths of the Pomme de Terre River and the Chippewa Rivers (Plate 6). A. ferussacianus was also found live in Pelican Creek, a northern tributary to the Pomme de Terre River and in the East Branch of the Chippewa River. Interestingly, A. ferussacianus occurred further north in the Pomme de Terre River than in the Chippewa River (Plate 6). The presence of dead shells only between sites with live individuals suggested that something local has deleteriously affected those populations. Sixty-eight dead specimens of A. ferussacianus were found in Drywood Creek (90-34), tributary to the Pomme de Terre River. This creek was a series of small pools connected by a trickle of water. Since several other species were found (all dead) at this site, it would be of interest to go back and see if mussels have



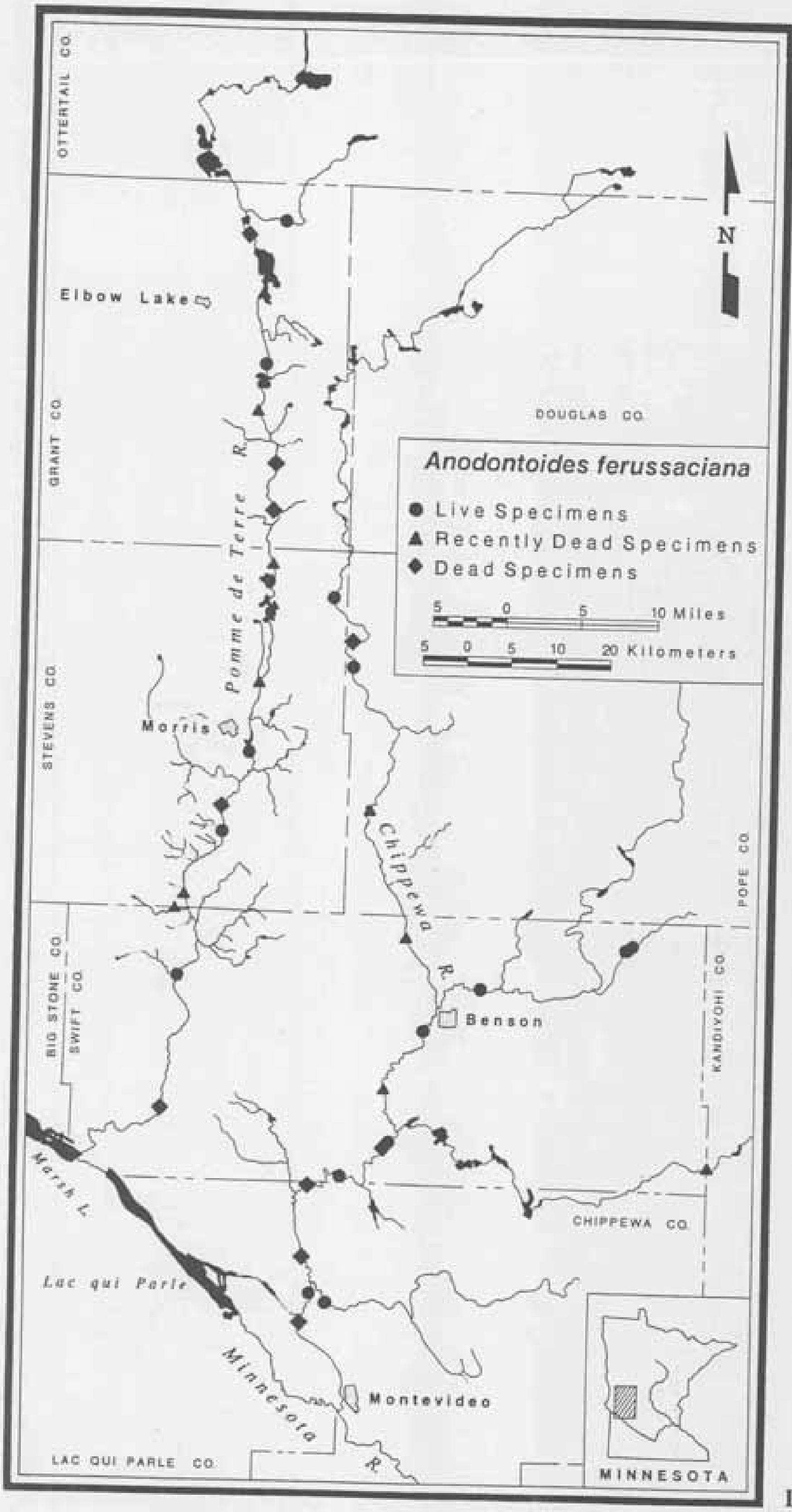
Anodonta grandis grandis
All Live Specimens, Chippewa River
y = 0.89324 * 10^(7.0264e-3x) R^2 = 0.693
N=273
Age (years)
Length (mm)
Anodonta grandis grandis
Chippewa River, Site 39
N= 32
Number of Live Mussels
Length Classes (10 mm)
Anodonta grandis grandis
Chippewa River, Site 49
N= 57
Number of Live Mussels
Length Classes (10mm)
Anodonta grandis grandis
Chippewa River, Site 51
N= 70
Number of Live Mussels
Length Classes (10mm)
54

Figure 18a



55

Figure 18b.



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

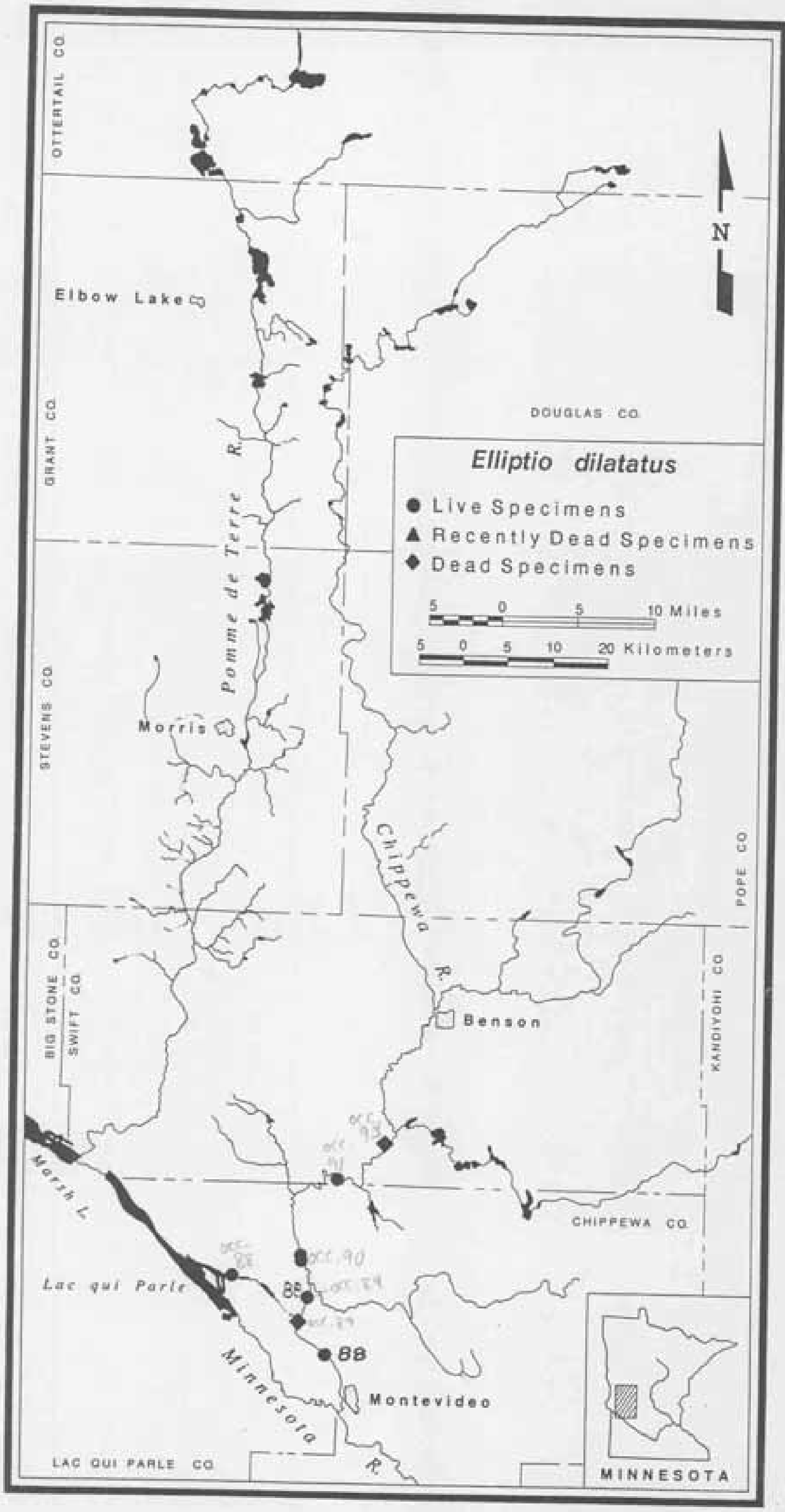
Plate 6

5

managed to recolonize the creek. In general, A. ferussacianus was rare and comprised a very small proportion of the mussel fauna in the Pomme de Terre and Chippewa Rivers (Figures 4, 5, 7, and 8). Based upon poor recruitment and the decline in range, we judge A. ferussacianus as in trouble in the Pomme de Terre and Chippewa Rivers.

Elliptio dilatata (spike)

Grant (1886) reported the Spike from the Minnesota River at Fort Snelling and at some time in the past it occurred as far upstream as Montevideo (Bright et al. 1990). Therefore, it was not surprising when E. dilatata was not found in the Pomme de Terre River (Plate 7). A few populations were found in the Chippewa River, all were downstream of Shakopee Creek, and upstream of the Watson Control Dam (Plate 7). However, Ostlie found live E. dilatata between the Watson dam and Montevideo in 1988 (Plate 7). That no recently dead or dead shells were collected upstream of Shakopee Creek indicated this species had a northern limit in the Chippewa River. One very exciting find was alive juvenile E. dilatata (12.5 mm in length) on a bissel thread in the Watson Sag, which could potentially place this species further upstream in the Minnesota River than has been reported in the past 100 years. One dead specimen was found just below the Watson water control dam (90-47). We believe the individual found in the Watson Sag came off a fish that migrated through the Watson Diversion Channel.



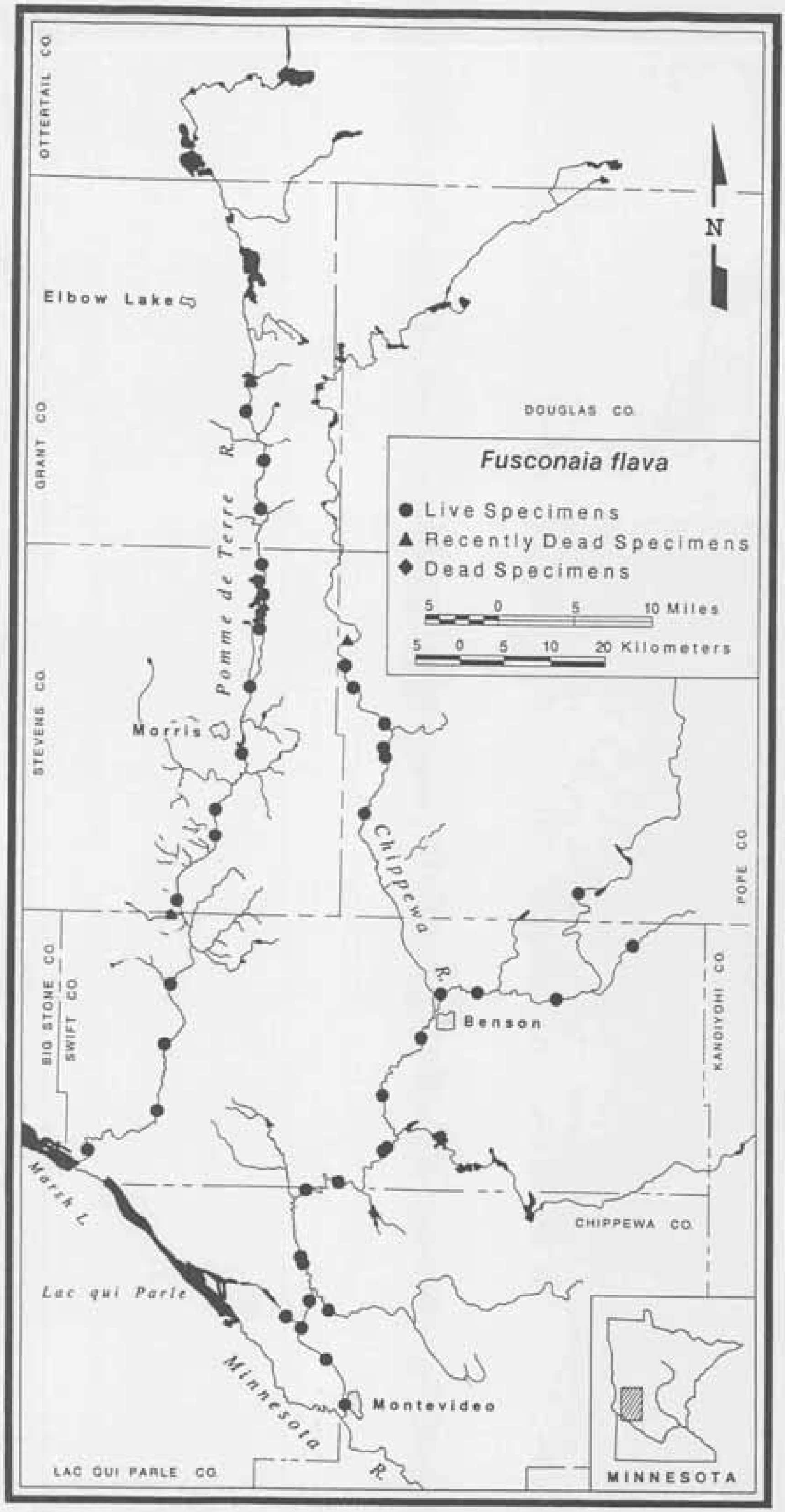
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 7

In total, 19 live individuals were collected in the Chippewa River and the Watson Sag (Table 2). Seventeen of the 19 live were found near Hagen, MN at sites 90-44 and 90-45 (Bright et al. 1994). The substrate at both of these sites consisted primarily of cobbles, pebbles, and sand (Figure 14). Good overhanging cover was also present. E. dilatata was rare in the Chippewa River. The presence of live E. dilatata was noted in 1988 where absence was noted in 1990 suggesting it may be jeopardized in the Chippewa River. Therefore, we suggest measures towards habitat preservation be given to these sites where E. dilatata is still holding on.

Fusconaia flava (pigtoe)

F. flava occurred throughout the lower two-thirds of the Pomme de Terre River (Plate 8). Density at each site was fairly uniform (Figure 7). The number of live (144) and dead (205) shells found were roughly the same, indicating that historically F. flava was not abundant in the Pomme de Terre River (Table 2). It comprised approximately 9 % of the river's mussel fauna (Figure 8). F. flava was found in a variety of sediment types from very fine (silt) to coarse (cobbles and pebbles), although it appeared to prefer a combination of sand and pebbles (Figure 9). As with A. plicata, one would not expect heavy shelled mussels inhabiting fine sediments. However, because of eroded stream banks and sedimentation problems in the Pomme de Terre, F. flava may be found in silt as a result of available habitat rather than preference. We found little evidence of recruitment, except at site 90-17 (Figure 19). Most of the populations of F. flava were 4 to 18 years old. At least half of the F. flava checked had orange or red



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 8

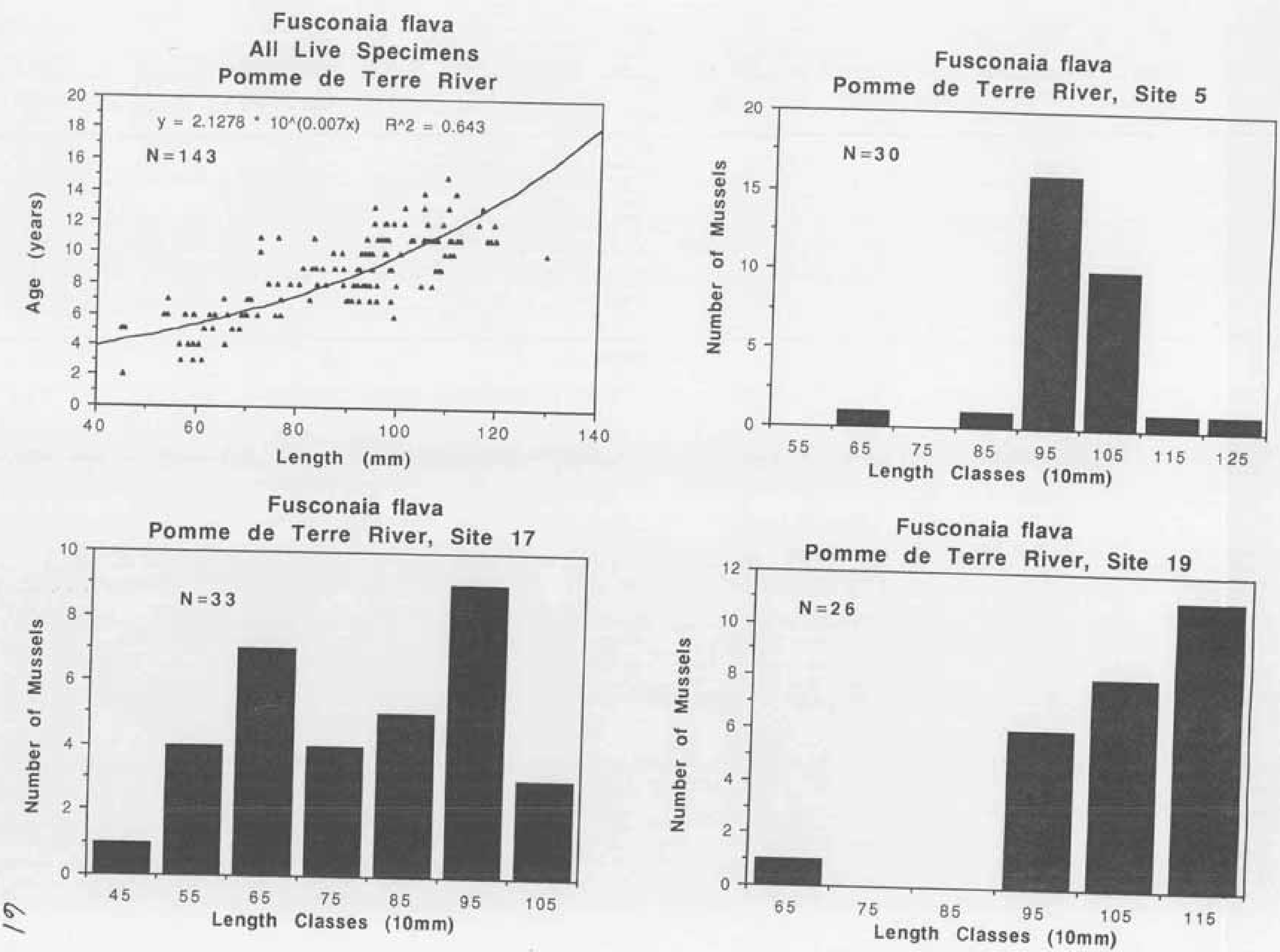

Fusconaia flava
All Live Specimens
Pomme de Terre River
y = 2.1278 * 10^(0.007x) R^2 = 0.643
N=143
Age (years)
Length (mm)
Fusconaia flava
Pomme de Terre River, Site 5
N=30
Number of Mussels
Length Classes (10mm)
Fusconaia flava
Pomme de Terre River, Site 17
N=33
Number of Mussels
Length Classes (10mm)
Fusconaia flava
Pomme de Terre River, Site 19
N=26
Number of Mussels
Length Classes (10mm)

Figure 19

61

gills, indicating they were females with eggs and possibly gravid (Baker 1928). Therefore, reproduction and recruitment may be occurring in the river, but because F. flava is not an exceptionally large-sized species, juveniles were extremely difficult to locate. For example, individuals 65 mm in length were estimated at 4 to 6 years old. F. flava was stable in the Pomme de Terre, but some concern over aging populations may be warranted.

F. flava was more abundant in the Chippewa River than in the Pomme de Terre River, although it only occurred in the middle and lower portions of the Chippewa (Plate 8). A total of 235 live specimens were collected at 25 sites, 5 of which were on the East Branch (Table 2, Plate 8). Recruitment was evident at several sites on the Chippewa River (Figure 20a-b). Because we rarely found more than 20 live individuals at a given site, histograms were only produced for 3 sites. Several length classes were missing at site 90-42 which were estimated to be the 3 to 5 year old (Figure 20a). Note these same age/length classes were missing in A. plicata (Figure 16b). Because site 90-42 was abundant in A. plicata, we believe the habitat was suitable for F. flava, but suspect fluctuating river flows dampened recruitment in recent years (Figures 11 & 12). The very young (1 to 4 years of age) juveniles collected at site 90-49 were found in deep pools (Bright et al. 1994). The larger length classes representing individuals over 20 years of age were also missing; likely due to the droughts in 1976 and 1977. F. flava was common in the Chippewa River, but not overly abundant, and appeared stable. No differences in distribution were noted between 1988 and 1990.

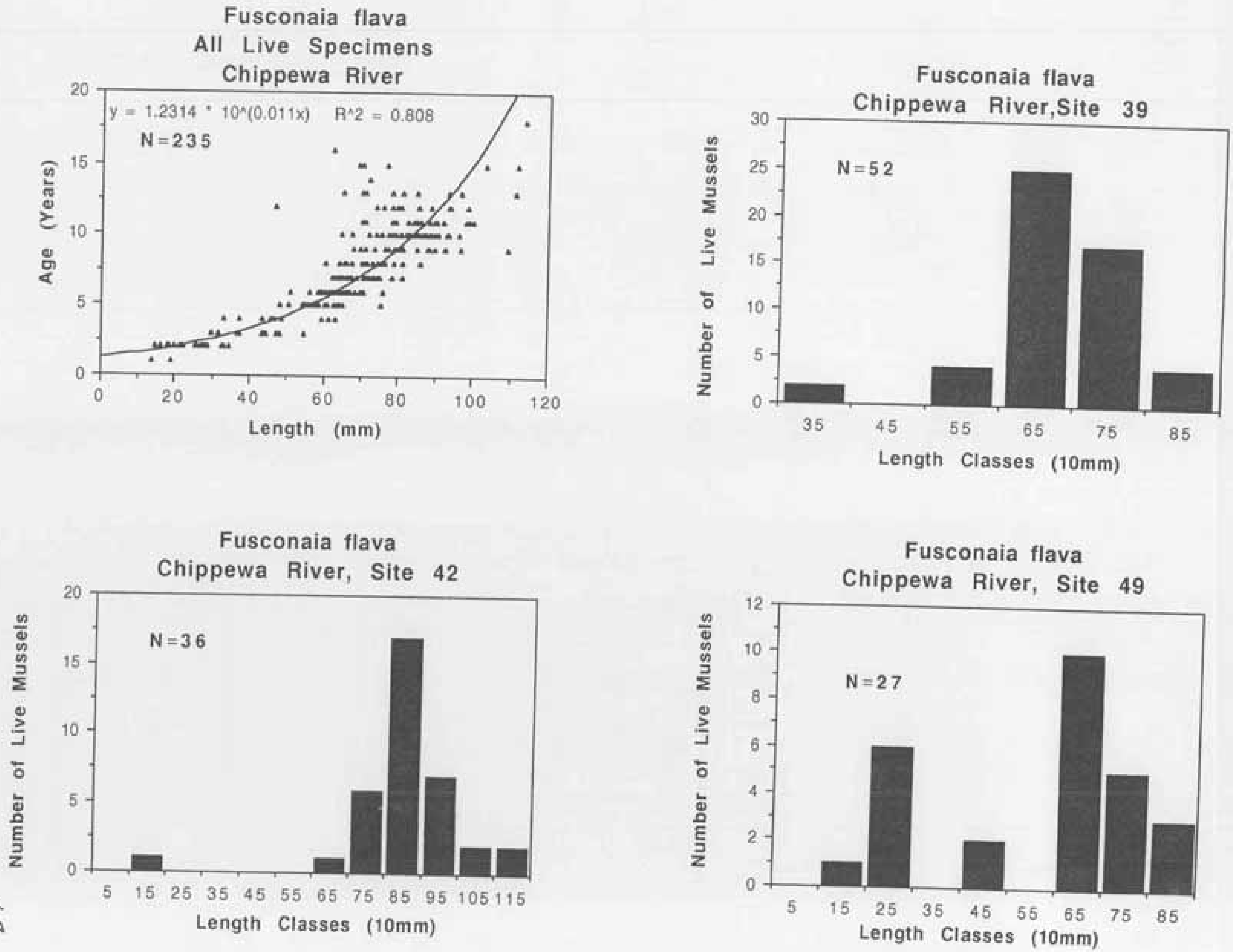


Figure 20a

63

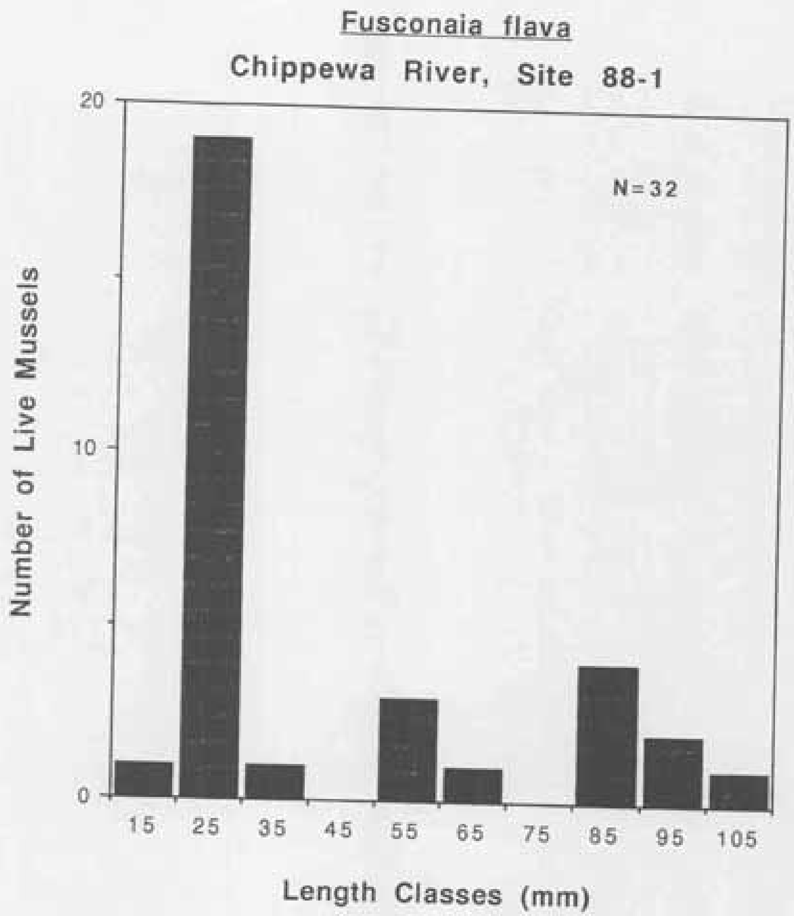
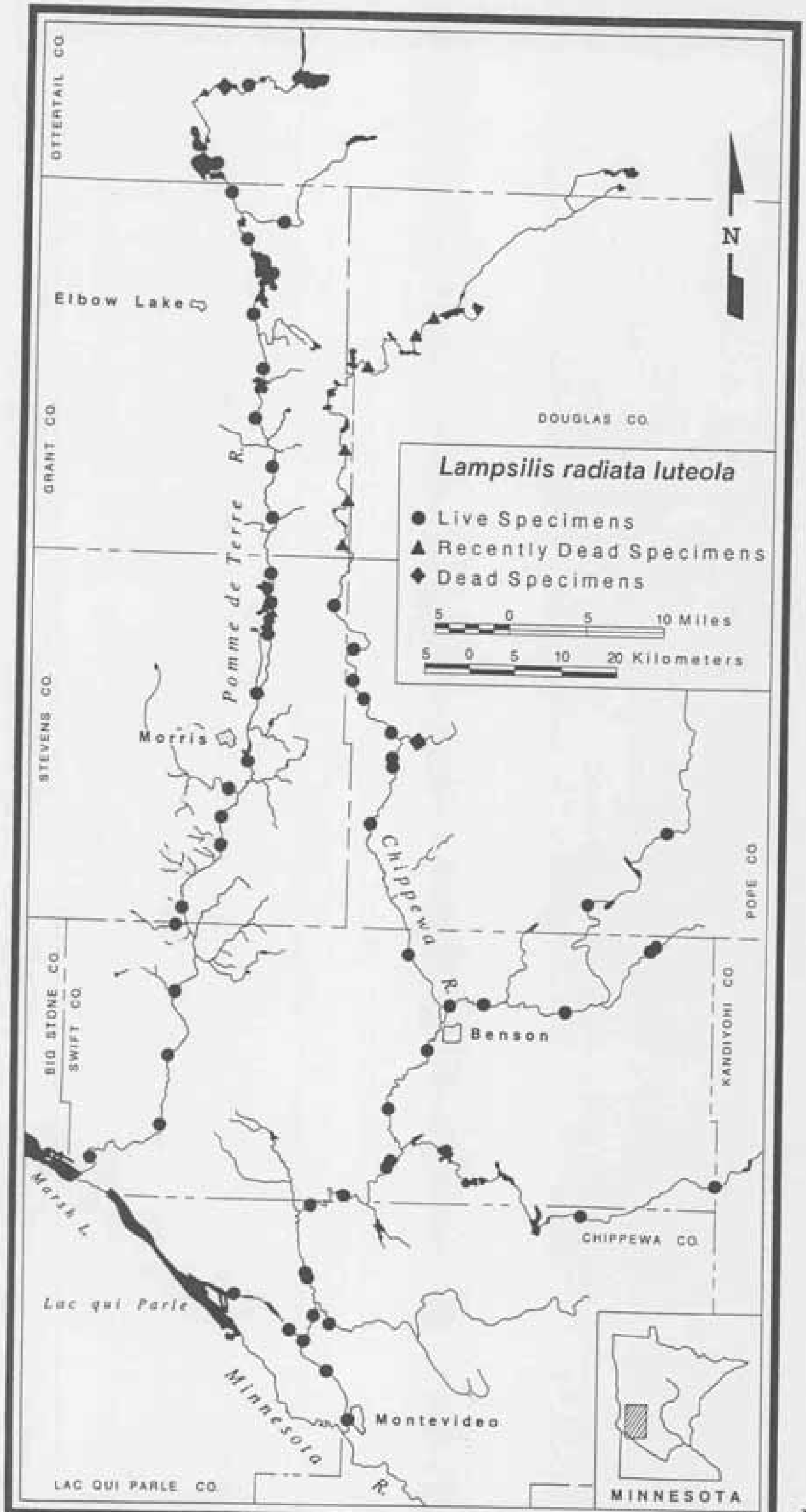

Fusconaia flava
Chippewa River, Site 88-1
N=32
Number of Live Mussels
0
10
20
15
25
35
45
55
65
75
85
95
105
Length Classes (mm)

Figure 20b.

