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A SURVEY OF THE MUSSELS OF THE ZUMBRO RIVER DRAINAGE, SOUTHEASTERN MINNESOTA

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ABSTRACT

A survey of the mussels of the Zumbro River drainage of southeastern Minnesota was made during the summer of 1988. Eighty-three sites were studied and 1184 specimens from 17 species were examined for size, condition, abundance and distribution. Both transects and timed searches were employed to gather data.

Mussel density was found to be low but similar to that of the adjacent Cannon River.

Both density and diversity were high below dams as the result of fish congregating there. However, the dams disrupt the distribution of some fish serving as glochidial hosts.

Some mussel species have been extirpated in parts of the drainage and recruitment was found to be poor at many sties.

Excessive siltation and unstable substrates appear to be the major limiting factor in the main stem of the Zumbro River, and long stretches are essentially devoid of mussels.

INTRODUCTION

The distribution of mussels in streams in Minnesota is unknown in vast areas (Bright et al, in preparation). The only thorough studies to date are of the Red River (Cvancara, 1970), St. Croix River (Doolittle et al, in preparation), Blue Earth River (Chelberg, unpublished), Cannon River (Davis, 1988), Mississippi River (Fuller, 1978, 1980), Chippewa River (Ostlie, unpublished), Pomme de Terre River (Schladwieler, unpublished), and some Canadian streams along the northern border (Clarke, 1973). Even fewer studies provide quantitative information about abundance: Cvancara (1970, Red River), Fuller (1978, 1980, Mississippi River) Davis (1988, Cannon River) and Ostlie (unpublished, Chippewa River). Thus we have a poor base upon which we can evaluate the status of changes of water quality of streams state-wide based on mussels or upon which we can assess the present or past condition of mussel populations.

In 1987 the Minnesota Department of Natural Resource Nongame Wildlife Program sponsored a study of the Cannon River Drainage (Davis, 1988) in order to improve the data base for mussels in southeastern Minnesota. Then, in 1988, they sponsored a similar one on the Zumbro River (this study).

Information regarding the mussels of the Zumbro of yesteryears is scanty at best. Although early Americans used mussels routinely as food along the Mississippi River, there is no evidence that they did so along the Zumbro.

The Zumbro apparently escaped serious exploitation by the button industry. The Olmsted County Historical Society has no records of clamming on the river and older residents of the area recall none. However, Lloyd Wilcox, a Wabasha resident, recalls harvesting mussels as a young boy with his father and uncle (personal communication, 1988). He recalls two trips a season to the Zumbro in the 1930's for a couple of years. They harvested between Mazeppa and Zumbro Falls where mussels were apparently abundant.

The earliest scientific record is that of Grant (1885) who reported a specimen of _Anodonta grandis_ found by Winchell somewhere along the Zumbro River in Wabasha County. Much later, in August 1938, Dawley collected from the North Fork at Kenyon and found four species (discussed later). All her specimens are vouchered in the Bell Museum of Natural History collection at the University of Minnesota. Two other specimens at the Bell Museum are recorded as being from the Zumbro, but specimen #2308 is probably from the mouth of the Cannon and specimen #2244 is probably from the mouth of the Whitewater.

The purpose of this study, then, was to determine the diversity, distribution and abundance of mussels in the Zumbro River System and also to evaluate the reproductive success of as many populations as possible.

THE STUDY AREA

The Zumbro River watershed is in southeastern Minnesota almost entirely in Goodhue, Wabasha, Dodge and Olmsted counties, and it is tributary to the Mississippi River (Plate 1). The rolling, loess- and till-covered uplands that were once mostly native prairie are now devoted to agriculture. From the headwaters in the west the streams flow eastward in a trellis-like pattern that was most likely controlled by ancient faulting and joint patterns in the early Paleozoic bedrock. The canyons are deep in many places, even on tributaries, and the river is over 500 feet below the uplands in its lower reaches. Trees and shrubs are common along the banks in many stretches on tributaries but in others the vegetation has been stripped for the convenience of farming. A hardwood woodland flourishes in the lower reaches of the watershed. Floodplains are farmed and drained where they are wide enough to produce crops. More complete descriptions of the region can be found in the Hydrologic Atlas of Minnesota (Dept., Cons., 1959) and in Streams and Rivers of Minnesota (Waters, 1977), but a few salient points need to be emphasized here.

The entire watershed is prone to spring flooding and to flash flooding during summer thunderstorms, many of the floods being destructive. Such a condition exists because there are essentially no wetlands in the system to slow rapid runoff, and what few existed previously have been mostly drained. In addition, runoff rates no doubt have been increased by the vast areas that have fallen to the plow. The flood stage at Zumbro Falls is the 18-foot mark on the gauge, and this mark was exceeded 11 times prior to 1959, the maximum flow there being 30,700 cfs compared to the normal 479 cfs (Dept. Cons., 1959). Many stretches on tributaries have been channelized, particularly where the floodplains are conducive to farming, and such practice has further compounded flood severity. Increased flood severity and increased erosion of upland soil since settlement have produced additional stress on Zumbro mussels.

The system is also prone to periodic low water levels that effect mussels; the summer of 1988 is a good example (this study).

The alkalinity of the Zumbro is about 225 ppm (Waters, 1977) so the streams are of the hard-water type, and the pH ranges from about 7-8. Most of the streams in the watershed are warm, but a few tributaries are cold and locally known as good trout streams. The water is often turbid in the spring but generally clears by fall, however increased erosion of farmland has raised mean-annual levels.

There are a number of dams in the Zumbro drainage, the largest being the one impounding Zumbro Lake on the South Fork. Dams are of note because they restrict the free movement of host fish that disperse glochidia.

MATERIALS AND METHODS

Mussels were examined at 83 sites (Plate 1) in the Zumbro system, the distance between them averaging 6.4 km (4 miles) and ranging from 1.6 km (1 mi) to about 12.8 km (8 mi) apart. Length of the sampling areas ranged from a few meters to about 500 m. Many of the sites correspond to the Minnesota Department of Natural Resources, Division of Fisheries, stream-survey sampling stations, which provide additional ecological data not collected in this survey. We paid special attention to the Rochester area because of the impending flood control project.

Two quantitative sampling techniques were used. One was developed by Davis (1988); it consisted of laying a fabricated set of frames (0.5m x 1m) across the stream from bank to bank (a transect), counting and measuring length, height, width of live mussels in each of the frames and recording the presence of dead individuals. In each transect the substrate was excavated to a depth of about 10 cm. The initial goal was to analyze three transects from both a pool and a riffle at each site. However, sampling riffles by this method was abandoned early in the season (as did Davis, 1988) because so few mussels were found that it proved very inefficient and uninformative relative to the time expended.

Transects were not examined at some pools (Appendix 1) for a number of reasons. Either the pool was dry, accessibility was too difficult to haul in SCUBA gear, the visibility was too poor to effectively use SCUBA, or an initial reconnaissance indicated extremely low numbers of mussels. Moreover, only one transect was made at a few sites (Appendix 1). Based on Davis' data (1988) from the Cannon River, it was thought that one transect might be sufficient. However, it was soon obvious that mussels were so scarce that three transects were a minimum. Some of those early sites were re-visited but some were not.

A second quantitative method was used that proved extremely useful - the timed search (Cvancara, 1970). This method consisted of wading, snorkeling and diving in a large area of a stream (much larger than the transects) discovering mussels by both sight and feel. The distance covered in the search was recorded as well as the time spent searching and produced the number of mussels per meter per hour. All specimens during such a search were identified and measured as in the transect method.

Random searches were also made at some sites where mussels were extremely rare to improve information about which species were present at a site. Both the timed-search and random search provided the opportunity to examine all the habitats in a stretch of stream rather than just pools.

The timed searches produced more mussels than did the transects, 864 and 320 respectively (Table 1), even though more time was required to complete transects in many instances. In addition more juveniles were found in the timed searches than in the transects simply because of the difference in area and variety of habitats examined.

Time did not permit replication and testing the reproducibility of density data from timed searches. However, Cvancara (personal communication, 1987) indicated that the method does produce "adequately" reproducible results, but that it needs further evaluation.

Significance of Dead Shells

Some Minnesota floodplain deposits contain beautifully preserved Unionid shells, some even with brightly colored nacre, that range from hundreds to thousands of years old. Where eroded from stream banks and re-deposited in a stream, these shells are often impossible to distinguish from those of modern mussels that have been dead for only years or decades. Floodplain deposits were carefully checked for the presence of fossil shells at 12 sites; only one yielded three identifiable fragments. It was concluded, therefore, that fossil shells are sufficiently rare in the Zumbro system that dead shells without periostracum are less than a few decades old (surely they would dissolve if submerged much longer). In contrast, shells of dead mussels still bearing periostracum or parts of the animal are convincingly recent (a year or so old). The above information improves confidence in concluding that some species had a formerly wider range fairly recently. For example, _Venustaconcha ellipsiformis_ was found live at two sites on the North Fork (Plate 18) but dead shells were found upstream so a wider distribution is indicated within the past few decades.

On the other hand, occasional dead shells downstream from a place where live mussels occur have less significance because the dead ones could have been washed in during floods.

Plate 7 shows that only dead shells of _Lampsilis radiata siliquoidea_ were found on the North Fork. That information indicates that it was formerly there, perhaps widespread, and that it is presumably extirpated. The term "extirpated" is used advisably herein because absence is difficult to prove!

Causes of Mortality

The year of 1988 was one of drought in southeastern Minnesota and water levels in the streams of the Zumbro were extremely low. Dry Run Creek was totally dry and there were major dry stretches on Cascade and Silver Creek late in the season. At Site 15 (Cascade Creek) the mussels that were found on 28 June were all dead on 23 August, when the stream was dry. In other places mussels were trapped in dry to near dry pools on the bank side of bars, as well as in small dry channels near banks and were dying or fresh dead.

At Site 53, on the South Fork, the water was but a few inches deep and there were dead and dying mussels everywhere. Some of the shells of dead ones were broken, which suggested that muskrats or raccoons were preying on some. The cause of the die-off is unknown.

Muskrats or raccoons had almost eliminated the mussels at Site 23, and at Site 3 on Salem Creek muskrats had just dined on all the *Amblema plicata*. Not many muskrat or racoon middens were found in the watershed as those animals are trapped down so predation is probably not a serious problem everywhere.

Mussel Distribution

The distribution of both live and dead specimens found during the 1988 season is shown in Plates 2-18. In general the maps show patterns of extirpation, formerly wider distributions, as well as restricted distributions within the Zumbro drainage. Further interpretation of each map follows in the species accounts.

Mussel Diversity

Live mussel diversity of the 83 sites ranges from one to a maximum of nine species (Table 2), the average being 3.2. The diversity at stations on the Cannon River is similar, the range being 1-11, with a mean of 3.45 (Davis, 1988). No live mussels were found at 24 sites on the Zumbro and only eight sites had more than five species (Table 2).

Dawley's 1938 collection provides the only opportunity to compare recent with older Zumbro data. Species she found on the North Fork at Kenyon are listed below alongside those found in this study.

	Dawley, 1938	Site 13, 1988
A. ferussacianus	Dead?	Live
A. grandis grandis	Dead?	Live
S. undulatus	Dead?	
L. complanata	Dead?	Dead
L. compressa		Live
V. ellipsiformis		Dead
L. radiata siliquoidea		Dead

Her finding of _Strophitus undulatus_ is of considerable interest because it was not found on the North Fork during this study (Plate 15). A re-examination of her single specimen (BellMNH 2800) showed that it was incorrectly identified and is actually _Anodontoides ferussacianus_. Thus, she only found three species. Moreover, all her shells appear to be from recently dead individuals as they retain the periostracum. The comparison shows three more species at Kenyon in 1988 than found 50 years earlier. The difference most likely stems from a much more thorough search during this study and not because species diversity has improved in 50 years.

Figure 1 shows changes of diversity from site to site along major stretches of streams in the Zumbro watershed. Diversity ranges from three to five in the upper half of the North Fork and then decreases in the lower half to its confluence with the main stem (Fig. 1A). Downstream the diversity is high again at Zumbro Falls (Site 78) and Hammond (Site 77) (those two sites have the most stable substrate examined on the main stem) but from there it generally decreases toward Kellogg.

On the South Fork diversity generally decreases downstream to its confluence with the North Fork (Site 70), with two major exceptions (Fig. 1B). Diversity is high just below both Silver Lake Dam and Zumbro Dam. The pattern is the same on the Middle Fork (Fig. 1D); decreasing diversity downstream and high diversity just below the dam at Oronoco (Site 57).

In contrast, the diversity of the South Branch of the Middle fork increases from the headwaters of Dodge Center Creek to its confluence with the North Branch. There are one to four species at each site above Mantorville Dam, whereas there are five to nine species at each site below the dam.

Diversity can also be viewed in a different perspective by summarizing stream segments as follows:

	No. Live Species
North Fork	5
North Branch Middle Fork above Pine Island	4
Middle Fork + Milliken Creek above Pine Island	8
South Branch Middle Fork not not including Dodge Center Creek	8
Dodge Center Creek	4
South Branch above Silver Lake	7

South Branch below Silver Lake + Main Stem	10

In a broad sense, then, the above list shows a general trend of increased diversity downstream in the Zumbro drainage (as it probably should be). However, that broad change is punctuated by very different trends when viewed by locality (Fig. 1).

It is recognized that as diversity changes from site to site or remains about the same over a segment of stream (Dodge Center Creek, Fig. 1), the composition of those faunas may differ markedly. Table 3 was assembled to show those differences. It indicates that *Anodontoides ferussacianus*, *Anodonta grandis grandis*, and *Lasmigona complanata* are generally dominant in most of the tributaries. *Lampsilis ventricosa* is clearly the dominant species in the largest streams and *Anodonta grandis grandis* holds second place. The remaining species are less common. If the entire drainage is considered as a whole, *Anodontoides ferussacianus* and *Lampsilis ventricosa* clearly represent the highest proportions and *Anodonta grandis grandis* and *Lasmigona complanata* are a distant third and fourth (Table 1).

Considered that way, the faunas of the Zumbro and the Cannon are very different, for Davis (1988) found *Proptera alatus* (some spell it *alata*), *Lasmigona complanata* and *Lampsilis radiata siliquoidea* to be of the highest proportions.

Mussel Density

Density data for each site is presented in two ways in Table 5 - pool density in the transects (mussels/m^2) and mussels m^{-1} hr^{-1} in the timed searches. In the transects pool density averaged 0.48 mussels/m^2, ranging from a high of 8 mussels/m^2 (Dodge Center Creek) to zero. Timed searches produced densities ranging from 0-11.4 mussels m^{-1} hr^{-1}, the highest being at Site 21 on the North Fork. The mean pool-density of the Zumbro (0.48 mussels/m^2) is comparable to that of the Cannon (0.55 mussels/m^2), the latter figure being recalculated from Davis' (1988) data by eliminating his atypically high locality CAN4C.

Davis (1988) calculated the mean pool-density of tributaries of the Cannon to be 0.50 mussels/m^2. In the broad view, then, pool densities in the two watersheds are quite similar.

Table 6 shows mussel densities of stream segments derived from transects and timed searches. Dodge Center Creek has by far the highest mean pool-density of any segment of the Zumbro River (2.65 mussels/m^2), but densities are lower outside the transects as shown in the timed searches. In contrast, the North Fork has average transect densities (0.47 and 0.55

mussels/m^2) whereas timed-search densities are at their highest (1.43 and 2.44 mussels m^{-1} hr^{-1}). The lowest mean pool-density was found between the Rochester Reclamation Plant and the head of Zumbro Lake (0.01 mussels/m^2). In fact only <u>two</u> live mussels were found along that stretch (one in a transect and one during the timed search). Density is also very low on the stretch between Zumbro Dam and the Mississippi River as shown in Table 3.

It was noted previously that transect and timed-search densities are not always positively correlated; that is, if transect density is high, time-search density may be high or low. However, Figure 26 shows that downstream trends of the two are quite consistent with a few exceptions.

In general densities are highest in headwater areas and decrease downstream, but show increases below each of the major dams (the dam at Mazeppa on the North Fork was not examined).

Substrate Preference

Substrate was recorded for 674 specimens. The standard Wentworth system was used to identify particle sizes with the exception of "granules", which were included with sand. Table 4 shows that the most important substrates in the Zumbro drainage contain size classes ranging from silt to sandy pebbles and that each species has its preference. Of the ten categories, substrates ranging from silty sand to sandy pebbles harbor the most species. Davis' study of the Cannon River (1988) showed essentially the same results.

Substrates that are cobbly or bouldery with sand or silt between the large particles are the most stable substrates on much of the Zumbro because they are the most resistant to floods. The substrates least resistant to floods appear to be silt, silty sand and sand.

Assessing Reproductive and Recruitment Success

Davis (1988) analyzed histograms of mussel length to assess the recruitment success on the Cannon River. He inferred that the larger the number of length-frequencies for which there were specimens, the more frequently juvenile recruitment had occurred. He also noted the paucity of specimens less than 30 mm long and concluded their scarcity was caused by sampling error or, in one case, [they do] "not exist due to growth patterns or, more probably, ...that no mussels were recruited in a past season." His comments raise two important perennial issues: why are so few small specimens typically ever found, and if young are typically scarce, how does one interpret reproductive and recruitment success?

Isley (1911) was one of the first to point out the problem and significance of the scarcity of very small mussels. He said, "I have collected many specimens from the size of a nickel to a quarter, but mussels under the size of a dime are rare. A number of experienced field workers have spoken to me of a similar difficulty in finding juvenile specimens". That difficulty still persists, as recently pointed out by Clarke (1986).

There are several hypotheses to explain the scarcity of juveniles in healthy, reproducing mussel populations. Baker (1928) stated that "After shedding the byssus the young mussels often bury themselves deeply in the bottom." Clarke (1986) presumed that "...burial in the sand must be the normal habitus" for Proptera capax in the St. Francis River in Arkansas. In southwestern Virginia, Neves and Widlak (in Clarke, 1986) found that some species bury in the stream bottoms, some as deeply as two feet. Clarke (1986) also argued that the normal "beautiful" condition of young shells is probably evidence that juveniles are hypobenthic. Thus, it seems possible that the absence of small specimens in healthy populations is simply that they are buried in the stream bed and therefore not easily found.

Recent observations in Minnesota have suggested a second hypothesis to explain the scarcity of young. In the late summer of 1988 young of Proptera alatus less than three years old were found on the St. Croix River (unusually low water) crawling about in a small shallow channel by the bank on a sandy substrate. At the extensive Faribault bed on the Cannon River young of Lasmigona compressa two and three years old were found in a similar situation in 1987. In both those cases the young were found about 30 meters from the adult populations that were living away from the bank in swifter and deeper water. No juveniles were found among the adults. Wayne Ostlie (personal communication) has found juveniles of several species on the Chippewa River and most were removed from adults. These observations suggest that juveniles sometimes might be more abundant in special habitats away from the major occurrences of adults.

Clarke (1986, Fig. 1) found no juveniles of Proptera capax in early August during his study, but did find some in mid to late September, indicating that the juveniles were emerging from the substrate in early fall. Thus, a third hypothesis is available to explain the scarcity of young: sampling does not extend far enough into the fall to permit finding them.

Although this survey was not specifically designed to test the foregoing hypotheses, it did produce some information bearing on each.

About 40 man-hours were spent sieving substrate in search of young mussels and at many likely localities substrate was excavated to depths of 25-50 cm. At the site below Mantorville Dam, one person screened substrate for two hours down to 50 cm. All those efforts produced no young even though many cubic yards of sediment were examined. The technique was disappointing and not at all useful on the Zumbro.

A few juveniles were found during transect surveys, but finds were sufficiently rare that the method was disappointing.

On the other hand, timed searches produced surprising numbers of young. In such searches each site was extensively checked for young in areas both with and without adults. Special attention was given to eddies associated with bars, rocks and snags as well as pools on the bank side of bars, riffles, and small shallow channels.

Efforts to find young were fruitful in the sense that a fair number of juveniles were recovered but they represented only four common species (A. grandis grandis, L. ventricosa, L. complanata, and A. ferussacianus) and one less common species (S. undulatus). About 10% of the 1184 specimens measured were young. Thus, with maximum effort (especially in timed searches) it was not too difficult to find young of common species that occurred in high densities.

Most of the juveniles found on the Zumbro were found at shallow depths in the substrate or at the surface. As many were found on the surface as buried at shallow depths, so this study cannot support the hypothesis that most juveniles are hypobenthic.

About half of the juveniles were found during the last two weeks of the survey (29 August - 9 September) but most of those were A. ferussacianus from Site 13. The remainder were found at various times during the period prior to 29 August. The only young with byssal threads (attached to cobbles in a moderate current) were of L. ventricosa and they were found 23 August and 1 September. Although it seemed that young were more common in the fall, the data do not bear out such a supposition. So this study provides little evidence either to support or refute fall emergence.

At Site 13 (on 26 August) the abundant young of A. ferussacianus were clearly separated from adults. They were all in the middle of the creek on the surface of the sand substrate. The adults, on the other hand, were mostly partly buried in silt near the banks in slower current. This case represents the only support for the contention that young might be separate from adults.

In order to avoid the problem of the scarcity of juveniles, Clarke (1986) recently proposed a novel method for using size-data to evaluate recruitment. His method involves the use of the mesoconch, a "...discrete shell stage which is ontogenetically intermediate between the nepioconch (the area of the beak sculpture) and adult stages". He claimed that the mesoconch, the hypobenthic stage which includes the sculpture bearing nepioconch, can be recognized by several criteria. If so, then the length of the mesoconch can be measured, and "...if mesoconch measurements of living specimens in a population demonstrate that hypobenthic emergence occurs principally, say, in the 3 to 5 cm size classes; but no living epibenthic specimens can be found at any time of the year which are smaller than, say 9 cm; this may be an early indication of reproductive failure."

Amblema plicata is the only Zumbro species that does not possess a mesoconch. It is easily recognized on the other ones but is difficult to identify with certainty on some specimens. The following data were derived for five Zumbro species:

	Mesoconch Length (mm)	
	$\overline{M}$	Range
Anodonta grandis grandis	45	40-50
Anodontoides ferussacianus	29	19-40
Lampsilis radiata siliquoidea	39	30-50
Lampsilis ventricosa	45	40-50
Lasmigona complanata	42	31-49

Length-frequency analyses can be presented for only five Zumbro species from a few stations and stream segments because data sets with fewer than 25 measurements were not considered adequate. The graphs (Figs. 2-25) include data from both methods. The white bar represents data from transects, and the black bar represents data from timed searches plus transects.

Interpretation of length-frequency analyses can be biased by size overlap and slowed growth rate in older populations (Haskins, 1954). This problem can be minimized if both age and length are known. Consequently a scattergram comparing length with age is provided for each species as an inset on Figures 2, 7, 15, 16, and 22. In instances where age could not be estimated closer than, say, 5-6 years it was plotted as 5.5 years. Some specimens were judged to be less than a year old and they were arbitrarily plotted as 0.5 years. Given the length of a specimen, then, its age can be estimated from the graph and length frequencies can be translated to approximate age frequencies. Males and females are not distinguished on either graph.

The age-length diagrams of L. ventricosa, A. ferussacianus and A. grandis grandis show increased scatter with length that most likely reflects slowed or varied growth rates in older individuals. Thus, age is less accurately predicted for large specimens than for small ones, the latter being within about a year.

Inspection of the length-frequency diagrams (Figs. 2-25) shows that they fall into four general types, as follows:

1 - No juveniles found. Length classes present just larger than the length of the mesoconch (both the range and mean length of the mesoconch should be considered). Figures 7 and 12 are good examples of this type. Figure 12 represents a small local population of A. ferussacianus on the North Fork that ranges in age from about 2-6 years and exhibits satisfactory recruitment (that part of the life cycle from attachment of glochidia on fish hosts to successful establishment of juveniles on a substrate). Reproduction (that part of the life cycle from production of sperm to extrusion of glochidia from the female) is presumed, but it need not have occurred right at Site 20 because fish hosts move about during spawning, low water, and in the fall during periods of decreasing temperature. Figure 7 is similar except that it depicts the entire population of Dodge Center Creek (6 sites). Both show that recruitment has been annual for 4-6 years.

2 - No juveniles found. Length classes absent between the length of the mesoconch and the next largest length class. Figure 15 shows that all the specimens L. radiata siliquoidea in the Middle Fork above Oronoco Dam are older than about four years. The graph indicates poor recruitment suggesting that the species might be in trouble over the entire stretch of stream.

In this case reproduction was established by finds of gravid females here and there, so any problem probably lies in the recruitment stage.

3 - Length-frequency diagram bimodal (Fig. 18) or polymodal (Fig. 16). Such a diagram is taken to indicate intermittent recruitment.

4 - Young found. All length classes represented. Figure 19 is the best example of this type and it indicates steady annual recruitment (but not high numbers).

The foregoing results provide a framework for discussing the status of the mussels of the Zumbro River.

DISCUSSION

Mussel Species of the Zumbro River

Actionaias carinata (Mucket)

Only one live specimen of A. carinata was found in the entire Zumbro River drainage. It was about 15 years old (sex undetermined) and was living in silt wedged between cobbles and boulders in a pool at Sportsmans Park at Zumbro Falls (Plate 2). Dead shell records (Plate 2) indicate that it occurred in the South Branch of the Middle Fork, the South Fork and questionably the North Branch of the Middle Fork some time in the recent past.

Nine of the twelve fish hosts of the mucket occur in the Zumbro system and four are known above the dam at Oronoco so fish-host availability does not seem to be a factor limiting its distribution.

Elsewhere the mucket's favorite habitat seems to be shallow swift water with a stable sand, gravel or cobbly substrate (Baker, 1928; Mathiak, 1979). Although such habitats are present in the Zumbro system, the species probably has been neither abundant nor widespread for reasons unknown. Davis (1988) found the mucket live at two localities in the adjacent Cannon River but concluded it was formerly "more widespread". Dawley (1947) considered *A. carinata* "... widely distributed in medium and large rivers, but not present in large numbers" in Minnesota. However, recent work (Bright et al, in preparation) shows it is restricted to only the Mississippi River drainage.

Because no evidence of either reproduction or recruitment was found and because it is so rare, the mucket probably is in danger of extirpation in the Zumbro drainage.

Alasmidonta marginata (Elktoe)

A. marginata is a minor component (Table 1) of the Zumbro River mussel fauna (22 live specimens). Dawley (1947) considered it as "not common, but found in both small and large rivers in Minnesota. It was not found in the Cannon River (Davis, 1988). It now lives in the lower half of the South Branch of the Middle Fork, below the dam at Oronoco and below Silver Lake Dam on the South Fork (Plate 3). It formerly lived in the North Branch.

Four of the five fish hosts listed by Fuller (1978) occur in the watershed and all four also exist above the dam at Oronoco. The specimens examined below Silver Lake (Site 2) in Rochester appeared to be in superb condition and recent recruitment was indicated by one individual about two years old, and one female was gravid. Reproduction was indicated elsewhere by a few gravid females.

Its favorite substrates in the Zumbro are stable sand to sandy pebbles, where it was always found buried so that only the siphonal aperture was exposed.

The elktoe probably never was common in the Zumbro as evidenced by its former distribution (Plate 3). And at present it appears to be barely "hanging on", even below Silver Lake Dam where only eight specimens were found. Its survival above Zumbro Lake Dam is questionable if the population becomes smaller for any reason because the chances of glochidial infection of local fish hosts will be significantly reduced. Moreover, the Zumbro Lake Dam precludes additional recruitment from infected fish migrating upstream from the Mississippi River.

Amblema plicata (Threeridge)

Only one live individual of A. plicata was found in the entire study area (Plate 4, Table 1). It occurred in a pool on the lower South Branch in gravelly sand. The dead specimens found on Salem Creek recently met their demise at the hands of a muskrat. It does not occur in the Cannon River (Davis, 1988).

Eleven of the fifteen fish hosts listed by Fuller (1978) occur in the Zumbro drainage, however far fewer occur above the major dams in the system.

Threeridge is widely distributed in Minnesota in both small and large streams (Dawley, 1947; Bright et al, in preparation), but its major concentrations appear to be in the Red River, lower St. Croix River and Mississippi River. In all likelihood it was never abundant or widespread in the Zumbro drainage and is now at risk of extirpation - the species is rare and no evidence of recruitment or reproduction was found.

Anodonta grandis grandis (Floater)

Plate 5 shows that the floater is one of the most widespread species in the study area, where it occurs from small headwater streams to the main stem of the Zumbro River. It is also a major component of the mussel fauna (Table 1), being one of the four most abundant species. Moreover, it is widespread and common throughout Minnesota (Dawley, 1947; Bright et al, in preparation).

In the smaller tributaries it is most commonly found near the banks buried in sandy silt and silt as well as in eddies. In the large segments of the Zumbro it tends to be most common in pools with silty sand and in sand among cobbles and boulders.

Recruitment and reproduction (evidenced by gravid females) appear to be successful on the whole in Dodge Center Creek (Fig. 2) and in the North Fork (Figs. 3 and 6). The bimodal nature of Figure 5 indicates intermittent recruitment at Site 24 on Dodge Center Creek. The general impression is that A. grandis grandis is successfully surviving on all the tributaries. However, between Zumbro Lake Dam and the Mississippi River (Fig. 4) no individuals less than 75 mm (about 4 years old) were found suggesting that recruitment is minimal. At many sites along this stretch adults were scarce and mostly old, but some gravid females were encountered.

There are 15 fish hosts for the species in the Zumbro drainage and they are widespread.

The species appears to be extirpated in the South Fork upstream from Rochester for reasons unknown.

Anodontoides ferussacianus (Cylinder)

In the Zumbro River system the cylinder is essentially confined to the small- and medium-sized tributaries (Plate 6) as it is in other parts of the state (Dawley, 1947; Bright et al, in preparation). In such places it is most often found partly buried in silt along the banks where it is commonly associated with Anodonta grandis grandis. It is the most abundant species in the Zumbro (Tables 1 and 3) and represents about one-third of the overall mussel fauna. Davis (1988) found it common and widespread in the adjacent Cannon River.

Nine species of fish serve as glochidial hosts for A. ferussacianus (Fuller, 1978) and six are known in the Zumbro watershed. Four or five of those are known above the major dams in the drainage.

Recruitment is good at all localities where it was abundant enough to evaluate quantitatively (Figs. 7-14) and even at other sites juveniles commonly were found. Successful reproduction is indicated by ubiquitous gravid females. It appears to be comfortably established throughout the tributaries. Its occurrence on the main stem (site 77) is considered accidental.

Lampsilis radiata siliquoidea (Fat Mucket)

Plate 7 shows the distribution of the fat mucket in the Zumbro River. It is mostly confined to the Middle Fork and South Fork. It is apparently extirpated in the North Fork and only four old live individuals were found in the stretch between Silver Lake and the mouth of the Zumbro. It was once more widespread in the South Branch of the Middle Fork than now. Davis (1988) found it widespread in the adjacent Cannon. Dawley (1947) viewed it as widespread in all parts of Minnesota and not restricted to any stream type.

The fat mucket was found in silt and sand along banks but was most common in pebbly-cobbly sand.

Density of the species is low enough at most sites that length-frequency could be examined only for the stretch on the Middle Fork above Oronoco Dam (Fig. 15). No length classes between the mesoconch length and 75 mm are apparent so recruitment is considered poor, all the specimens being older than about four years. In fact only one of the 41 specimens on the North Fork was less than four years old. Young of the species 1-3 years old were found at a few sites, but they are uncommon everywhere. Gravid females were identified at some localities but they were not common. L. radiata siliquoidea may be in trouble in the Zumbro drainage.

Fuller (1978) listed 13 fish hosts for the species and 11 occur within the Zumbro drainage. At least five of those live upstream from the major dams.

Lampsilis ventricosa (Pocketbook)

In the Zumbro system, *L. ventricosa* is restricted to the lower reaches of the Middle Fork and South Branch of the Middle Fork and to the South Fork and main stem (Plate 8). Overall it is about the second most common species (Tables 1 and 3) in the fauna and at several sites it represented over 60 percent of the individuals encountered (Table 3). Davis (1988) found it far less common and widespread on the Cannon. Dawley (1947) claimed it to be common in small, medium and large rivers in Minnesota.

Large local populations exist on the South Fork just upstream from the mouth of Cascade Creek, in the headwaters of the South Fork (Site 53) and in the main stem at Site 77. Elsewhere it is rare to common.

The pocketbook's favorite substrate in the Zumbro is in firm sand, pebbly sand and sandy pebbles. It was found near the banks, in bars, in pools and in eddies behind boulders and logs.

Four of the six fish hosts listed by Fuller (1978) occur in the Zumbro drainage. Only the white crappie lives above Mantorville Dam on the South Branch of the Middle Fork. No fish hosts are known on the North Fork above the dam at Mazeppa, which perhaps explains its absence there.

This is the only species for which young were found still attached to byssal threads. They occurred at Sites 2 and 78.

Figures 16-21 show the length-frequency analyses for the pocketbook. Only 28 specimens of *L. ventricosa* were recovered from the South Branch of the Middle Fork between Mantorville dam and the mouth and most of them were older than 5-6 years (Fig. 16). Recruitment along that stretch is slow and intermittent (Fig. 16) and few gravid females were found. On the South Fork, above Silver Lake Dam, recruitment is currently slow but persistent (Fig. 17) and gravid females indicate reproduction. Taken as a whole, the population between Zumbro Lake Dam and the river mouth appears to be in a state of minimal and intermittent recruitment (Fig. 18); few gravid females were found along that stretch in the scattered, low-density local populations. At Site 53, on the South Fork, recruitment is negligible and intermittent (Fig. 21) and most of the local population is over 5-6 years old. But gravid females were found indicating reproduction. The healthiest local population of the pocketbook is just below Silver Lake Dam (Fig. 19), where both reproduction and recruitment are sound.

In the 20 ft.-deep pool just below the outlet of Zumbro Lake Dam the youngest *ventricosa* was about 10 years old and the oldest was about 28 years. It is rare between the Rochester Reclamation Plant and Zumbro Reservoir as well as in the main stem downstream from Site 77 (Hammond).

Lasmigona complanata (White heelsplitter)

The white heelsplitter represents about ten percent of the live mussels found in the Zumbro (Table 1). It is never abundant, but it occurs at 24 sites, primarily in the Middle Fork and its tributaries (Plate 9). It is absent in the main stem below Zumbro Falls and is apparently extirpated in Salem Creek. It is more widespread and abundant in the adjacent Cannon River (Davis, 1988). Dawley (1947) showed its distribution to be state wide, but sporadic in occurrence. In the Zumbro drainage it is most abundant in the North Branch of the Middle Fork and the Middle Fork (Table 3, Plate 9).

Its favorite habitats are sandy silt, pebbly sand and pebbly cobbly sand (Table 4) near banks and in pools with a firm bottom.

All four fish hosts, including the european carp (facultative), exist in the drainage. However, only the green sunfish occurs in the North Fork above the dam near Mazeppa, so the fate of L. complanata is tied to that of the single fish species. Two fish hosts (carp and green sunfish) exist above the dam at Oronoco and three fish hosts live above the Mantorville Dam (carp, green sunfish and white crappie).

Figures 22-25 show length-frequency data for the species. The population on the Middle Fork above Oronoco Dam indicates recent recruitment (Fig. 22) but a big gap between the 45 and 75 mm length classes. Most of the individuals are more than about eight years old and a few gravid females indicate reproduction. Thus recruitment has been intermittent but the population overall appears temporarily safe. In the South Branch of the Middle Fork (below Mantorville Dam, Fig. 23), at Site 47 (Middle Fork, Fig. 24) and at Site 67 South Branch of the Middle Fork, Fig. 25), local populations exist showing no recruitment, and individuals ranging from about six to nine years old, although a few gravid females were found. The white heelsplitter apparently is not recruiting well anywhere and is just hanging on in the Middle Fork above Oronoco Dam.

Lasmigona compressa (Creek Heelsplitter)

The creek heelsplitter is supposedly widespread and abundant in streams and small rivers in Minnesota according to Dawley (1947), however, there are insufficient literature or voucher records to confirm her statement. Widespread maybe, but certainly not abundant. Davis (1988) found it at only five localities on the Cannon, but it is more widespread in the Zumbro drainage (Plate 10). The main populations occur in the North Fork, the Middle Fork, and Dodge Center Creek (Table 3). It represents but a few percent of the overall fauna (Table 1).

It was normally found in pools with a sand or silt substrate.

The fish that host its glochidia are (is) unknown.

No more than a few individuals were found at any site and most of them were large. No signs of recruitment were found, and only eggs were seen in a few females. All of which suggests a species that is merely "hanging on".

Lasmigona costata (Fluted Shell).

Lasmigona costata was found live at but four places on the Zumbro (Plate 11). At one time it lived in the South Branch, the lower North Branch and lower Cascade Creek. Davis found it live at only three places on the Cannon. It is recorded from less than 30 sites in the state (Bright et al, in preparation) primarily from the Red River and St. Croix drainages and southeastern Minnesota.

In the Zumbro it inhabits pools with bottoms of pebbly sand and sandy pebbles.

The only known fish host is the european carp (Fuller, 1978).

Only four of these mussels were found live during the survey, they were all old, and the one below Oronoco Dam was deformed. One gravid female was found. The fluted shell must be on the brink of extirpation in the Zumbro drainage.

Leptodea fragilis (Fragile Papershell)

The fragile papershell is a large river species known only from the lower St. Croix, lower Minnesota, and Mississippi River below St. Anthony Falls (Bright et al, in preparation). Davis (1988) reported it from the lower Cannon. In the Zumbro it was found live only in the area below Zumbro Lake Dam and at Site 75 on the main stem (Plate 12). It might have been more widespread in the past, but the dead shells could have been washed downstream.

Its single host is the drum, which occurs only below Zumbro Lake Dam.

Only seven live specimens were found and they were all old. Several gravid females were seen but there was no sign of recruitment. Either L. fragilis is on the verge of extirpation or it represents a species never common and one that only sporadically and accidentally becomes established in the Zumbro.

Ligumia recta (Black Sandshell)

This species was found only at Zumbro Falls, where two very old live specimens (sex undetermined) were found at Sportsman's Park (Plate 13). It is rare on the Cannon (Davis, 1988). Dawley (1947) indicated its occurrence in all drainages in the state, being "common in all but the smallest rivers".

Four of its five fish hosts occur in the river below Zumbro Lake Dam.

This species is so rare that it cannot survive in the Zumbro River unless it becomes re-established by recruitment from the Mississippi River.

Proptera alatus (Pink heelsplitter)

The pink heelsplitter was probably a bit more widespread than it is now (Plate 14), but at present it only exists at two sites on the main stem where the substrate is stable. There, a few old individuals (sex undetermined) live in sand sandwiched between boulders and cobbles. It is quite common in the adjacent Cannon (Davis, 1988) and in some places along the Mississippi. It also occurs in the Red River and the lower Minnesota and St. Croix Rivers.

Its only host is the drum, which occurs below Zumbro Lake Dam.

This species is another one that is so rare in the Zumbro system that it probably cannot survive, without recruitment from the Mississippi River.

Strophitus undulatus (Squawfoot)

The squawfoot lives only in the Middle Fork, South Branch of the Middle Fork, just below Silver Lake Dam, and at one locality on the South Fork (Plate 15). It apparently lived further up the South Branch and in Cascade Creek in the recent past. Davis (1988) found it only in the upper stretch of the Straight River, a tributary of the Cannon, at three sites. Dawley (1947) noted that it occurred in "small rivers in the St. Croix and Red River systems, and in the Mississippi River south of St. Anthony Falls, not common but found in both small and large rivers".

Three of the fish hosts listed by Fuller (1978) occur in the Zumbro system. At least two of them exist above the major dams at Mazeppa, Mantorville, Oronoco and Mayowood.

Only 29 live individuals were found and nine of those occurred just below the Oronoco Dam (Site 57). No evidence of recruitment was found but an occasional gravid female was noted. The squawfoot is another mussel species just hanging on in the Zumbro drainage even though its glochidia are capable of development without a fish host (Lefevre and Curtis, 1911).

Toxalasma parvus (Lilliput)

The lilliput is confined to southeastern Minnesota in the Mississippi River, lower St. Croix River and lower Minnesota River (Bright et al, in preparation). Fuller (1985) considered it abundant. It occurs live at only four sites in the Zumbro drainage (Plate 16) and is rare. Davis (1988) did not find it in the Cannon system.

All five of its fish hosts listed by Fuller (1978) occur in the Zumbro.

Fuller (1985) considered it a species of "soft substrate" in the Mississippi and there it was found in the Zumbro in silty sand and sand in various habitats.

Although no evidence of reproduction or recruitment was found in the Zumbro drainage its status is difficult to access because it is so easy to miss on account of its small size.

Truncilla truncata (Deertoe)

Only one individual was found on the Zumbro River at Site 80 (Plate 17). Even though both the specie's fish hosts exist in the drainage, it is not expected to survive unless re-established by recruitment from the Mississippi River where it is common. It's present occurrence, on the other hand, might be accidental.

It is known to have occurred in the lower St. Croix and Minnesota Rivers as well as the Mississippi below St. Anthony Falls (Bright et al, in preparation).

Venustaconcha ellipsiformis (Ellipse)

The ellipse was unknown in Minnesota until Davis (1988) discovered it in the Cannon River, where he found it live at five localities. It is now also known from nine sites on the Zumbro River (Plate 18). It was previously further upstream in the North Fork than now and is apparently extirpated from Cascade Creek and the North Branch of the Middle Fork. It represents about 14% of the fauna in the South Fork upstream from Rochester (Table 3).

It was found in both riffles and pools, partly to completely buried in firm sandy silt or silt. In the riffles it occurred in firm sand among pebbles and cobbles.

Its fish host(s) are unknown.

No recruitment was evident in the Zumbro drainage as all specimens were uniformly large, but gravid females were commonly encountered indicating healthy reproduction.

General

The present mussel fauna of the Zumbro River can be separated into three general communities. In the headwaters of the tributaries the dominant species are Anodontoides ferrascianus, Anodonta grandis grandis and Lasmigona complanata. As one proceeds downstream Lampsilis radiata siliquoidea, Strophitus undulatus, Venustaconcha ellipsiformis, Alasmidonta marginata and Lampsilis ventricosa appear, but vary in abundance from place to place. They constitute a sort of "mid-stream" community. As the Zumbro increases in volume and size downstream to its mouth a third community is evident that is dominated by Lampsilis ventricosa and Anodonta grandis grandis. Less common species in the latter community include Leptodea fragilis, Alasmidonta marginata and Proptera alatus.

There is no doubt that the natural composition of the midstream and "big water" communities has been altered by erection of dams. For example, no reason is evident to preclude the occurrence of Proptera alatus (Plate 14) living upstream from Zumbro Lake were it not for the dam blocking dispersal of its host fish.

The scattered and low-density occurrences of such species as Truncilla truncata, Actionaias carinata, Leptodea fragilis, Ligumia recta and Proptera alatus downstream from Zumbro Lake beg for explanation and two come to mind. Much of the stream bed below Zumbro Lake appears to be unstable, as witnessed by the constantly moving bed load of sand (even in low water periods) and bars that are soft and always shifting. This condition is especially pronounced between the confluence with the North Fork and Zumbro Falls and below Theilman. Such places constitute minimal habitat for mussels and they are rarely found there. However, where the subrate consists of protected areas of sand or silt between cobbles and boulders mussels are often found buried in the sand and/or silt (such as the sites at Hammond and Zumbro Falls). Excessive input of silt and sand from the North Fork might therefore be creating long stretches of stream bed that are simply unsuitable for mussel infestation and therefore account for their low densities and scattered occurrences. On the other hand the species mentioned above could always have been rare in the main stem, representing nothing more than rare and random recruitment via the odd infected fish moving upstream from the Mississippi River - after all, most species in a community are rare. Although both hypotheses are viable explanations, either together or separately, the fact that mussels are found in places with stable substrates lends strongest support for excessive siltation being the major limiting factor on the main stem of the Zumbro.

It was pointed out above that both density (Fig. 26) and diversity (Fig. 1) of mussels tend to be high just below the major dams on the Zumbro and that Davis (1988) had found high densities below dams on the Cannon River (but not necessarily high diversity). It is a well known observation that fish tend to congregate below dams periodically (J. Underhill, personal communication). Davis (1988) pointed out that such congregations could enhance the local population of mussels by improving recruitment and therefore mussel density. Then, as density increases, the chance of fish infection by glochidia improves. Moreover, as density of the mussels increases so does the chance of fertilization. That positive feedback system, coupled with the more or less stable habitat the dam provides, probably accounts for the finding of high densities below dams on the Zumbro.

The high diversity of mussels below Zumbro dam can be explained in a similar fashion. Fish that are infected elsewhere might migrate to dams and congregate there, shed the parasitic juvenile mussel, and thereby increase the number of mussel species below the dam. Moreover, the artificial habitat stability may improve recruitment of less common species.

Experience leads to the opinion that mussel density in the Zumbro drainage is lower than it was earlier in the century, however, evidence is scanty. Baker (1928) noted densities of 1 to 20 per square yard in Oneida Lake, Wisconsin and as many as 10 per square foot in Sturgeon Bay, but that the density of mussels in rivers "...greatly exceeds that of lakes." Many sites on the Zumbro produced densities less than Baker's and in fact many had no mussels at all. Cvancara (1970, Fig. 8) found more than 100 mussels per hour throughout much of the Red River system, but the maximum found in the Zumbro was 114/hr and averaged only 17.8/hr. Lastly, Lloyd Wilcox's recollections (personal communication, 1988) indicate that mussels were sufficiently abundant in the upper main stem of the Zumbro in the 1930's to be commercially important, which they are not now. The trend, then, seems to be toward depletion of mussels in many parts of the drainage.

Density is highest in headwaters, probably because those areas of the drainage are the least effected by human alteration. In fact the unusually high densities recorded (Fig. 26) at such places as Site 47 on the Middle Fork, Site 21 on the North Fork and Site 24 on Dodge Center Creek might be a window to the past, those sites representing relictual densities that occurred more commonly in the Zumbro before the advent of human disturbance.

CONCLUSIONS

The transect method of assessing mussel density developed by Davis (1988) was thoroughly tested during this survey. Although it proved useful, two problems became apparent. First it produced low diversity at most sites, especially where mussel distribution was scattered and patchy and where mussel densities were extremely low. Second, it was not cost effective where density was low and the transects were very long.

Timed searches were added at most sites to augment the transect data. This method consistently increased diversity over that of the transects (Fig. 1). Moreover, it produced density data at sites where no mussels were found in the transects. However, standardizing the time spent searching would improve the method. This technique should be included in future surveys.

Random searches proved to be ineffective as they yielded no quantitative information.

Both SCUBA and snorkeling improved efficiency at most sites and SCUBA proved invaluable in the deep pools.

Density and diversity of mussels in the Zumbro River are similar to those in the Cannon (Davis, 1988).

The Zumbro River is a highly altered aquatic ecosystem as evidenced by low mussel density, long stretches devoid of mussels, retracted distribution of some mussel species, extirpation of some mussel species from entire tributaries, poor recruitment at some sites and dams limiting the distribution of fish that serve as mussel glochidial hosts. Humans have altered the system by chemical and organic pollution, dam construction and increased siltation and runoff from agricultural areas. The results of this study provide one basis for future monitoring of the aforementioned conditions.

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TABLE 1. Proportions of Live Species in the Zumbro River System, 1988

	Transects		Transects & Timed Searches	
	N	%	N	%
Actionaias carinata			1	.1
Alasmidonta marginata	12	3.8	22	1.9
Amblema plicata			1	.1
Anodonta grandis grandis	34	11.0	191	16.1
Anodontoides ferussacianus	108	33.8	368	33.1
Lampsilis radiata siliquoidea	6	1.9	76	6.4
Lampsilis ventricosa	108	33.8	250	21.1
Lasmigona complanata	31	9.7	158	13.3
Lasmigona compressa	4	1.3	33	2.8
Lasmigona costata	2	.6	3	.3
Leptodea fragilis			7	.6
Ligumia recta			2	.2
Proptera alatus			3	.3
Strophitus undulatus	10	3.1	33	2.8
Toxalasma parvus			1	.1
Truncilla truncata			1	.1
Venustaconcha ellipsiformis	5	1.6	34	2.9
	320		1184	

	Living	Dead	Total
50	0	0	0
51	3	6	9
52	7	1	8
53	7	1	8
54	5	2	7
55	3	0	3
56	1	0	1
57	9	0	9
58	0	0	0
59	5	1	6
60	0	5	5
61	0	0	0
62	0	0	0
63	1	0	1
64	1	2	3
65	2	3	5
66	1	4	5
67	7	2	9
68	2	3	5
69	5	2	7
70	1	3	4
71	2	0	2
72	3	0	2
73	3	2	5
74	1	1	2
75	1	2	3
76	1	1	2
77	5	3	8
78	5	4	9
79	6	1	7
80	3	2	5
81	0	0	0
82	0	0	0
83	6	2	8

TABLE 3. Proportion (%) of Live Species by Stream Segment: Transects + Timed Search

	A.feru	A.gran	L.compl	L.compr	V.ellip	L.rs	L.vent	L.cost	A.marg	S.und	L.frag	P.alat	A.plic	L.rec	T.trun	A.cari	T.parv
North Fork	60.4	29.8	.9	5.5	3.4												
N. Br. Middle Fork - above Pine Island	47.7	4.7	45.3	2.3													
Middle Fork - above Pine Island	21.6	10.8	27.7	2.8	1.9	26.8	5.6			2.8							
S. Br. Middle Fork - including Dodge Center Creek	56.7	22.3	8.9	4.5	4.0	.05	1.8		.05	.05			.05				
Dodge Center Creek	64.8	24.9	6.2	4.2													
S. Fork; above Silver Lake Dam	1.4		5.6	1.4	13.9	4.2	70.8			2.8							+
S. Fork; Rochester Recl. Plant - Silver Lake Dam		1.8	2.6			.9	75.4	1.8	9.7	7.7							+
Zumbro L. Dam - Miss. River		30.8	.8			1.7	54.2	.8			5.8	2.5		1.7	.8	.8	

+ = present

TABLE 4. Substrate Preference

Species	Clay	Silt	Sandy Silt	Gravelly Cobbly Silt	Silty Sand	Sand	Pebbly Sand	Pebbly Cobbly Sand	Sandy Pebbles	Sandy Cobbles & Boulders
A. cari										x
A. marg						28.6	7.1	14.3	50.0	
A. plic						x				
A. gran	0.9	7.2	25.2	3.6	37.8	2.7	11.7	10.8		
A. feru	1.6	10.0	13.2	14.2	49.5		7.4	3.7	0.5	
L. rs		12.8			5.1	5.1	2.6	71.8		2.6
L. vent					3.0	55.0	37.8	5.5	48.2	
L. compl		3.6	19.5	9.8	6.1	7.3	14.6	34.1	4.8	
L. compr			26.7		53.3		13.3	6.7		
L. cost							x		x	
L. frag							x			
L. rec										x
P. alat						x				x
S. und					4.2	54.2	16.7	8.3	16.7	
T. parv					x	x				
T. trun		x								
V. ellip			24.0			56.0		12.0		8.0
Overall	0.6	5.2	11.7	5.8	23.7	5.6	19.0	13.6	14.2	0.4

N = 674

"Sand" includes granules

x = present

	Transects			Timed Search
Site #	# Live clams	Area (m^2)	Mussels/m^2	Mussels m^{-1} hr^{-1}
48	3	11	.27	.115
49	4	17.8	.22	.128
50	-	-	-	-
51	2	19.1	.10	.173
52	3	26	.12	.043
53	8	8	1.0	1.325
54	1	13.6	.07	.0636
55	-	-	-	0
56	0	8.8	0	.033
57	-	-	-	.206
58	0	5.8	0	0
59	1	26.2	.04	.0032
60	0	18.5	0	0
61	-	-	-	-
62	0	9.8	0	0
63	0	4	0	.052
64	1	31.0	.03	0
65	3	13.8	.22	.022
66	0	14.2	0	.00286
67	15	36.2	.41	.0755
68	0	2.5	0	.20
69	1	51.0	.02	.029
70	0	2.5	0	.0107
71	0	5.7	0	.044
72	13	16.1	.81	.22
73	0	70.4	0	.005
74	0	27.2	0	.00046
75	0	17.0	0	.00167
76	0	22.8	0	.00296
77	11	62	.18	.254
78	0	16	0	.115
79	11	24	.46	.0215
80	0	24	0	.023
81	-	-	-	0
82	0	9.8	0	0
83	4	14.5	.28	.0365
			$\bar{m}$ .48	$\bar{m}$ .451
			SD 1.20	SD 1.71