Lampsilis siliquoidea (Lampsilis radiata luteola) (fat mucket)

Dawley (1947) observed the fat mucket throughout Minnesota and found it was not restricted to any stream type. Therefore, it was not surprising that we found L. siliquoidea the most ubiquitous species in both the Pomme de Terre and Chippewa Rivers (Plate 9). A total of 718 live individuals were found in the Pomme de Terre, comprising approximately 43% of the fauna (Table 2, Figure 6). L. siliquoidea was the dominant mussel species throughout the Pomme de Terre (Figure 5). Although found in larger-sized substrates such as cobbles and pebbles, L. siliquoidea preferred sandy substrates (i.e. anything in combination with sand) (Figure 9). We found evidence of recruitment at nearly all of the sites surveyed (Figure 21 a-b). However, as with other species in the Pomme de Terre, the maximum individual age was roughly 17 years, indicating the droughts in 1976 and 1977 have affected the whole mussel fauna in the Pomme de Terre (Figures 11, 12, & 21 a). The 2 year old age class was missing from site 90-10, which we assumed to be due to sampling difficulty (Figure 21 a). L. siliquoidea was common and stable in the Pomme de Terre River.

In the Chippewa River, a total of 1708 individuals were found, comprising approximately 44 % of the mussel fauna (Table 2, Figure 8). L. siliquoidea was the dominant species in the Chippewa River and were found primarily in sandy substrates (Figures 7 and 13). Recruitment was evident at several sites surveyed (Figure 22a-g). However, the young of the year to 3 year-old classes were missing in the tributaries (90-50), (90-51), and in the Watson Diversion Channel (90-53). Ostlie found evidence



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 9

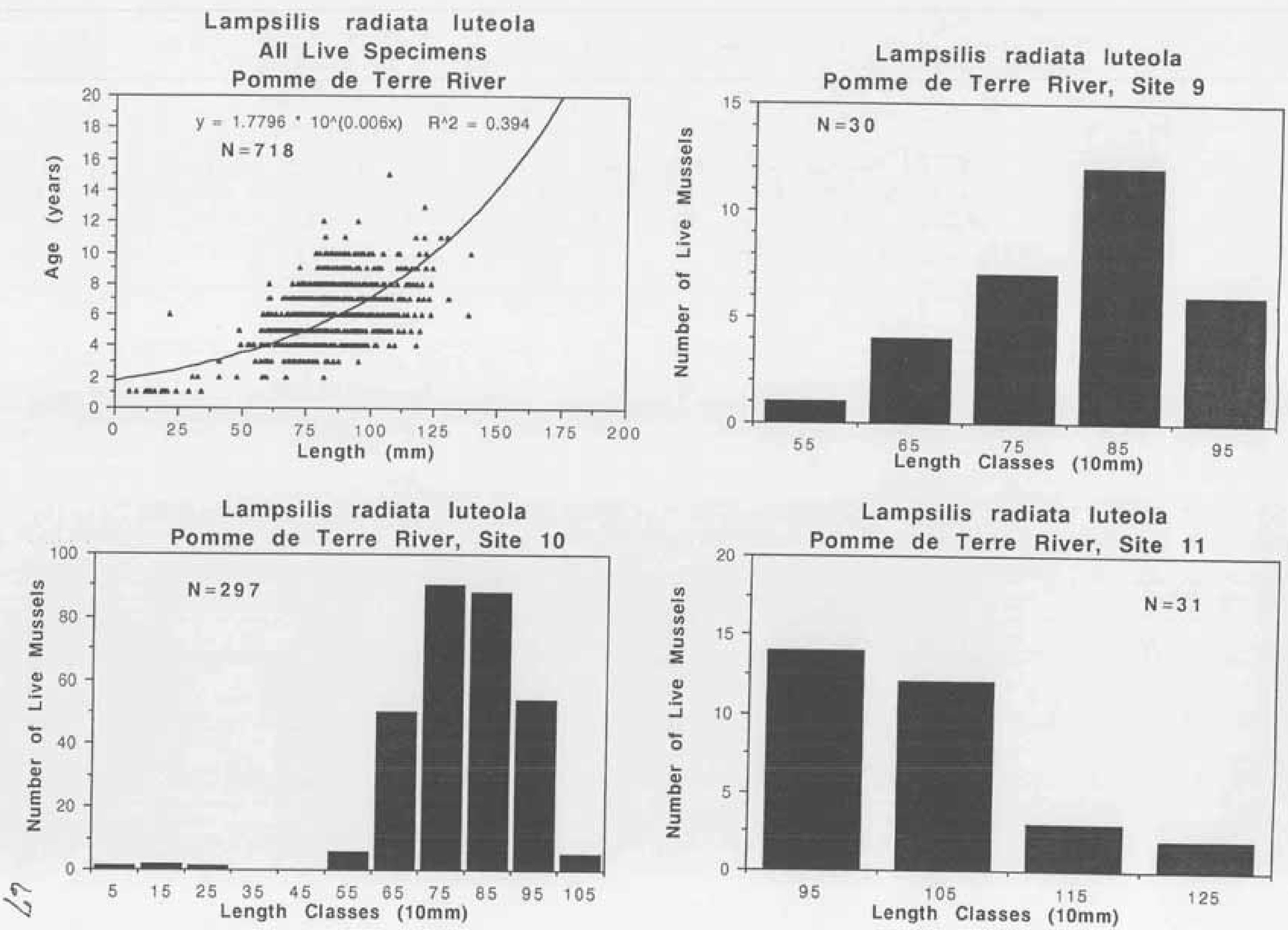
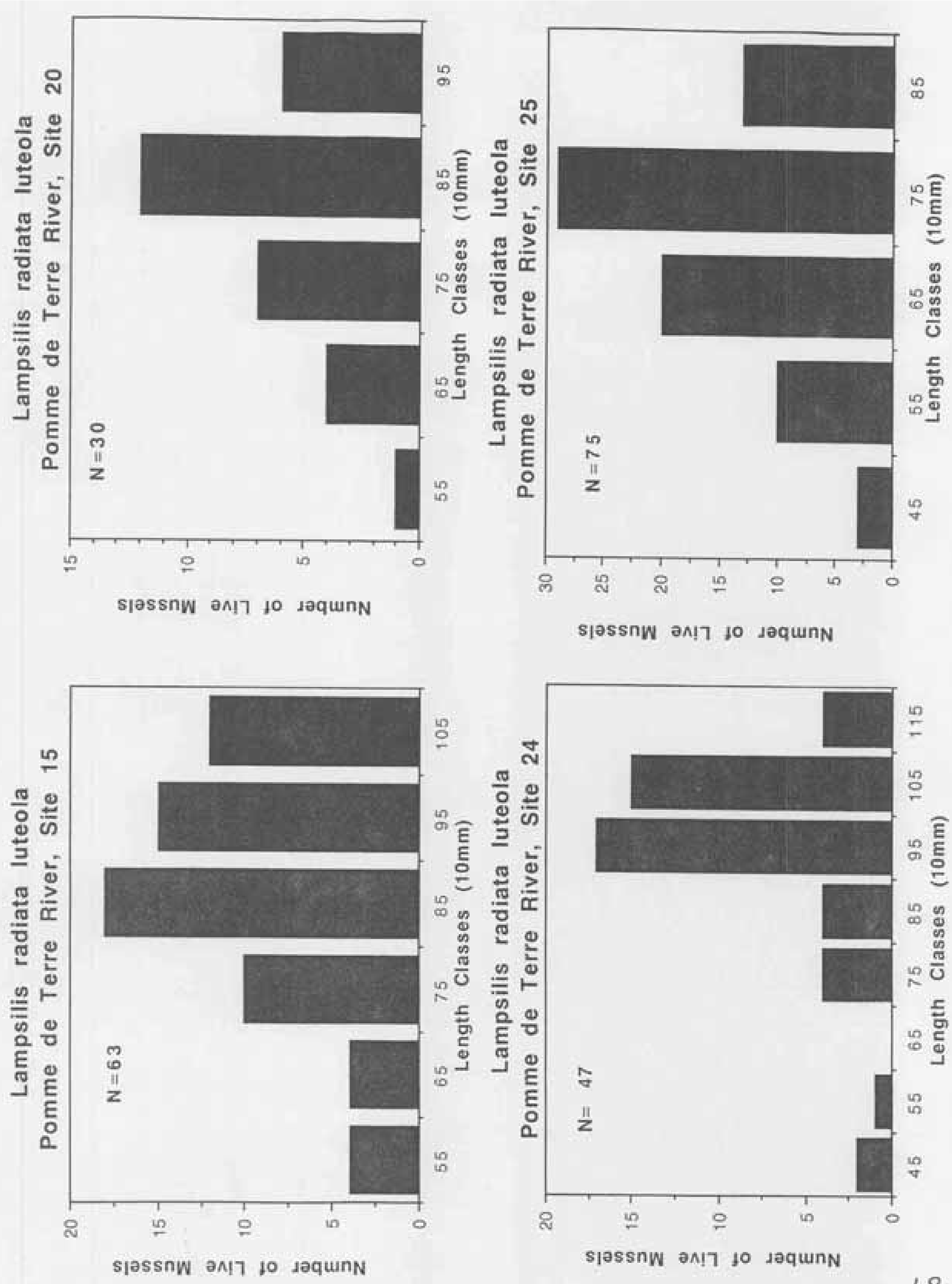


Figure 21a.

67



68

Figure 21 b.

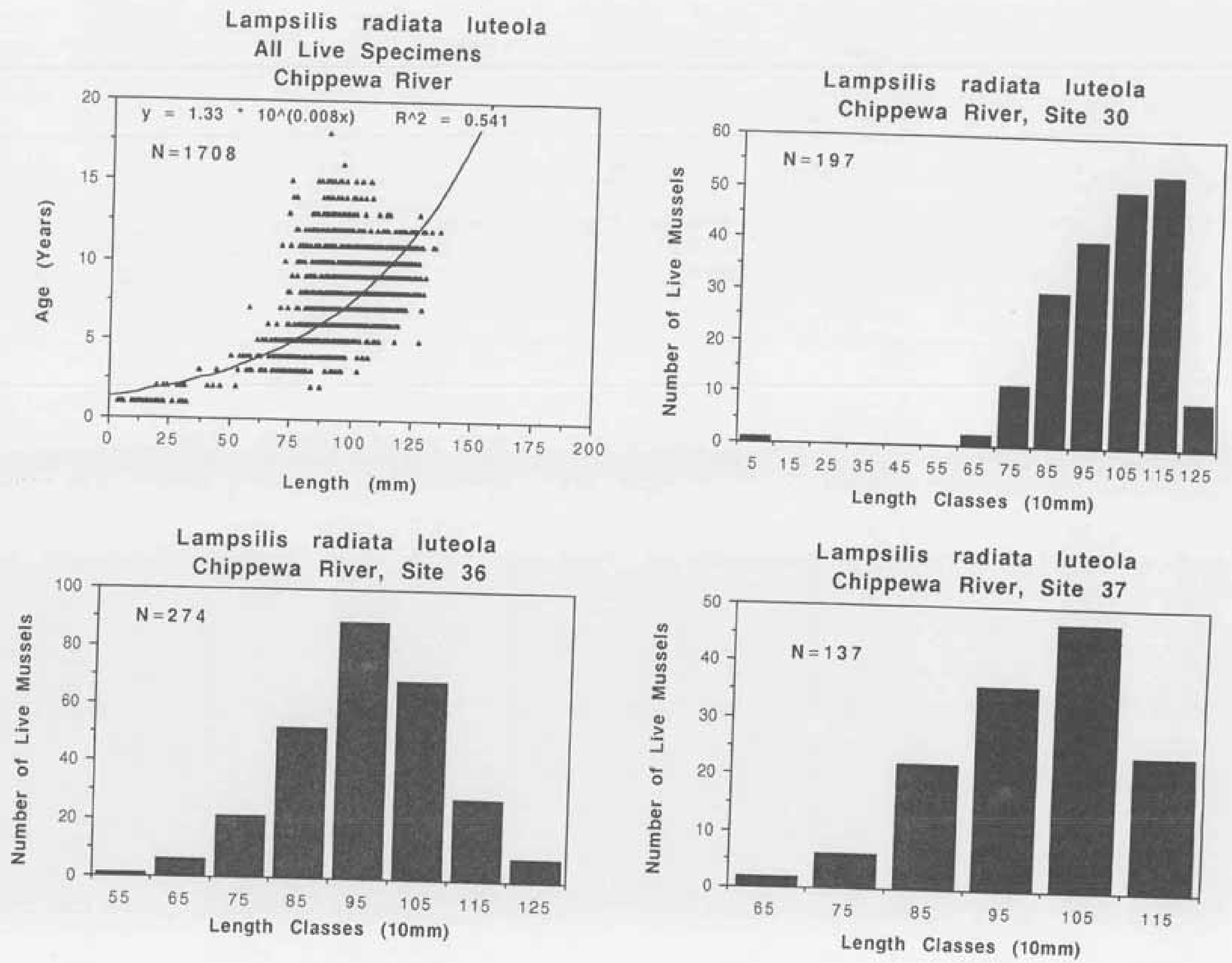
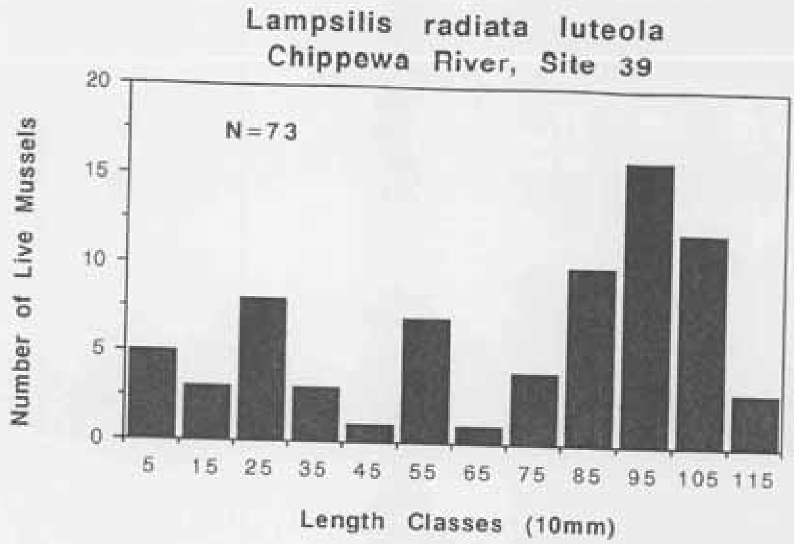
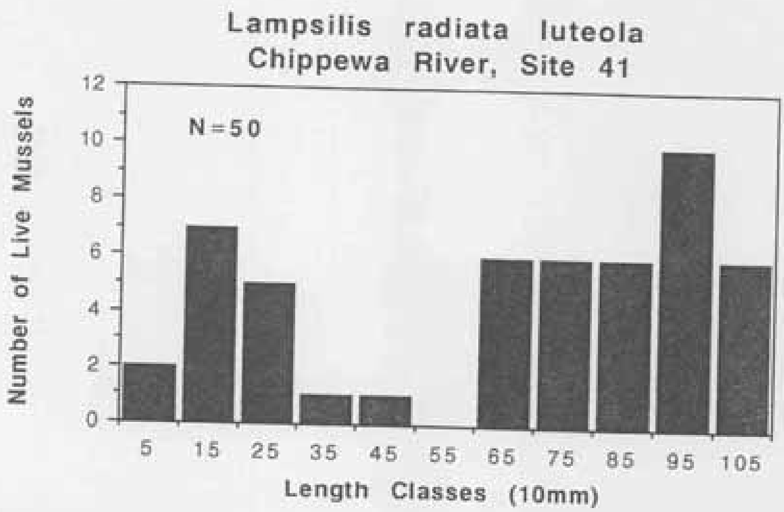
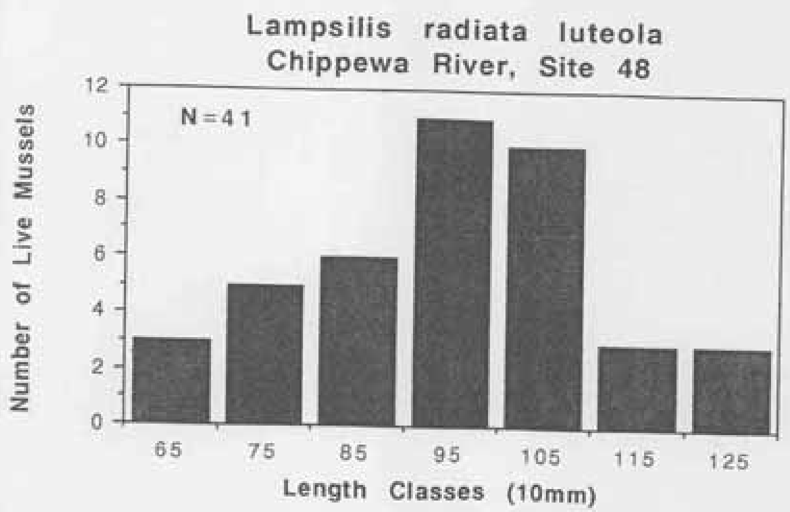