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

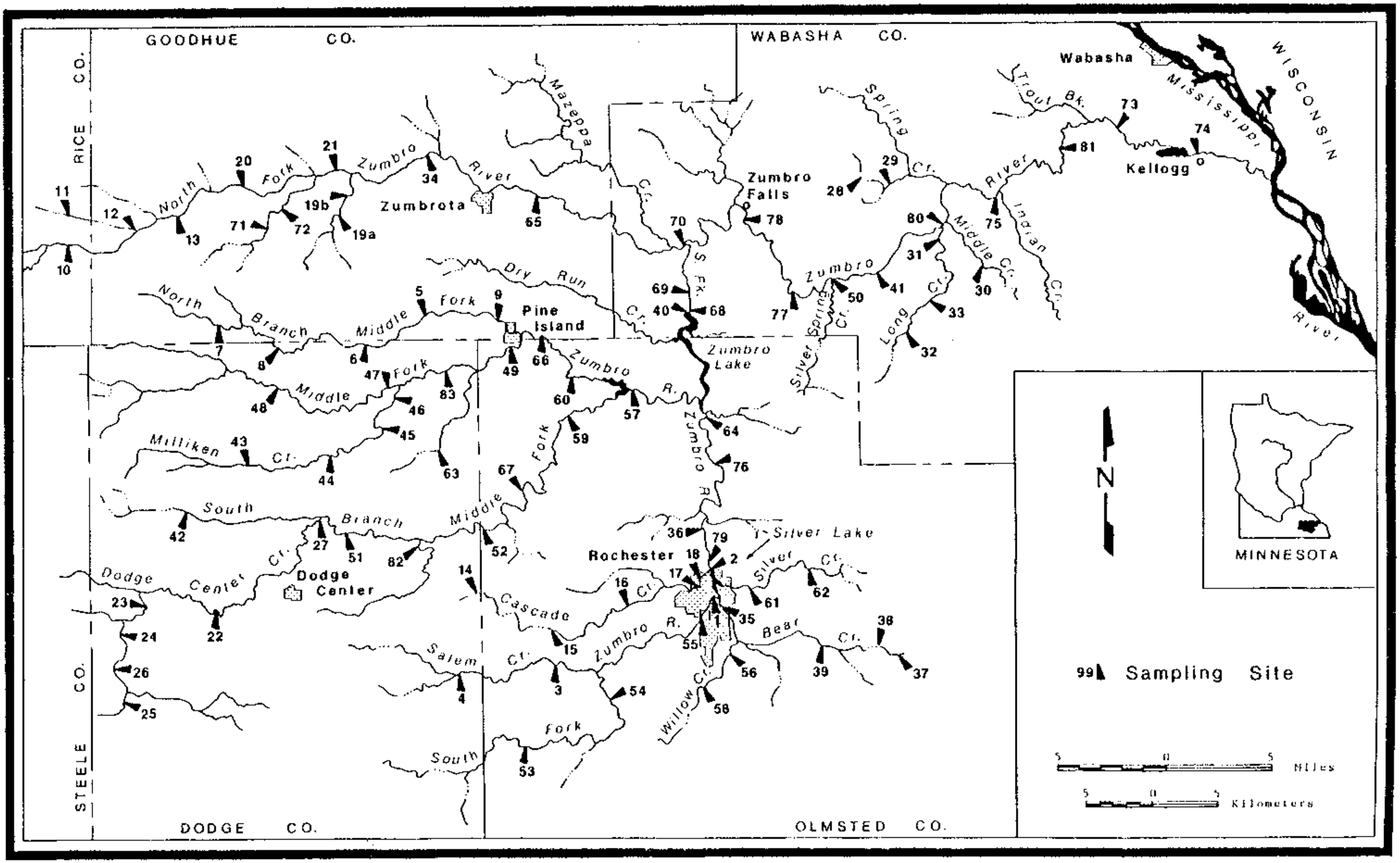
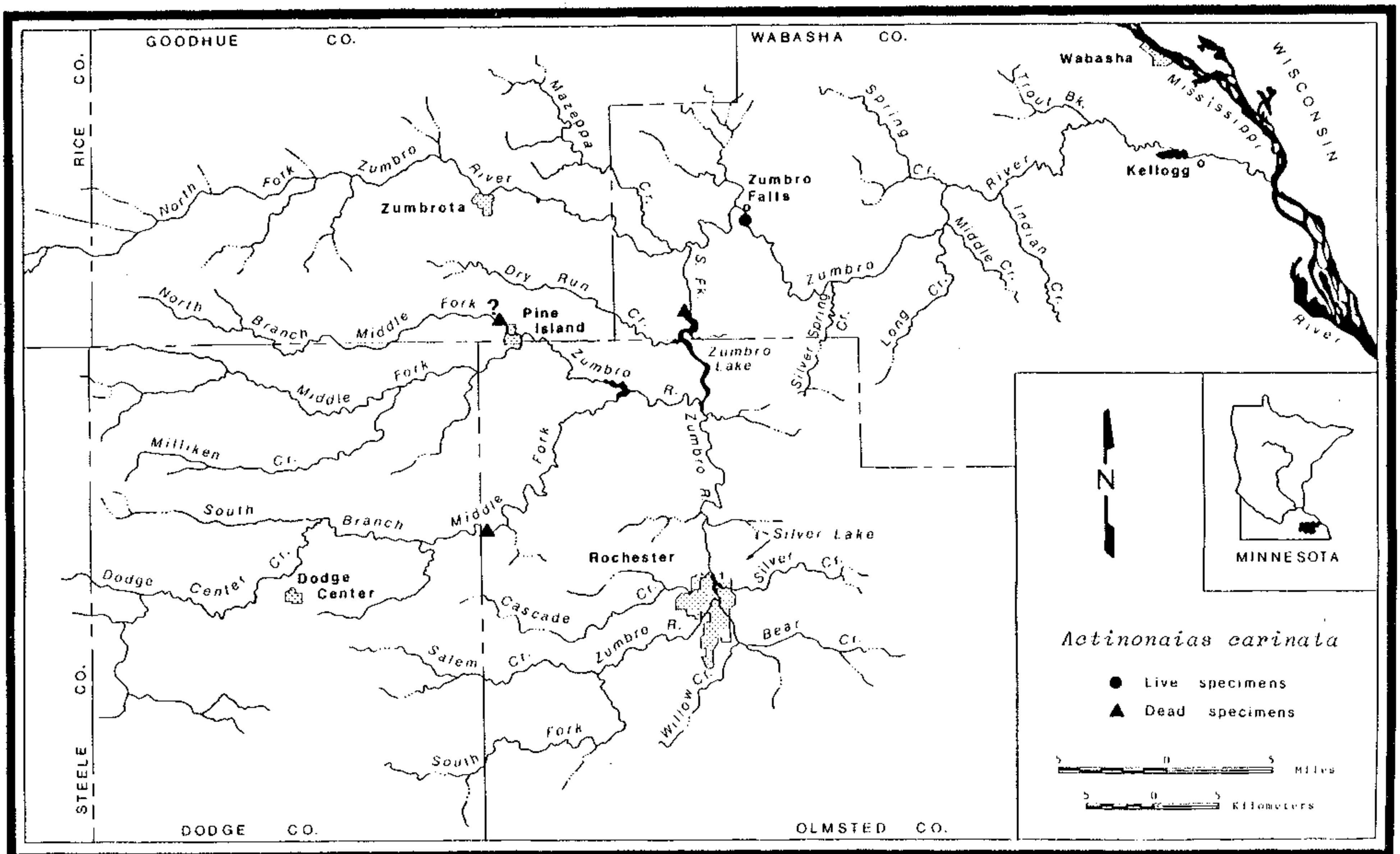
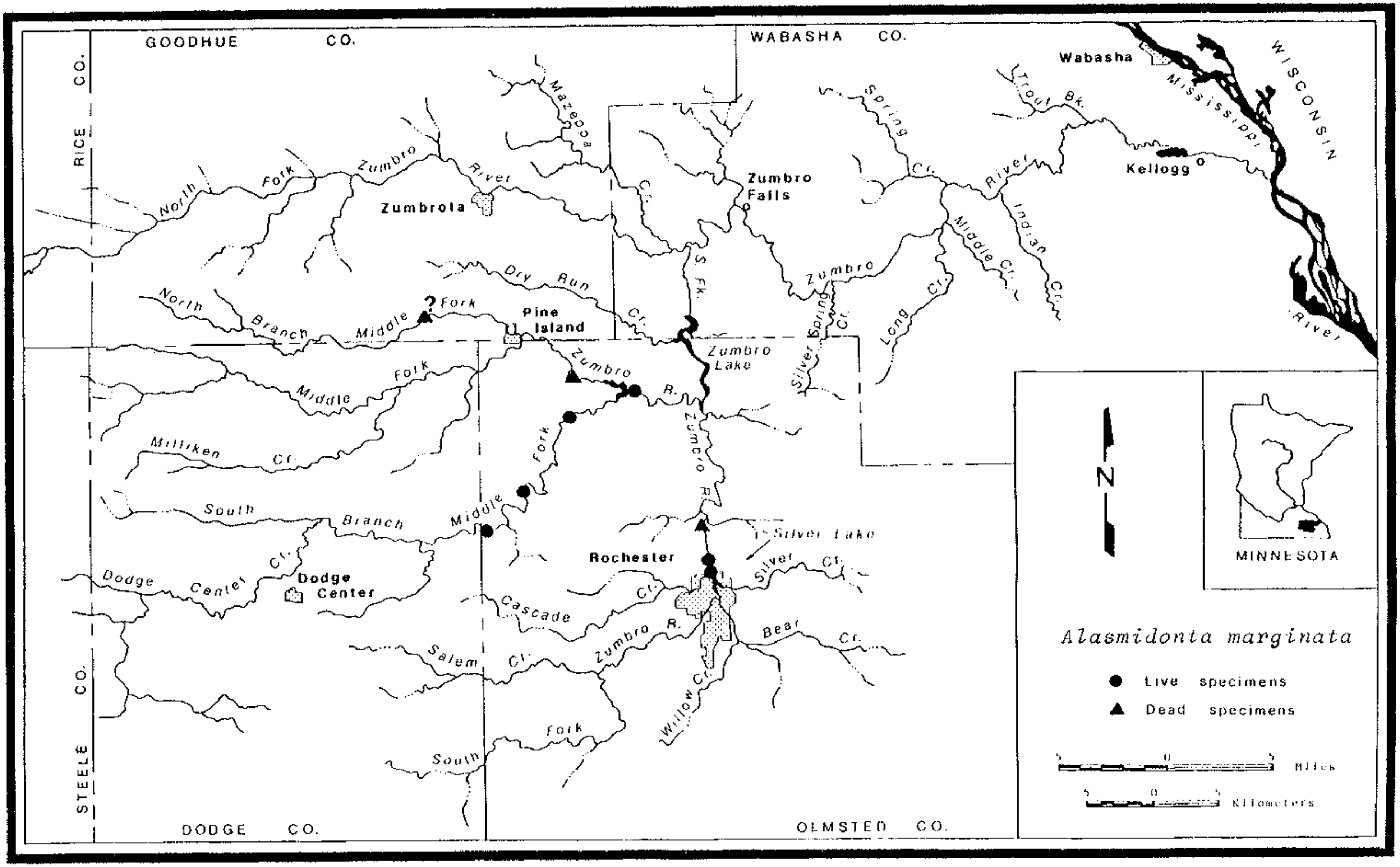


Plate 1

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

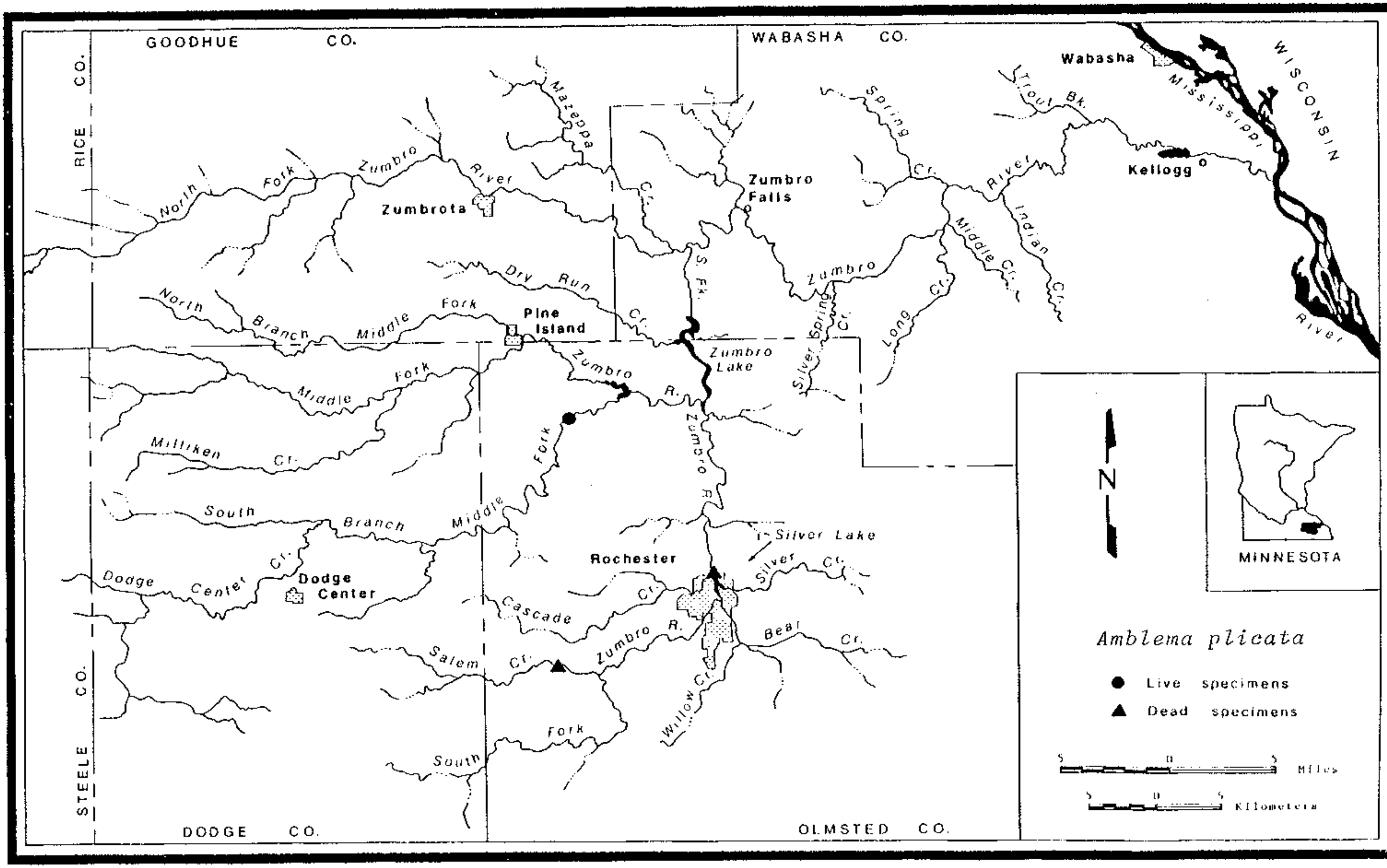


Plate 4

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

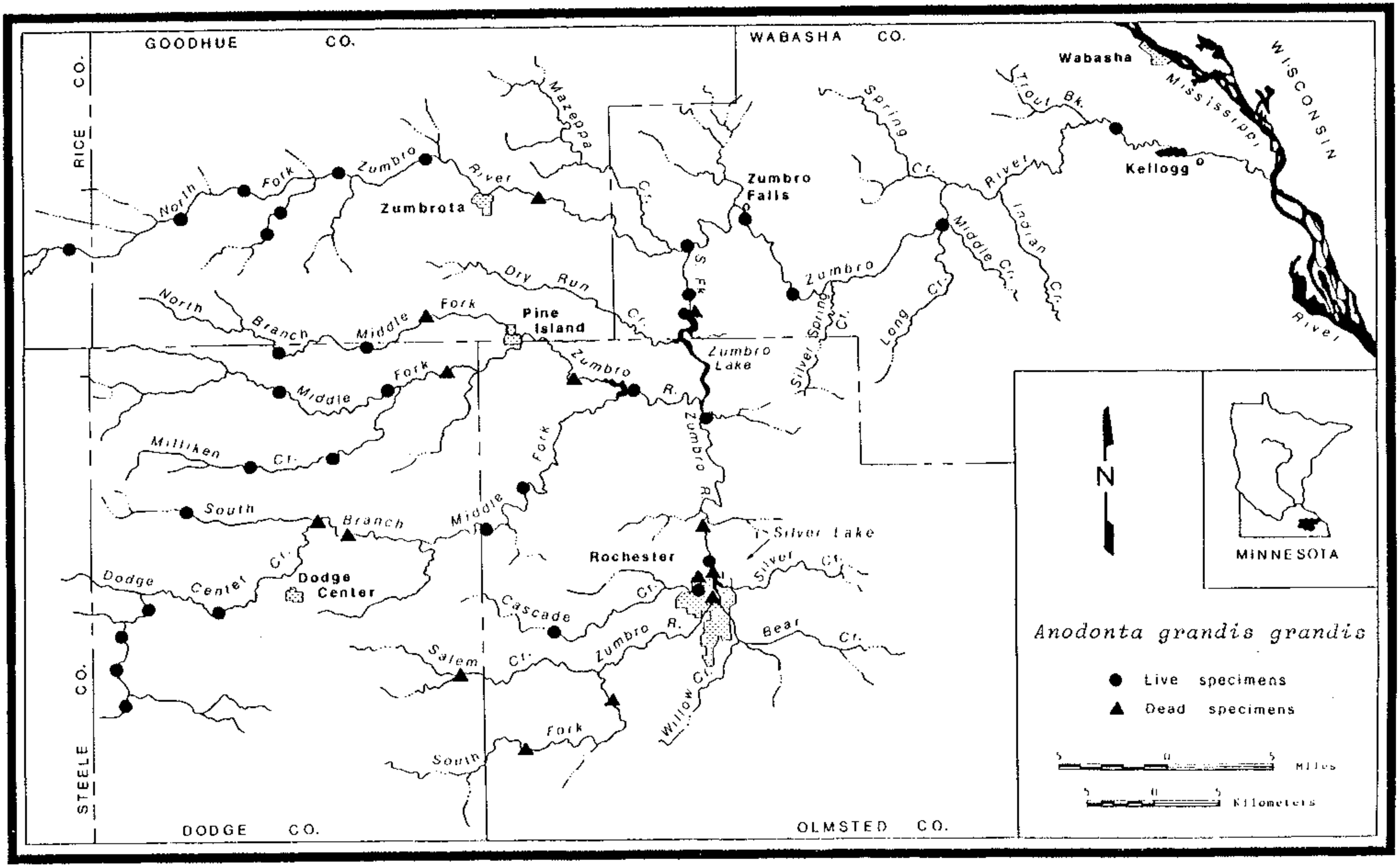
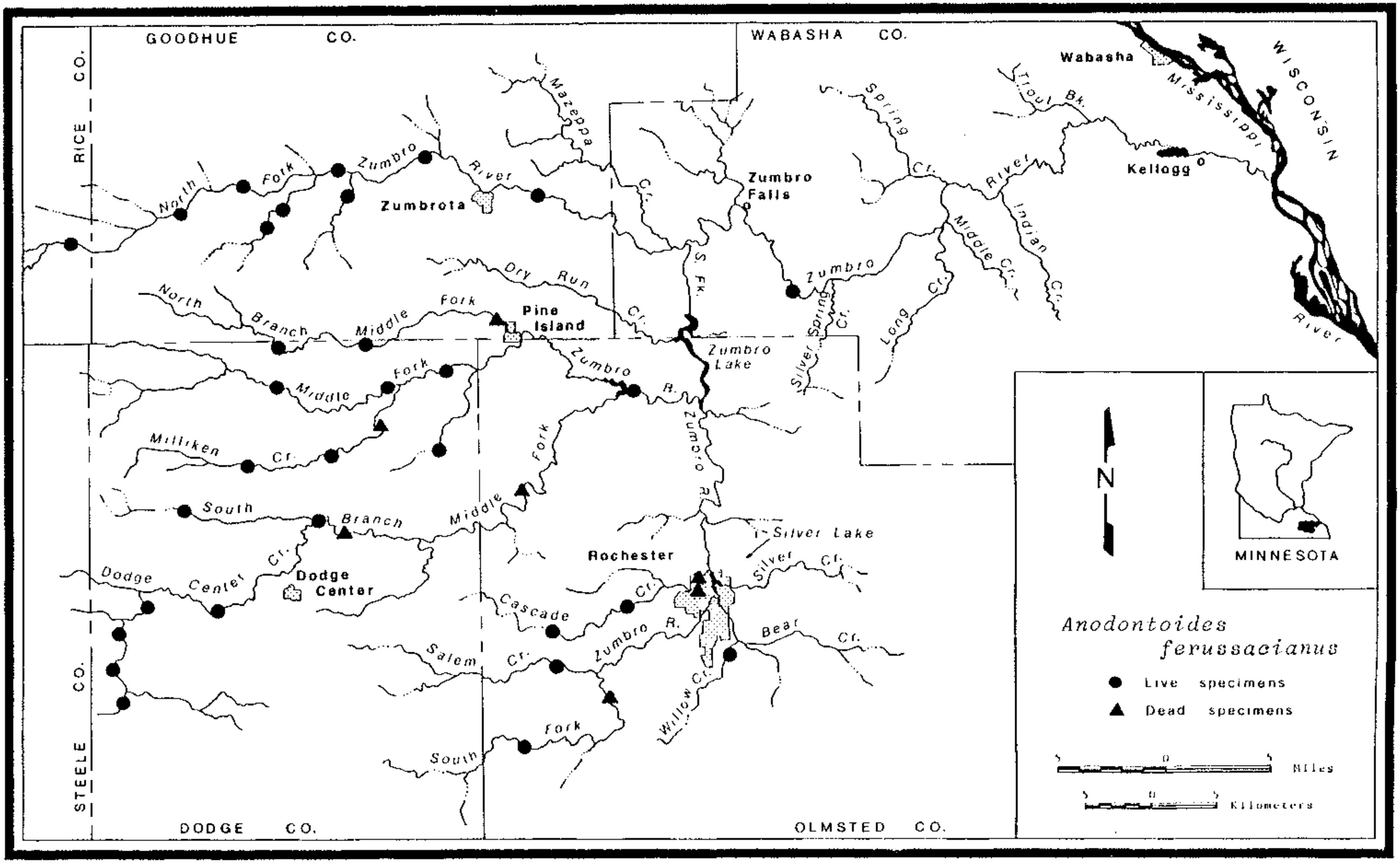