Figure 22a

69

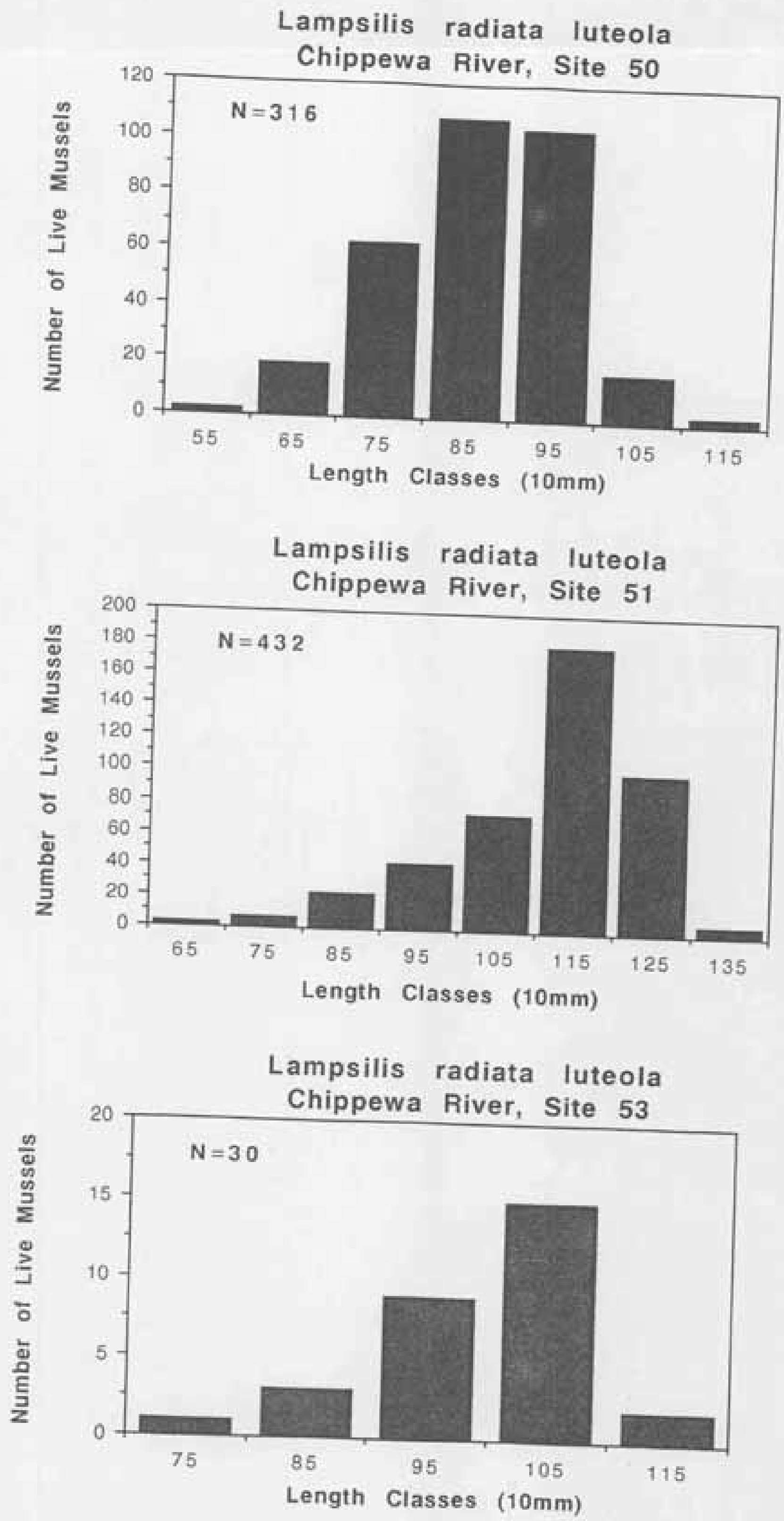






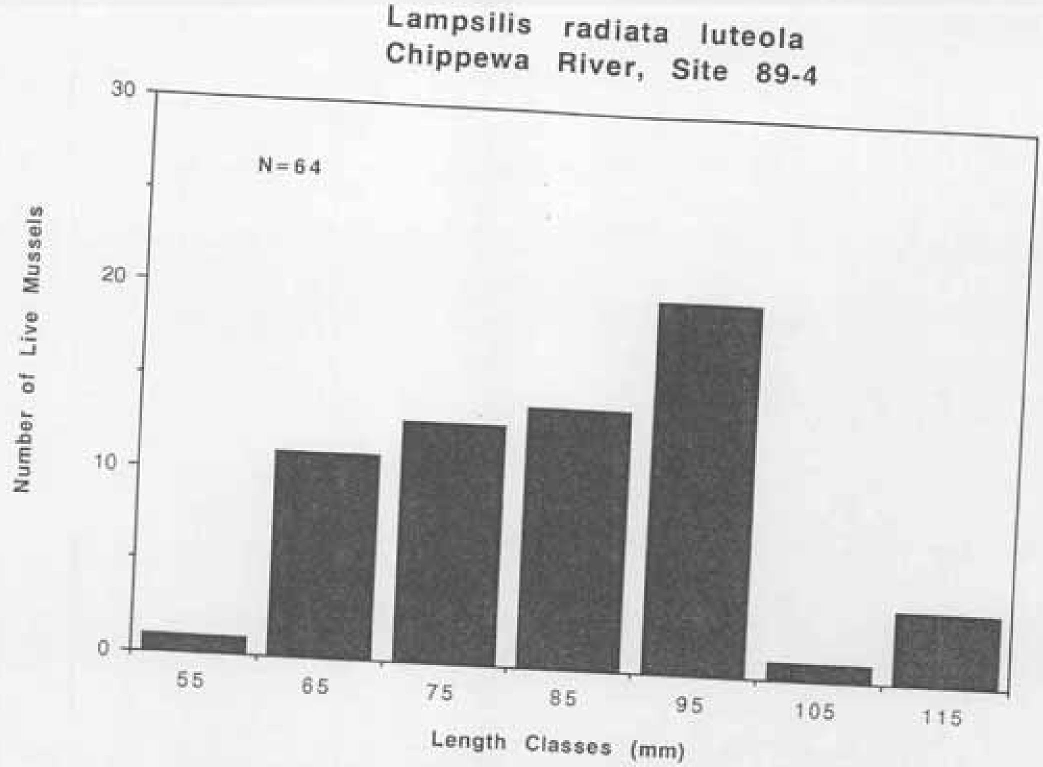
70

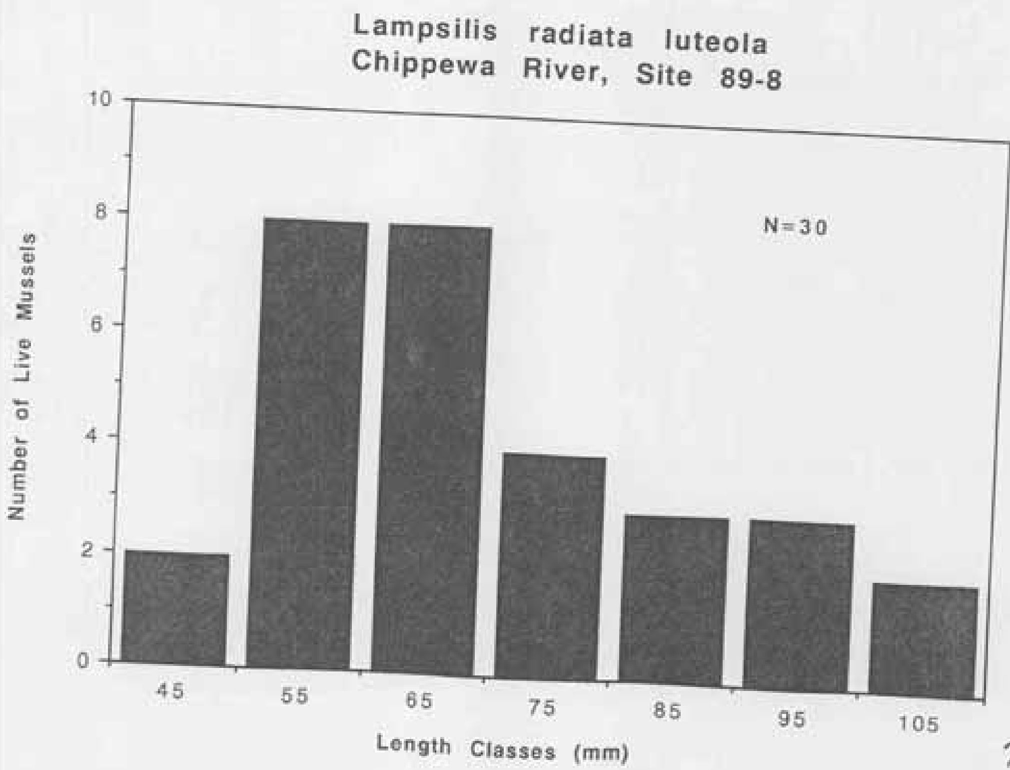
Figure 22b



71

Figure 22c

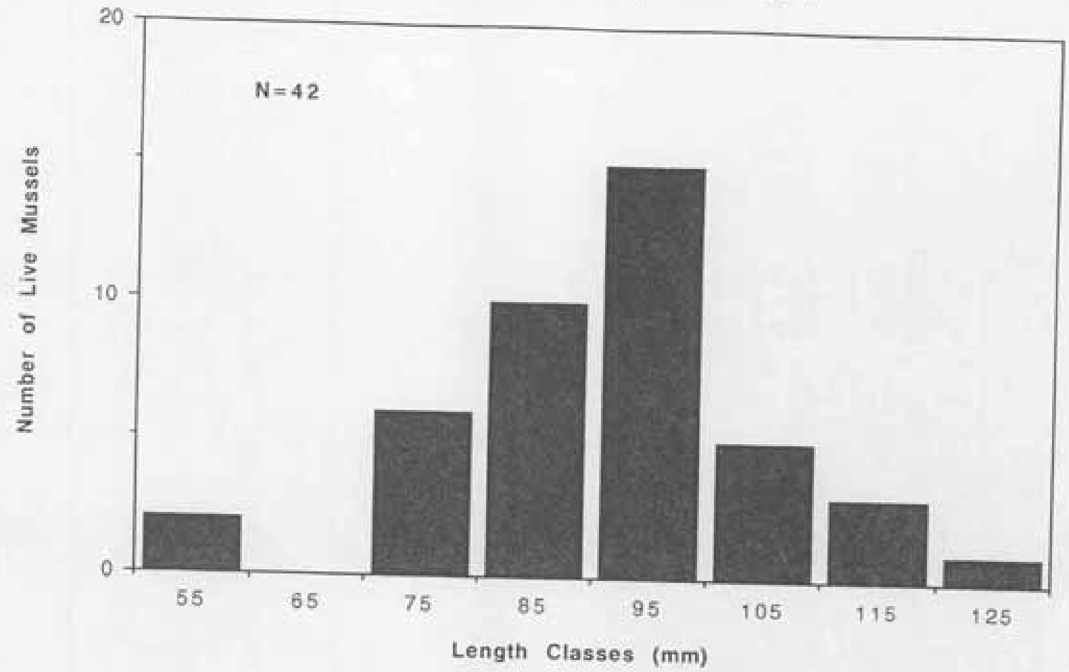




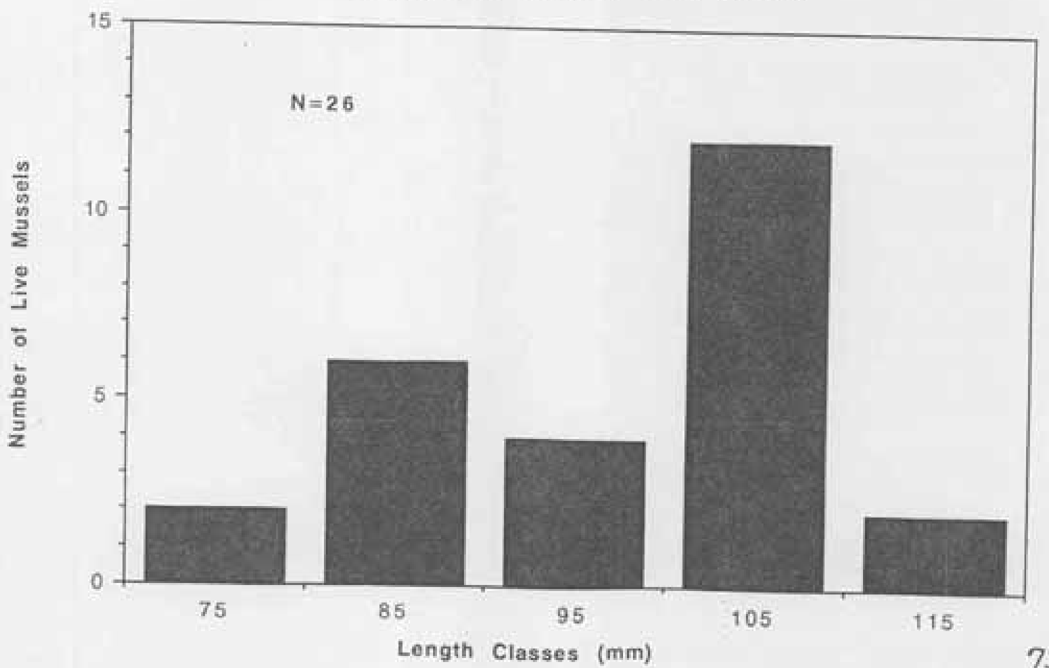
72

Figure 22d

Lampsilis radiata luteola
Chippewa River, Site 89-9

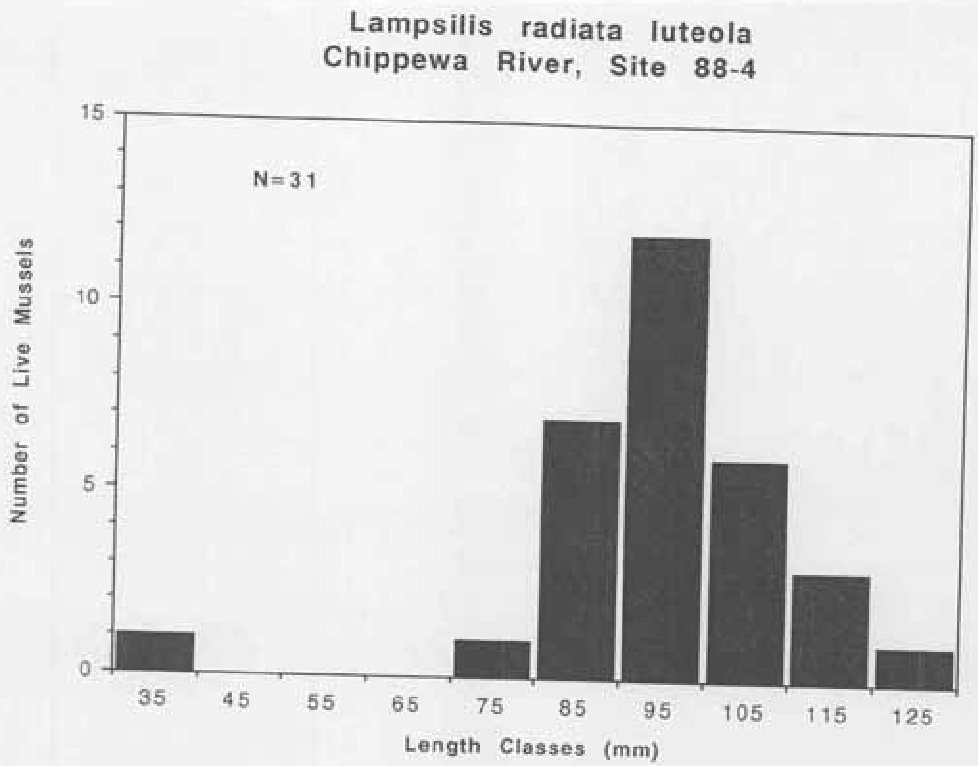


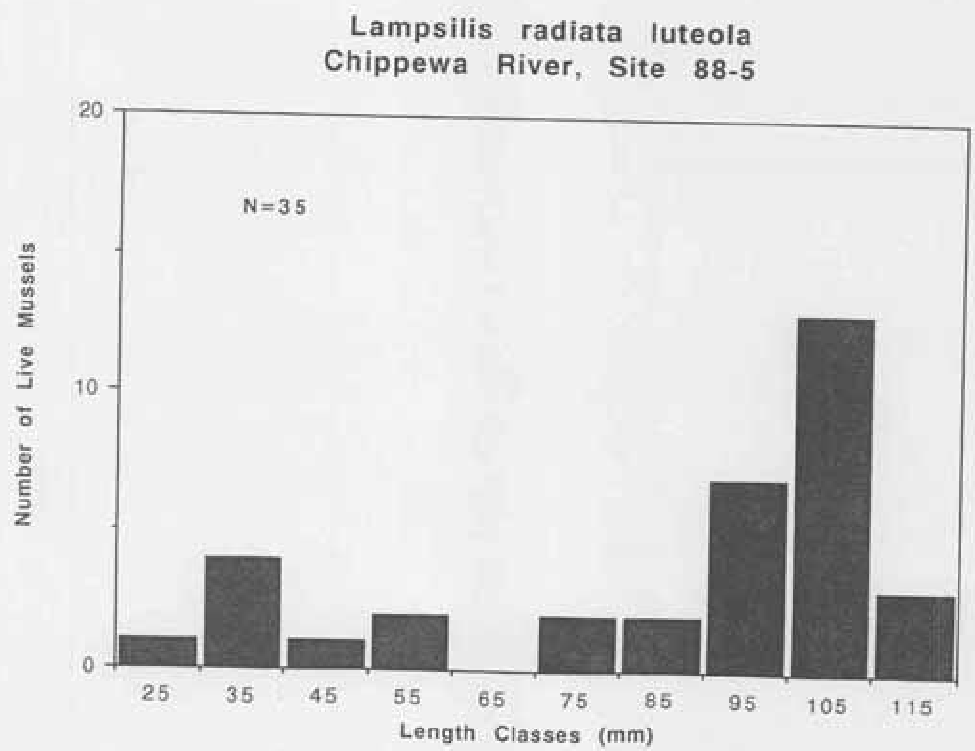
Lampsilis radiata luteola
Chippewa River, Site 89-10



73

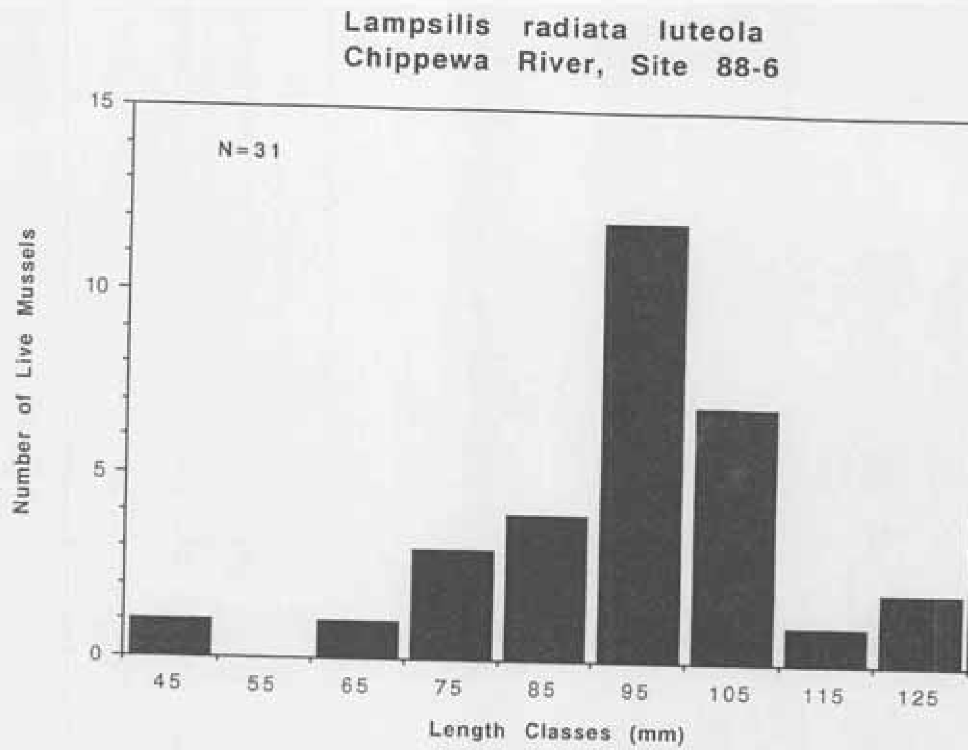
Figure 22e

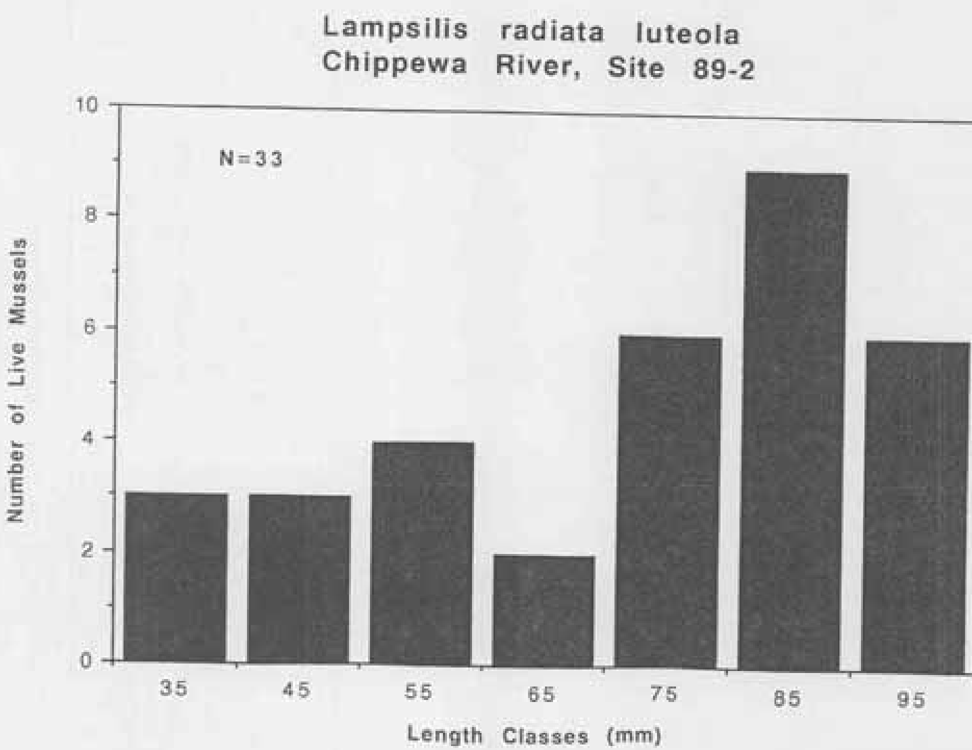




74

Figure 22f





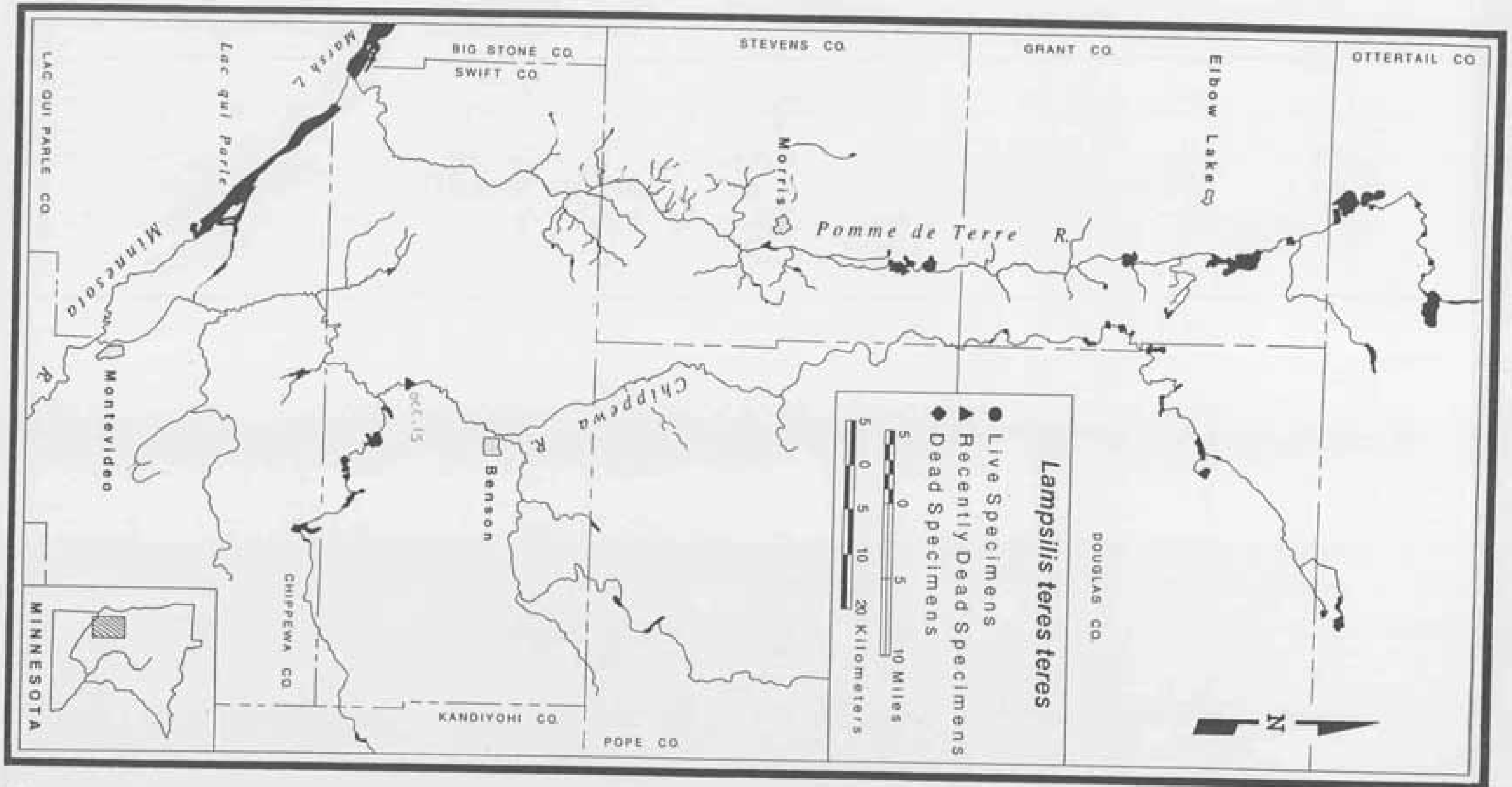
75

Figure 22g.

of recruitment at some sites in 1988 and 1989, but also reported missing the 1 to 3 year old classes in 1989 (Figure 22 d-e). Low flows certainly affected recruitment, but we also suspect difficulty in locating juveniles responsible for missing length classes at some sites. The maximum individual age was approximately 18 years. No differences in distribution were noted between 1988 and 1990 (Plate 9). We found L. r. luteola common and stable in the Chippewa River. However, Bright et al. (1990) found only dead specimens of L. siliquoidea in the Minnesota River near and downstream of Montevideo. Therefore, it is likely vulnerable to some level of environmental pressures, such as siltation or changes in water chemistry.

Lampsilis teres (yellow sandshell)

Only one recently dead specimen of L. teres was found in the Chippewa River at site 90-42 (Plate 1Q). Bright et al. (1990) reported only dead specimens of L. teres in the Minnesota River and these were found at Granite Falls, which is downstream of the mouths of both the Pomme de Terre and Chippewa Rivers. The oldest records of L. teres in the Chippewa River are from 1985 and 1988 (Bell Museum Collections). Four of its fish hosts occur in the Chippewa River and six of its fish hosts occur in the Pomme de Terre River (Fuller 1974, Bell Museum Collections). L. teres probably never occurred in the Pomme de Terre River and is extirpated in the Chippewa River.



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 10

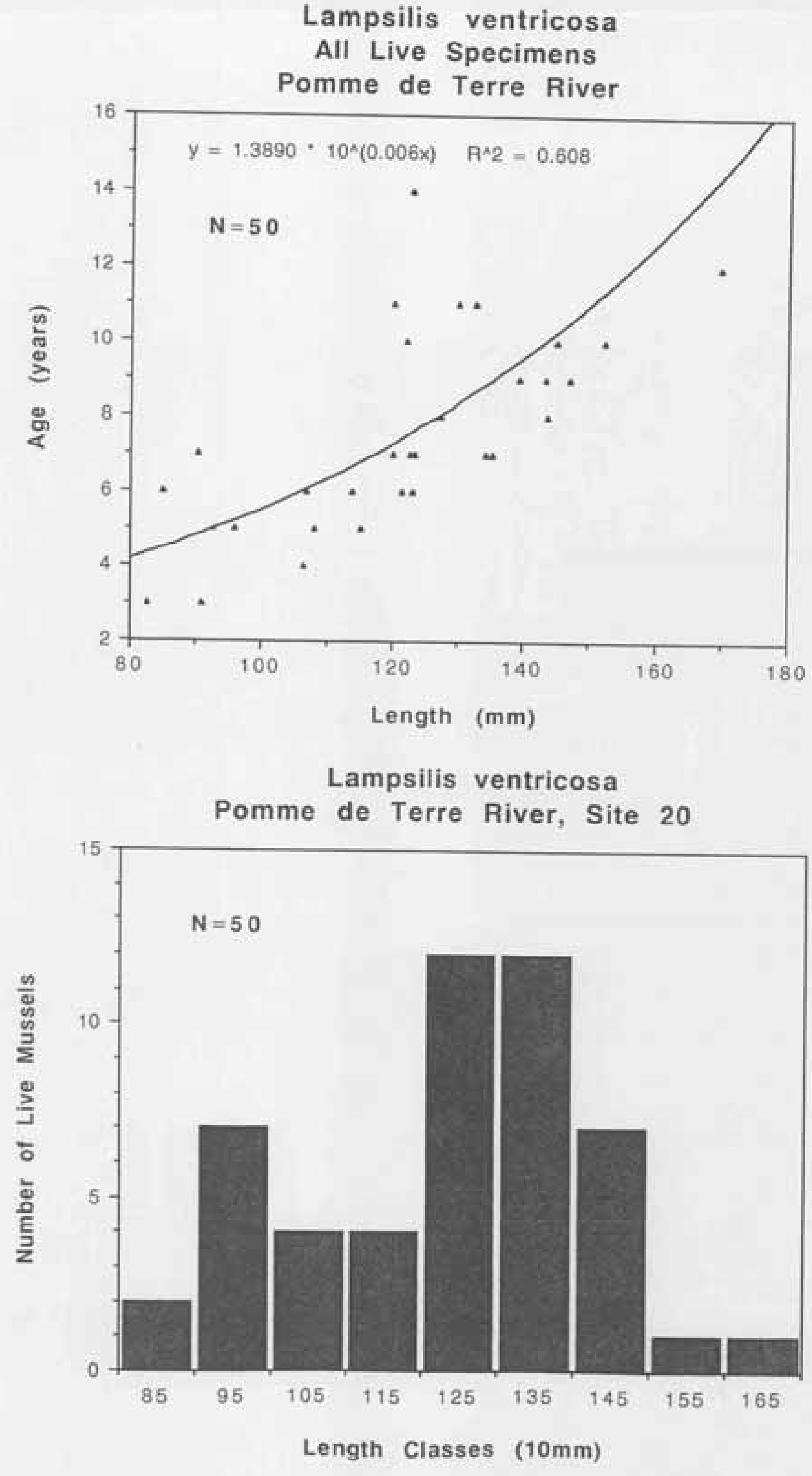
Lampsilis ventricosa (pocketbook)

L. ventricosa was found live only at site 90-20, near the mouth of the Pomme de Terre River but dead specimens were found as far upstream as site 90-11, near Barrett, MN (Plate 11, Figure 4). Therefore, L. ventricosa appears to have had a wider range in the recent past but is now limited to the very end of the Pomme de Terre River. In total, 50 specimens were collected at site 90-20, comprising 3 % of the mussel fauna in the river (Figure 5). L. ventricosa was found in silt, sand and pebble substrates (Figure 9). Fish hosts occur in the Pomme de Terre River. However, recruitment was modest if at all. The youngest individuals found were estimated at 3 years of age (Figure 23). Bright et al. (1990) found only dead specimens in the Minnesota River (Marsh Lake) near the mouth of the Pomme de Terre but found live L. ventricosa just upstream of Marsh Lake and occasionally downstream of Granite Falls. We speculate that recruitment is being hindered by the lack of a locally effective population size, or that poor water quality and unsuitable habitat is limiting L. ventricosa in the Pomme de Terre River.