Plate 5

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

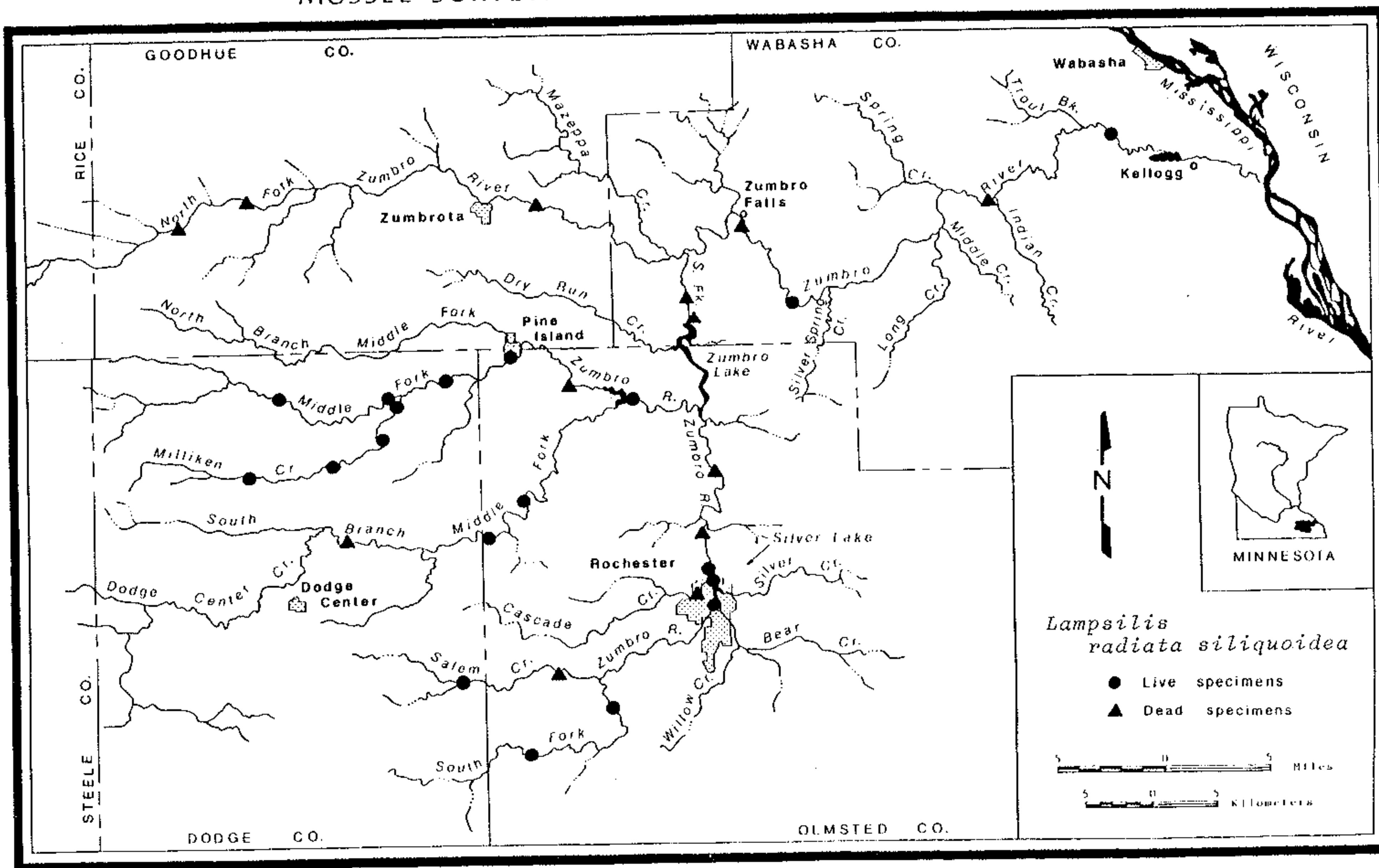


Plate 7

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

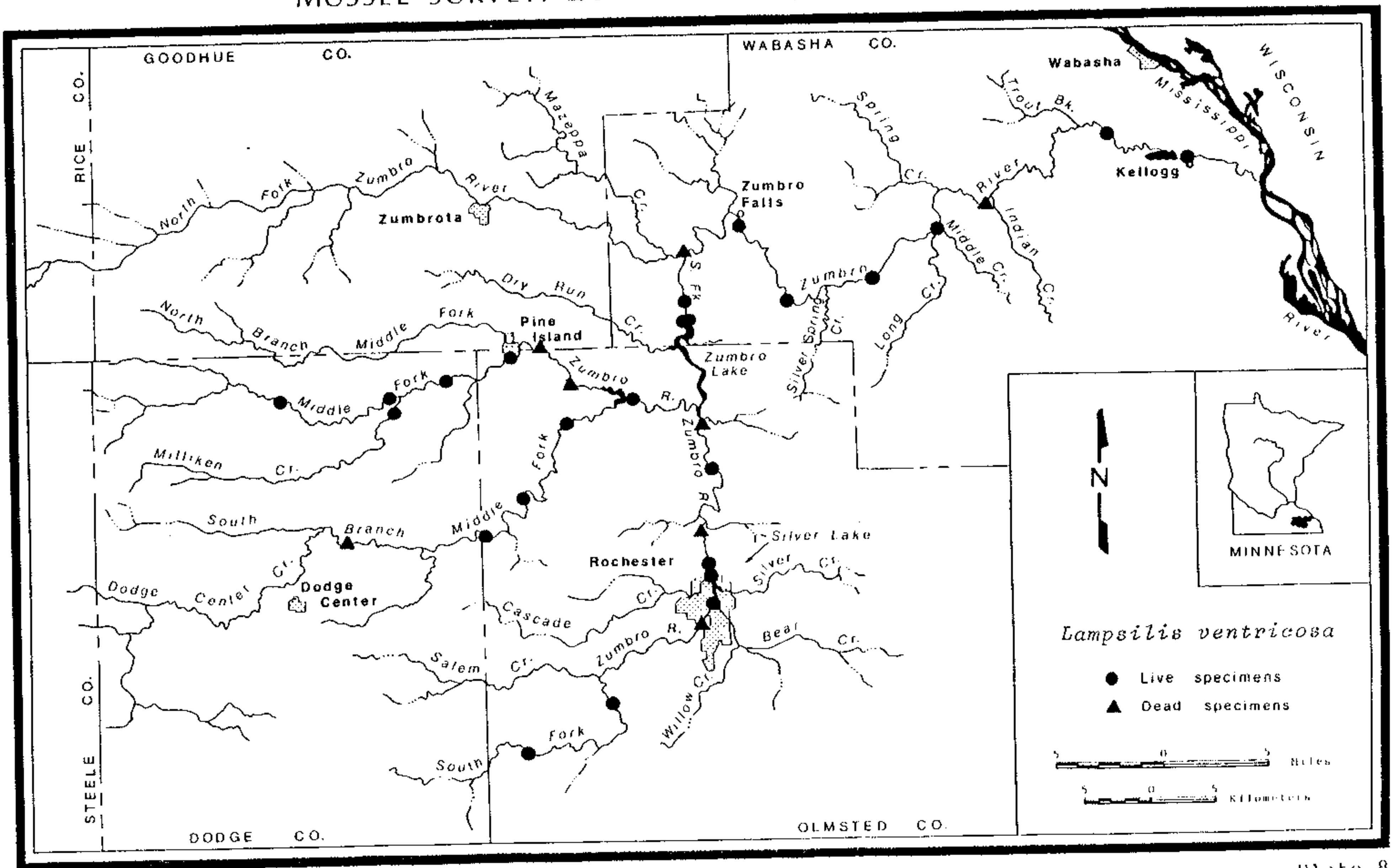
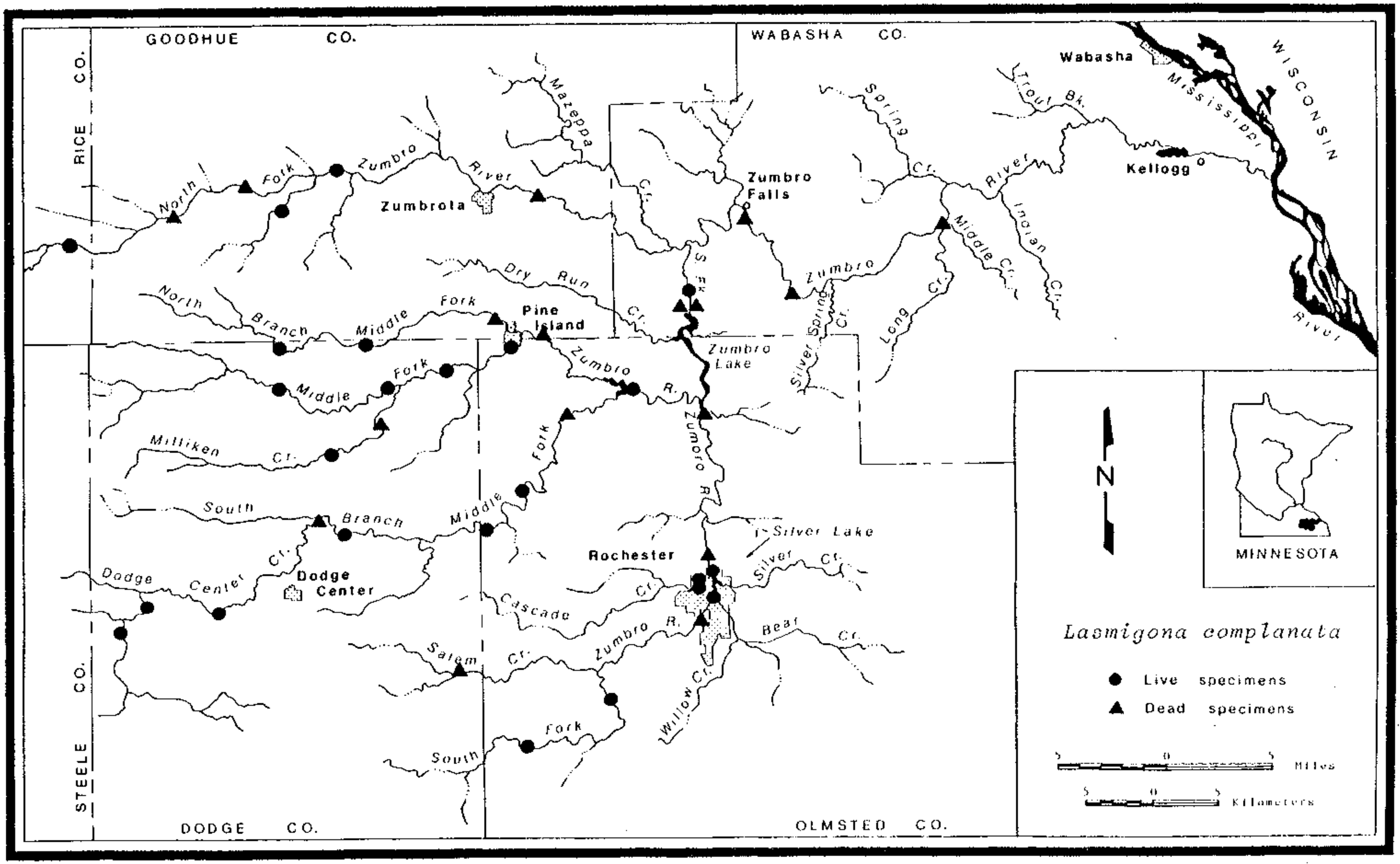
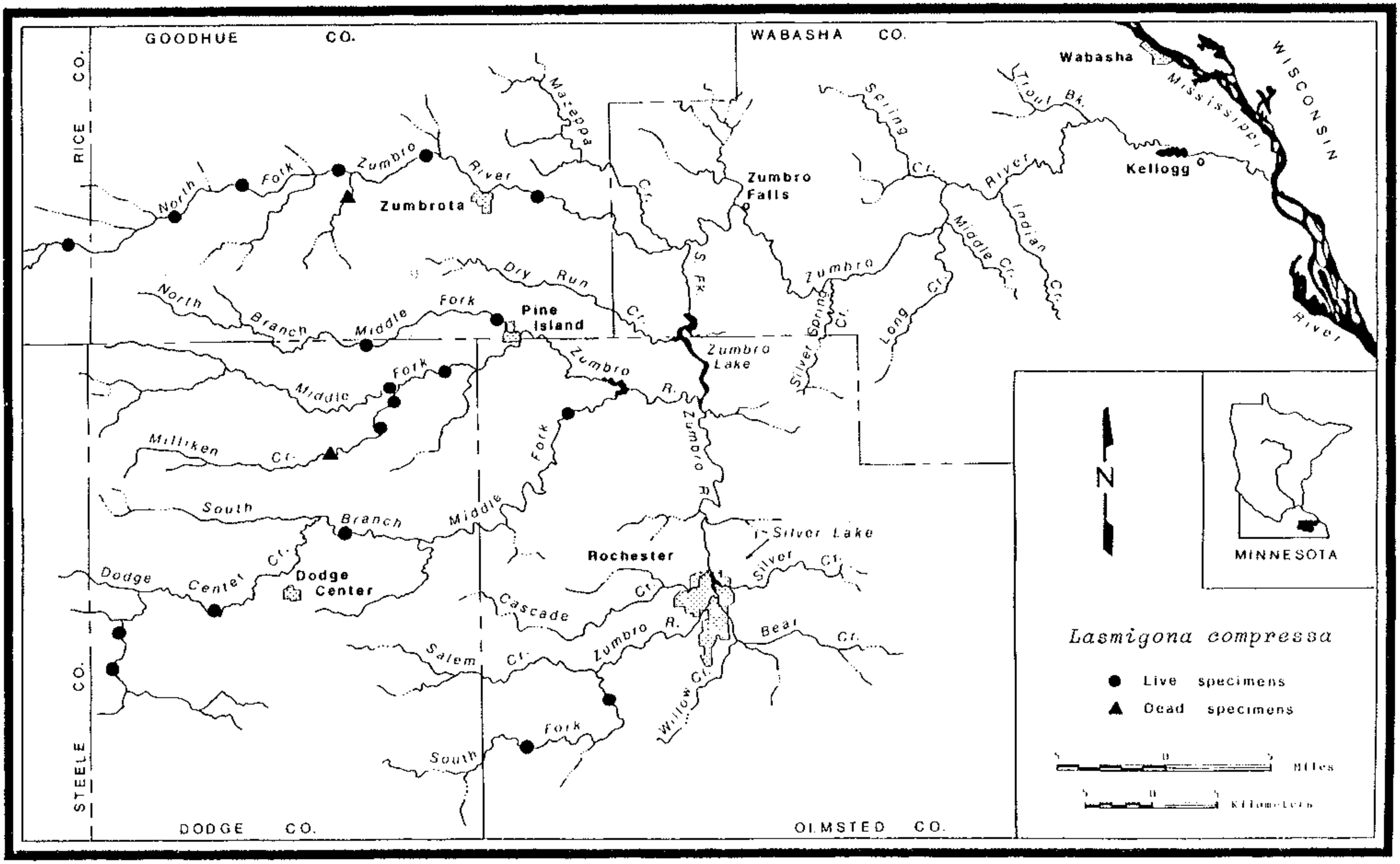


Plate 8

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

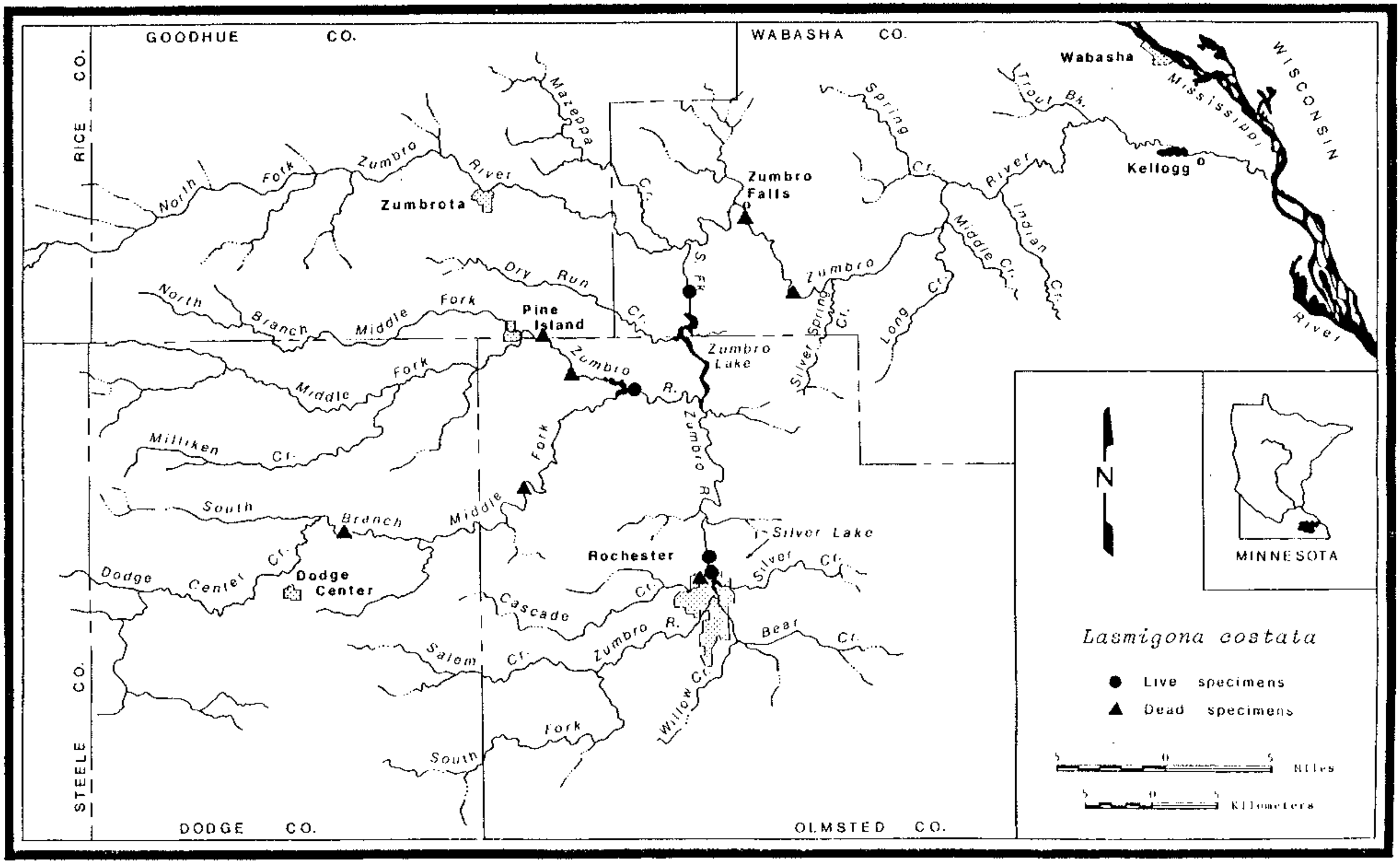


Plate 11

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

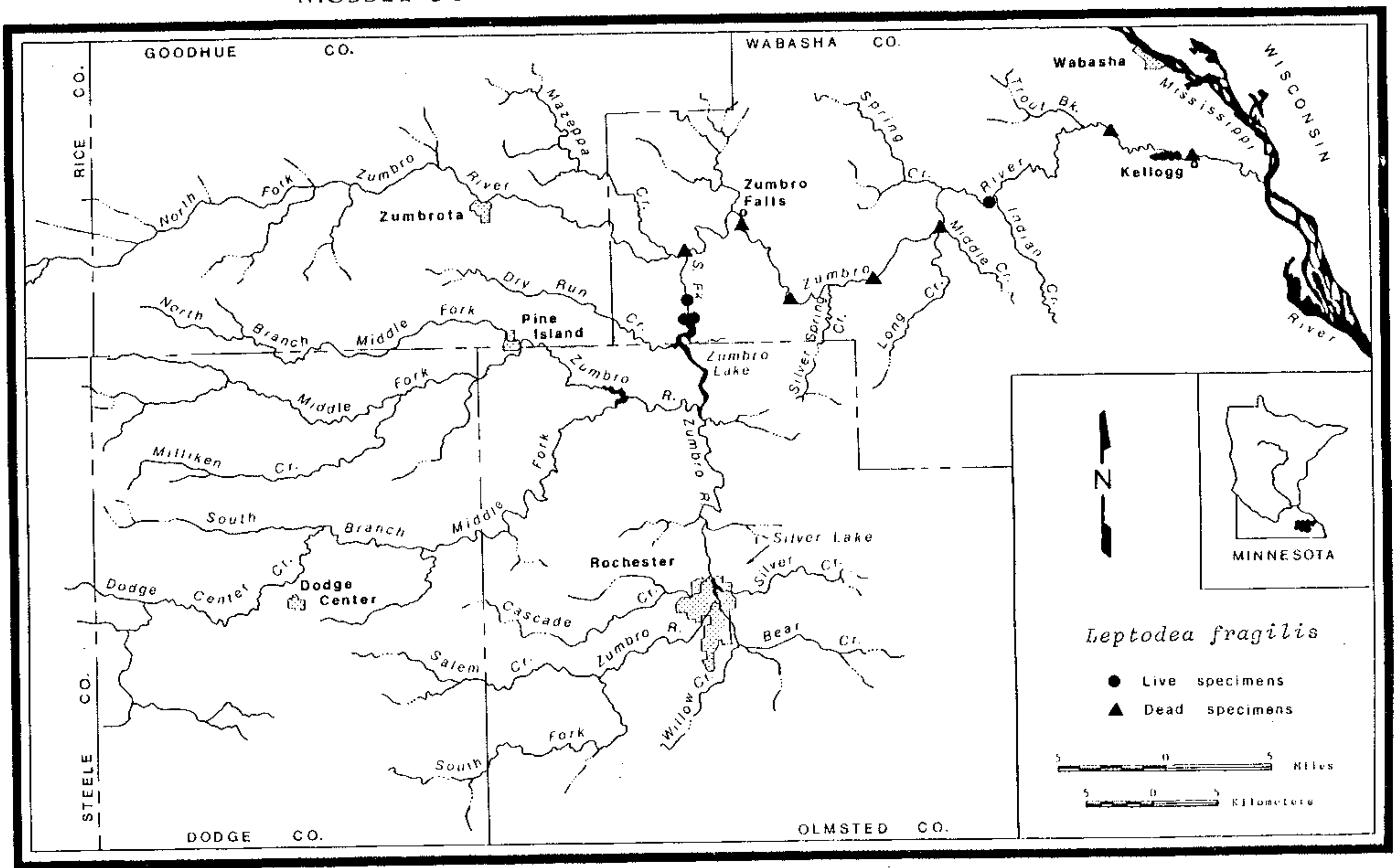
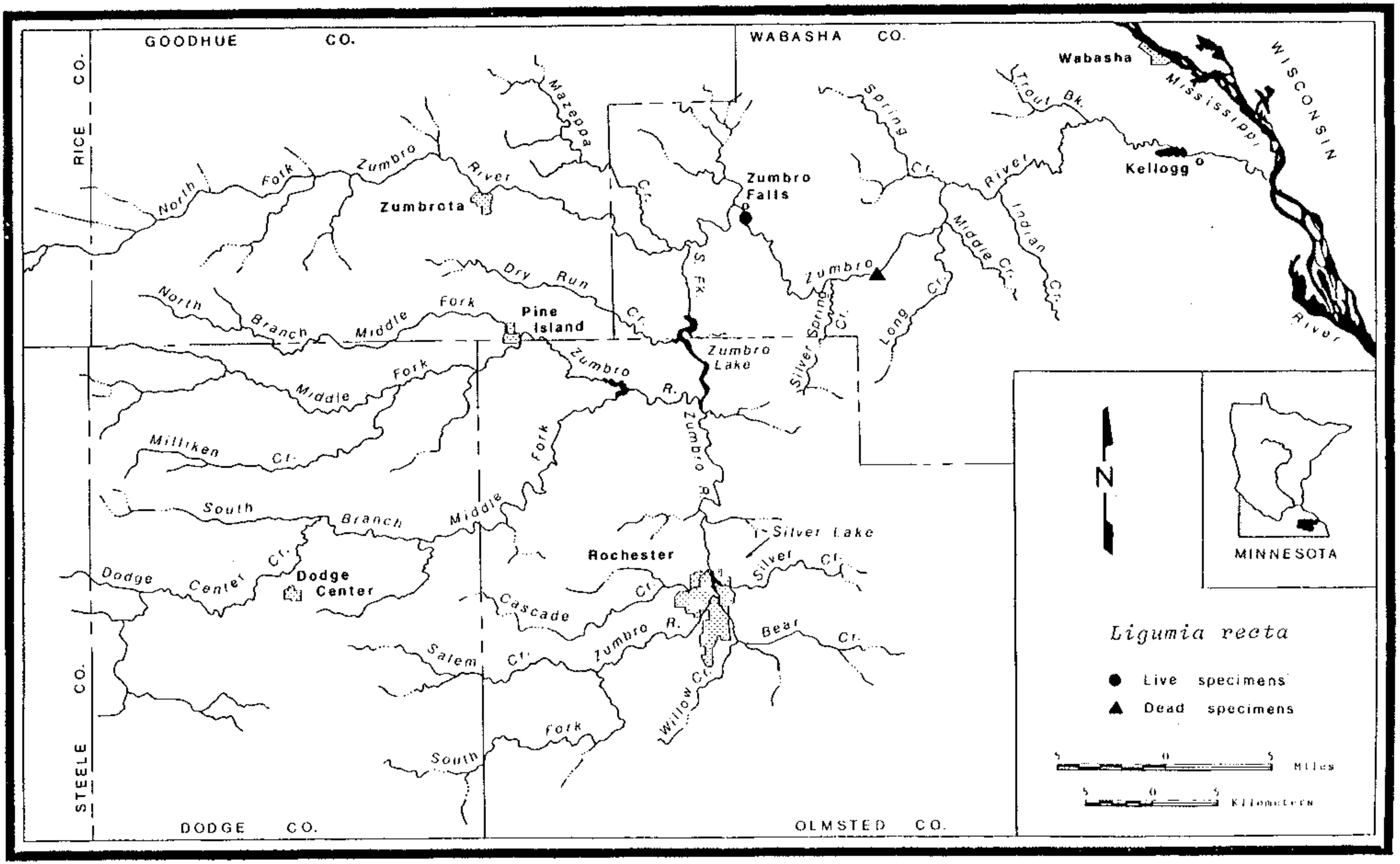
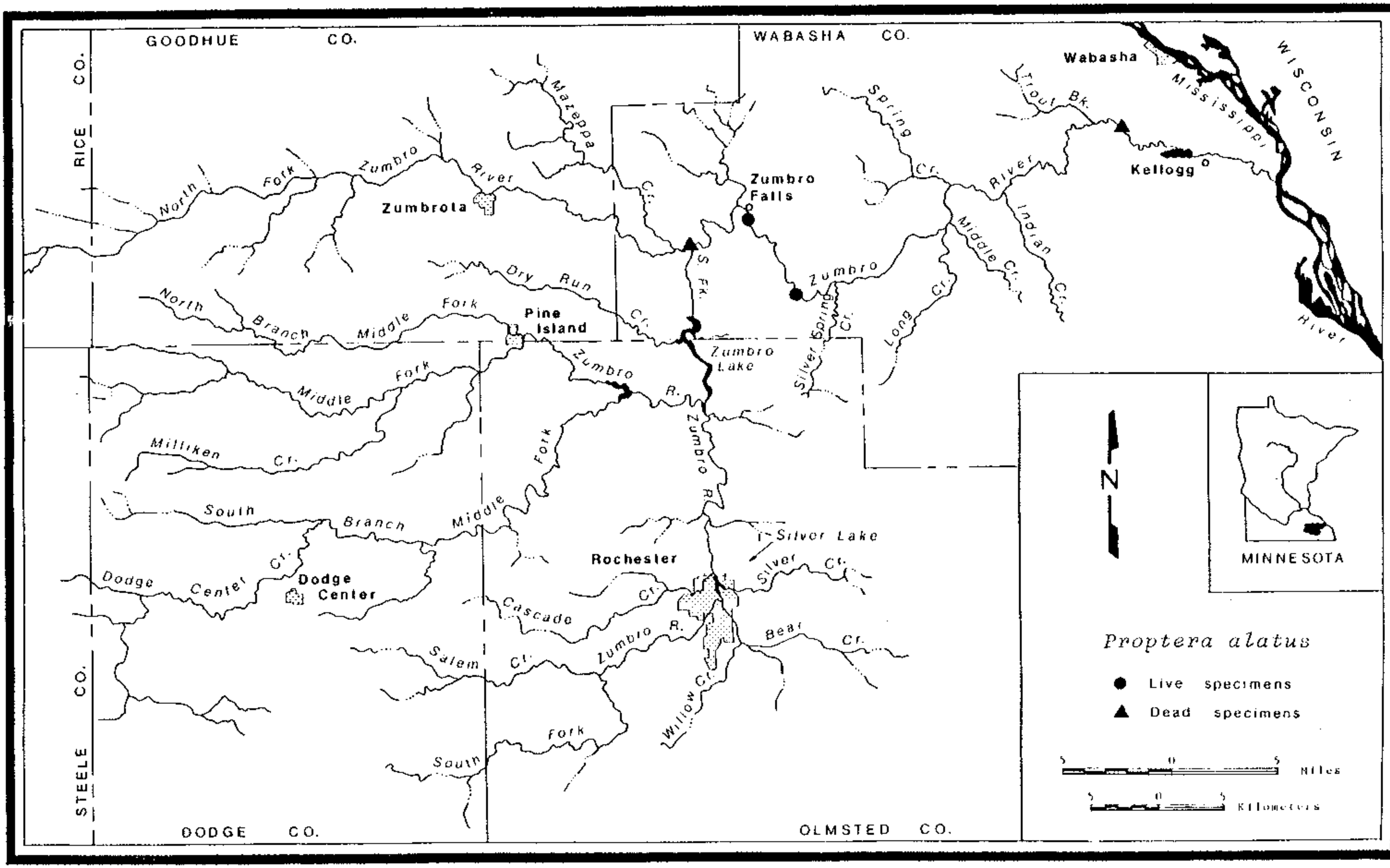


Plate 12

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

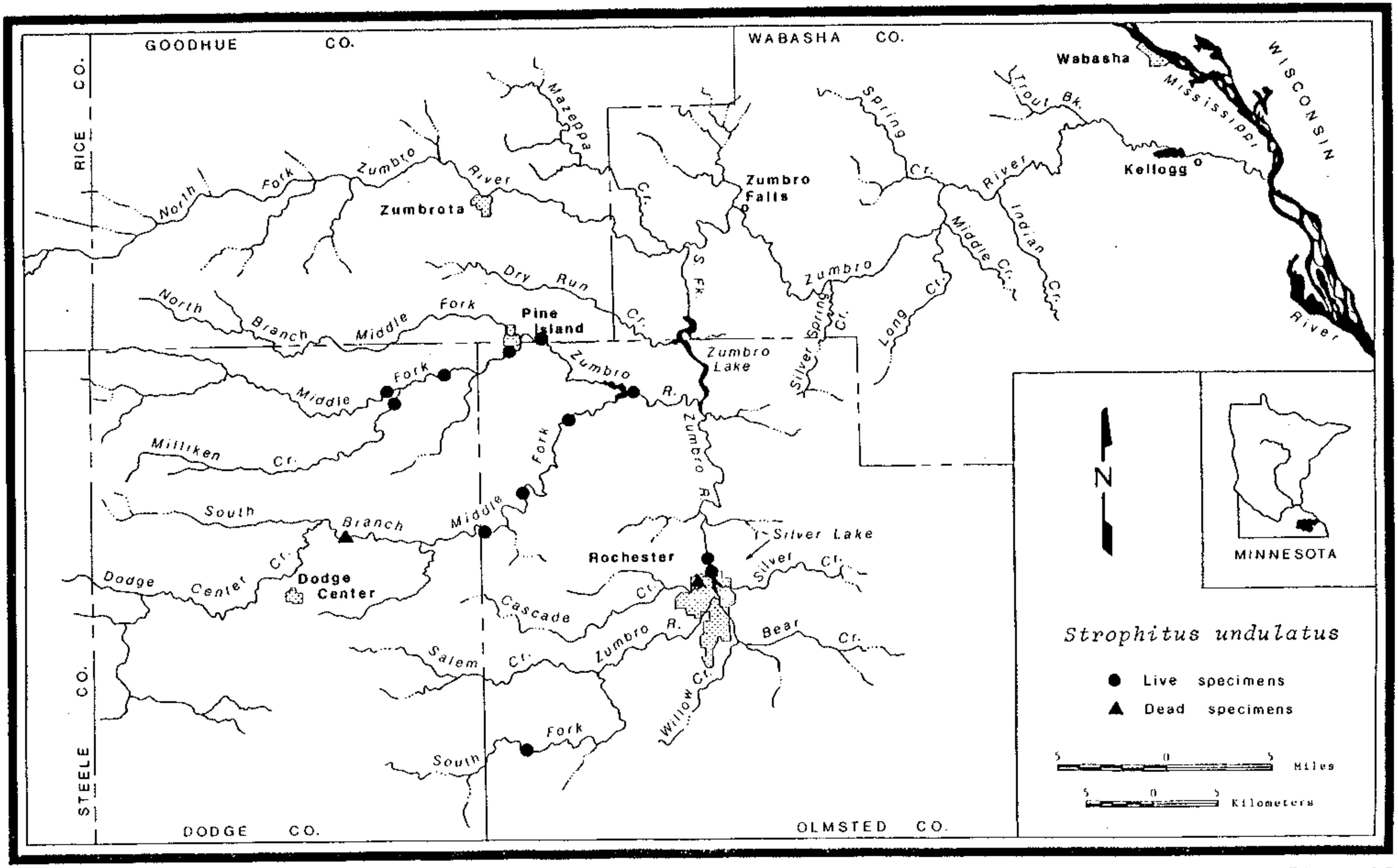
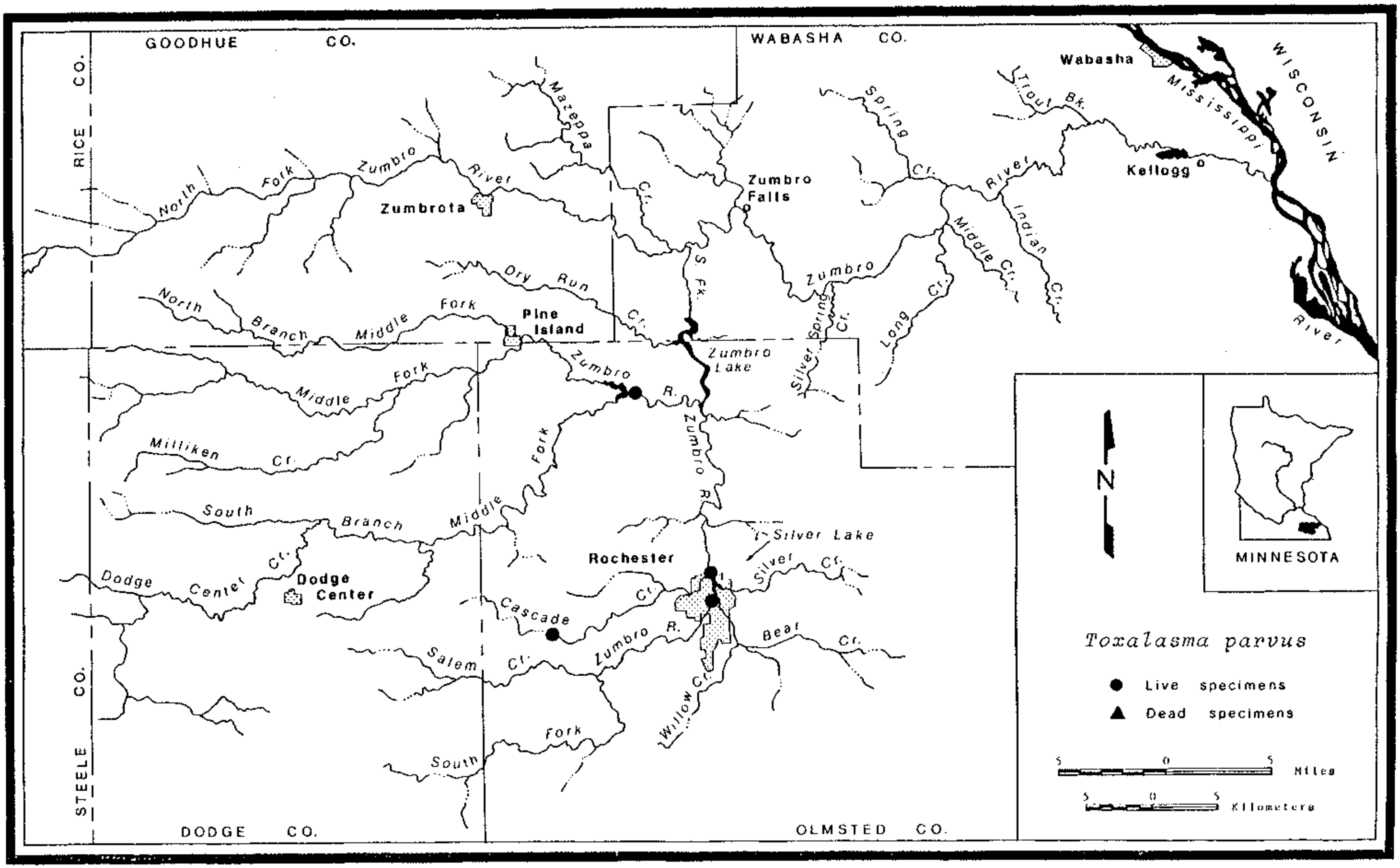


Plate 15

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988

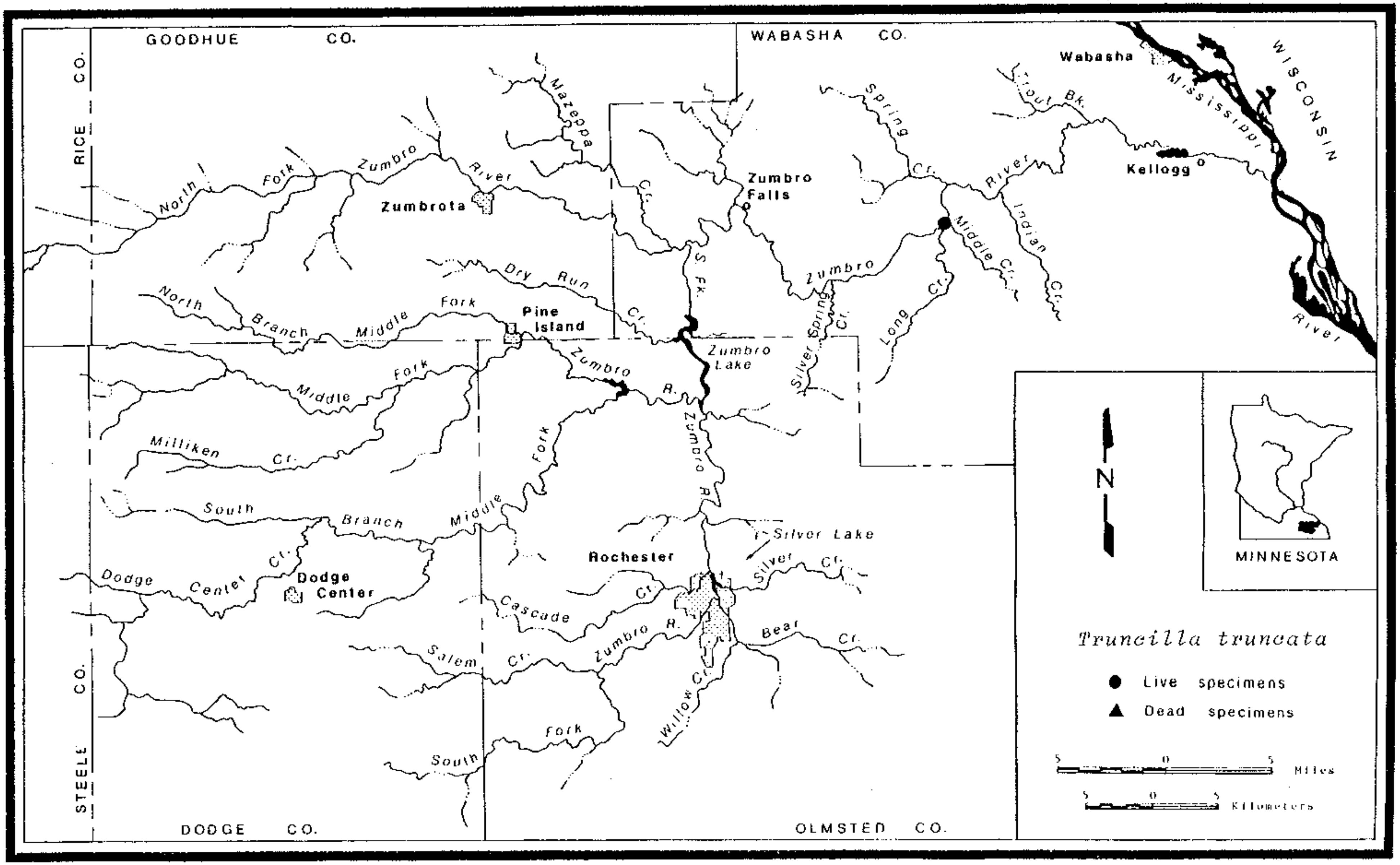
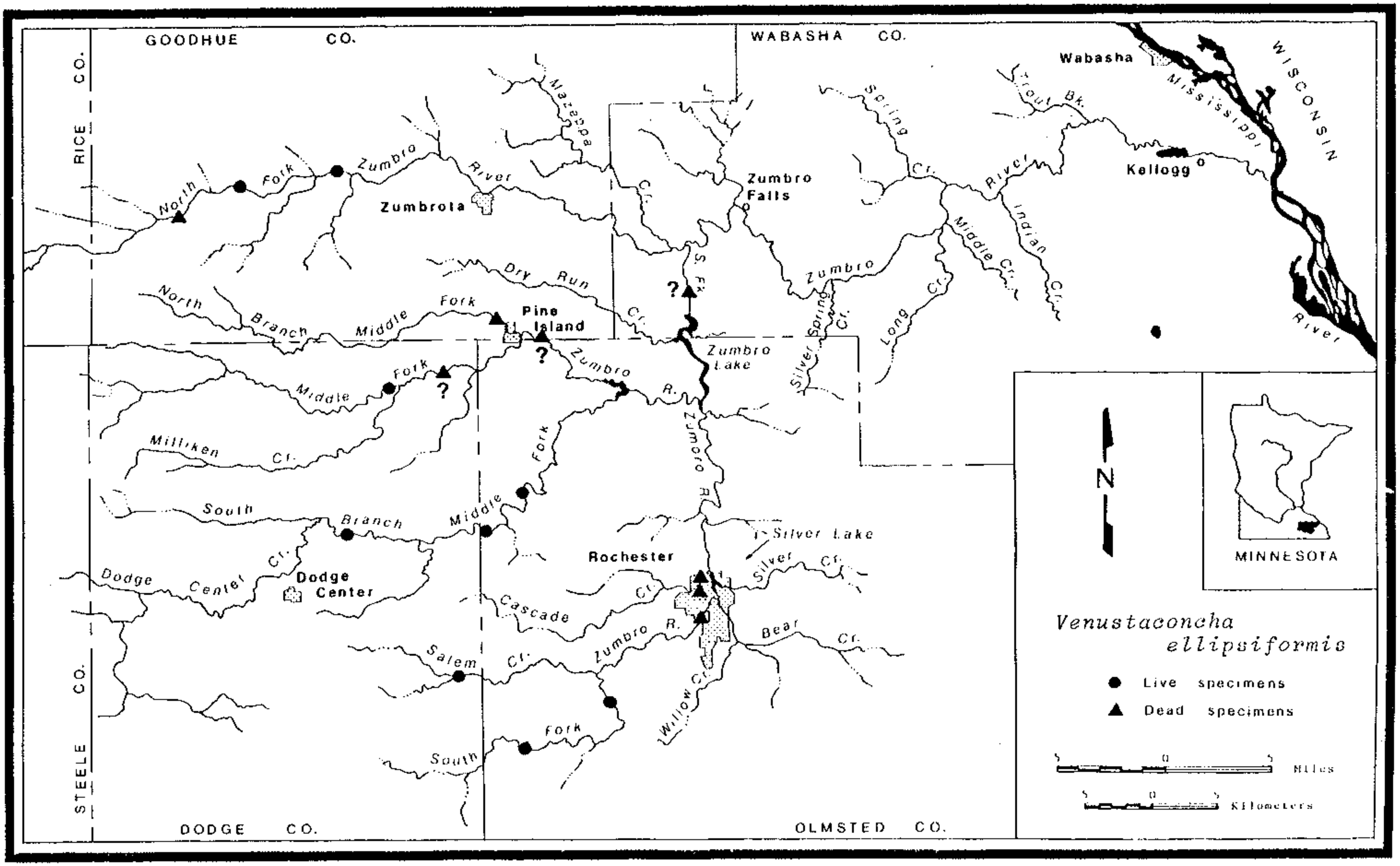


Plate 17

MUSSEL SURVEY: ZUMBRO RIVER, MINNESOTA, 1988



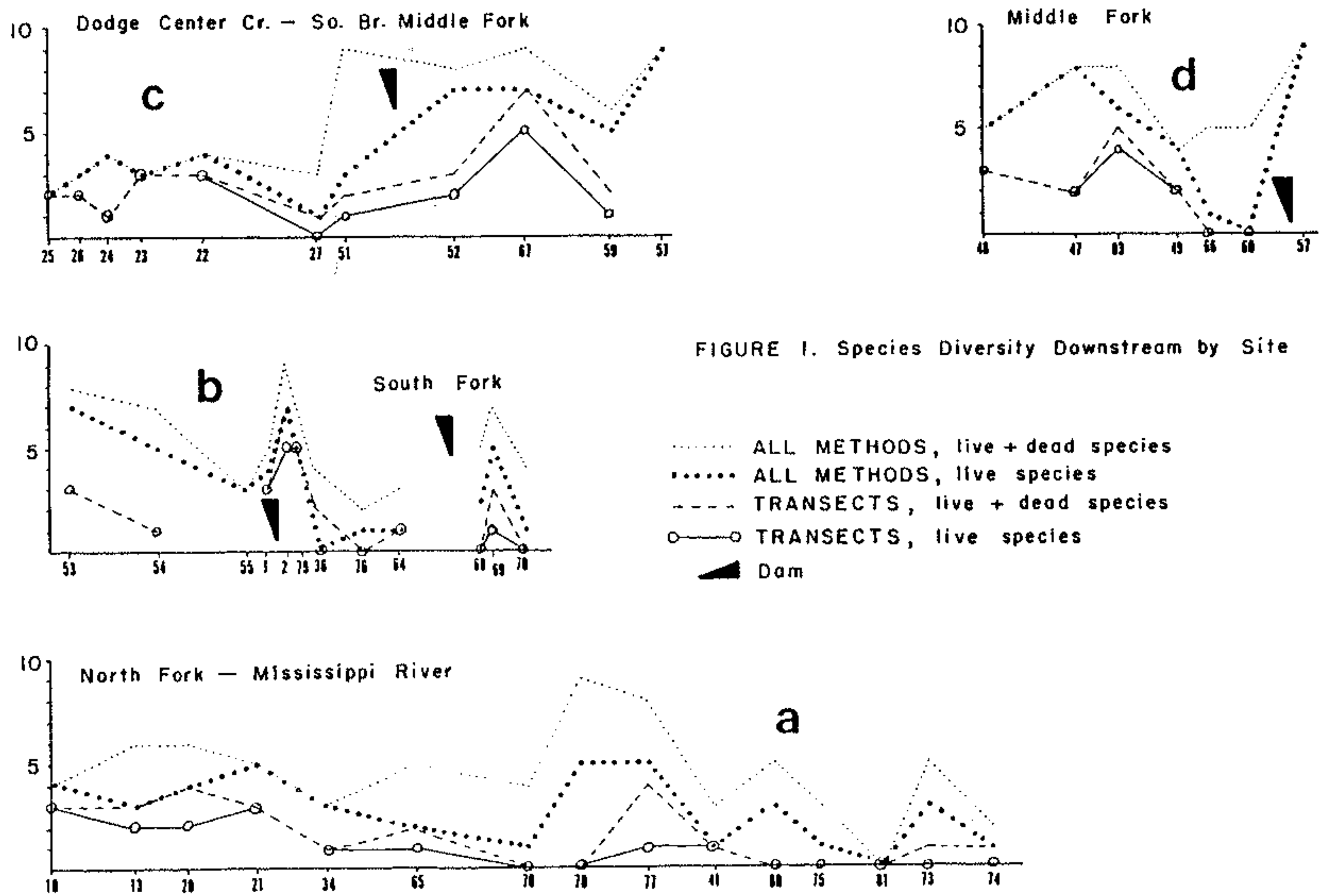
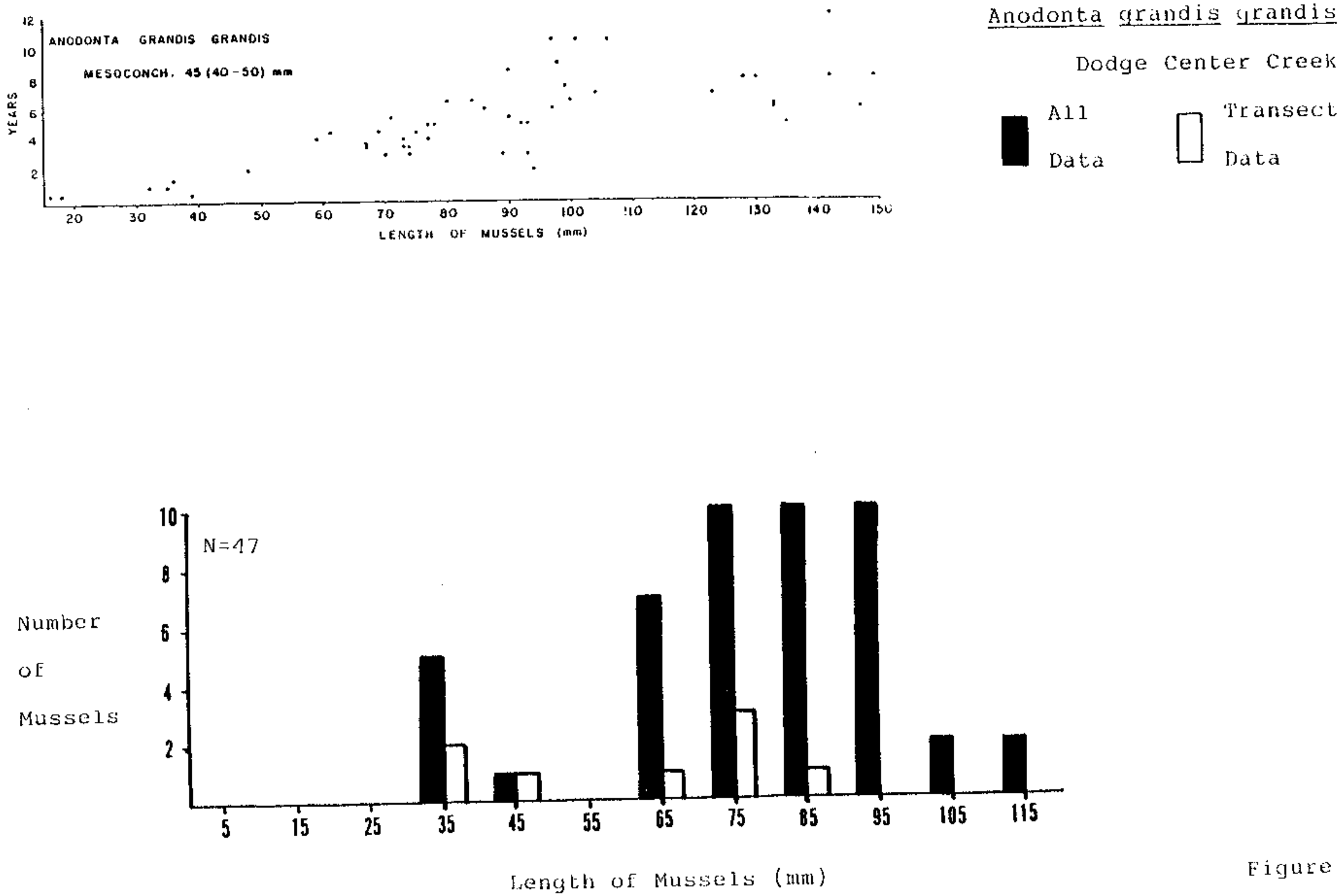


FIGURE I. Species Diversity Downstream by Site



ANODONTA GRANDIS GRANDIS
MESOCONCH. 45 (40-50) mm
YEARS
LENGTH OF MUSSELS (mm)
Anodonta grandis grandis
Dodge Center Creek
All Data
Transect Data
N=47
Number of Mussels
Length of Mussels (mm)