L. ventricosa was more abundant in the Chippewa River than in the Pomme de Terre, but occurred only in the lower half of the river (Plate 11, Figure 7). The distribution of live and dead shells indicated that L. ventricosa may have never occurred in the upper half of the Chippewa River. A total of 198 live specimens were found, comprising 5 % of the mussel fauna (Figure 8). L. ventricosa preferred smaller substrates with some combination of silt, sand, granules, and pebbles, but was occasionally found behind boulders and in

Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 11


Lampsilis ventricosa
All Live Specimens
Pomme de Terre River
y = 1.3890 * 10^(0.006x) R^2 = 0.608
N=50
Age (years)
Length (mm)
Lampsilis ventricosa
Pomme de Terre River, Site 20
N=50
Number of Live Mussels
85
95
105
115
125
135
145
155
165
Length Classes (10mm)

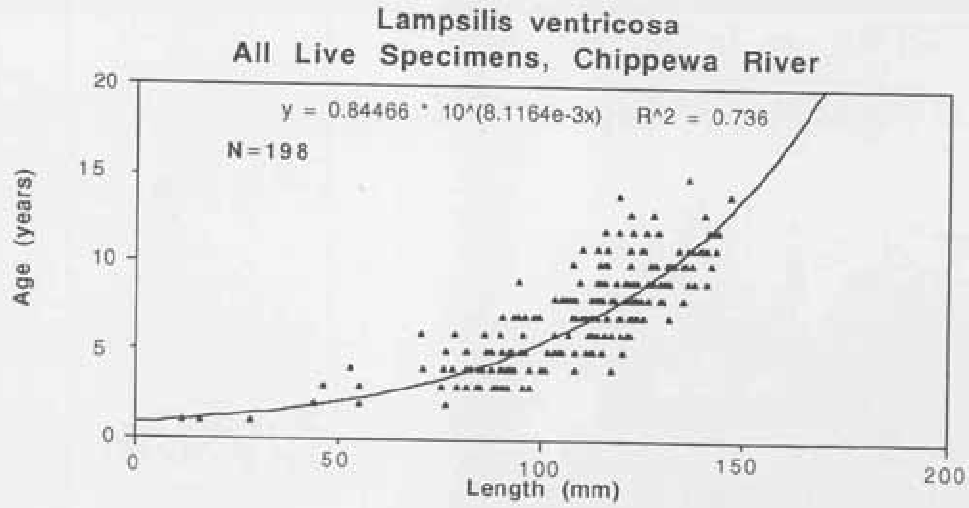
80

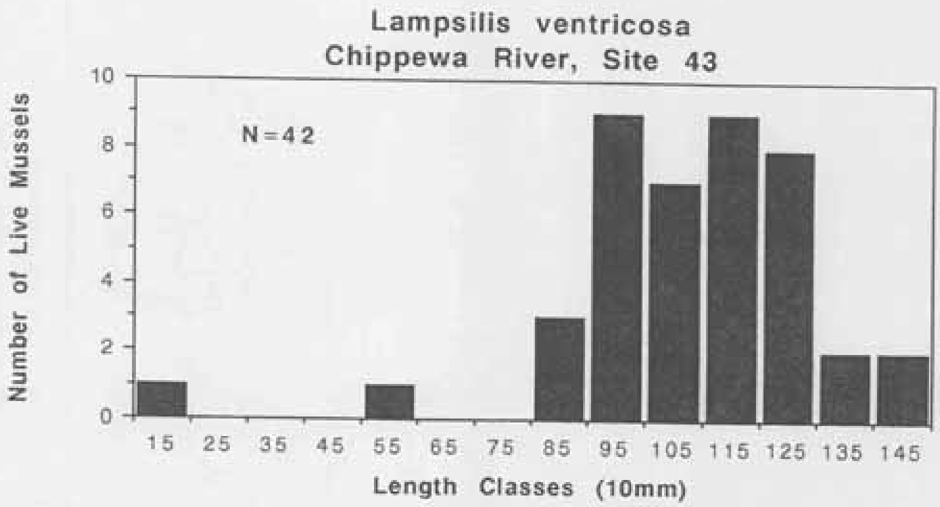
Figure 23

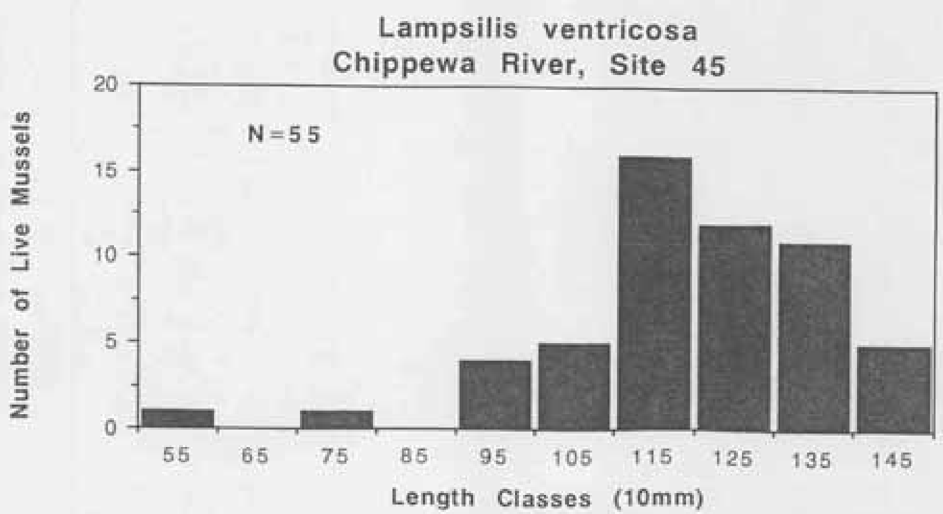
cobbles (Figure 14). L. ventricosa appears to be in decline. Ostlie found more specimens in 1988 (535) than were found in 1990 (198) (Figure 24a-c). In addition, sufficient quantities were found in 1988 to produce histograms at 5 sites; whereas, we could produce histograms at only 2 sites in 1990 (Figure 24b,c). Ostlie found recruitment at several sites in 1988. We found little evidence of recruitment in 1990. L. ventricosa may be hanging on in the Chippewa River, but was experiencing some trouble.

Lasmiqona complanata (white heelsplitter)

L. complanata was found live throughout the lower two-thirds of the Pomme de Terre (Plate 12, Figure 4). L. complanata was found recently dead at two sites, 90-23 and 90-16, where "piles of dead and dying clams" were noted by local residents during the droughts of 1988 and 1989 (Plate 12). Although 123 live specimens were found which comprised roughly 8% of the mussel fauna, sufficient quantities were found at only one site to produce a histogram (Figures 5 and 25). In general, we found little evidence of recruitment. The majority of individuals were over 3 years to a maximum of 15 years of age; one 2 year old was found at site 90-20 (Figure 25, Bright et al. 1994). Gravid females were not observed during our sampling season, which began on June 19, 1990. This was not surprising since L. complanata are gravid between September and April or May; releasing their glochidia in June (Baker 1928). Again, we suspect fluctuating river flows have affected the age distribution of this species, but do not rule out our difficulty in locating juveniles.

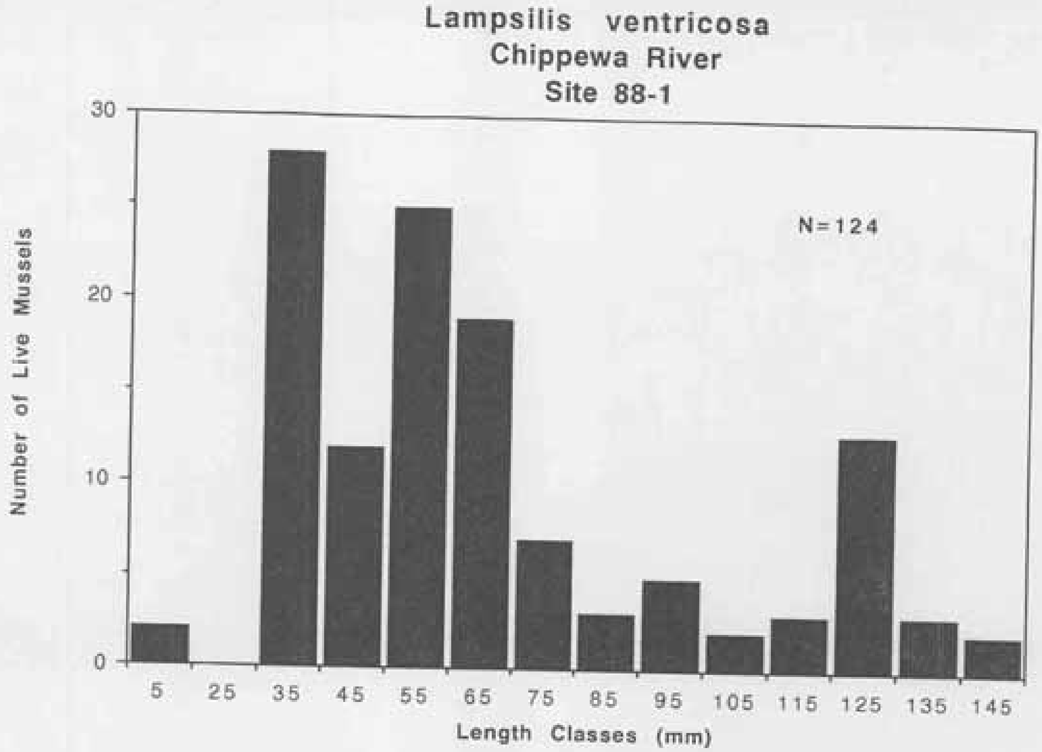


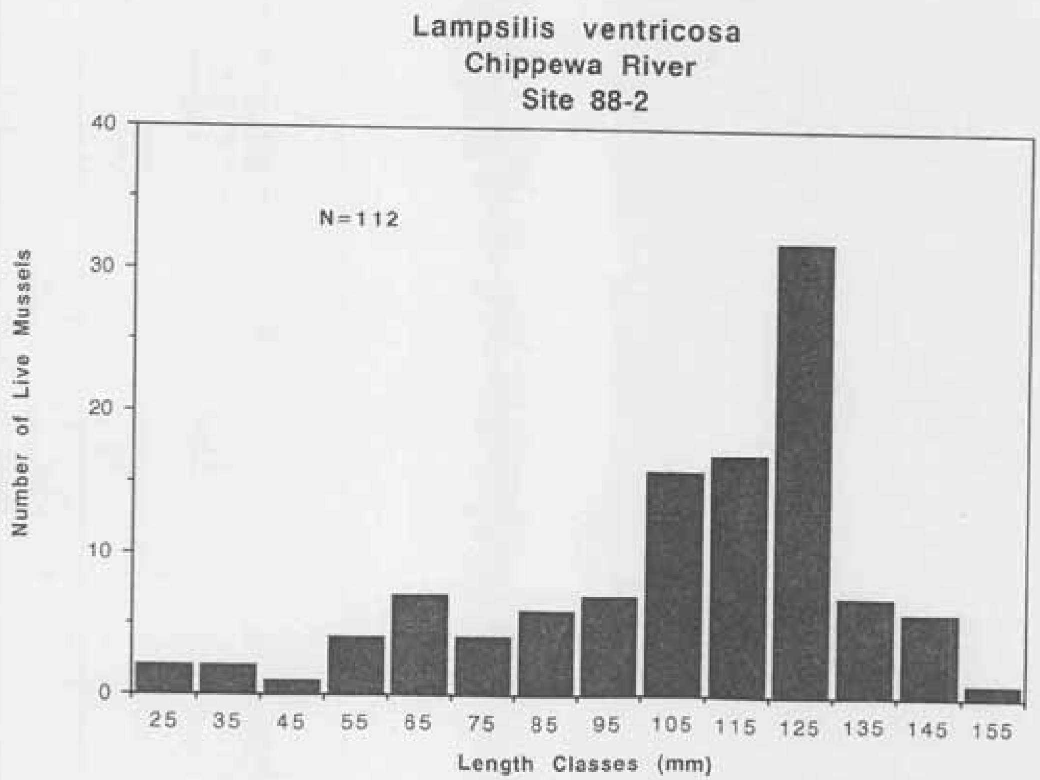




82

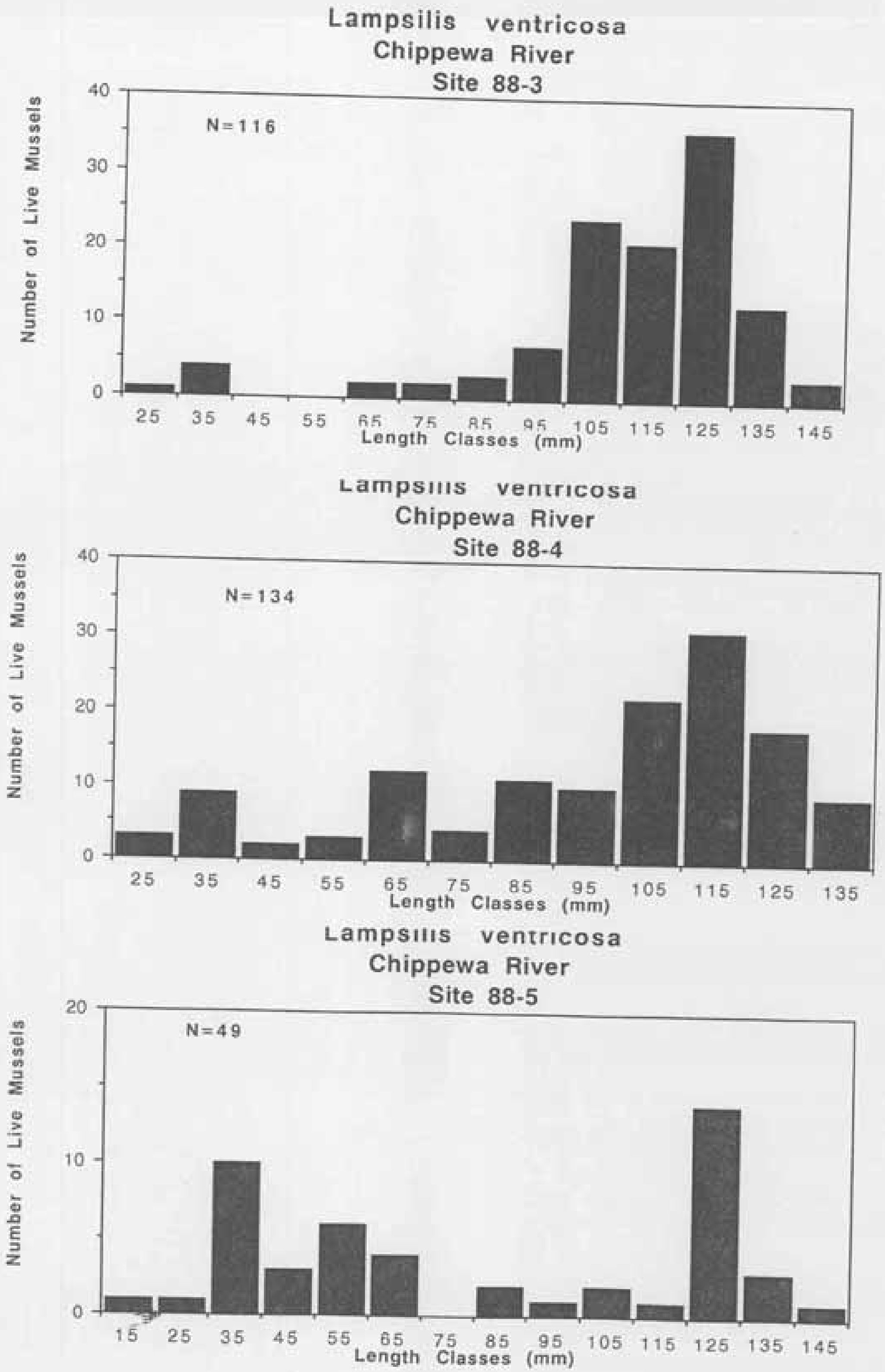
Figure 24a





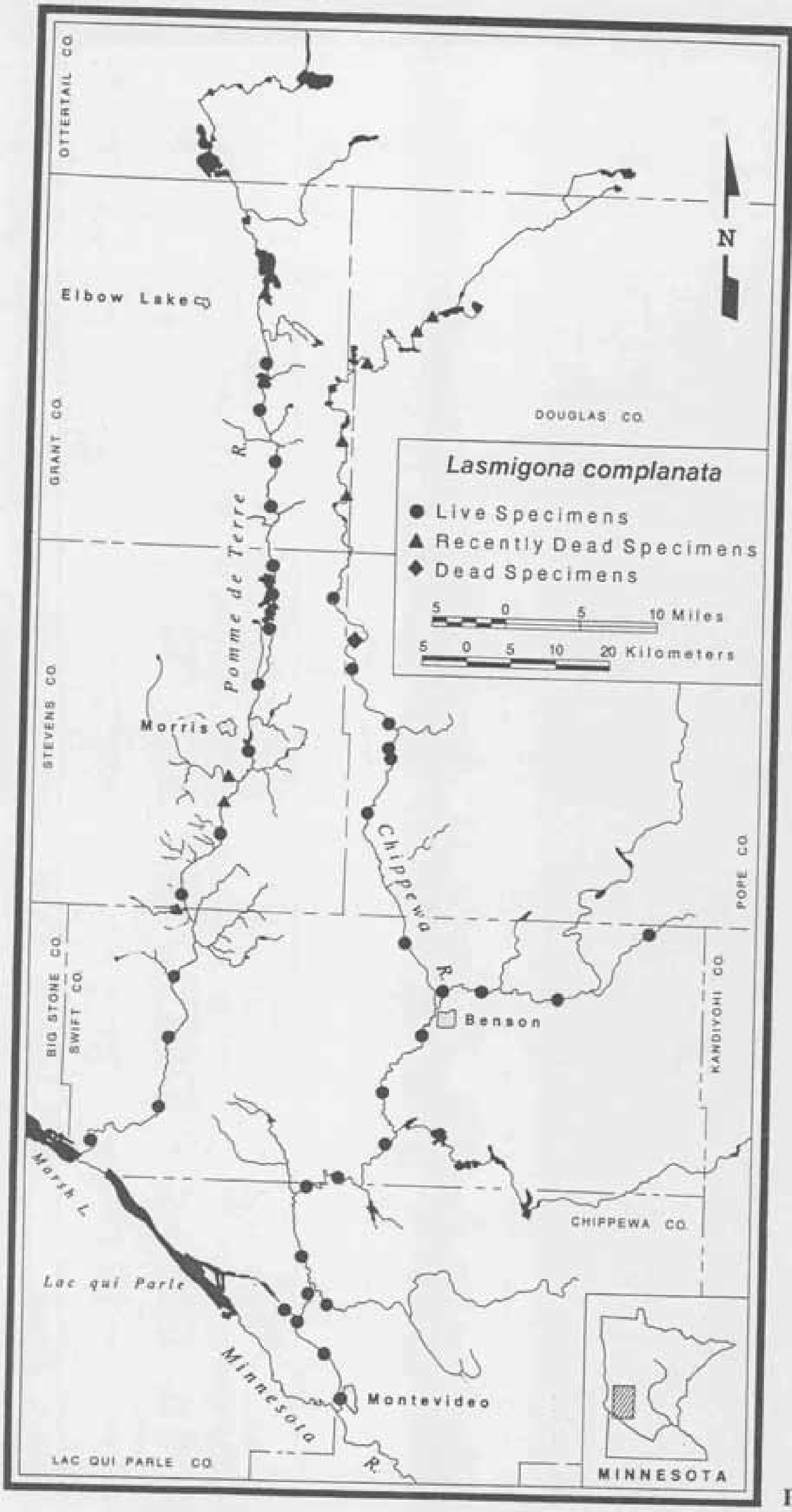
83

Figure 24b



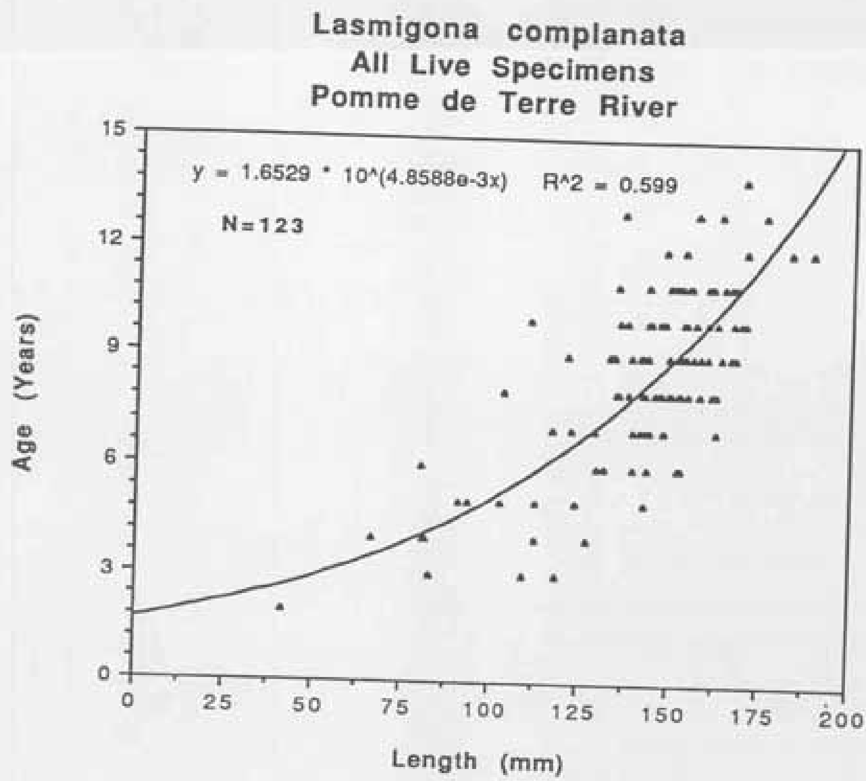
84

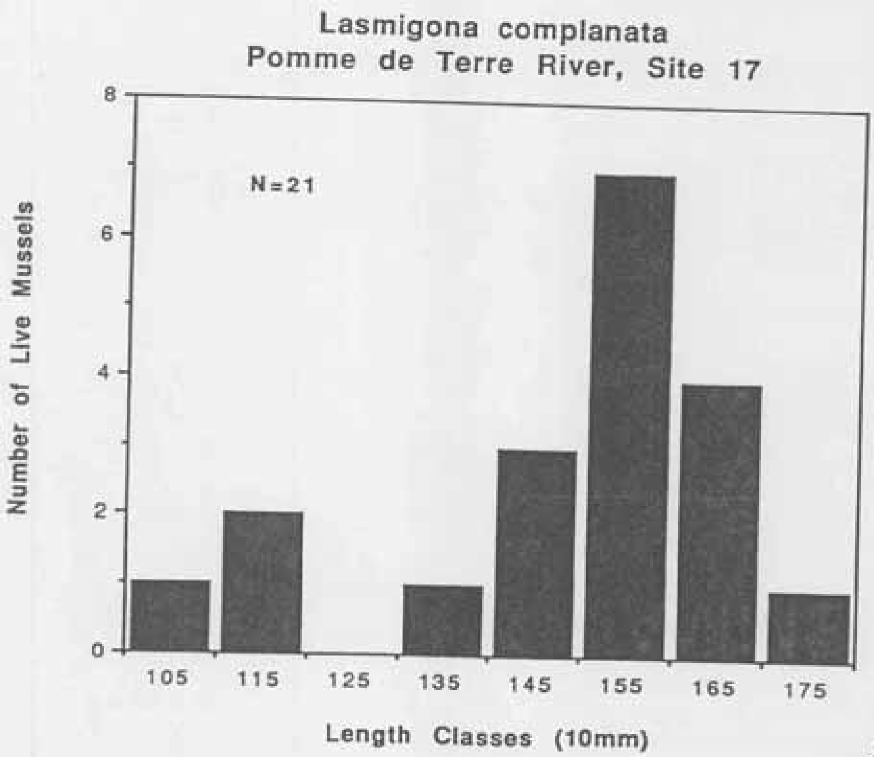
Figure 24 c



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 12


Lasmigona complanata
All Live Specimens
Pomme de Terre River
y = 1.6529 * 10^(4.8588e-3x) R^2 = 0.599
N=123
Age (Years)
Length (mm)
0
3
6
9
12
15
0
25
50
75
100
125
150
175
200

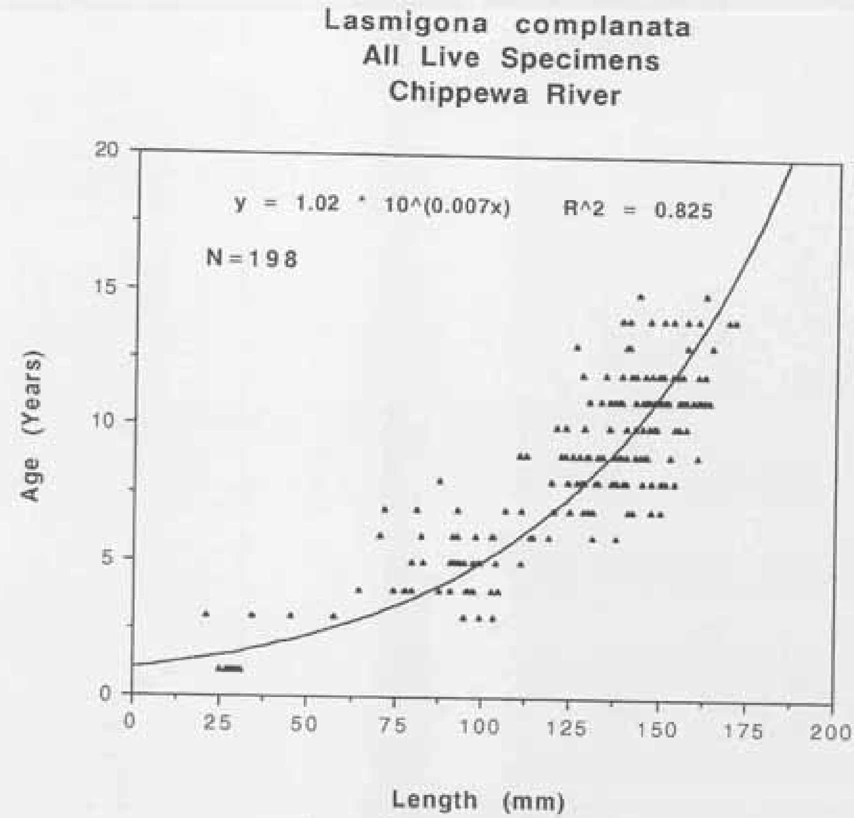

Lasmigona complanata
Pomme de Terre River, Site 17
N=21
Number of Live Mussels
Length Classes (10mm)
0
2
4
6
8
105
115
125
135
145
155
165
175

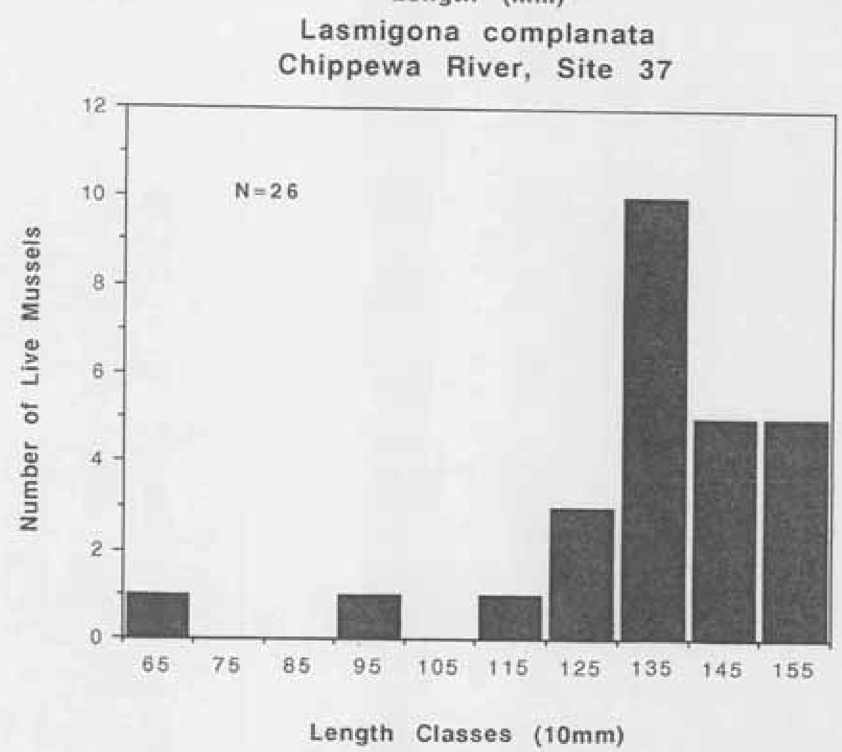
86

Figure 25

L. complanata was found primarily in sand, pebbles and cobbles, and occasionally in silt in combination with larger-sized sediment particles (Figure 9). L. complanata was common and may be troubled in the Pomme de Terre River (Figures 7 and 8). A comparison of the number of dead shells with the number of live specimens indicates that it has never been overly abundant in the river (Table 2).