Figure 2

Anodonta grandis grandis

North Fork

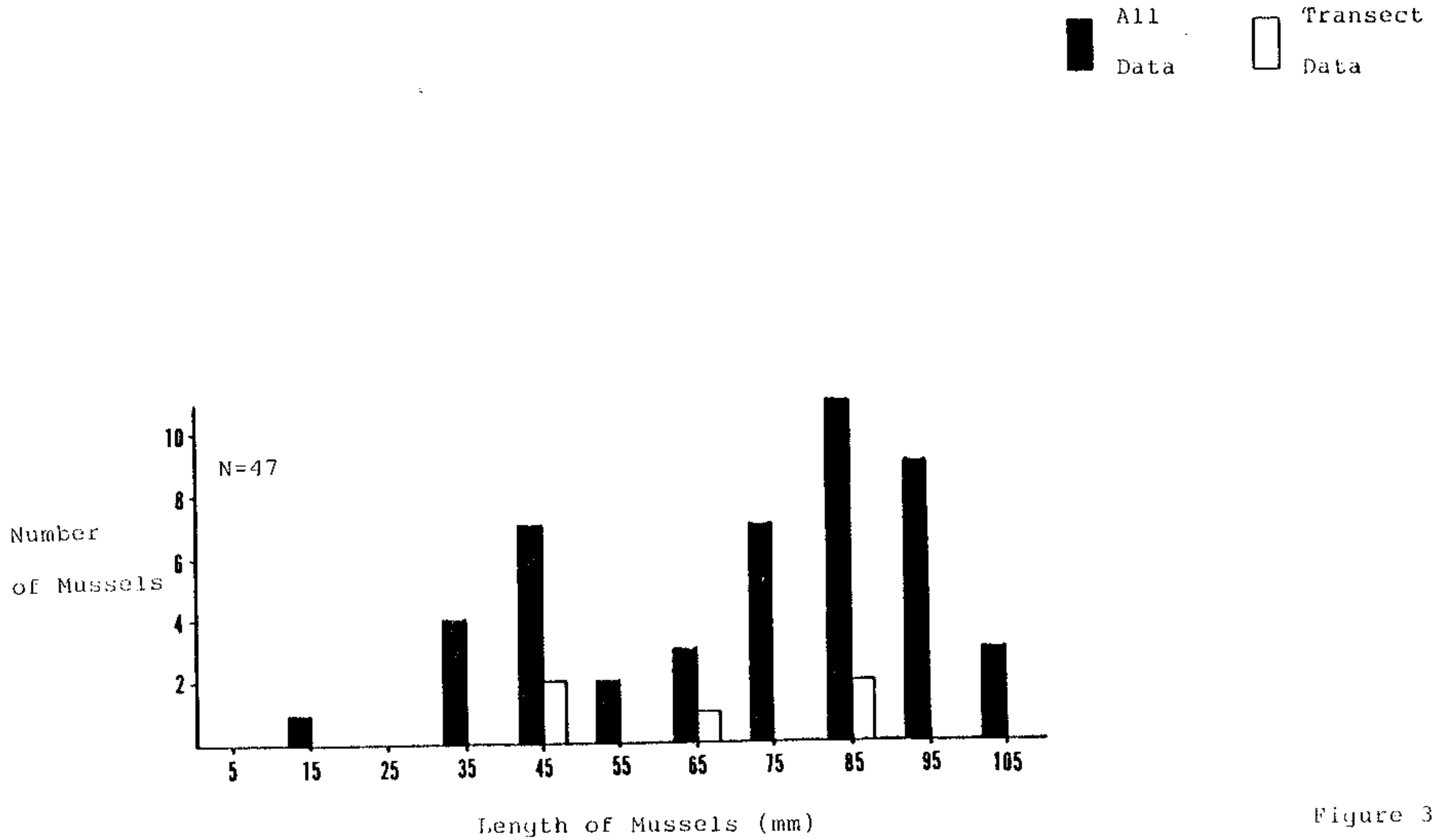


Figure 3

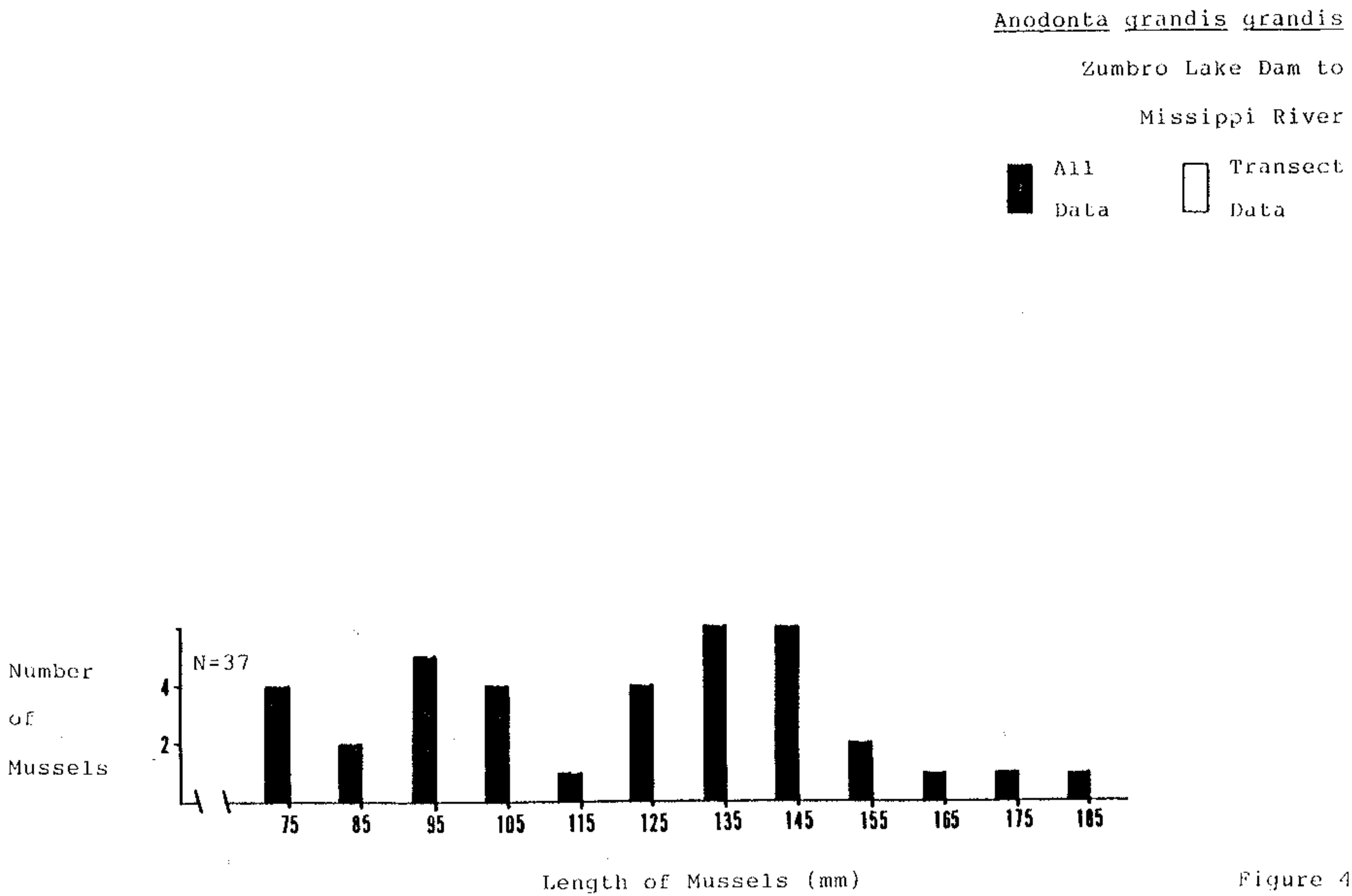

Anodonta grandis grandis
Zumbro Lake Dam to
Missippi River
All
Data
Transect
Data
Number
of
Mussels
4
2
N=37
75
85
95
105
115
125
135
145
155
165
175
185
Length of Mussels (mm)

Figure 4

Anodonta _grandis_ _grandis_

Site 24

All Data

Transect Data

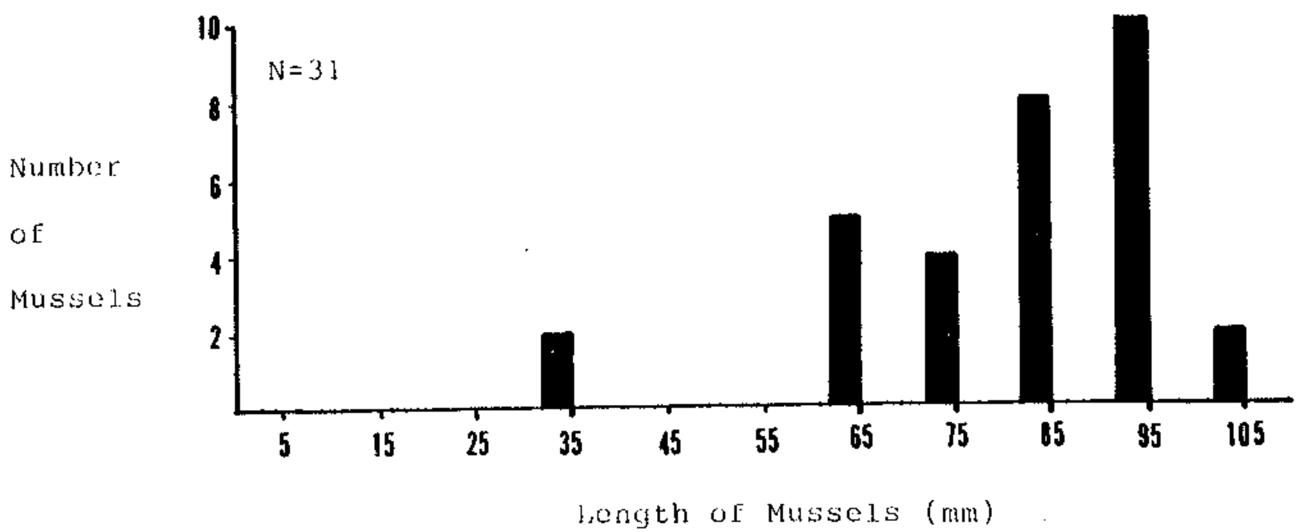
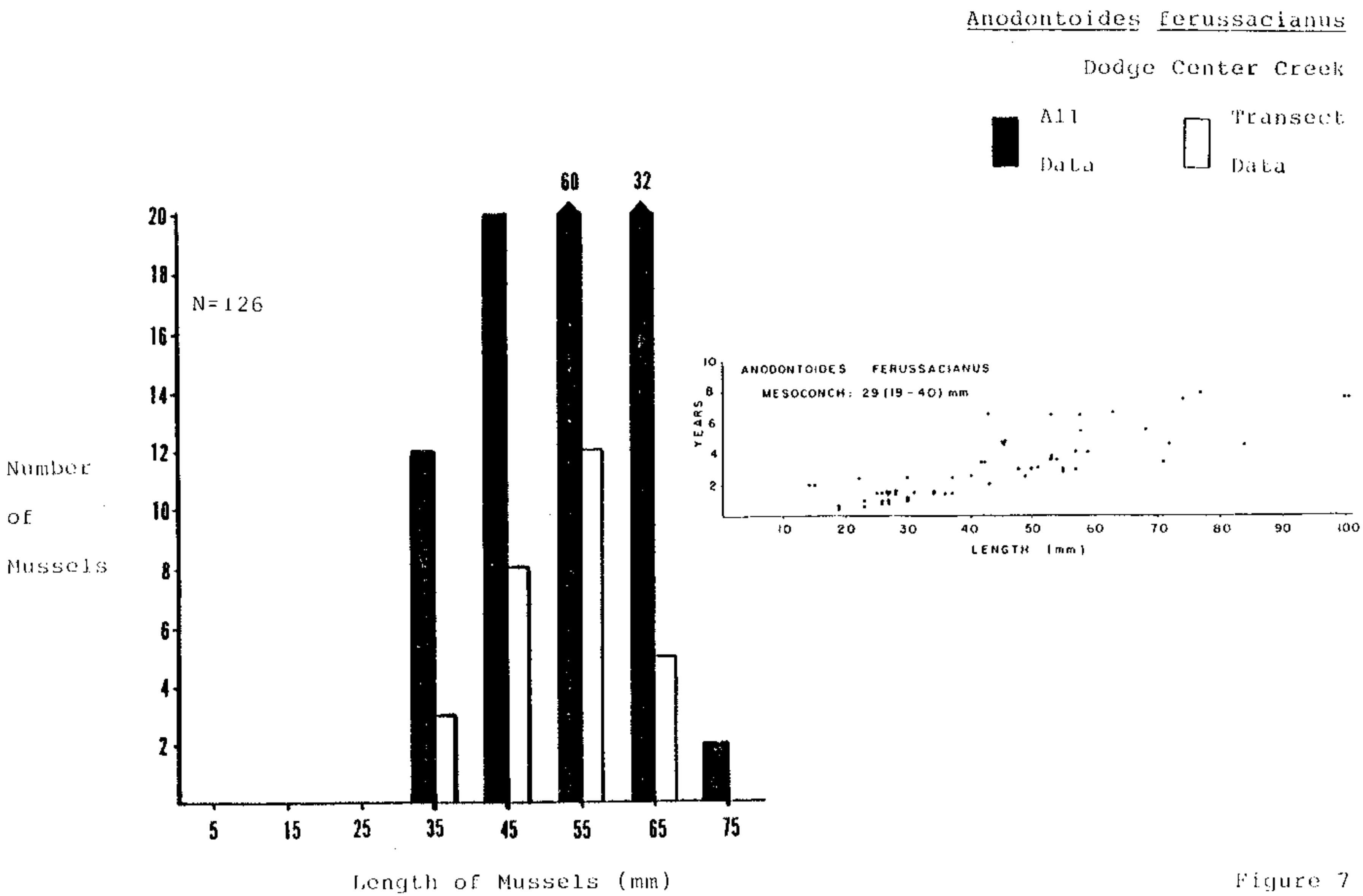


Figure 5

Length of Mussels (mm)

Figure 6



Anodontoides ferussacianus
Dodge Center Creek
All Data
Transect Data
N=126
60
32
Number of Mussels
20
18
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
Length of Mussels (mm)
ANODONTOIDES FERUSSACIANUS
MESOCONCH: 29 (19 - 40) mm
YEARS
LENGTH (mm)

Figure 7

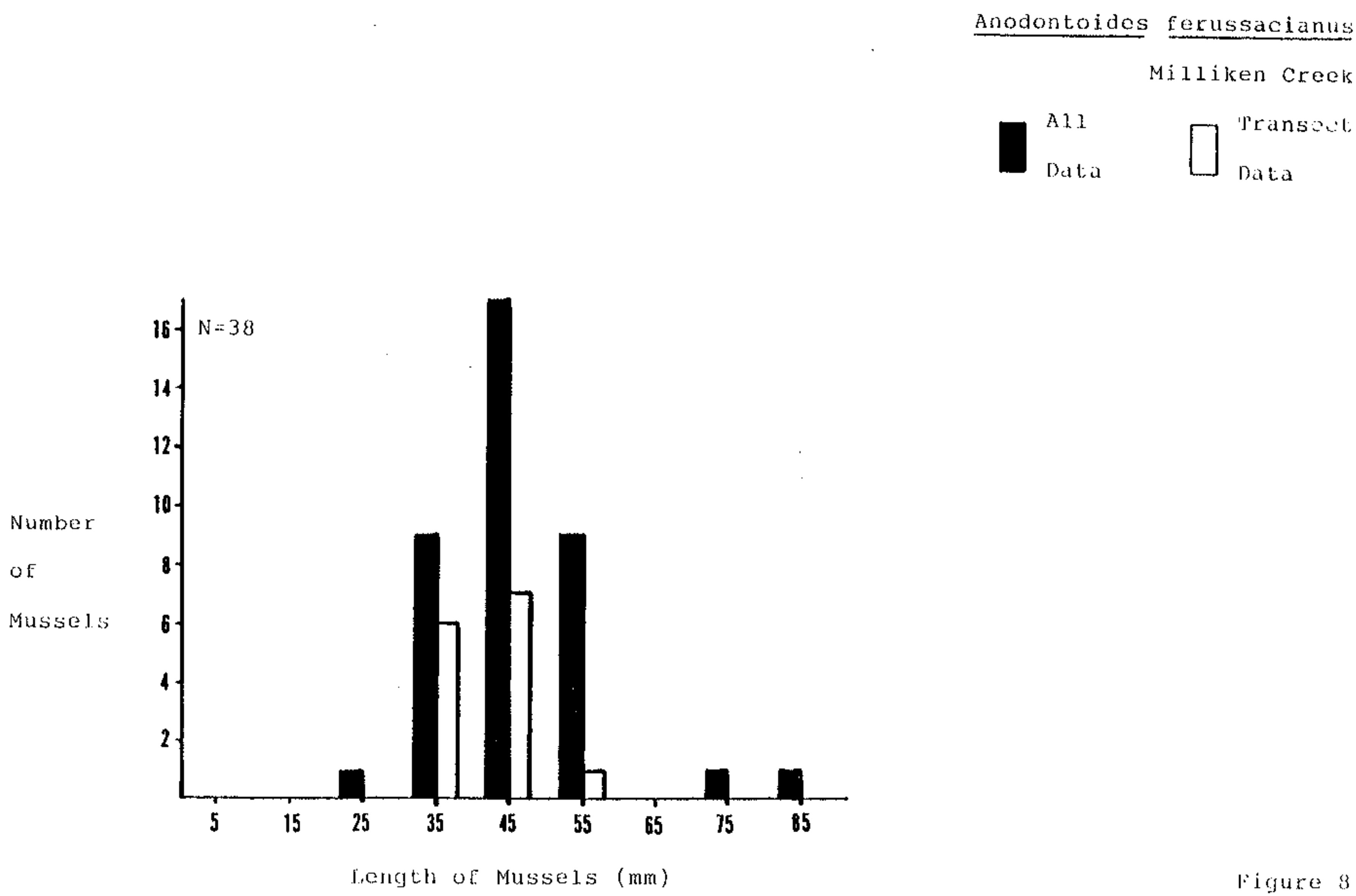
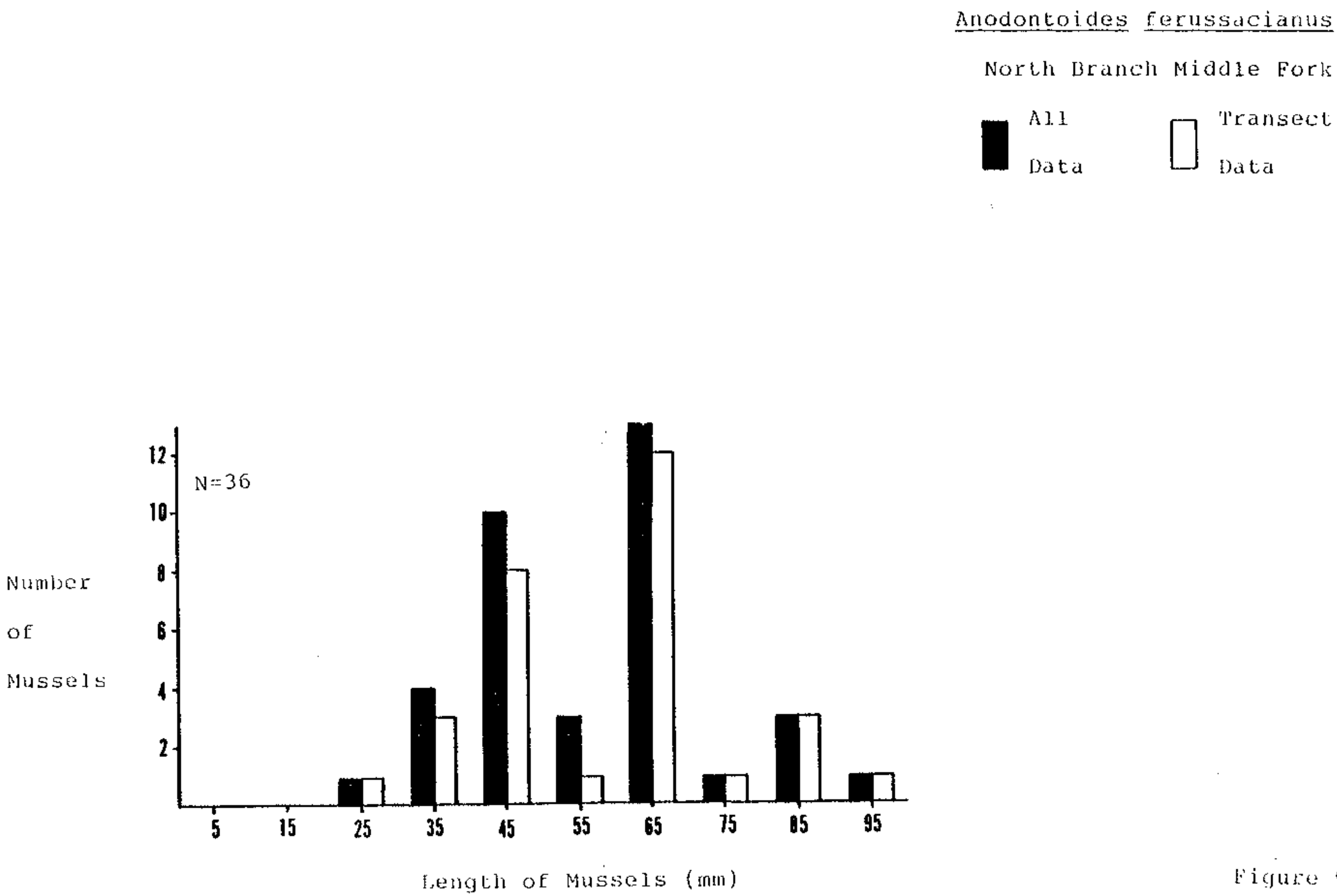

Anodontoides ferussacianus
Milliken Creek
All Data
Transect Data
N=38
Number of Mussels
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
Length of Mussels (mm)

Figure 8



Anodontoides ferussacianus
North Branch Middle Fork
All Data
Transect Data
N=36
Number of Mussels
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
95
Length of Mussels (mm)

Figure 9

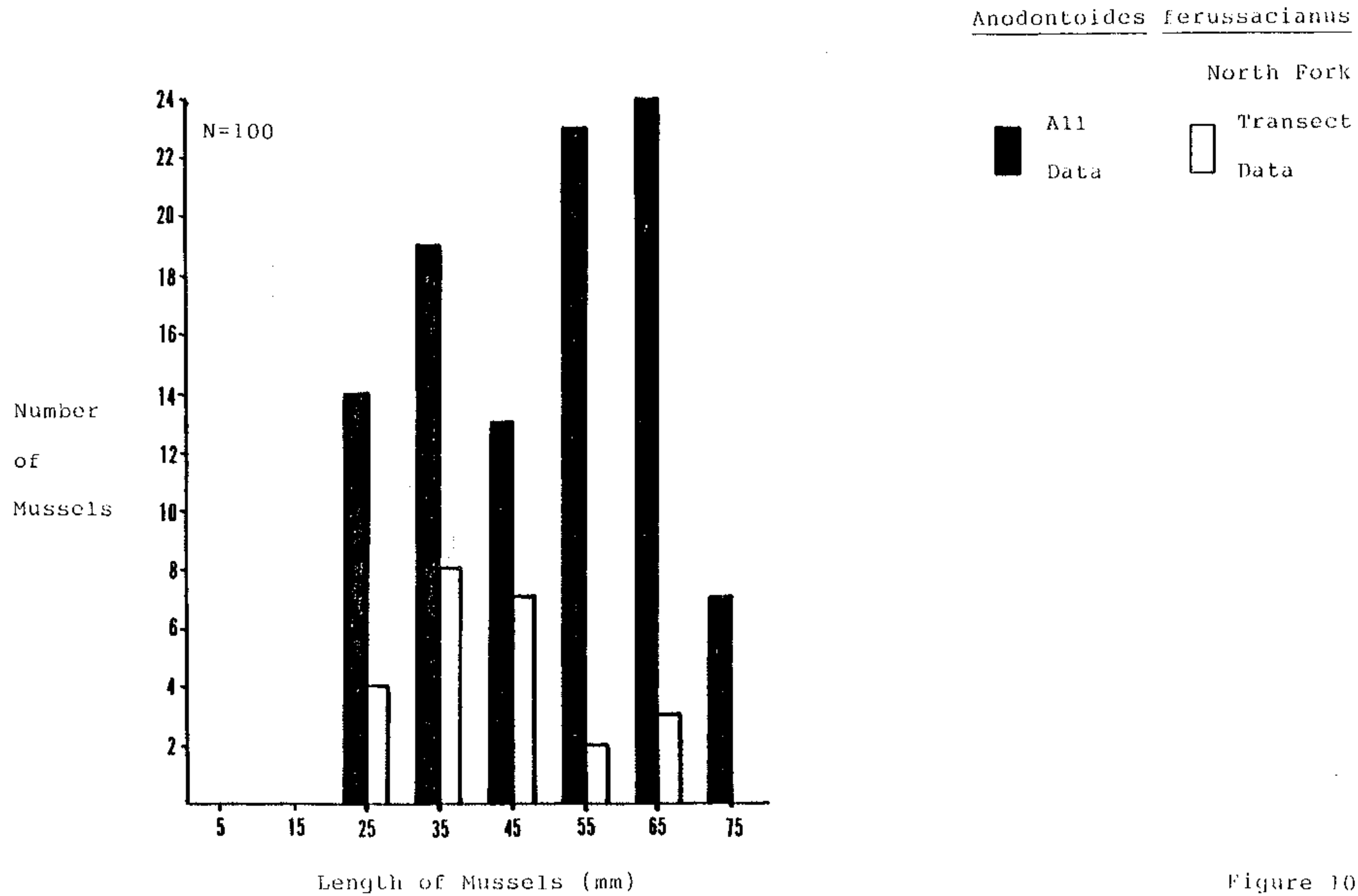

Anodontoides ferussacianus
North Fork
All Data
Transect Data
N=100
Number of Mussels
24
22
20
18
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
Length of Mussels (mm)