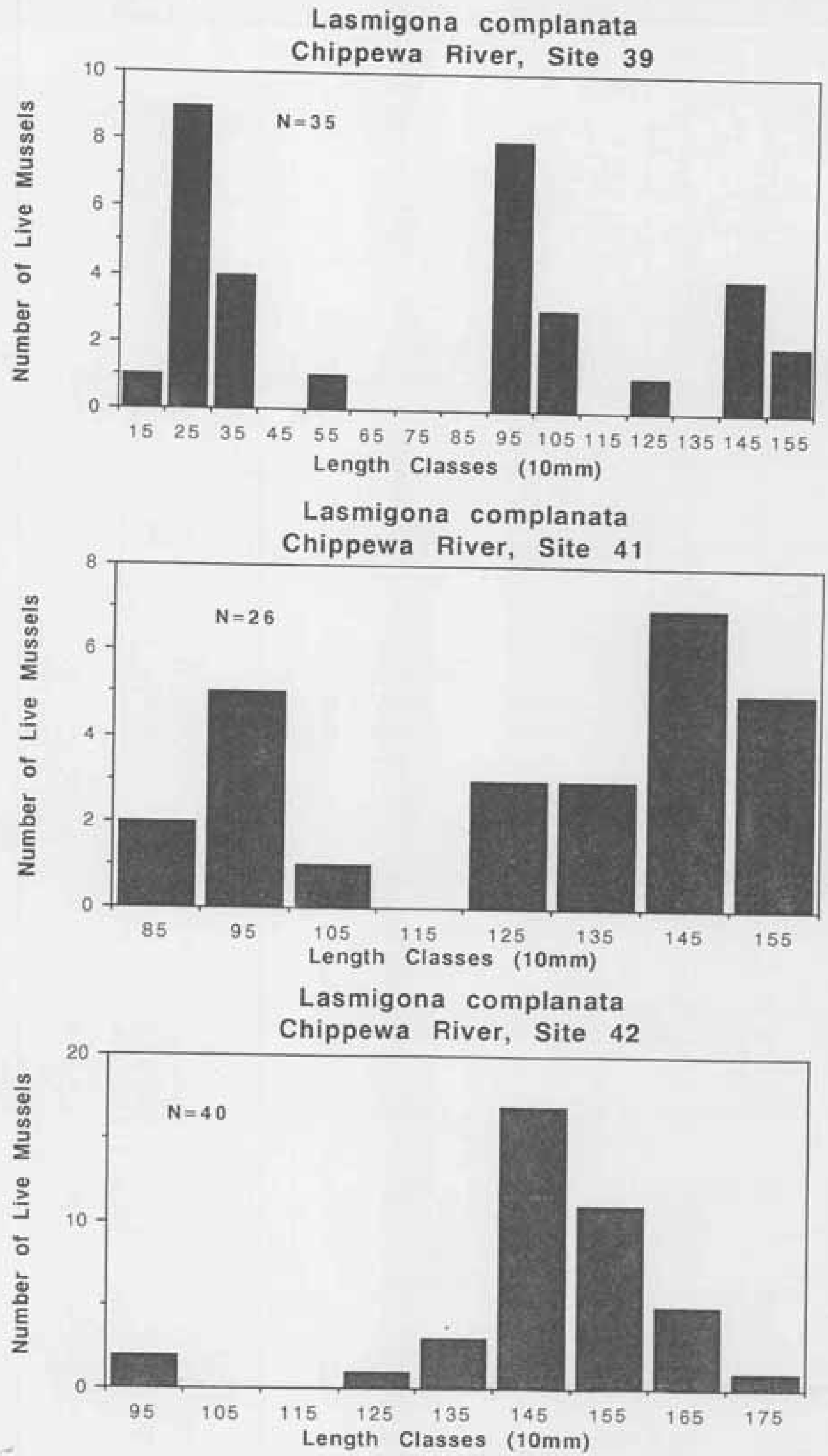
L. complanata was found throughout the Chippewa River and in the East Branch (Plate 12). However, only dead specimens were found in the upper third of the Chippewa River. According to several local residents near site 9028, "the river was just a trickle last summer [1989] . . . raccoons had a field day with the mussels" and near site 90-29, " the river was dry last summer [1989] . . . there were occasional pools filled with clams". We found no live mussels above site 90-30 in Stevens Co, estimated river mile 67.6 (Plate 12). Therefore, we believe low flows in 1989 and 1988 caused mass mortality of mussels in the upper Chippewa. A total of 198 live individuals were found, comprising approximately 5% of the mussel fauna (Figure 8). L. complanata appeared common but may be troubled in the Chippewa River (Figure 7). A comparison of the number of dead shells with the number of live specimens suggests that it hasn't been overly abundant in the past few decades (Table 2). L. complanata was found in sandy substrates in combination with granules, pebbles, cobbles, and silt (Figure 13). Recruitment was evident only at sites 90-39 and 88-1 (Figures 26a-c). Age/length regressions indicated the majority of specimens found in 1990 were 4 to 15 years of age. It is likely that reproduction and recruitment was taking place at other sites in the Chippewa River, but just enough to maintain local populations.





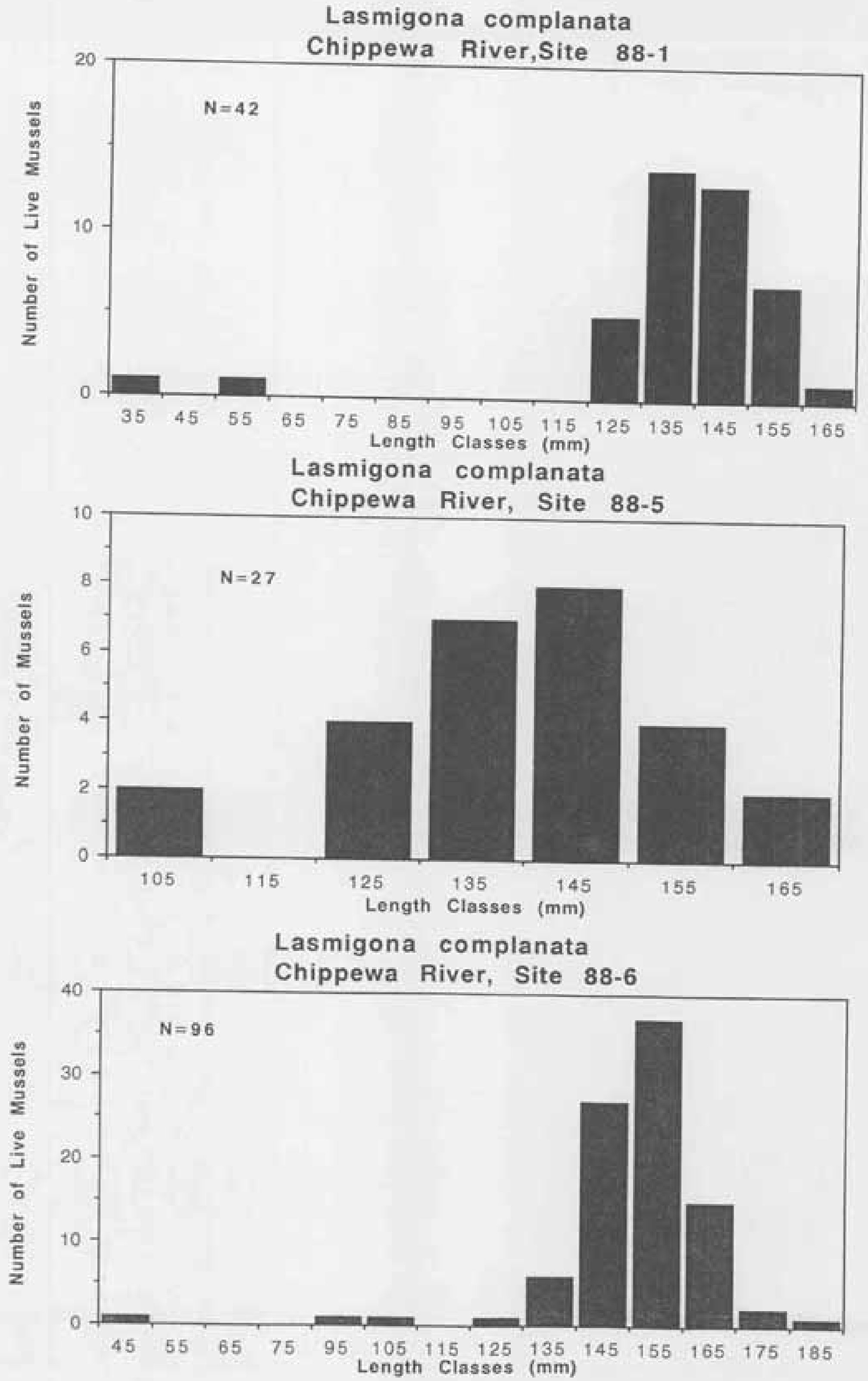
88

Figure 26a



89

Figure 26 b



90

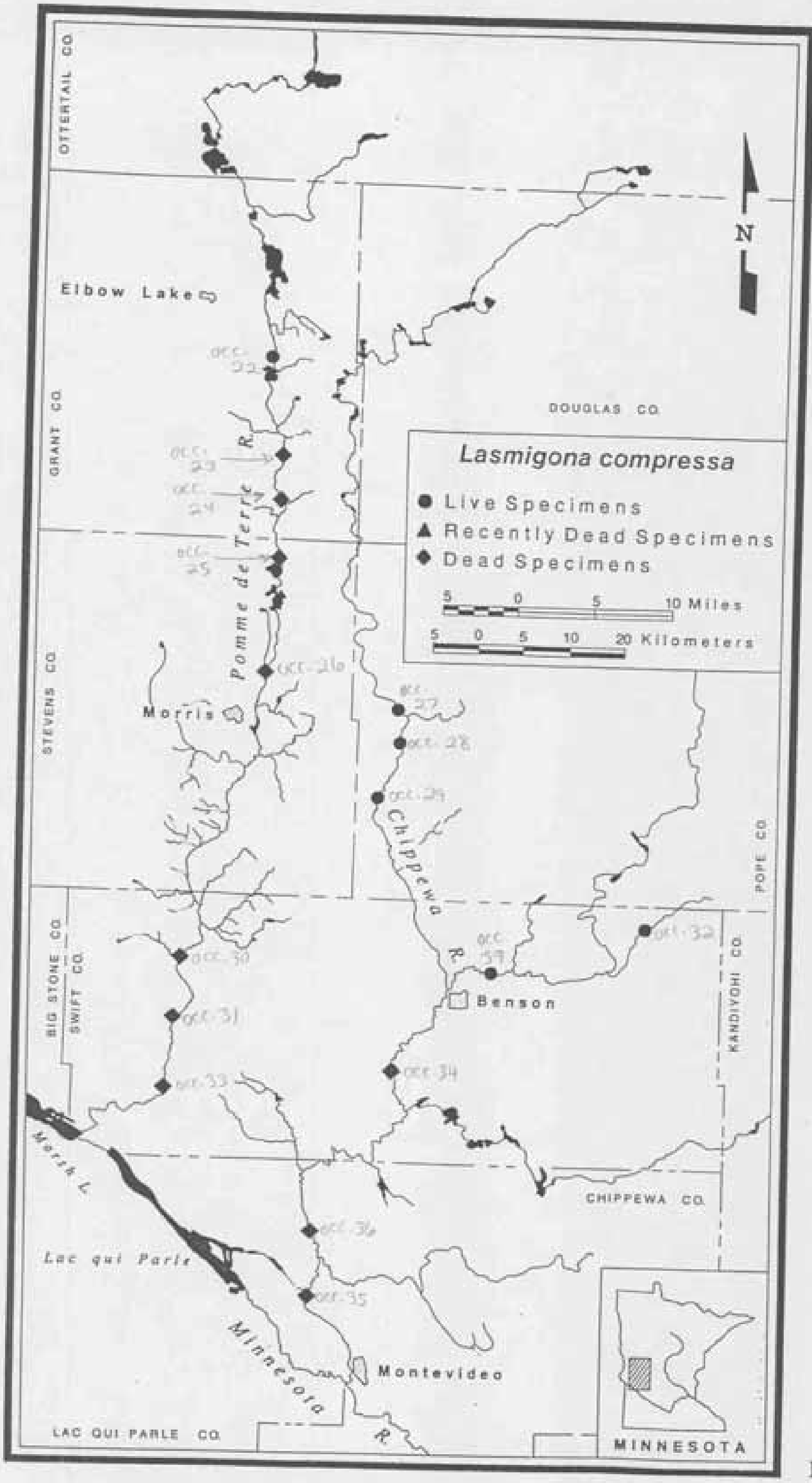
Figure 26c

Lasmigona compressa (creek heelsplitter)

Based upon the distribution of live and dead shells observed in 1990, L. compressa appears to have had a wider range but is now in risk of extirpation in the Pomme de Terre River (Plate 13). Only one live L. compressa was found in the Pomme de Terre River at site 90-10, estimated river mile 61.4 (Plate 13, Figure 4). Five live individuals were found in the Chippewa River. Interestingly, these were all found in the middle portion of the Chippewa river and in the East Branch and Mud Creek tributaries (Plate 13). These specimens were sized at 95.5 to 107.1 mm in length, and aged from 6 to 10 years (Bright et al. 1994). No recruitment was evident. This species appears to be in jeopardy of extirpation in the Chippewa River as well (Figures 7 and 8). Two of the four known fish hosts for L. compressa are known from the Pomme de Terre and Chippewa Rivers (Hove et al. 1995, Bell Museum Collections). Thus, fish host availability was not limiting L. compressa's distribution.

Lasmigona costata (fluted-shell)

L. costata appears extirpated in both the Pomme de Terre and Chippewa Rivers (Plate 14). Because only dead shells were found at one site in the Pomme de Terre River and at two sites in the Chippewa River, it is questionable whether L. costata was ever established in these rivers or if these finds were introductions due to fish stocking. Bright et al (1990) reported L. costata extirpated in the Minnesota River, and that it was once only sparingly established in the Minnesota River.



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 13

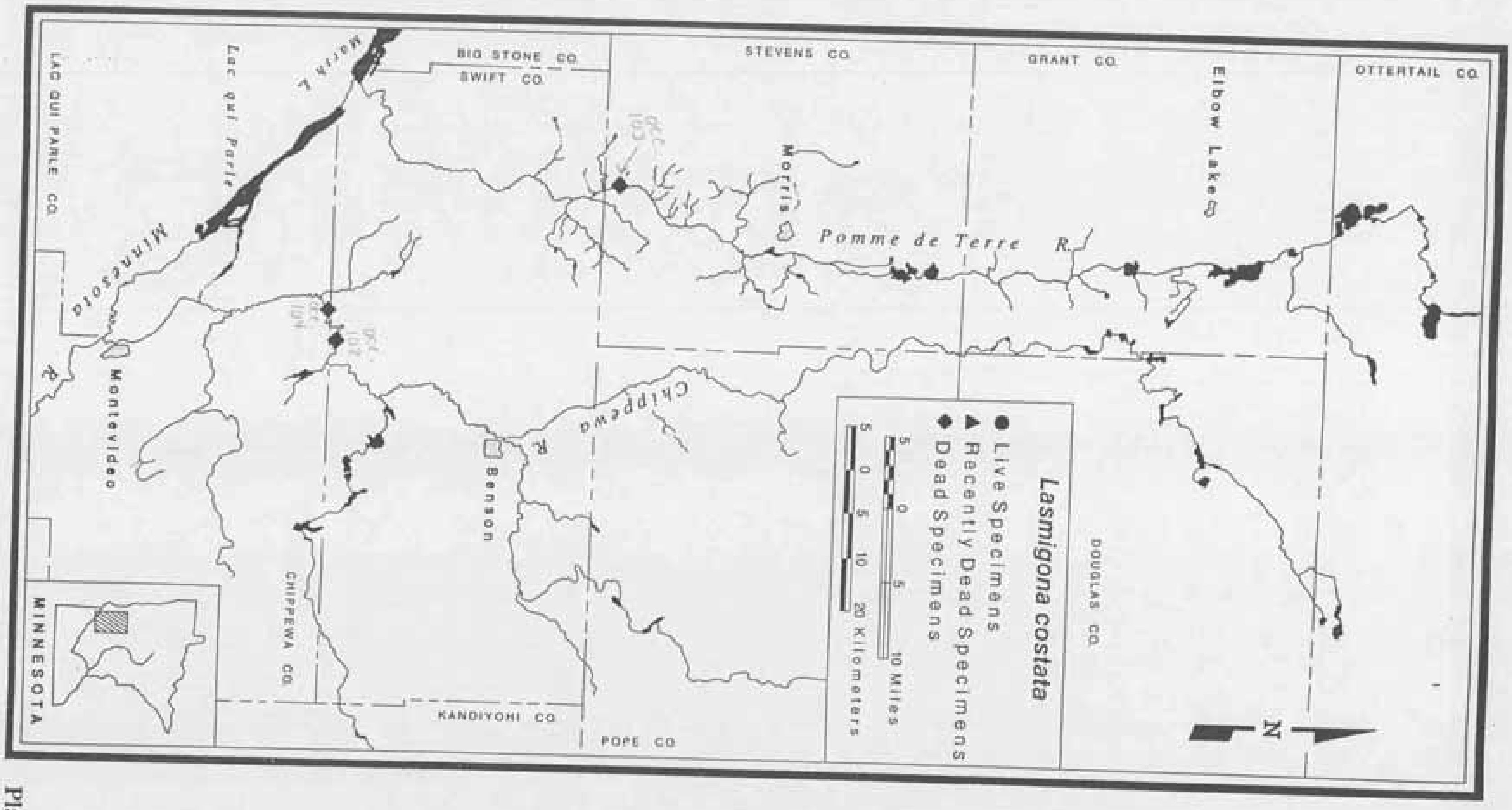


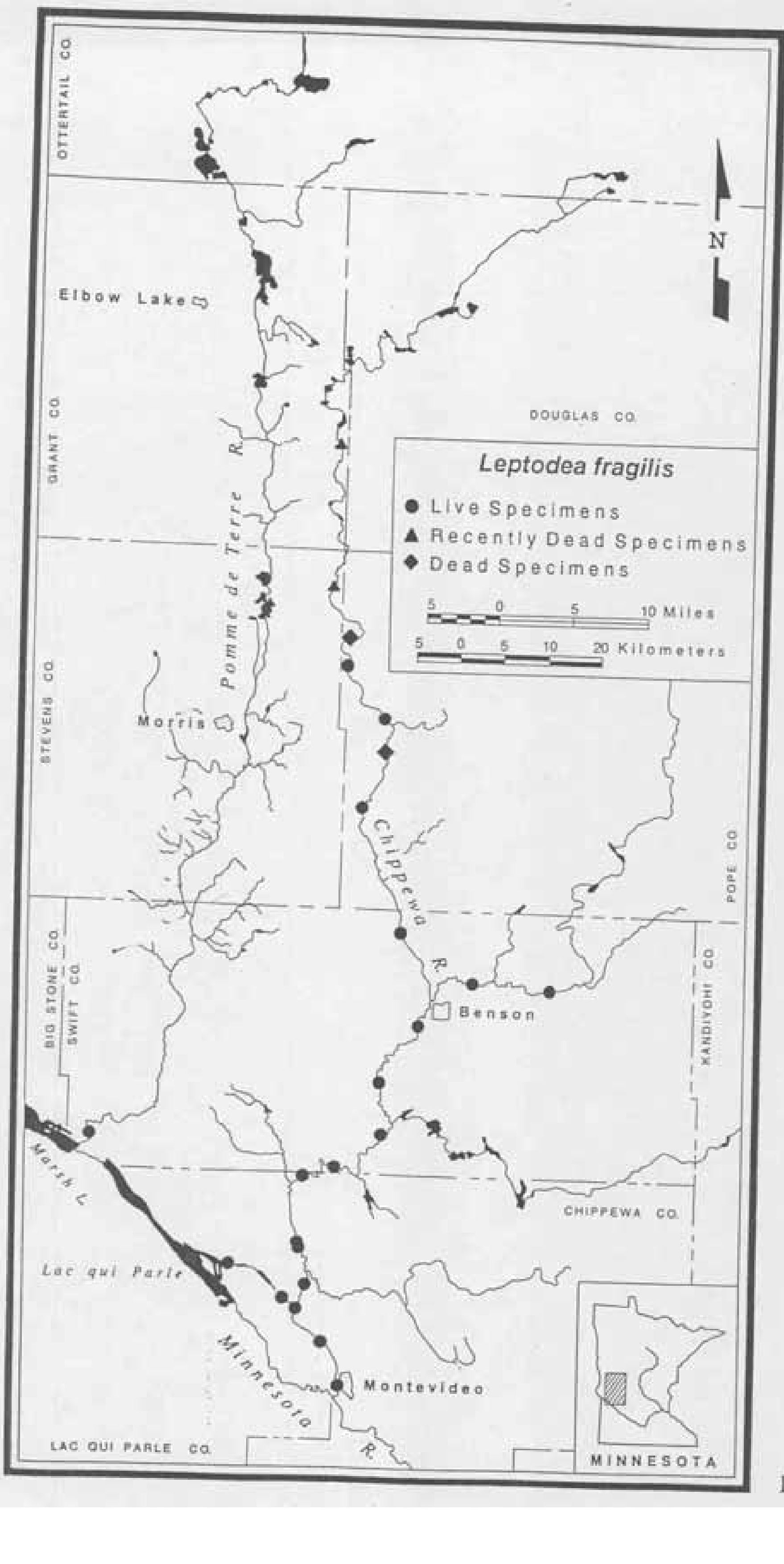
Plate 14

Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Leptodea fragilis (fragile papershell)

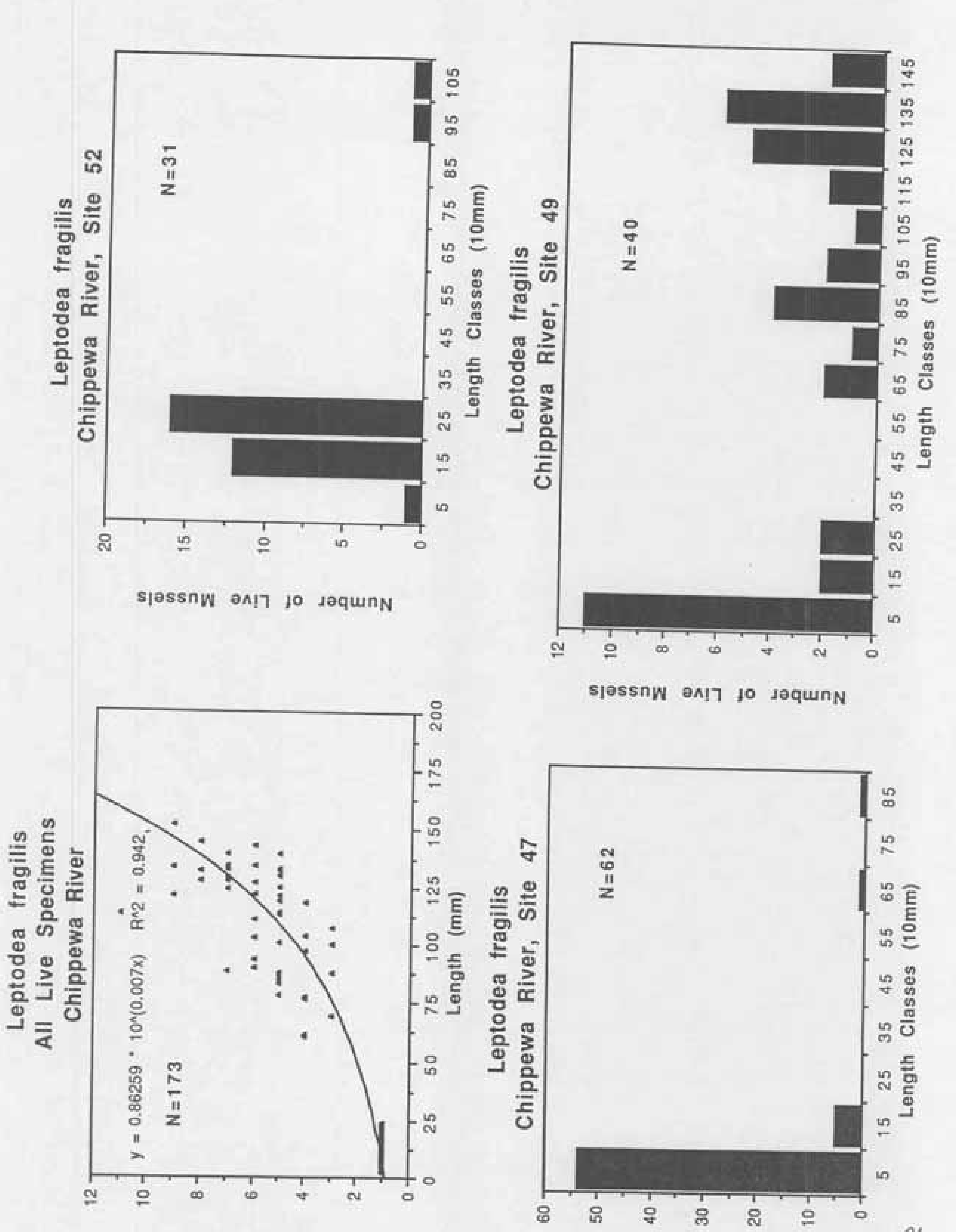
In the Pomme de Terre, L. fragilis was limited to the lower end of the river, near Marsh Lake (Plate 15). Aplodinotus grunniens. (Freshwater Drum), the only known fish host for L. fragilis has not been reported in the Pomme de Terre River (Bell Museum Collections). However, it has been reported in the Minnesota River in Lac Qui Parle County. Therefore, it was not surprising that L. fragilis was found at the mouth of the Pomme de Terre River, where it joins the Minnesota River, and found nowhere else in the Pomme de Terre River. Gravid females were observed at site 90-20 (Bright et al. 1994).

Since the freshwater drum has been reported in the Chippewa River, the presence of L. fragilis in the Chippewa River was expected (Plate 15, Bell Museum Collections). A total of 173 individuals were collected, comprising approximately 4% of the total mussel fauna (Figure 8). A comparison of the number dead shells with number of live specimens indicates that it was probably not formerly abundant in the Chippewa River (Table 2). L. fragilis preferred silt and sandy substrates and occasionally pebbles and cobbles in combination with sand (Figure 13). Recruitment was evident at a couple of sites in the lower portion of the river and in the Watson Sag (Figure 27). Several age classes, representing the 2 to 3 year old, were missing. L. fragilis appears to be holding on, but based on the low numbers found at each site and poor recruitment, it could be in some trouble (Figure 7).



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 15



Leptodea fragilis
All Live Specimens
Chippewa River
y = 0.86259 * 10^(0.007x)   R^2 = 0.942
N=173
Age (years)
Length (mm)
Leptodea fragilis
Chippewa River, Site 52
N=31
Number of Live Mussels
Length Classes (10mm)
Leptodea fragilis
Chippewa River, Site 47
N=62
Number of Live Mussels
Length Classes (10mm)
Leptodea fragilis
Chippewa River, Site 49
N=40
Number of Live Mussels
Length Classes (10mm)

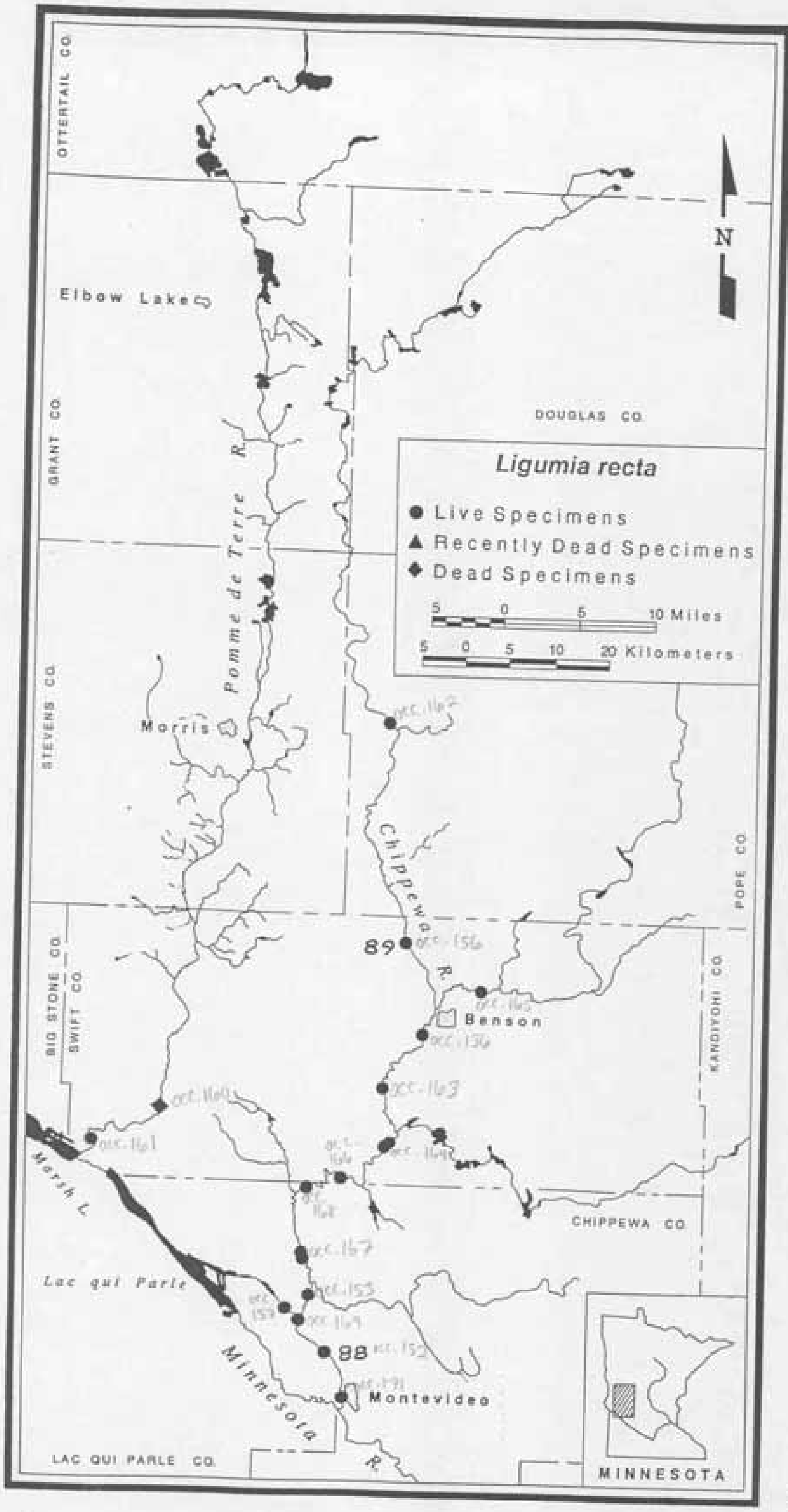
96

Figure 27

Ligumia recta (black sandshell)

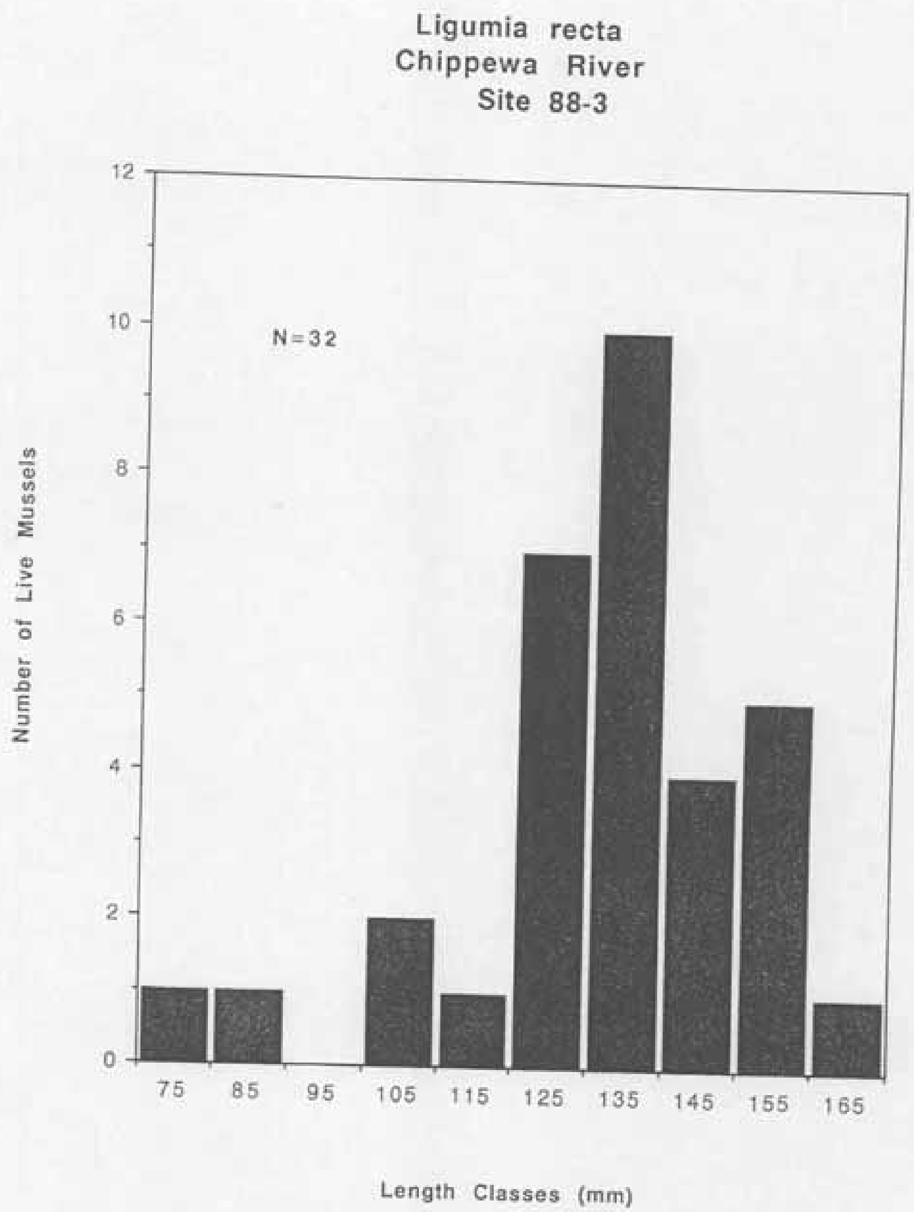
L. recta was rare in the Pomme de Terre River (Figure 4). Live L. recta was found only at site 90-20, near the mouth of the Pomme de Terre, comprising less than 1 % of the mussel fauna (Plate 16, Figure 5). L. recta was found in sandy substrates (Figure 9). Bright et al. (1990) reported that L. recta was formerly widespread in the Minnesota River but was in risk of extirpation. Fish hosts for L. recta are known to occur in the Pomme de Terre River and gravid females were noted at site 90-20. L. recta may be recolonizing the river, but the lack of dead specimens found in the middle to upper portions of the river indicates it was not formerly widespread in the Pomme de Terre River.

L. recta were found in the middle and lower portions of the Chippewa River (Plate 16). In total, 56 individuals were found, comprising approximately 1% of the mussel fauna (Figure 8). Sufficient quantities of live mussels were not found at any one site in 1990 to produce a length frequency histogram. Ostlie found 32 specimens at site 88-1, in 1988, and some evidence of recruitment (Figure 28). We found 11 at the same site (90-45), indicating that L. recta may be in decline. Gravid females with glochidia and eggs were noted in 1990 at several sites in the Chippewa River. In addition, "juveniles" aged 3 years, 98.5 to 105.5 mm in length, were found at several sites in 1990 indicating recruitment has occurred with in the last 3 years (Bright et al. 1994). However, the populations are so low, L. recta should be considered troubled.



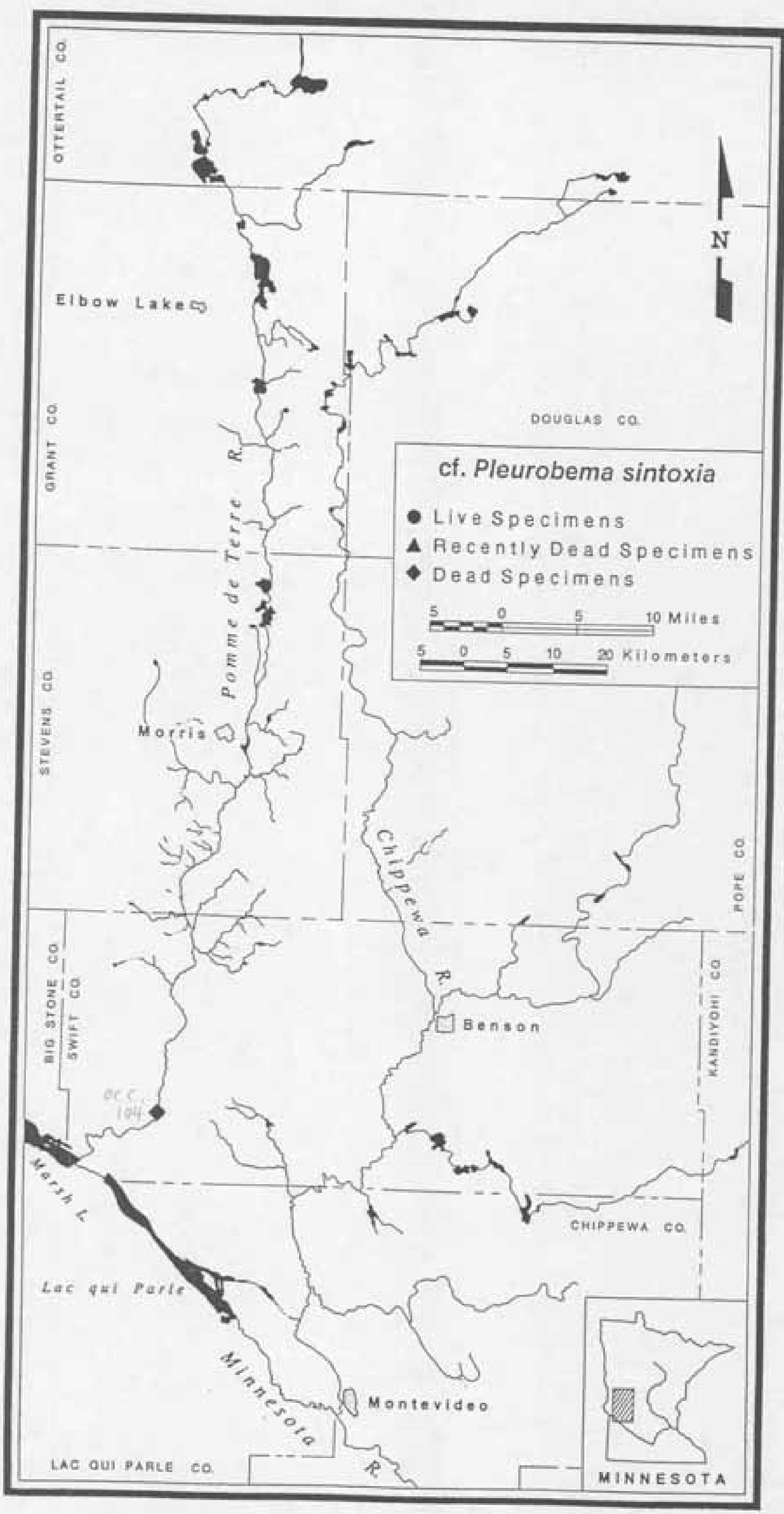
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 16


Ligumia recta
Chippewa River
Site 88-3
N=32
Number of Live Mussels
Length Classes (mm)
0
2
4
6
8
10
12
75
85
95
105
115
125
135
145
155
165

99

Figure 28



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

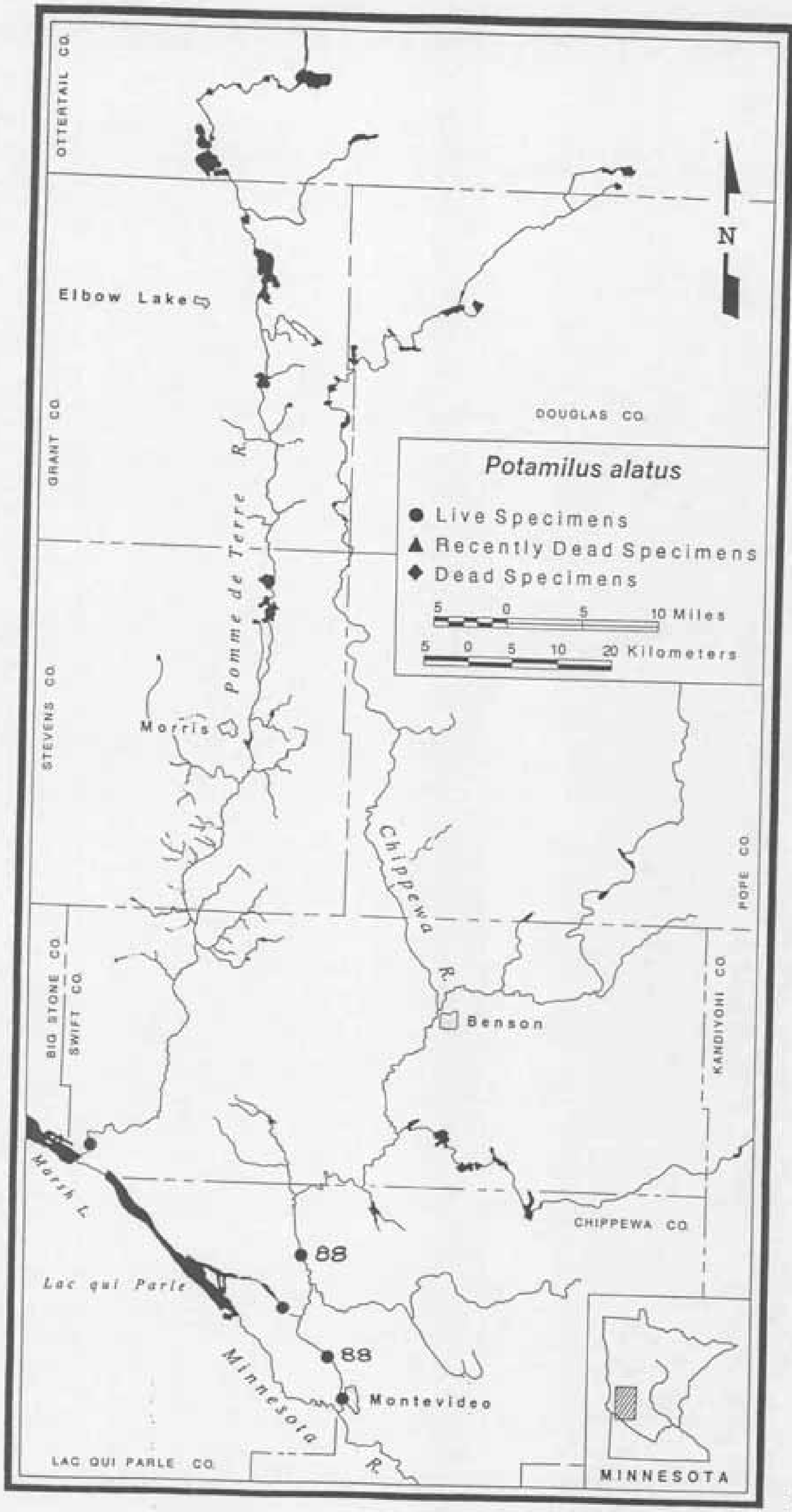
Plate 17

Pleurobema sintoxia (Ohio pigtoe)

P. sintoxia is known only from the Minnesota, Mississippi, and St. Croix Rivers in Minnesota (Bell Museum Collections). Only one dead record was found in the Pomme de Terre, and this identification is suspect (Plate 17). In addition, no live specimens were found in the Minnesota River in 1989, and no specimens (live or dead) were found above Montevideo (Bright et al. 1990). If it was ever established in the Pomme de Terre River, P. sintoxia is surely extirpated now.

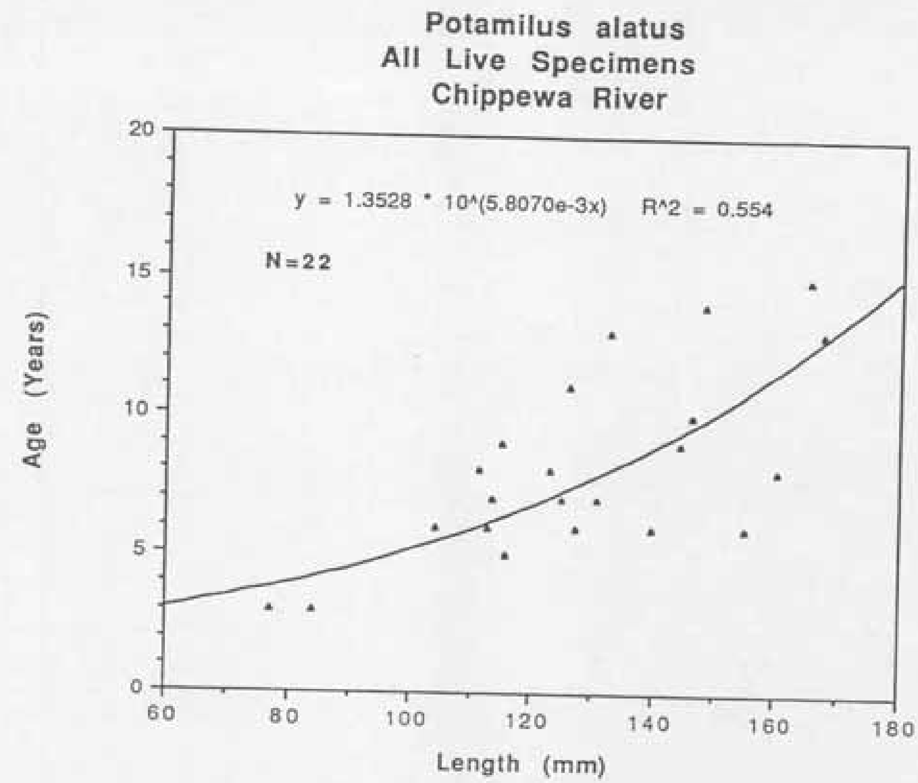
Potamilus alatus (pink heelsplitter)

In the Pomme de Terre, P. alatus, is limited to the lower end of the river, near Marsh Lake (Plate 18, Figure 4). Aplodinotus grunniens. (freshwater drum) is the only known fish host for P. alatus (Fuller 1974). The freshwater drum has not been reported (yet) in the Pomme de Terre River (Bell Museum Collections). However, it has been reported in the Minnesota River in Lac Qui Parle County (Bell Museum Collections). Therefore, it was not surprising that P. alatus was only found at the mouth of the Pomme de Terre River, where it joins the Minnesota River, and nowhere else. P. alatus was found in sand, granule, and pebbles (Figure 9). Gravid females were observed at site 90-20, indicating reproduction was occurring. The lack of live or dead specimens in the middle and upper reaches of the Pomme de Terre River indicates that P. alatus has



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 18


Potamilus alatus
All Live Specimens
Chippewa River
y = 1.3528 * 10^(5.8070e-3x) R^2 = 0.554
N=22
Age (Years)
Length (mm)
0
5
10
15
20
60
80
100
120
140
160
180

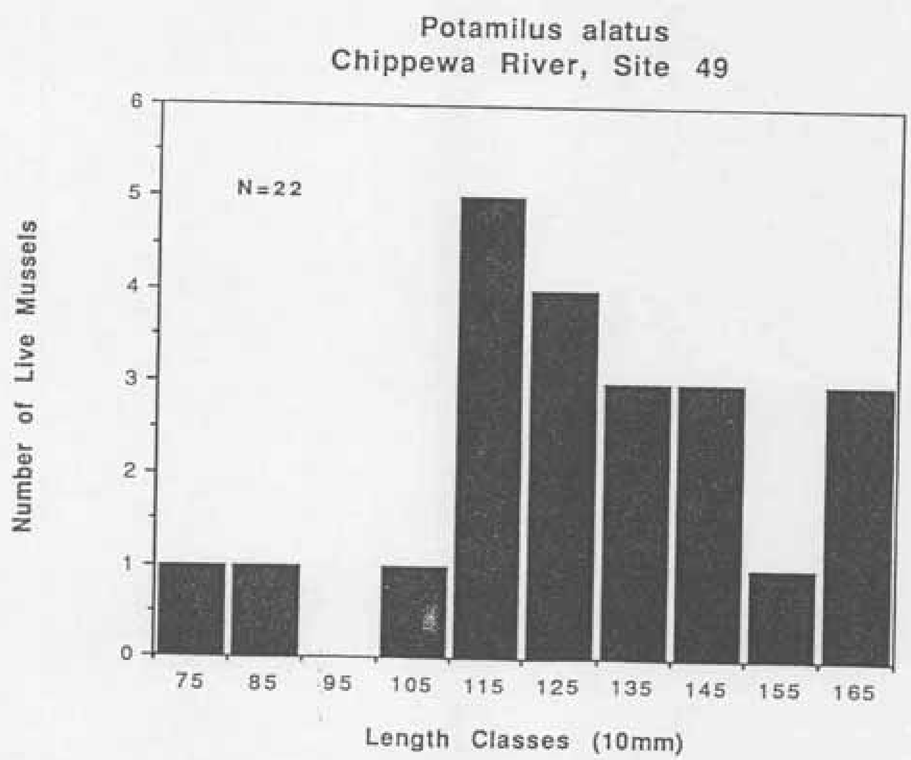

Potamilus alatus
Chippewa River, Site 49
N=22
Number of Live Mussels
Length Classes (10mm)
0
1
2
3
4
5
6
75
85
95
105
115
125
135
145
155
165

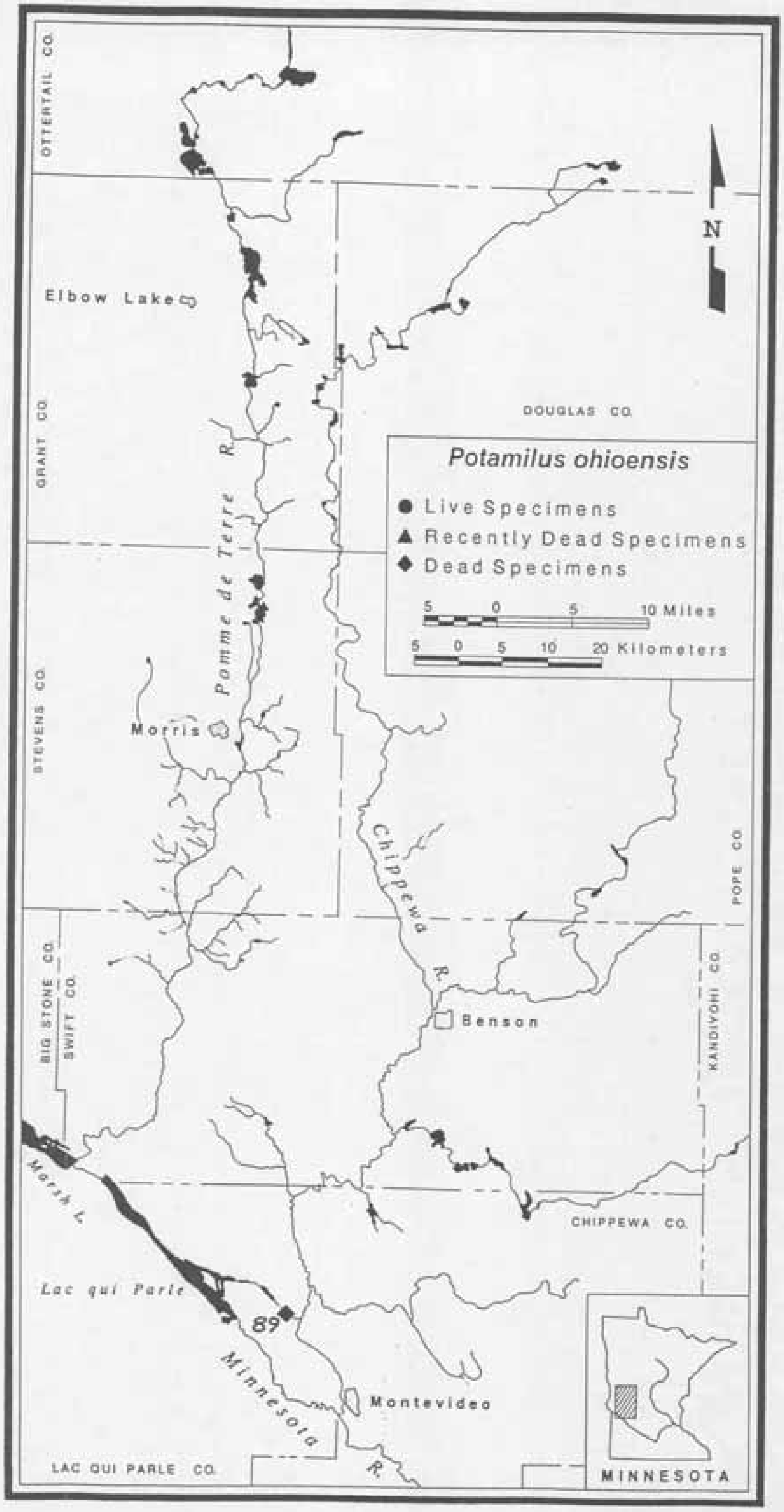
Figure 29

probably never been established in the Pomme de Terre River (Plate 18). Based upon its low abundance, it should be considered troubled in the Pomme de Terre River (Figure 5).