Figure 10

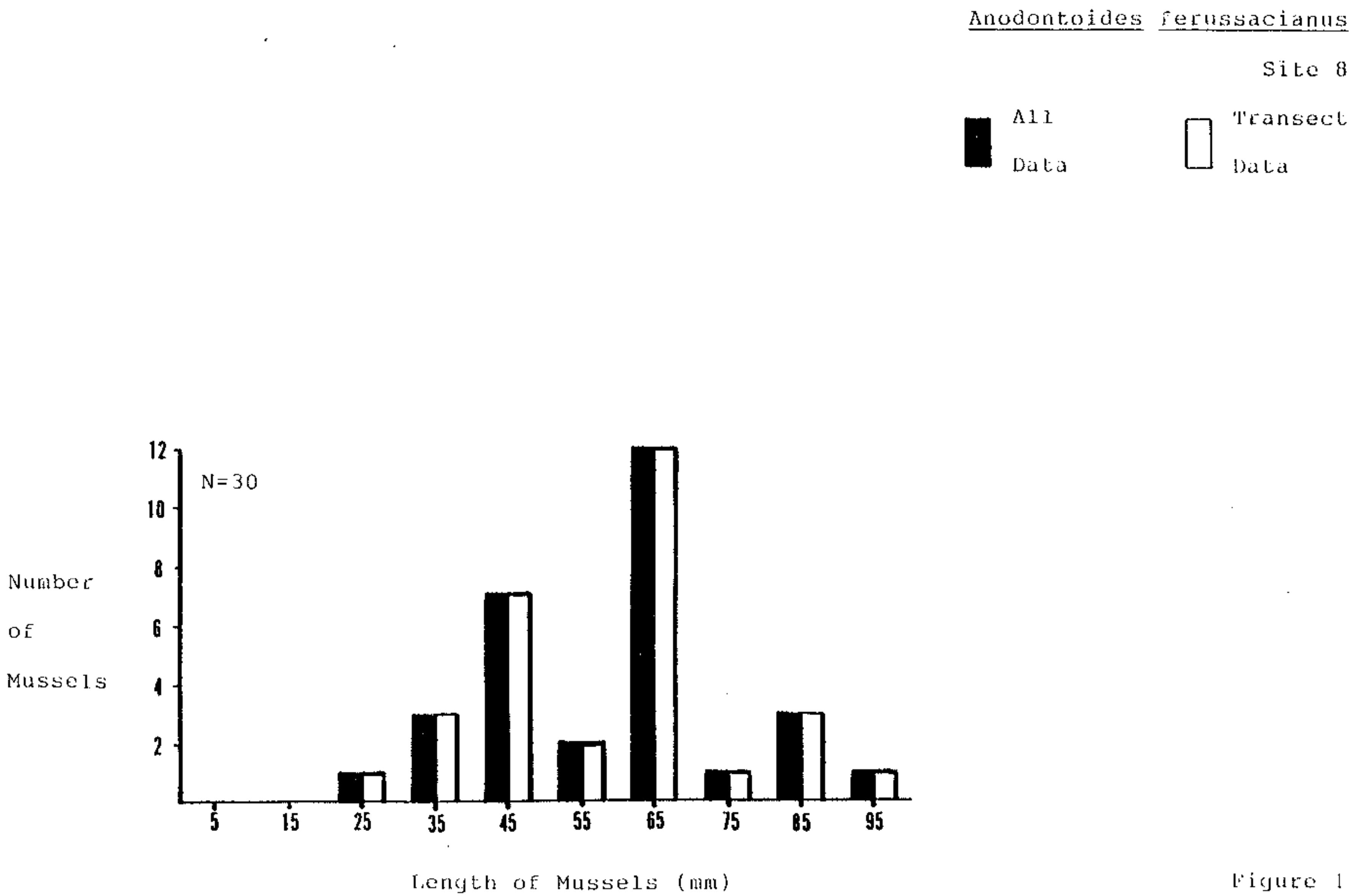
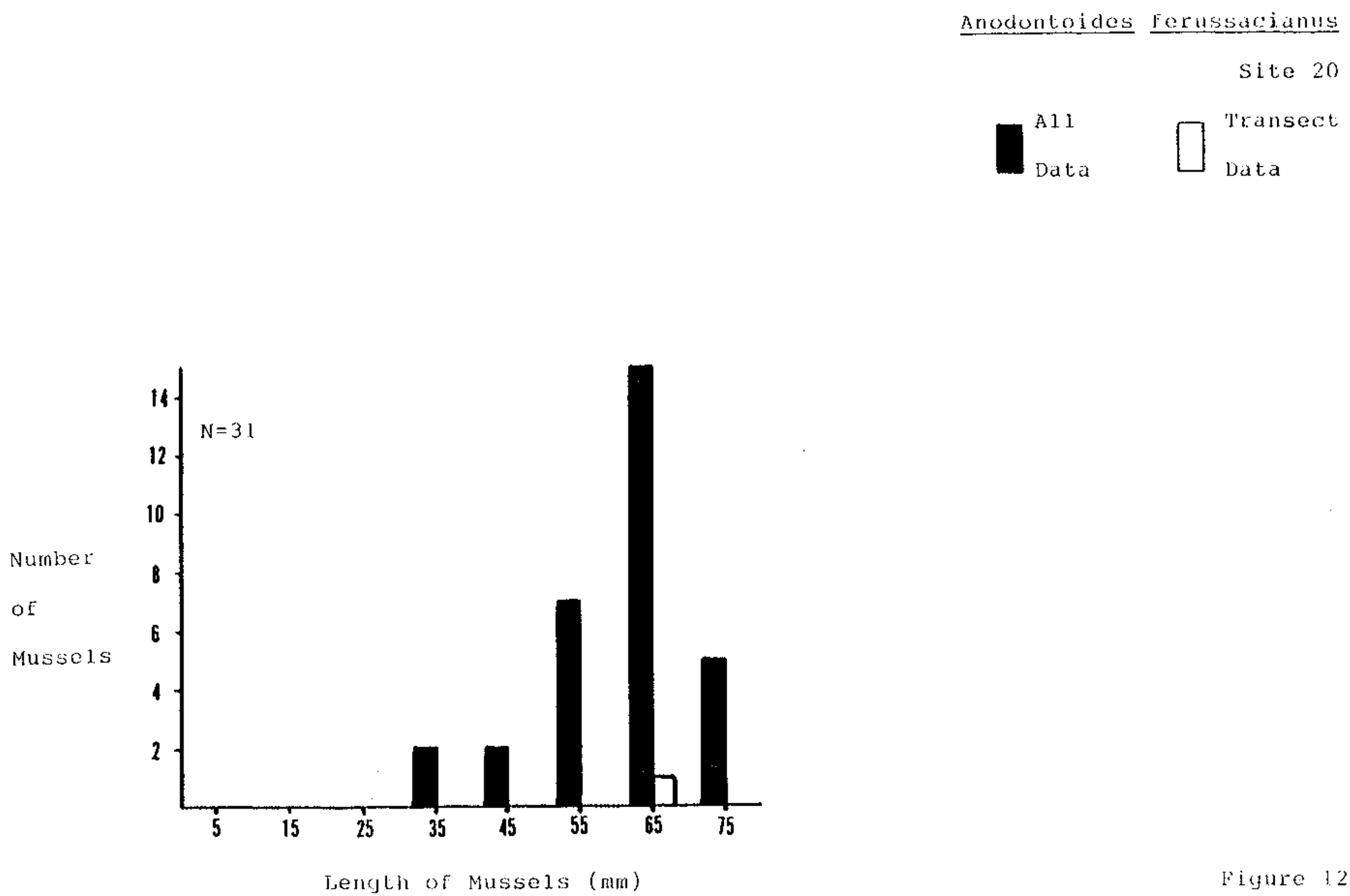
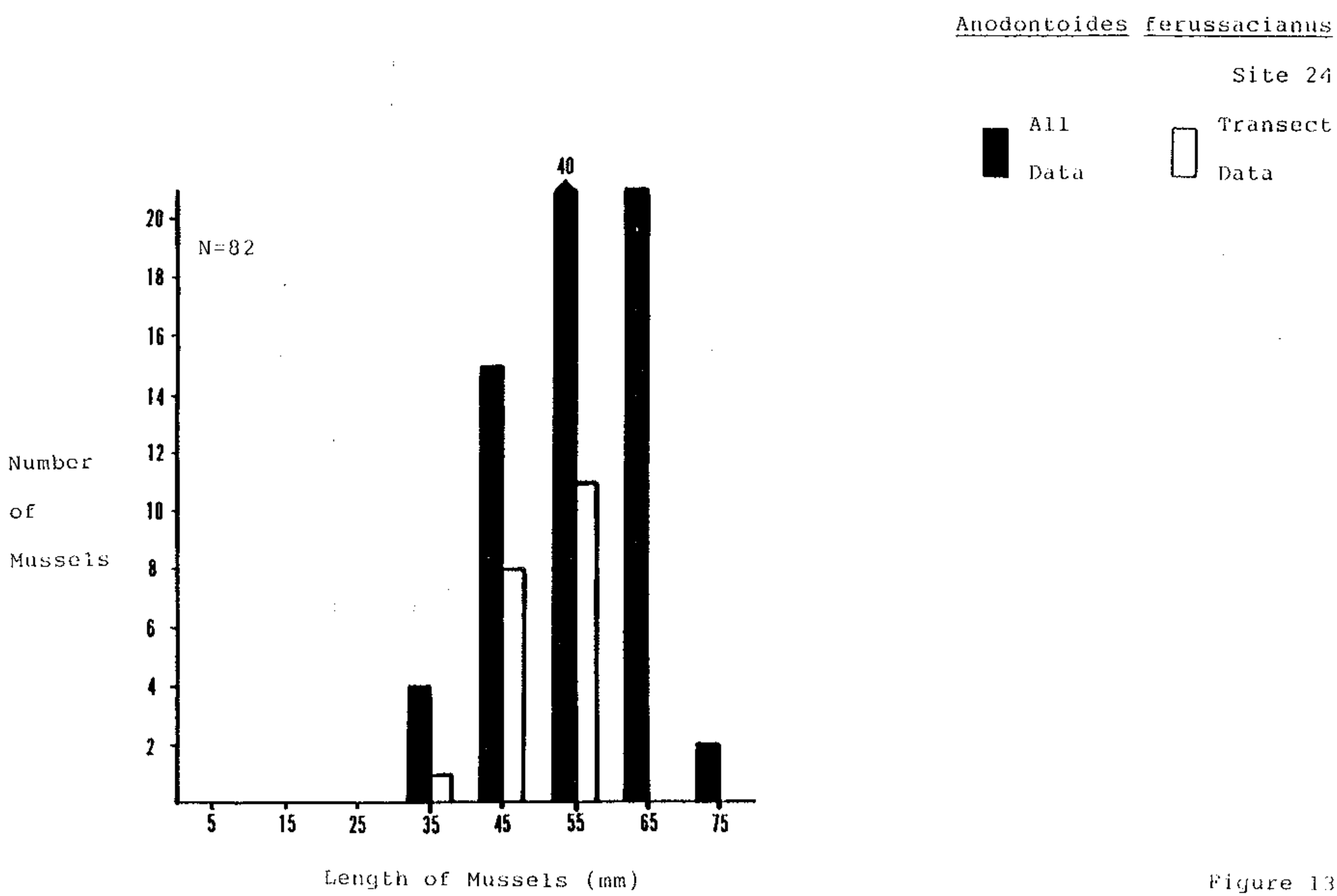

Anodontoides ferussacianus
Site 8
All Data
Transect Data
N=30
Number of Mussels
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
95
Length of Mussels (mm)

Figure 11



Anodontoides Ferussacianus
Site 20
All Data
Transect Data
N=31
Number of Mussels
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
Length of Mussels (mm)

Figure 12



Anodontoides ferussacianus
Site 24
All Data
Transect Data
N=82
40
Number of Mussels
20
18
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
Length of Mussels (mm)

Figure 13

Anodontoides ferussacianus

Site 26

All Data

Transect Data

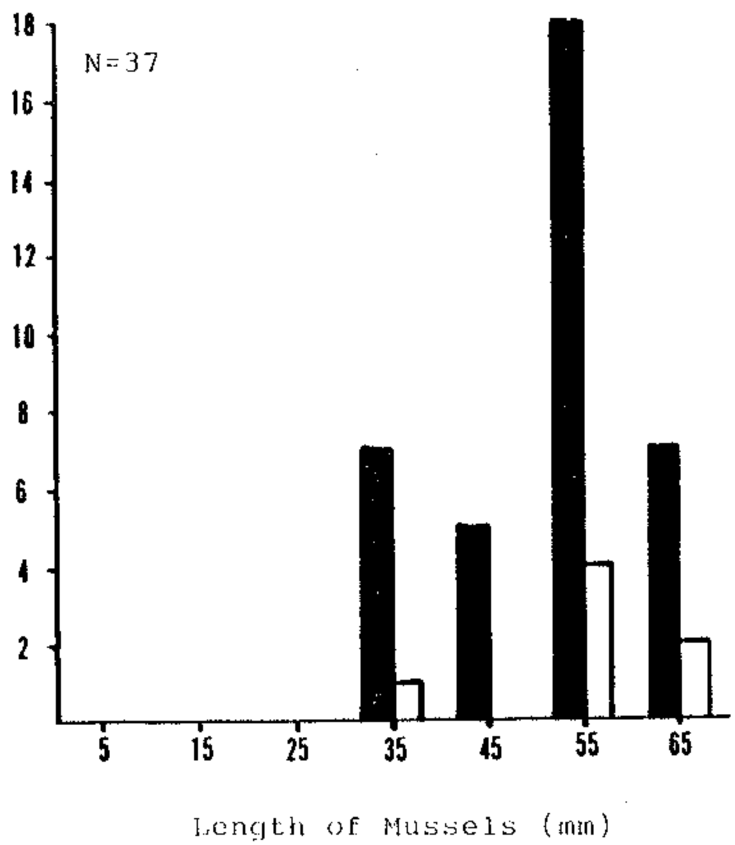
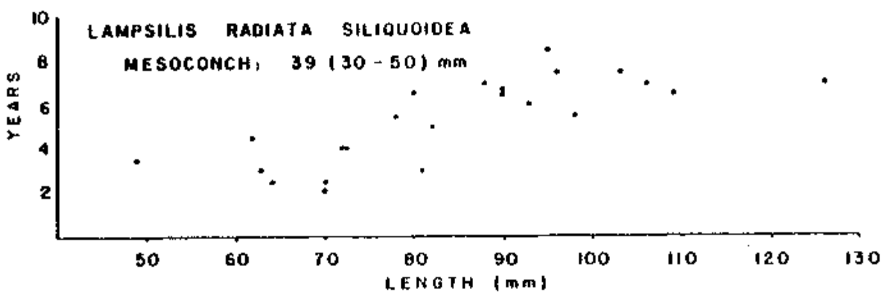


Figure 14



Lampsilis radiata siliquoidea

Middle Fork above Oronoco Dam

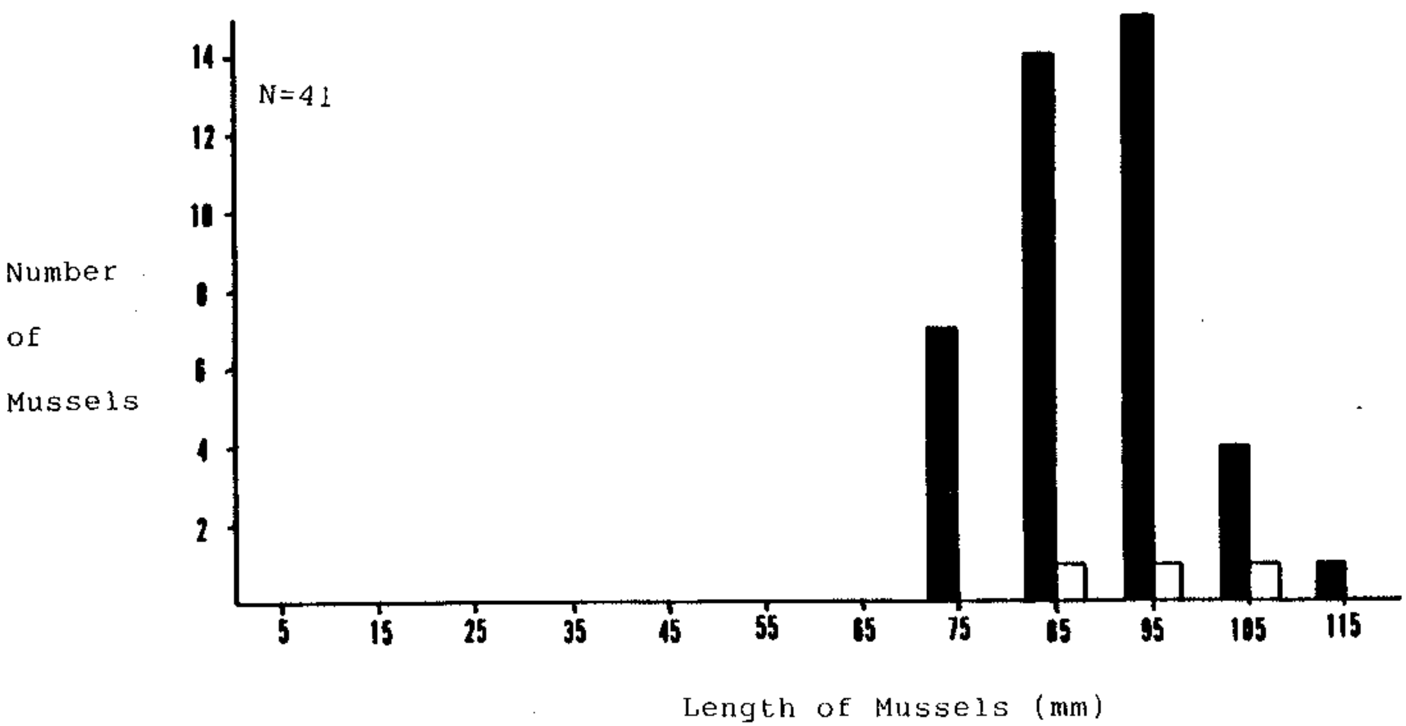
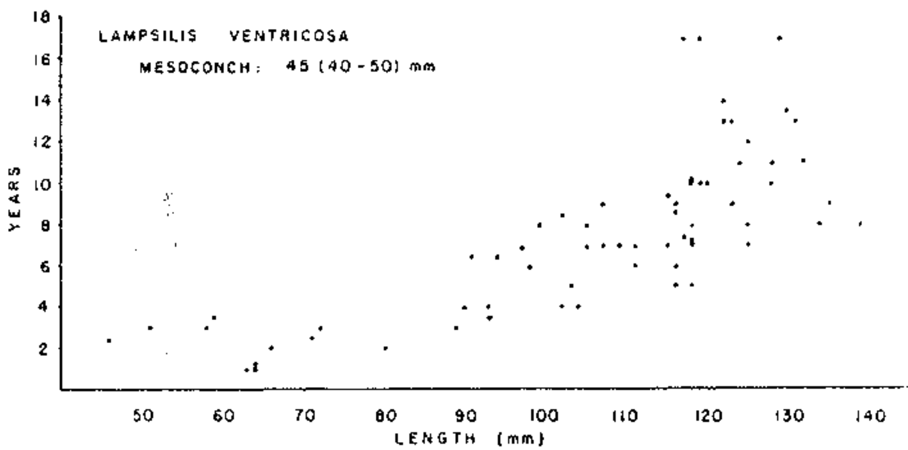


Figure 15



Lampsilis ventricosa

South Branch Middle Fork

Mantorville Dam to Mouth

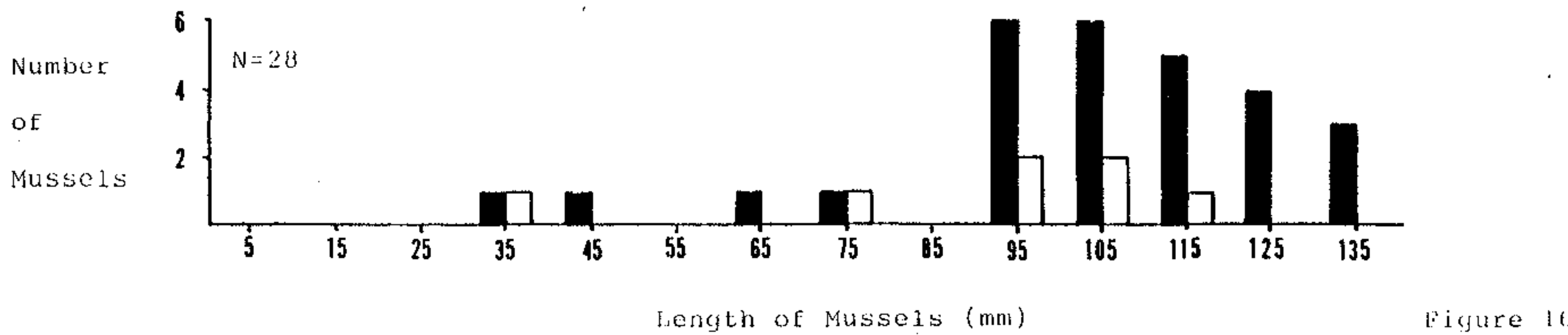


Figure 16

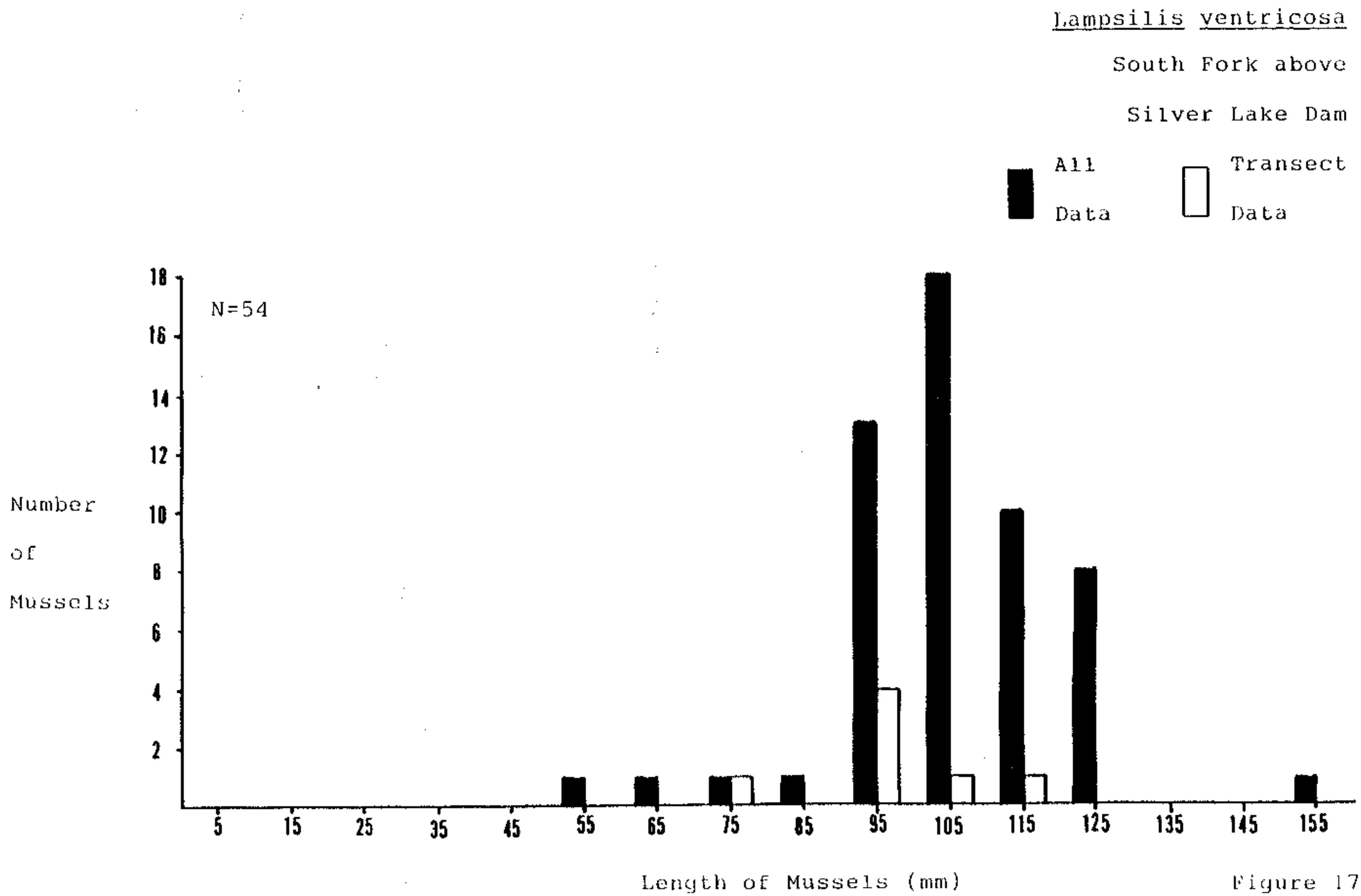

Lampsilis ventricosa
South Fork above
Silver Lake Dam
All Data
Transect Data
N=54
18
16
14
12
10
8
6
4
2
Number of Mussels
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
155
Length of Mussels (mm)

Figure 17

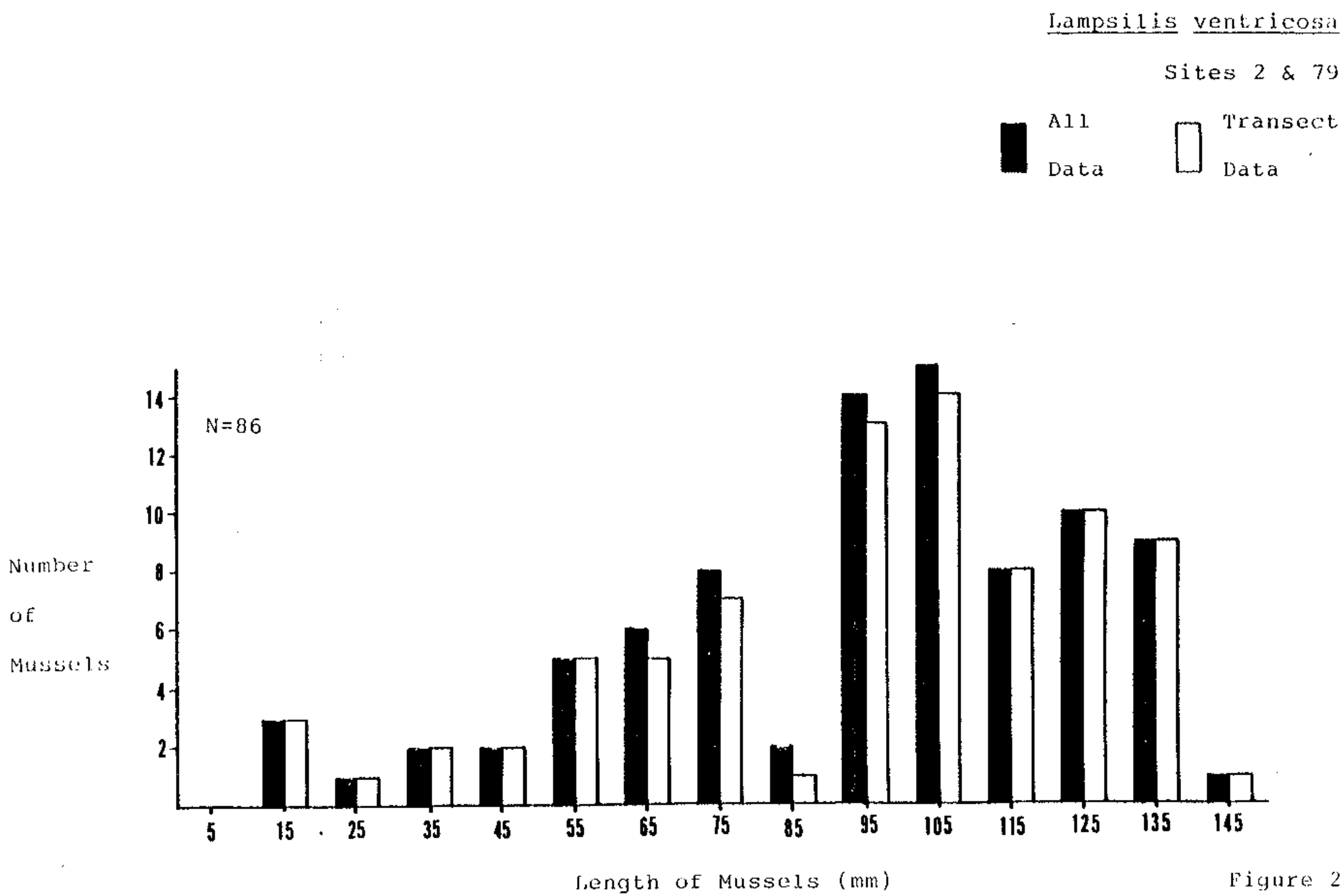

Lampsilis ventricosa
Sites 2 & 79
All Data
Transect Data
N=86
Number of Mussels
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
Length of Mussels (mm)