P. alatus was rare in the Chippewa River, and was probably not formerly established in large numbers (Plate 18, Figures 7 and 8). Regardless of its scarcity in the Chippewa River, some decline was apparent. Live P. alatus was found upstream of Montevideo in 1988, but no live specimens were found in 1990 (Plate 18). P. alatus were observed most frequently in some combination of sand, pebbles, and cobbles (Figure 14). Several gravid females were found at site 90-49 in the lower portion of the river indicating reproduction was occurring but no juveniles were found to indicate recruitment (Figure 29). Interestingly, a 9 year-old individual was found in the Watson Sag Diversion Channel (Plate 18). This individual could have entered the channel during high flow from the Chippewa River or could have washed downstream from the Minnesota River by way of Lac Qui Parle. In any case, it is doubtful that P. alatus has established itself in the channel. In general, P. alatus is in trouble in the Chippewa River.

Potamilus ohioensis (pink papershell)

Only one dead specimen was found in the Watson Sag Diversion Channel (Plate 19). How this specimen ended up in the diversion channel is unknown since Dawley (1947) viewed it as a rare species limited to large rivers.



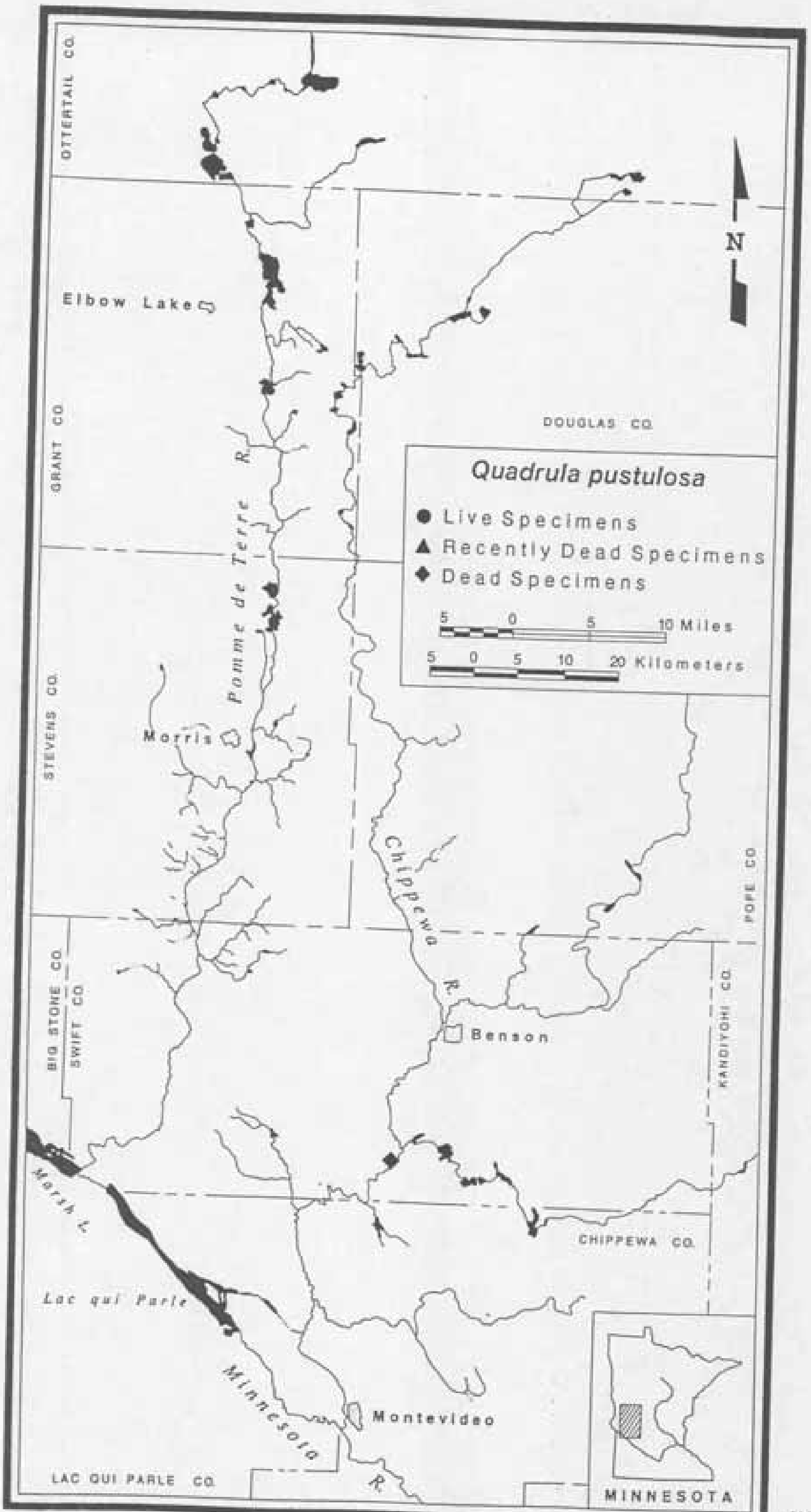
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 19

In addition, the furthest upstream in the Minnesota River that Bright et al. (1990) found P. ohioensis (live or dead) was Granite Falls, which is downstream of the mouths of the Pomme de Terre and Chippewa Rivers. One of P. ohioensis' fish hosts, Pomoxis annularis (white crappie) is known to occur in the Pomme de Terre and the Chippewa Rivers (James Underhill, pers. comm.). In addition, its other fish host, the freshwater drum, has been collected in the Chippewa River (Bell Museum Collections). Therefore, fish host availability does not appear to be liming this mussel's distribution. P. ohioensis was probably never established in either the Pomme de Terre or the Chippewa Rivers.

Quadrula pustulosa (pimpleback)

No specimens were found in the Pomme de Terre River (Plate 20). A single dead specimen was found in the Chippewa River at site 90-43, downstream of Shakopee Creek (Plate 20). It has occurred as far upstream in the Minnesota River as Montevideo, but was found live only between Granite Falls and New Ulm in 1990 (Bright et al. 1990). Four of Q. pustulosa's known fish hosts occur in the Chippewa River (Fuller 1974, Bell Museum Collections). However, if this species was ever established in the Chippewa River, it is certainly extirpated now. It probably never occurred in the Pomme de Terre River.



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

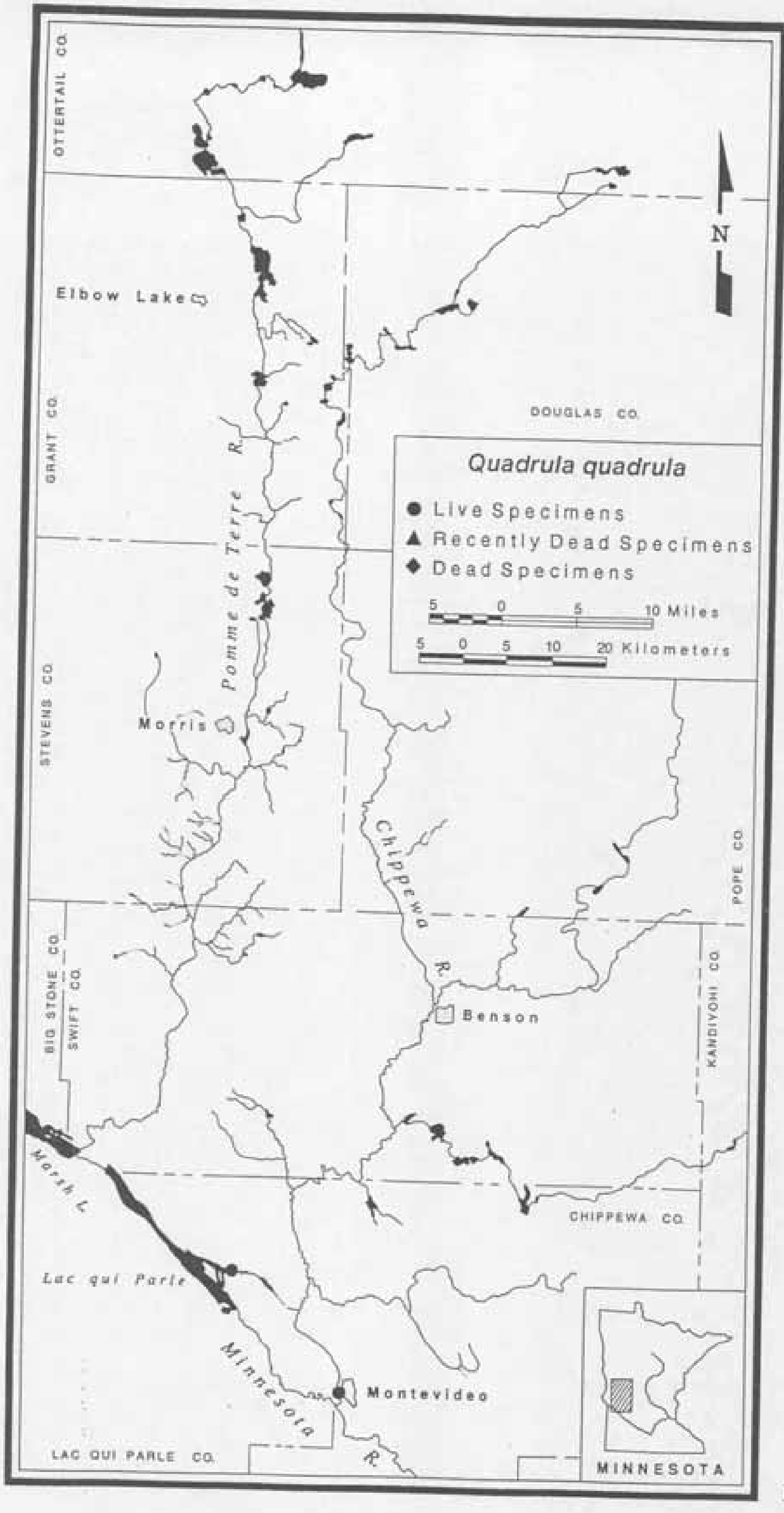
Plate 20

Quadrula guadrula (mapleleaf)

Q. quadrula was generally restricted to the mouth of the Chippewa River (Plate 21). Only 9 live specimens were found at site 90-49. Interestingly, a live specimen was found in the Watson Sag, lending some credence to the theory that mussels could be emigrating into the Sag through the diversion channel. No live or recently dead specimens were found in Lac Qui Parle [Minnesota River] or in the mainstem of the Minnesota River near Montevideo (Bright et al. 1990). However, several populations were found upstream near Ortonville and Marsh Lake [Minnesota River] (Bright et al. 1990). The population found in the Chippewa River ranged in age from 3 to 13 years, and 23.0 to 99.4 mm in shell length (Bright et al. 1994). Q. quadrula was found in silt, sand, and sand with clay and pebbles (Figure 14). Based upon shell evidence, it is difficult to say whether Q. quadrula was ever established in the Chippewa River. Thus, it's status was undetermined. It is certainly rare and may be just holding on at the mouth.

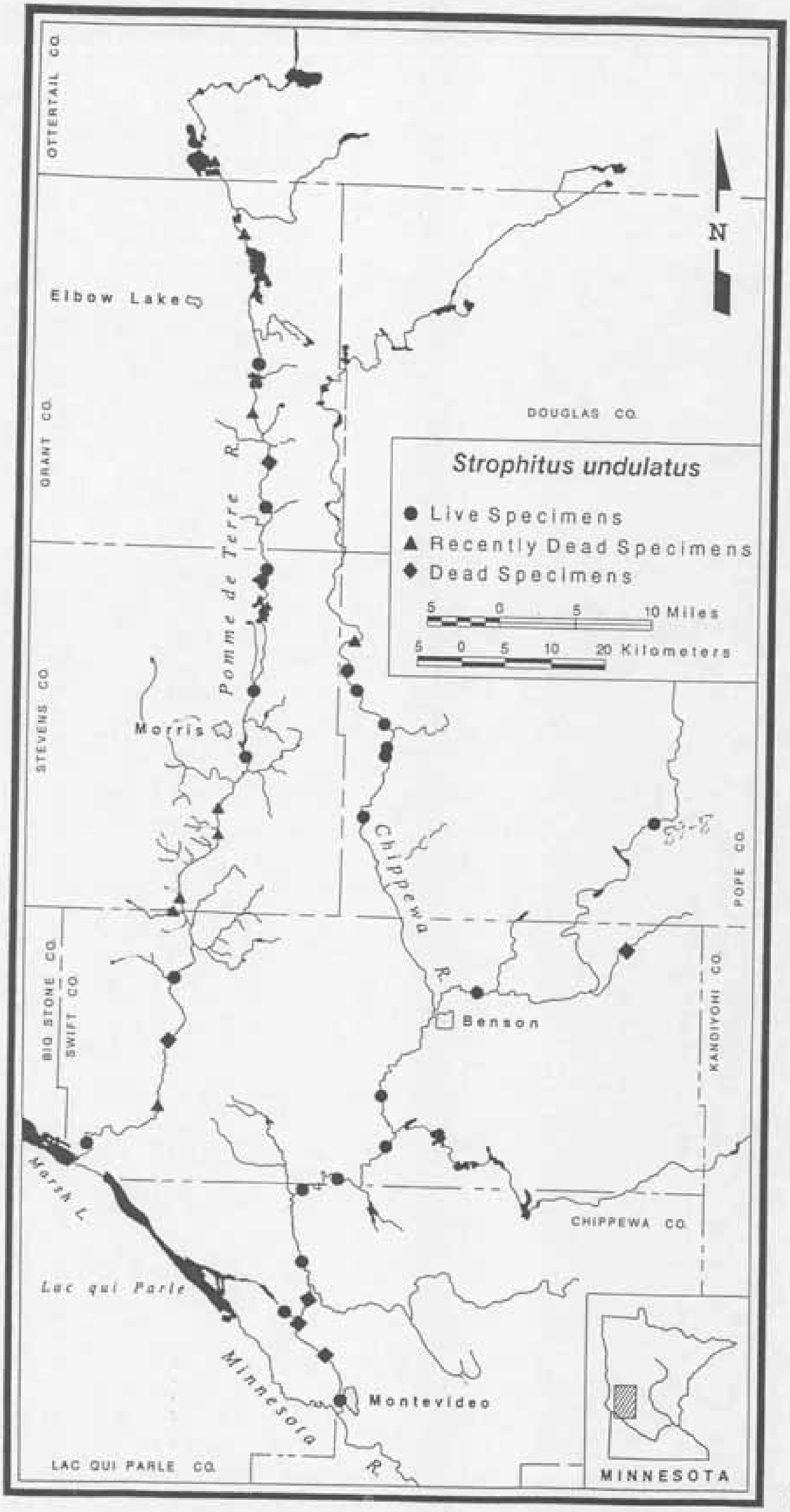
Strophitus undulatus (strange floater)

S. undulatus was rare in the Pomme de Terre River (Plate 22, Figure 5). It was formerly widespread in the river but is now restricted to seven sites in the river (Plate 221 Figure 4). Possibly the habitat had changed, or water quality had degraded at some locales such that these became unsuitable for S. undulatus. Frequently, S. undulatus



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 21

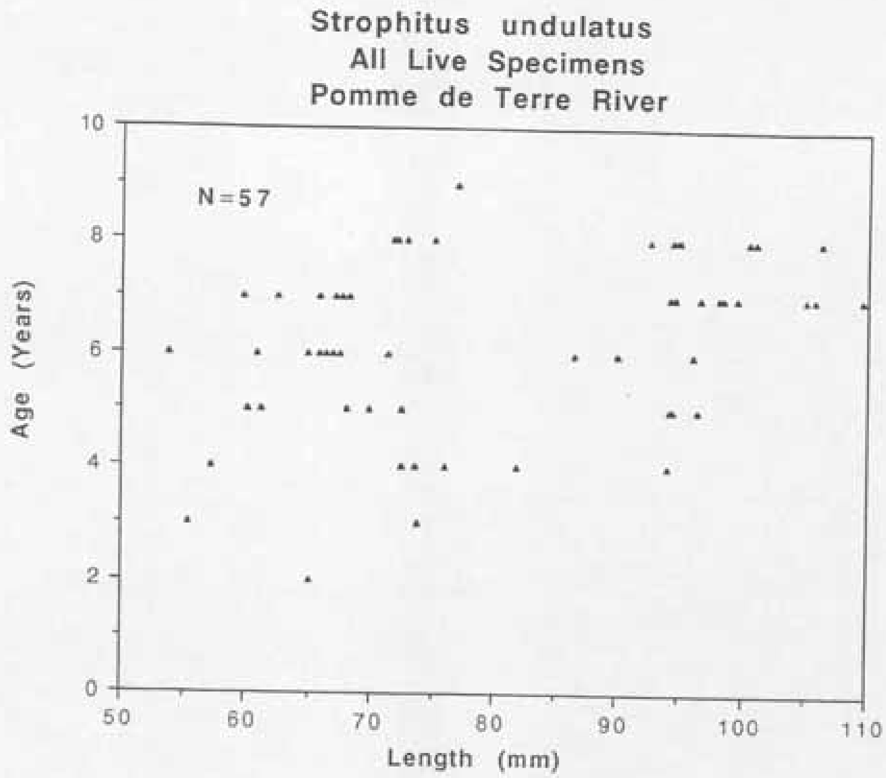


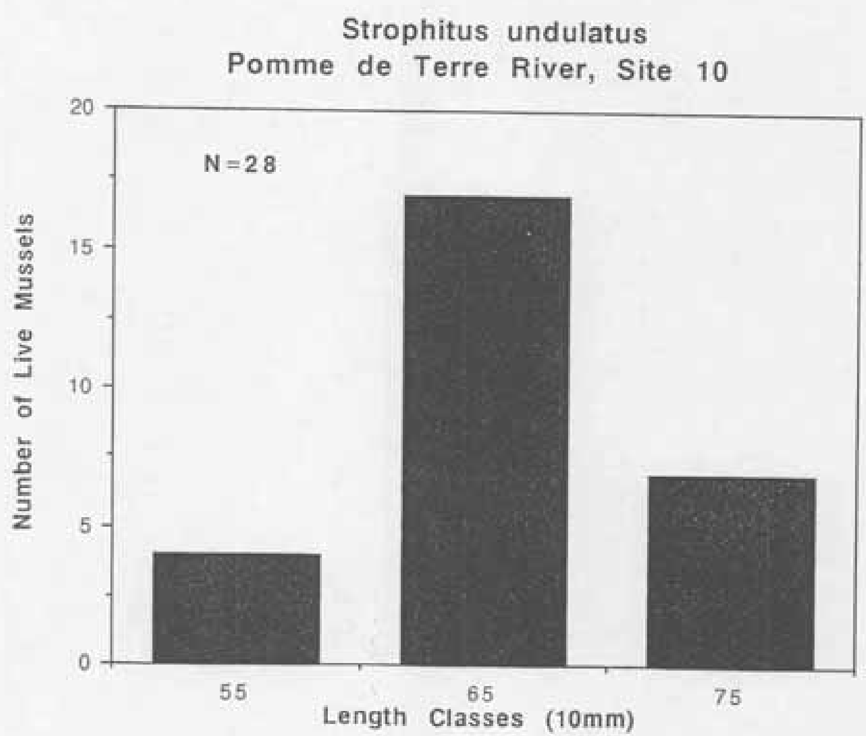
Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

Plate 22

was found immediately upstream of a lake but was not found immediately downstream of a lake, indicating habitat preferences or fish host limitations (Plate 22). The greatest abundance of S. undulatus was found at site 90-20 near the mouth of the Pomme de Terre River (Figure 4). Growth rates of S. undulatus were highly variable, likely due to the varying environmental conditions of these scattered populations. Thus, poor correlation was found in our age/length regressions (Figure 30). Regardless of the difficulty in predicting age from length, some recruitment was evident at site 90-10 (Figure 30). Individuals 55 mm in length were aged at 2 to 3 years old. However, no young of the year were found. The populations in the middle portions of the Pomme de Terre River were aged from 4 to 7 years old and ranged in shell length from 72.4 to 109.7 mm. No gravid females were found (Bright et al. 1994). A single 3-year old, 73.8 mm in length was found at site 9020, near the mouth of the river (Bright et al. 1994). Thus, recruitment occurred within the last 3 years in the upper and lower sites on the Pomme de Terre River. We do not know whether recruitment has occurred in the recent past in the middle portion of the Pomme de Terre River. Low flows in 1988 and 1989 have probably affected survival of these younger age classes. Dawley (1947) viewed, S. undulatus ". . . not common but found in both small and large rivers" in Minnesota. Based on it's reduction in range and low abundance, we view S. undulatus as troubled in the Pomme de Terre River.

S. undulatus was rare in the Chippewa River (Plate 22, Figure 8). It was fairly widespread in the river but was missing from a portion of the river approximately 10 miles upstream and downstream of Benson (Plate 22, Figure 7). In addition, only dead shells were





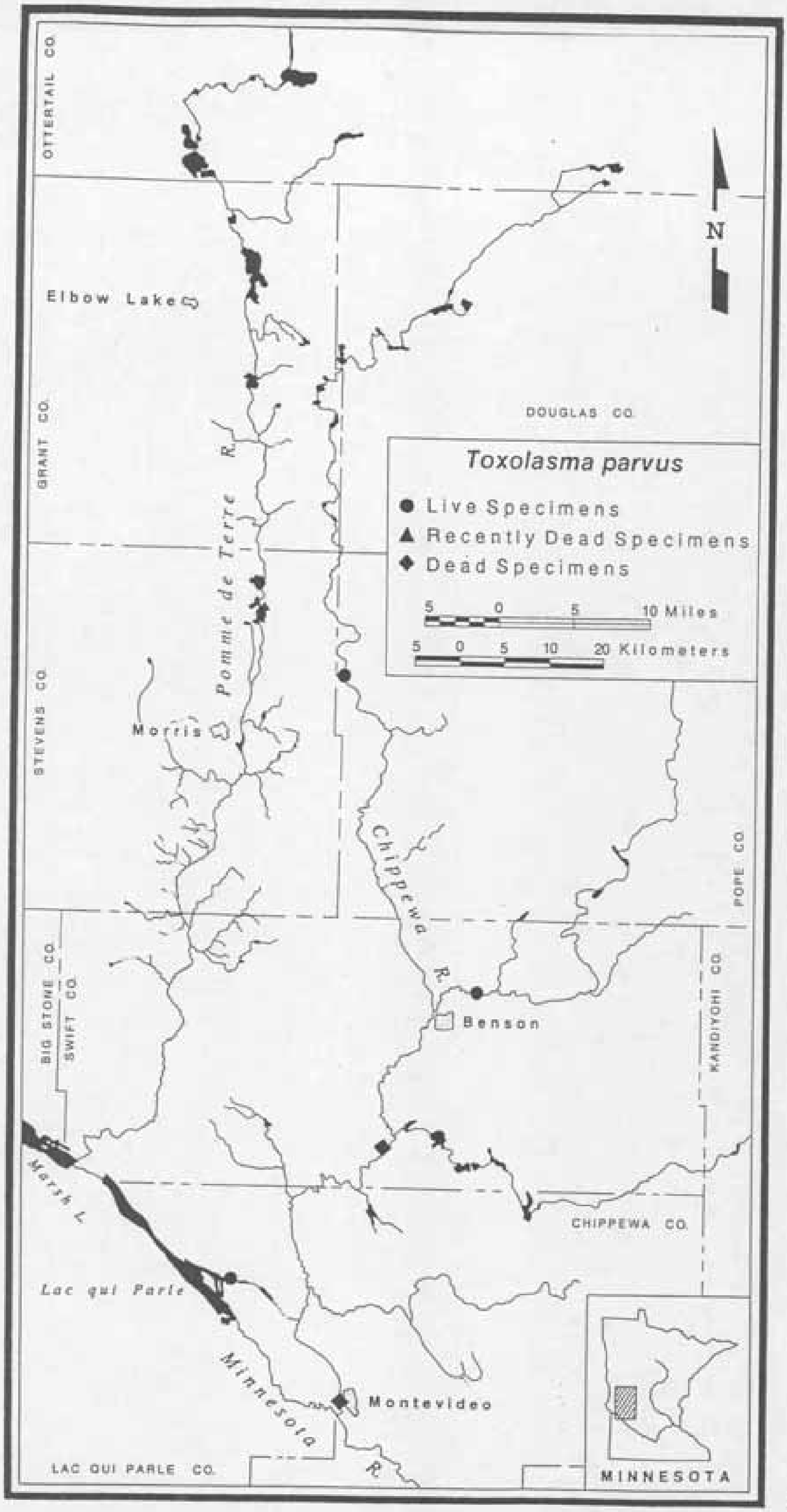
112

Figure 30

found in the main stem near Watson, but live individuals were found in the diversion channel (Plate 22). We speculate that as a result of dredging in Swift County, the habitat became unsuitable for S. undulatus. The greatest abundance (13 live) were found at site 90-37 (Figure 7). In total, only 67 live individuals were found in the Chippewa River (Table 2). Reproduction (females with eggs) was evident at several sites. A single gravid female aged 3 years and 64.8 mm in length, was found in the Watson Diversion Channel. These observations were made in August. Individual ages ranged from 4 to 11 years, with a single 1 year old found at site 90-39 (Bright et al. 1994). Shell lengths ranged from 62.0-119.1 mm. The 1-year old was 29.5 mm in length. Thus, recruitment appeared minimal and may not be enough to maintain the populations. Based on S. undulatus' low abundance and poor recruitment, we view it as troubled in the Chippewa River.

Toxolasma parvus (lilliput)

The lilliput was previously known from southeastern Minnesota in the lower St. Croix, Mississippi, lower Minnesota, and Zumbro Rivers (Grant 1886, Fuller 1978, Bright et al. 1989). Fuller (1980) found it abundant in many pools in the Upper Mississippi River but absent in the Twin Cities area. In 1989, Bright et al (1990) found T. parvus live in the upper Minnesota River between Ortonville, MN and Marsh Lake. In this study, we found T. parvus live only in the Chippewa River (Plate 23). It was rare and did not appear to have been formerly widespread in the Chippewa River (Plate 23).



Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

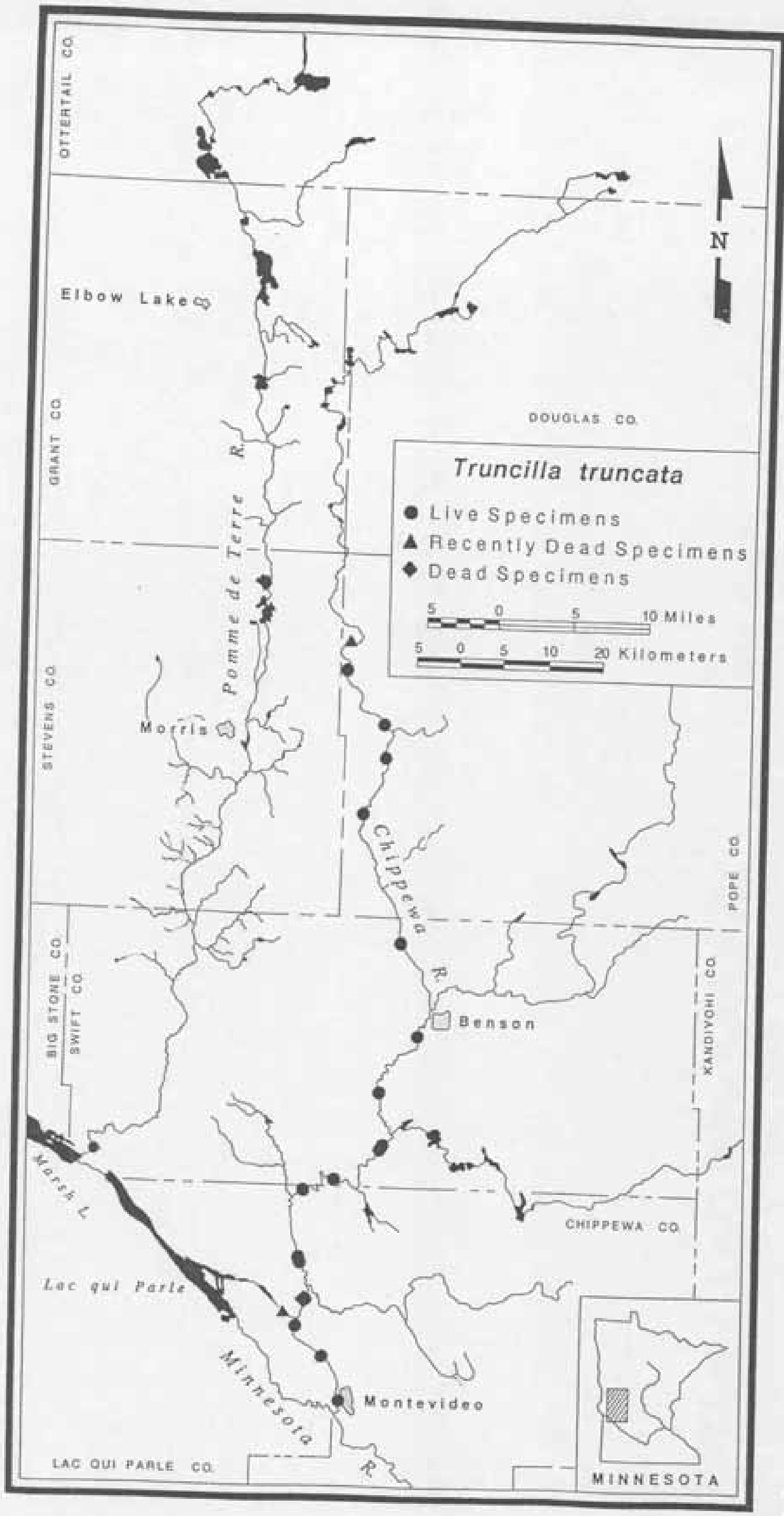
Plate 23

One live individual was found at site 90-36, in Pope County (Bright et al. 1994). It was 28.6 mm in length and estimated to be 7 years old. It was not gravid. Another live individual was found in the East Branch Chippewa, site 90-46 (Bright et al. 1994). This specimen was 34.6 mm in length and estimated to be 8 years old, and was not gravid. Bright et al. (1990) found T. parvus in “soft" substrates such as silt or silty sand. Fuller (1978) noted it was most common in a substrate of muddy sand in shallow and slow-water areas. Our findings were in accord with these former observations of T. arvus' habitat preferences. In the Chippewa River, T. parvus was found in a combination of sand and silt in slow waters. Because T. parvus was rare and showed a decline in range, we viewed T. parvus in jeopardy of extirpation in the Chippewa River.

We expected to find T. parvus in the Pomme de Terre since it was found in the Minnesota River near Marsh Lake (Bright et al. 1990). Although its fish hosts occur in the Pomme de Terre River, the absence of dead shell material indicated that T. parvus has not formerly occurred there (Plate 23). Possibly, habitat requirements of T. parvus were not met in the Pomme de Terre River.

Truncilla truncata (deerfoot)

T. truncata was found live in the Pomme de Terre River at site 90-20 near the mouth (Plate 24). Its fish hosts, Aplodinotus grunniens, the freshwater drum, and Stizostedion canadense, the sauger, are not known to occur in the Pomme de Terre River (Fuller 1974, Bell Museum Collections). However, they (sauger and freshwater

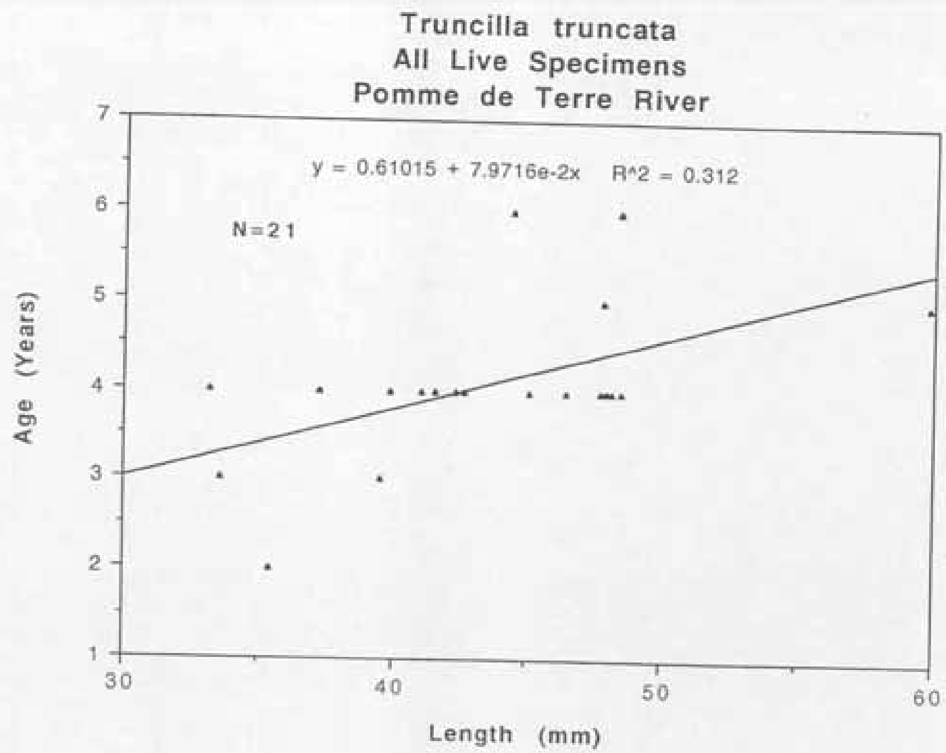


Mussels of the Pomme de Terre and Chippewa Rivers, Minnesota

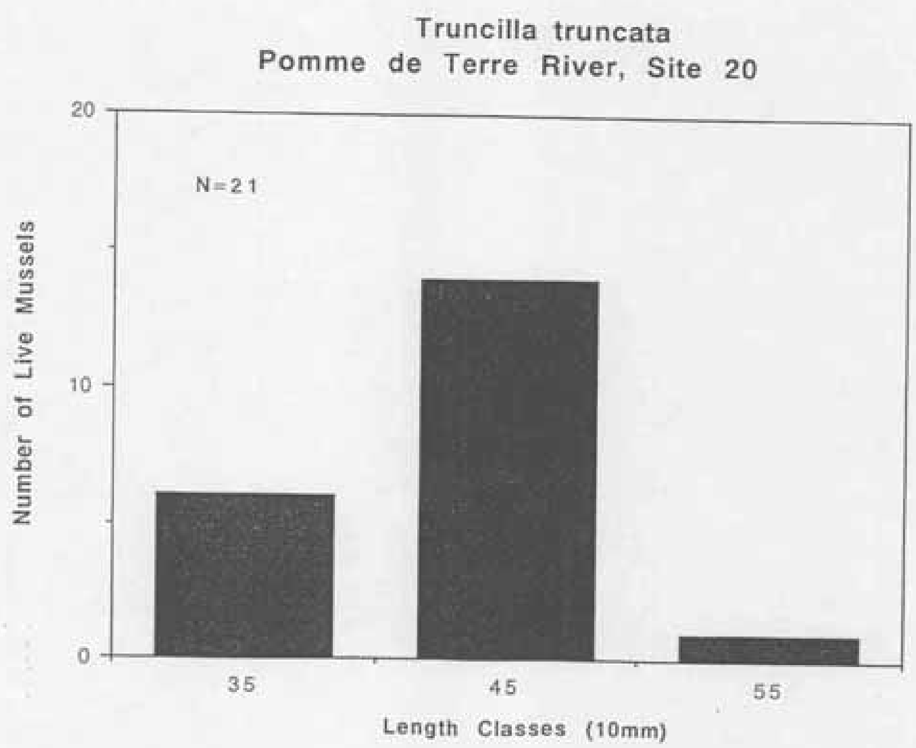
Plate 24

drum) are found throughout the Minnesota River. The presence of this mussel species near the mouth, but not in the rest of the Pomme de Terre River, may be the result of immigration via their host fish from Marsh Lake and the Minnesota River. A total of 21 live individuals were found, estimated at 3 to 5 years old (Figure 31). Two females with eggs were noted (Bright et al. 1994). However, evidence of recruitment was not found. This may be due to the difficulty in locating juveniles, especially of such a small-sized species. It was questionable whether T. truncata was ever established in the Pomme de Terre River (Plate 24, Figure 4). Presently, an effective population exists near the mouth of the Pomme de Terre River, and may even be expanding its former range.

T. truncata was found live throughout the lower two-thirds of the Chippewa River (Plate 24). The absence of dead shells above site 90-35 indicated an upper limit in T. truncata's range in the Chippewa River. A total of 199 live individuals were found, comprising approximately 5% of the mussel fauna (Figure 8). A comparison of the dead shells with the number of live specimens suggested that it had never been overly abundant (Table 2). T. truncata to was found primarily in sand in combination with silt, granules, pebbles, cobbles, and silt; the greatest number were found in silty, sand (Figure 13). Recruitment was evident at the lower sites on the Chippewa River where we found sufficient quantities of individuals to produce histograms (Figure 32). Seven juveniles on bissel threads were found at sites 90-49, in sand, silt, and clay with granules or pebbles (Bright et al. 1994). Reproduction and recruitment was taking place at other sites in the Chippewa River, but probably just enough to maintain local populations. Females with eggs were noted on August 1, and 2, at sites 90-37, 90-38 in



Truncilla truncata
All Live Specimens
Pomme de Terre River
y = 0.61015 + 7.9716e-2x
R^2 = 0.312
N=21
Age (Years)
Length (mm)



Truncilla truncata
Pomme de Terre River, Site 20
N=21
Number of Live Mussels
Length Classes (10mm)

Figure 31

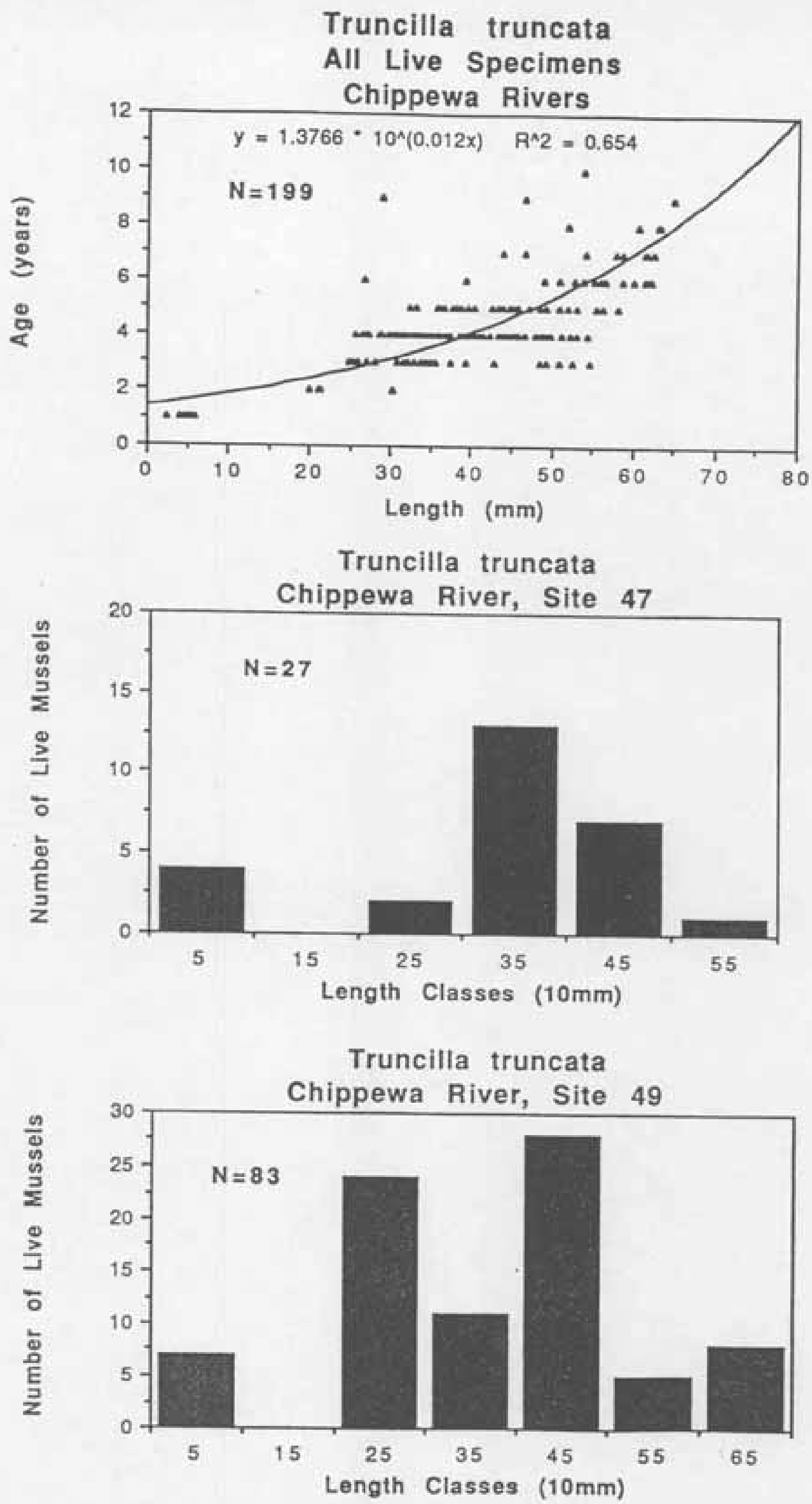

Truncilla truncata
All Live Specimens
Chippewa Rivers
y = 1.3766 * 10^(0.012x) R^2 = 0.654
N=199
Age (years)
Length (mm)
Truncilla truncata
Chippewa River, Site 47
N=27
Number of Live Mussels
Length Classes (10mm)
Truncilla truncata
Chippewa River, Site 49
N=83
Number of Live Mussels
Length Classes (10mm)

Figure 32

Pope County, MN. Several 2 year old, 20-21 mm in length, were also noted at site 90-36 (Bright et al. 1994). Age/length regressions indicated that the majority of specimens found were 3 to 9 years of age and the larger length classes representing individuals over 15 years of age were missing. As with most of the mussel species in the Chippewa River, low flows and droughts have likely affected recruitment. T. truncata was common and appeared stable though not abundant in the Chippewa River (Figure 7).

DISCUSSION

Density

In a 1989 meeting between some of the commercial mussel harvesters (clammers), representatives of the MNDNR, and Bob Bright from the Bell Museum, it was revealed that mussels had been harvested for several years but that the catch per unit effort had become so low that harvesting was no longer profitable. In addition, the clammers indicated that some harvest had occurred on the Chippewa River, but with a lower intensity as had occurred on the Pomme de Terre River.

We found the density of mussels in the Pomme de Terre River to be low. No explanation could be found for the large number of mussels found at site 10, just north of Barrett, MN. However, because the river had been subject to harvesting throughout its range, site 90-10 may have been overlooked by commercial clammers in the past. The decline in mussel density downstream of Morris, MN (site 90-16) was likely due to a drought in 1988 and 1989 where one landowner observed " piles of dead and dying clams" . . . and only " a couple of pools remained where live clams congregated". In

July, the river near Morris was approximately 1 to 3 feet and downstream of the dam at Appleton was about 5 feet deep. However, in August of 1990, the minimum daily discharge near Appleton, MN was nearly zero (Figure 11). The large number of mussels found downstream of Appleton (site 90-20) was likely due to a combination of greater usable habitat where the Pomme de Terre River joins the Minnesota River and fish hosts' congregating below the dam. In addition to harvest, the density of mussels have probably been affected by frequent droughts and poor habitat quality. A significant proportion of the Pomme de Terre River's stream banks lacked vegetation and were severely eroded.

The lack of live mussels found in the upper 30 river miles of the Chippewa River may be due to a combination of poor habitat or the dams located at Solberg Lake, Long Lake, and Stowe Lake which likely hindered fish movement. Thus, fish hosts would not be available for the mussel's parasitic live stage. However, these dams should only impact the three uppermost sites located between river miles 94 and 79. In general, the habitat in the middle and lower sections of the Chippewa River was highly suitable for mussels. A variety of substrate sizes characterized the stream bed. Excessive siltation and sedimentation was not apparent. Fallen trees and submergent vegetation were present which provided pool/run habitat and cover for fish hosts. The wide range of mussel densities throughout the river indicated that site specific events have deleteriously affected the mussels. Certainly low flows in the Chippewa River have affected recruitment. From conversations with landowners in Kensington, MN and residing at river miles 72-79 (90-27, 28, 29), we know that the "river was dry last summer (1989) . . . there were occasional pools filled with clams" . . . "mink and raccoons had a field day with the mussels". Harvesting of shell material may account for some of the fluctuation in mussel densities throughout the Chippewa River. However, we may also be observing the natural population fluctuations and changes in distribution of mussels in rivers.

The mean density of mussels found in the Pomme de Terre River using quadrats, or the grid sampling method, were similar to those found in the Cannon, Zumbro, and Minnesota Rivers but quite different from that found in the Chippewa River (Davis 1988, Bright et al. 1989, Bright et al. 1990) (Table 1). The number of live individuals collected was also similar among the Pomme de Terre, Cannon, Zumbro, and Minnesota Rivers but very different from the number of live collected in the Chippewa River (Table 1). The mussel fauna in the Pomme de Terre, Cannon, Zumbro, and Minnesota Rivers are in serious trouble. Long stretches devoid of mussels have been reported for each of the rivers, along with poor recruitment, extirpation of some species, and shrinking distributions. Although the Chippewa River is experiencing some of the same maladies, such as poor recruitment and areas with low densities, the mussel fauna there appeared more stable than in the Pomme de Terre River.

The quadrat method seems to be a robust tool for general comparisons of densities among different rivers. However, the quadrat sampling method does not seem appropriate for determining gross population numbers in a river (Table 1, Figures 1 and 2). Because the distribution of mussels is clumpy or patchy in nature, the timed search method in which a person purposely seeks the best mussel habitats results in finding a greater number of live individuals than are typically found using the grid method. The quadrat method does allow one to sample a wide variety of habitat types and thus better identify habitat requirements of mussel species.

Diversity

Species assemblages differed between the Pomme de Terre and Chippewa Rivers (Table 2). Three live species (E. dilata, Q. quadrula, and T. parvus) were found in the Chippewa River that were not found in the Pomme de Terre River. One live species (A. marginata) was found in the Pomme de Terre River but not found in the Chippewa River (Table 2). Truncilla truncata was tremendously more abundant, and Leptodea fragilis and Lampsilis ventricosa were more common in the Chippewa River than in the Pomme de Terre River (Table 2, Figures 4 and 7). L. ventricosa was found throughout the Minnesota River in 1990. However, only dead specimens were found just below Marsh Lake where the Pomme de Terre enters the Minnesota River. This might explain why few L. ventricosa were found in the Pomme de Terre River. In contrast, live specimens of L. ventricosa were found in the Minnesota River at the mouth of the Chippewa River; hence L. ventricosa was more abundant in the Chippewa River than in the Pomme de Terre River. The fish distributions in the Pomme de Terre and Chippewa Rivers are distinctly different (Bell Museum Collections). For example, the freshwater drum, the recognized host fish for P. alatus and L. fragilis glochidia has not been reported in the Pomme de Terre River but is in the Chippewa River (Bell Museum Collections). Thus, the distribution of mussels in both of these rivers were also distinctly different. In comparison with Ostlie (1988, 1989) the mussel species composition in the Chippewa River has not changed since 1988 (Table 2). However, it is likely that Amblema plicata was more abundant as recently as 1985 since we believe some harvesting of shell material was conducted in the Chippewa River.

Because E. dilatata was found live at only sites 90-44 and 90-45 near Hagen, MN on the Chippewa River, we believe a special note about the habitat is warranted. The habitat at site 90-44 was a combination of pools, riffles, and glide. The depth was approximately 1 m, and secchi depth was 40 cm. The riparian zone was in good condition; no erosion of stream banks was noticed. The substrate consisted of boulders, cobbles, pebbles, granules, and sand. The habitat at site 90-45 was primarily a glide with some riffle areas. The depth was approximately 1 m, and secchi depth was also 40 cm. The substrate consisted of primarily sand in the main channel with occasional boulders, cobbles and pebbles. Granules, pebbles, sand and a very minimal amount of silt characterized the areas near shore to 5 m into the channel. The left ascending bank was steep. Large cottonwood trees were present, some overhanging way into the stream channel.

The grid method adequately determined live species diversity at a given site and compared well with the timed search method where mussel densities were abundant. However, where the mussel densities were low, we consistently found fewer live species using the grid method than were found in the timed search (Figures 1, 2, 3, and 6). Because the timed search method involves searching for prime mussel habitat, this method is biased towards finding more live animals. Thus, one would also find more live species using the timed search method than one would find using the grid method where mussels are low in abundance.

Conclusions

The causes of the decline in mussels in the Pomme de Terre River were probably anthropogenic and appeared to be the result of habitat degradation and overharvest. Most sites on the Pomme de Terre River had severe bank erosion problems coupled with siltation on the streambed. Agricultural chemicals, which are commonly used throughout the Pomme de Terre drainage, have also been implicated as the cause for the decline in mussels throughout the United States (Williams et al. 1993). Our results agreed with what the clammers had said regarding the density of mussels in the Pomme de Terre River; namely, that the densities were especially low. An average of nineteen mussels harvested per person per hour on the Pomme de Terre River would not yield a profitable income. We recommend no harvest of shell material on the Pomme de Terre River until the populations have restored themselves.

While the mussels in the Chippewa River do not appear to be in decline, several species showed poor recruitment. In addition, the droughts have wiped out several age classes. Thus, in-stream flow regulations are needed that address the freshwater mussels life history requirements. Our average harvest rate of forty-one mussels per person per hour on the Chippewa River is probably not profitable . We recommend no harvest of shell material on the Chippewa River until the populations show evidence of recruitment and a normal distribution of age classes. Because of the habitat quality and L. recta and E. dilatata populations found between estimated river miles 34.0 to 8.0, especially near Hagen, MN (sites 90-44, and 90-45) on the Chippewa River, we suggest special attention be given to preservation of these prime mussel locales.

Literature Cited

Baker, F. C. 1928. The Fresh water Mollusca of Wisconsin; Part 2, Pelecypoda. Wisconsin Geol. and Nat. History Survey, Bull. 70, Part 2, 495 p.

Banarescu, . 1990. Zoogeography of freshwater. Vol 1 General distribution and dispersal of freshwater animals. AULA-Verlag Wiesbaden. 511 pp.

Bright, R. C., D. Olson and E. Plummer 1989. A survey of the mussels of the Zumbro River drainage. Unpublished report to the Minnesota Dept. Nat. Resources. 27 pp. + Tables and Figures.

Bright, R. C., C. Gatenby, D. Olson, and E. Plummer. 1989. A survey of the mussels of the Minnesota River. Unpublished report to the Minnesota Dept. Nat. Resources. 36 pp. + Tables and Figures.

Bright, R., C. , C. Gatenby, R. Heisler, E. Plummer, and K. Stramer. 1994. Mussel survey data on the Pomme de Terre and Chippewa Rivers of Minnesota, 1989. Appendix to final report to the Minnesota Dept. Nat. Resources.

Cummings, K. S. and C. A. Mayer. 1992. Field guide to freshwater mussels of the midwest. Illinois Natural History Survey Manual 5. Champaign, IL. 194 pp.

Davis, M. 1988. Freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Cannon River drainage in southeastern Minnesota. Unpublished report to the Minnesota Dept. Nat. Resources.

Dawley, C. 1947. Distribution of aquatic mollusks in Minnesota. American Midi. Nat., vol. 38, p. 671-697.

Fuller, S L. H. 1974. Clams and mussels (Mollusca: Bivalvia). In Pollution Ecology of Freshwater Invertebrates, C. W Hart Jr. and S. L. H. Fuller (eds.), Academic Press, New York and London, pp. 215-273.

Fuller, S. L. H. 1978. Freshwater mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: Observations at selected sites within the 9foot channel navigation project on behalf of the United States Army Corps of Engineers. Acad. nat. Sci. Philadelphia, 441 p.

Fuller, S. L. H. 1980. Freshwater mussels of the Upper Mississippi River: Observations at selected sites within the 9-foot navigation channel project for the St. Paul district, U. S. Army Corps of Engineers, 19771979. Acad. Nat. Sci. Philadelphia, Vol. ii, appendices, 401 p.

Hoeh, W R. 1990. Phylogenetic relationships among eastern North American Anodonta (Bivalvia: Unionidae). Malacological Review 23: 63-82.

Hove, M. C., R. A. Engelking, M. E. Petoler, and E. M. Peterson. 1995. Life history on the creek heelsplitter, Lasmigona comgressa. unpublished Triannual Unionid Report. National Biological Survey, Asheville, NC. 6: 21.

Minnesota Department of Conservation. 1959. Hydrologic atlas of Minnesota. Division of Waters, State of Minnesota, Bull. 10.

Moyer, L. R. and O. G. arid Dale. 1916. History of Chippewa and Lac Qui Parle Counties, Minnesota. B. F. Bowen and Company, Inc. Indianapolis. 1: 68-86.

Nachtrieb, H. R. 1908. Report on the pearl mussel investigations of the Minnesota River and its tributaries made in 1908. Unpublished report to the U. S. Bureau of Fisheries.

Ortmann, 1919. Monograph of the Najades of Pennsylvania. Part III. A systematic account of the genera and species. Memoirs of Carnegie Museum.

Ortmann, A. E. and B. Walker. 1922. On the nomenclature of certain North American naiades. Occa. Papers, Mus. Zool. Univ. Mich., No. 12, pp. 175.

Putnam, J. D. 1971. A taxonomic study of two forms of the Lampsilis ovata complex in the Ohio River drainage system. (Mollusca: Bivalvia: Naiadoida). M. S. Thesis. Ohio State University. Colombus, Ohio.

Rafinesque, C. S. 1820. Monographie des coquilles bivalves et fluviatiles de la Riviere Ohio, contenant douze genres et soixante-huit especes. Ann. Gen. Sci. Phys., Bruxelles, V, pp. 287-322, pl. 80-82.

Stein, C. 1973. Life history of Amblema lip~c to (Bivalvia: Unionidae). PhD. Dissertation. Ohio State University. Columbus, Ohio. 174pp.

Turgeon, D. D., A. E. Bogan, E. V. Coan, W K. Emerson, W. G. Lyons, W. L. Pratt, C. F. E. Ropper, A. Scheltema, F. G. Thompson, and J. D. Williams. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. Am. Fish. Soc. Special Publication 16.
277pp.

Waters, Thomas F. 1977. The streams and rivers of Minnesota. University of Minnesota Press, Minneapolis, Minnesota 373 pp.

Water Resources Data for Minnesota, 1976. U. S. Geological Survey, Water-Data Report MN-76-1.

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. Journal of Geology, 30: 377-392.

Williams, J., D., M. L. Warren, K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation Status of Freshwater Mussels of the United States and Canada. Fisheries, 18(9): 6-22.