Figure 20

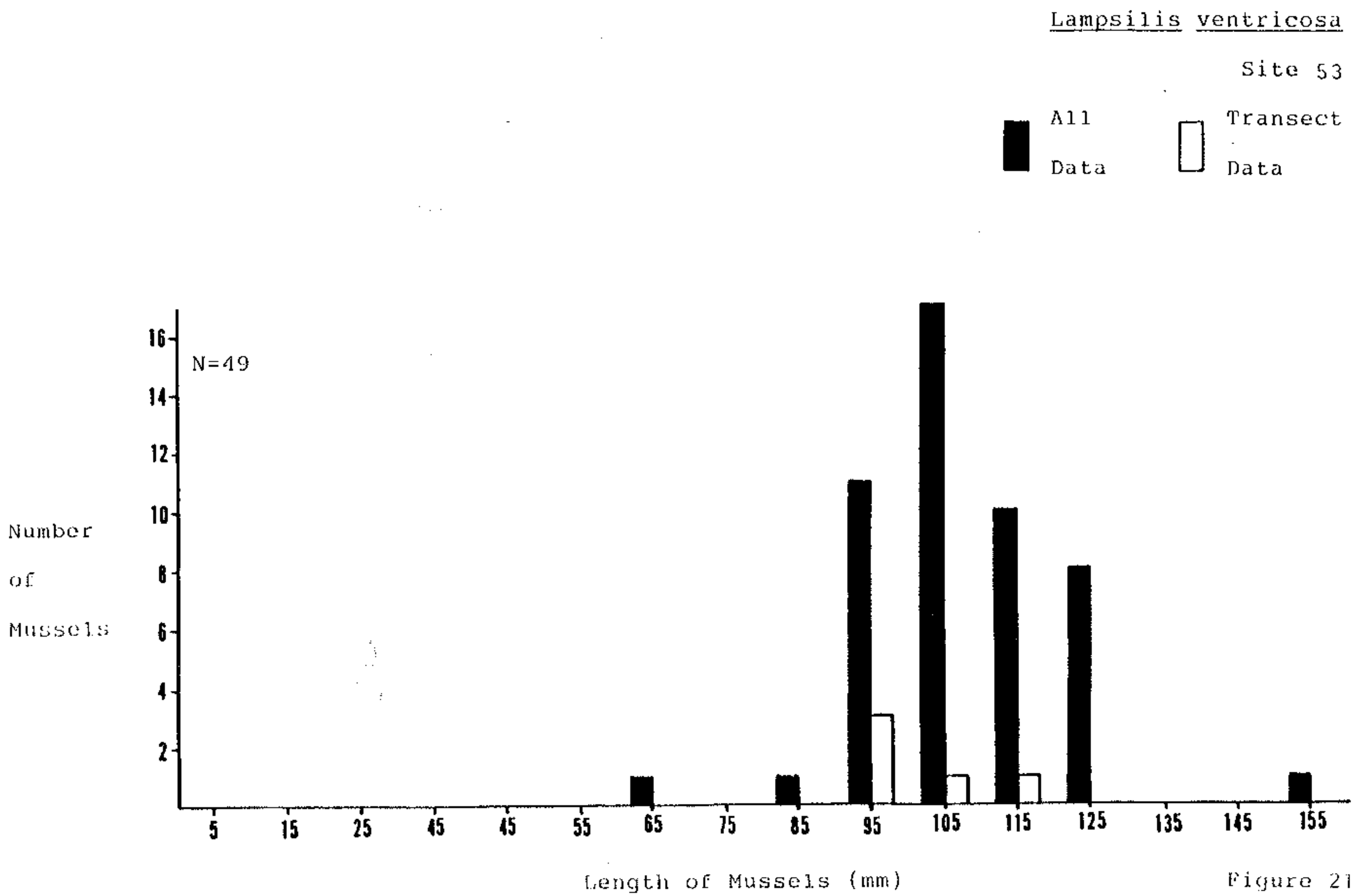

Lampsilis ventricosa
Site 53
All Data
Transect Data
N=49
Number of Mussels
16
14
12
10
8
6
4
2
5
15
25
45
45
55
65
75
85
95
105
115
125
135
145
155
Length of Mussels (mm)

Figure 21

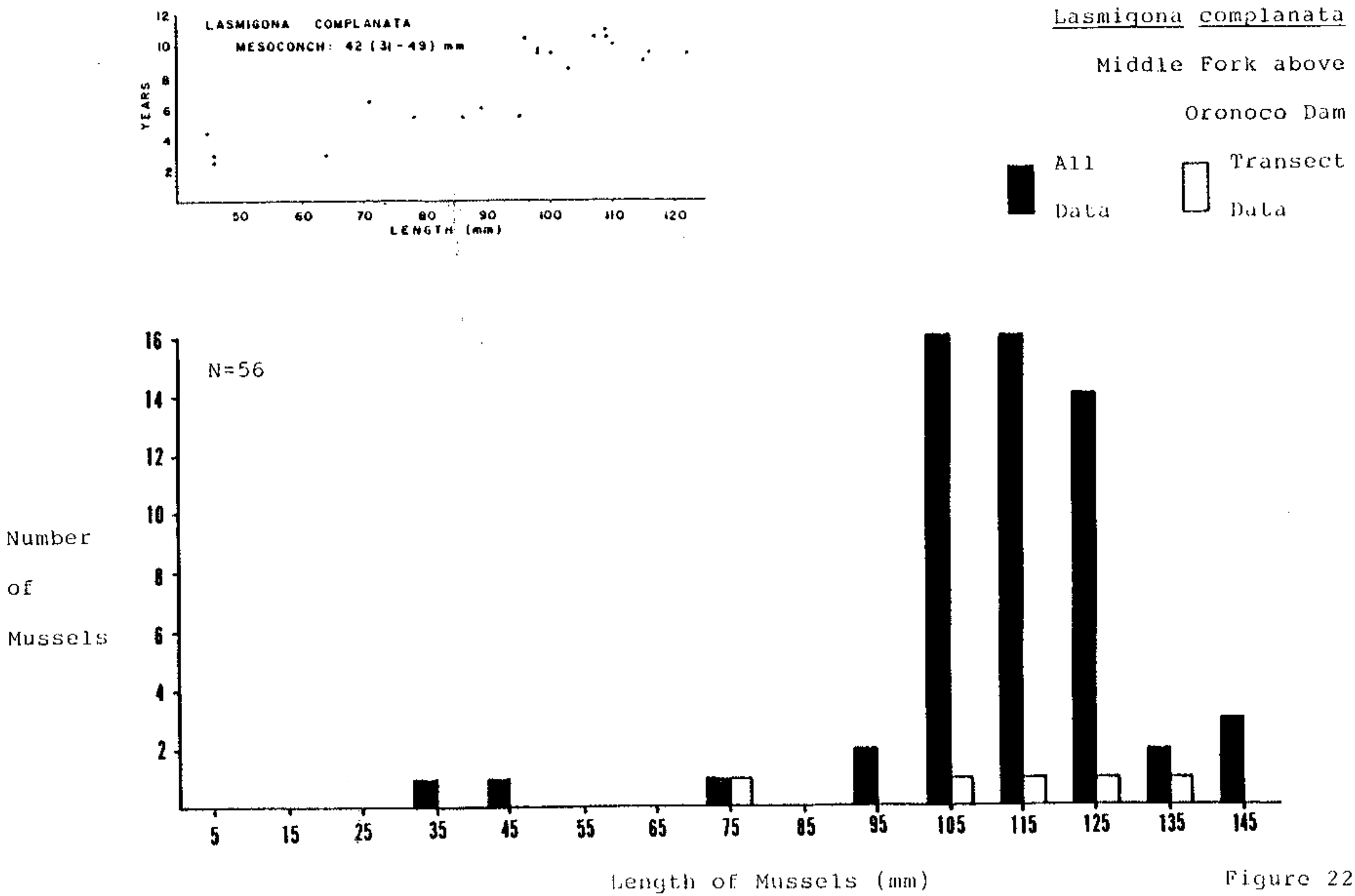

LASMIGONA COMPLANATA
MESOCONCH: 42 (31-49) mm
YEARS
LENGTH (mm)
Lasmigona complanata
Middle Fork above
Oronoco Dam
All Data
Transect Data
N=56
Number of Mussels
Length of Mussels (mm)

Figure 22

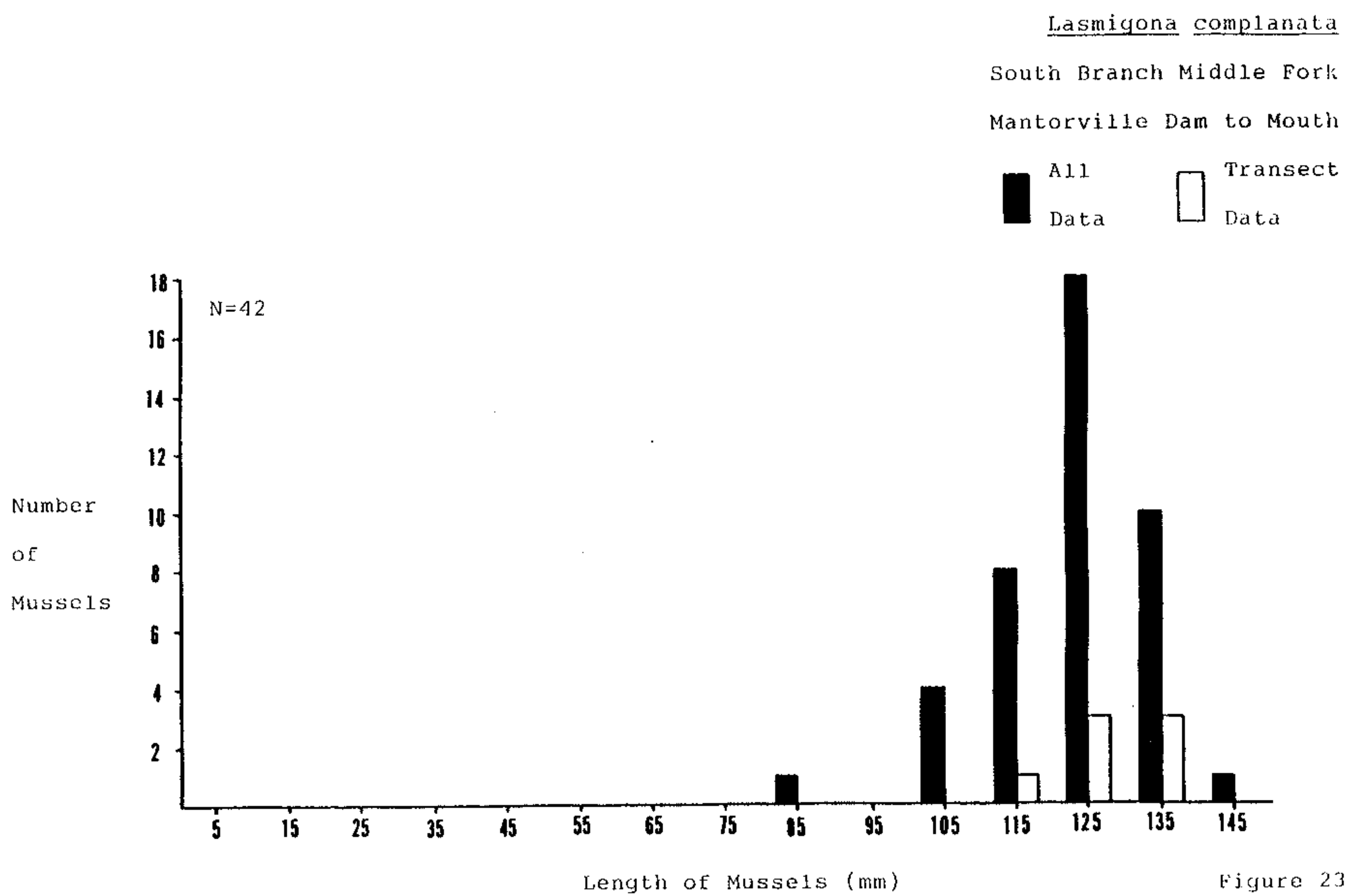

Lasmigona complanata
South Branch Middle Fork
Mantorville Dam to Mouth
All Data
Transect Data
N=42
Number of Mussels
18
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
Length of Mussels (mm)

Figure 23

Lasmigona complanata

Site 47

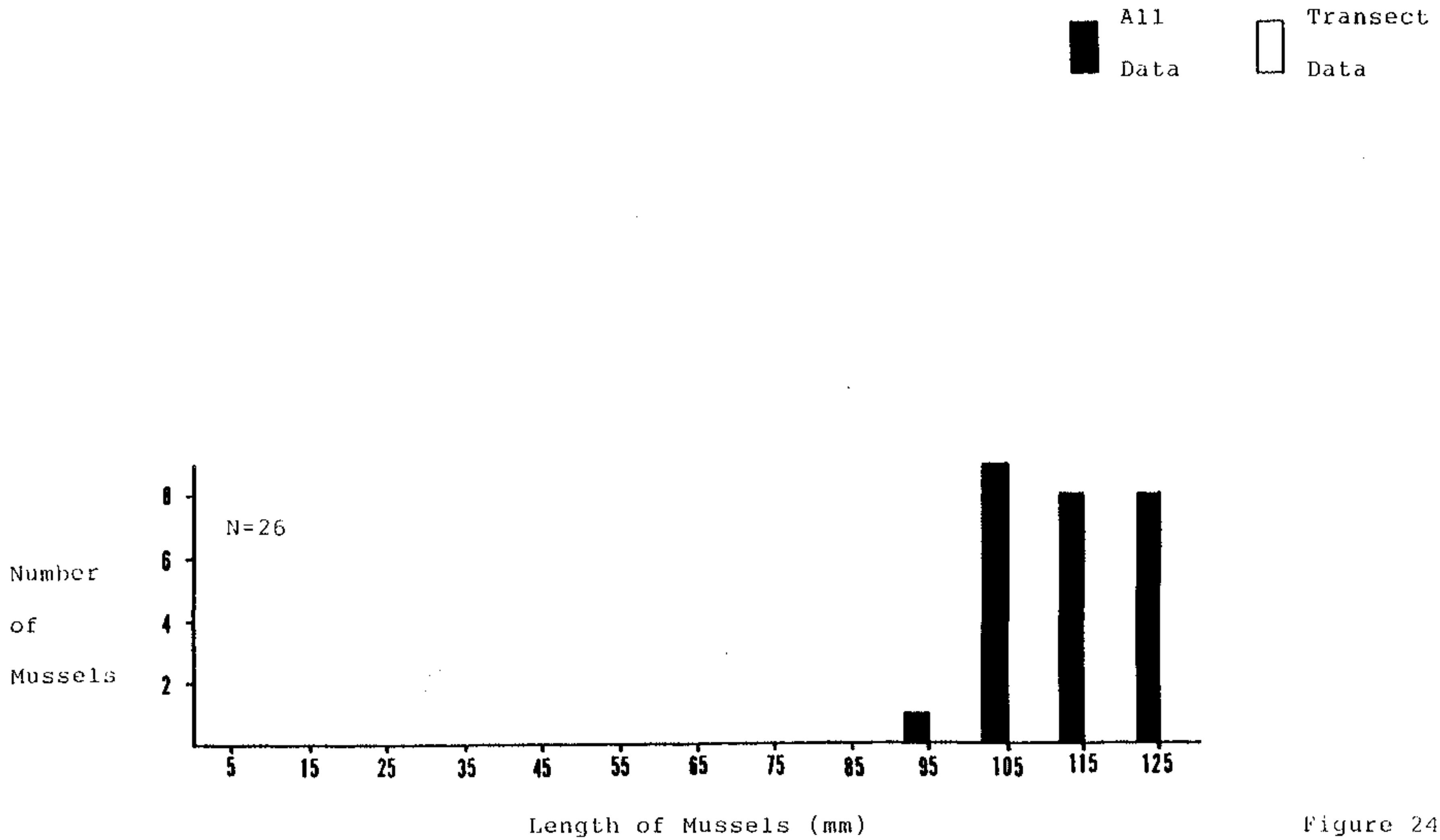
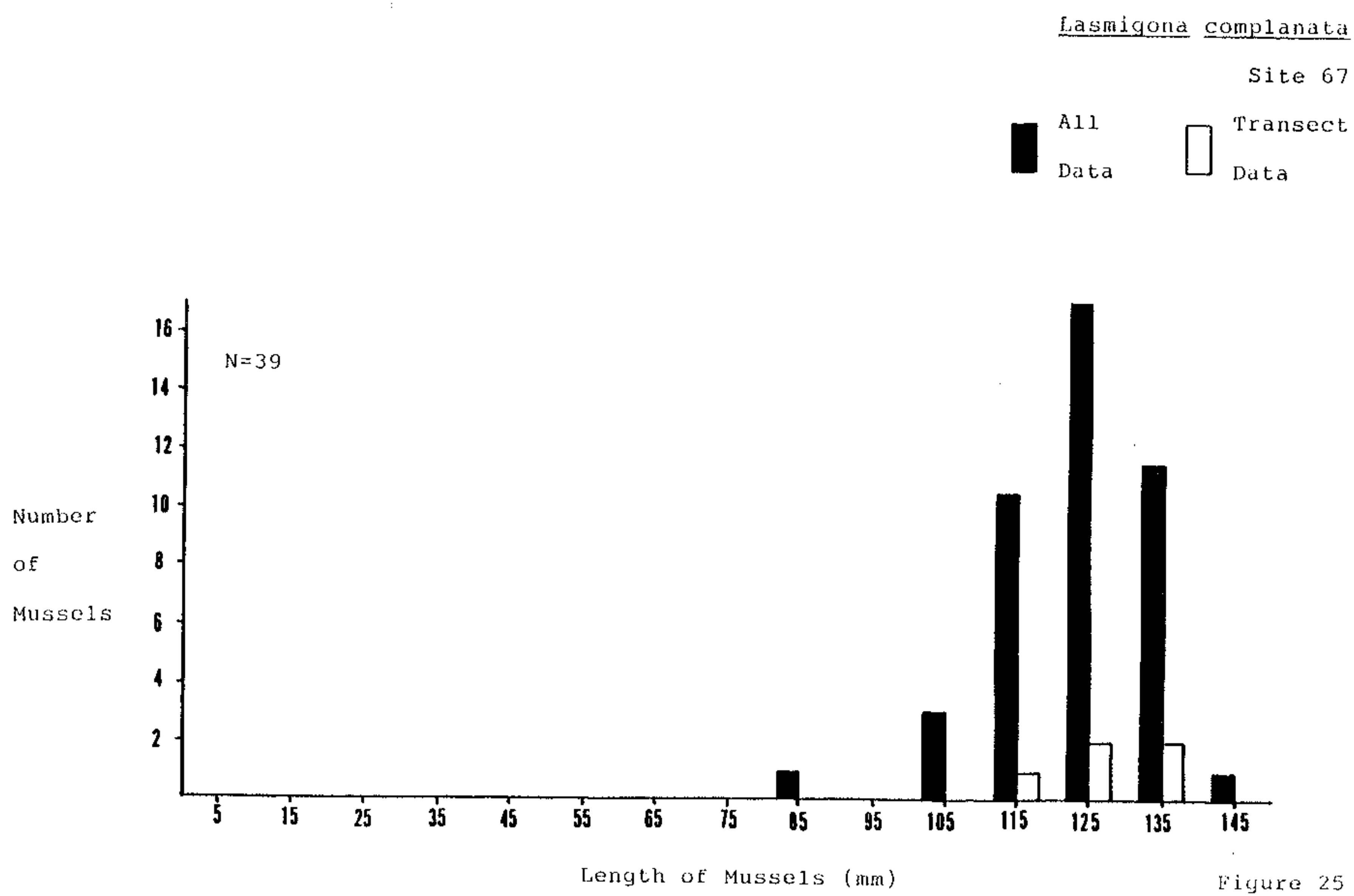


Figure 24



Lasmigona complanata
Site 67
All Data
Transect Data
N=39
Number of Mussels
16
14
12
10
8
6
4
2
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
Length of Mussels (mm)

Figure 25

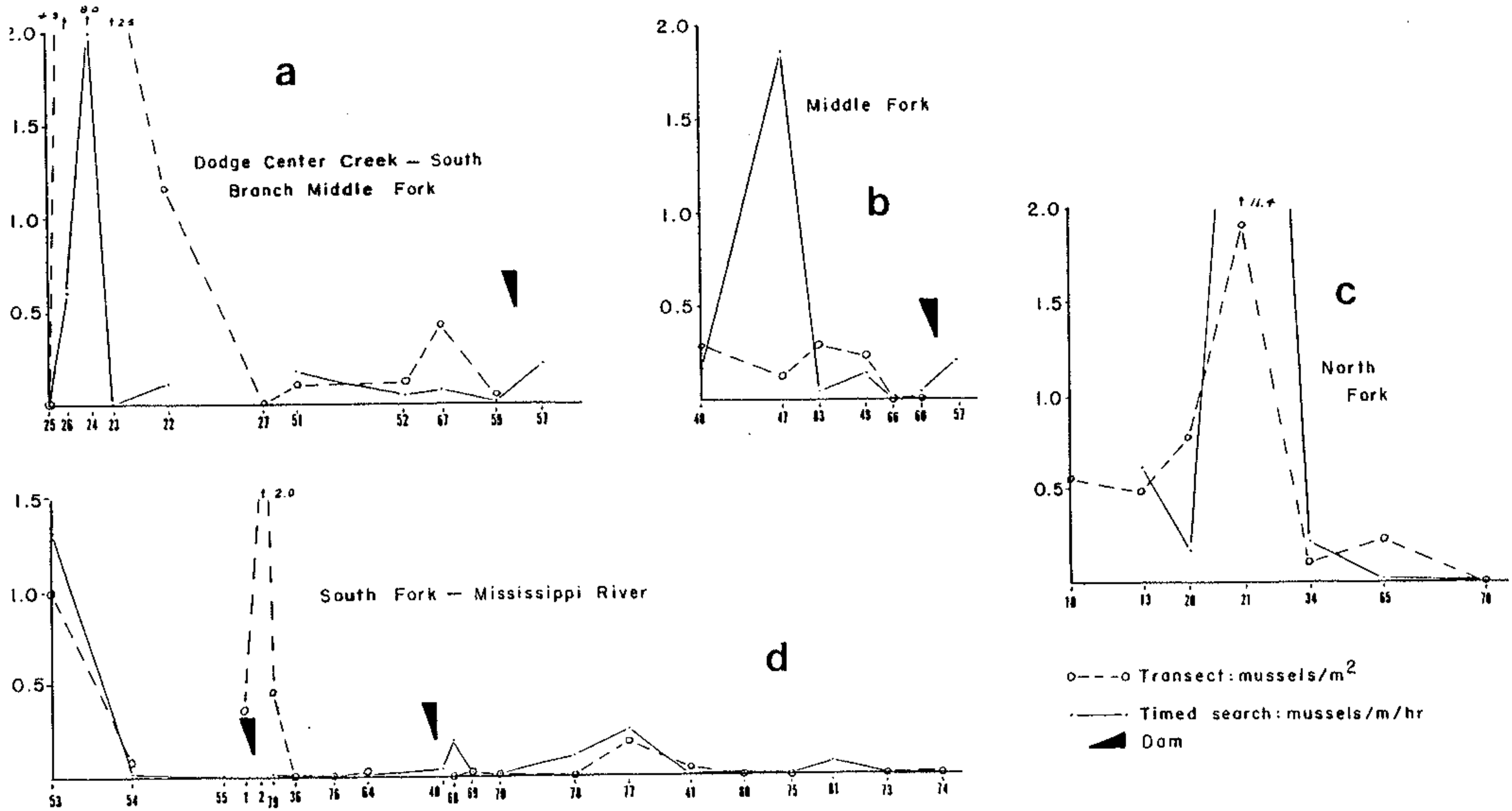


FIGURE 26. MUSSEL DENSITY DOWNSTREAM BY SITE

APPENDIX I

Site Data

SITE 1

Location: E 1/2 Sec 2, T106N, R14W. South Fork; 0-200 m upstream from Hwy 63 bridge, NE corner Soldiers Field Park, Rochester.

DNR Fish Station Number: -

Date: 20 June 1988

Water Temperature: -

Transect Location: 100 m upstream from bridge.

Range of the Mean Depth of Pool Transects: 130 cm

Duration of Timed Search: -

SPECIES		Transect L	Transect H	Transect W	Timed Search L	Timed Search H	Timed Search W
Lampsilis radiata siliquoidea		60.1	38.4	24.4			
Lampsilis ventricosa		72.5	40.0	23.8			
		92.2	64.9	41.5			
	$\overline{m}$	82.4					
	SD	13.9					
Lasmigona complanata		98.5	74.6	27.7			

RANDOM SEARCH (Presence noted)

Toxolasma parvus (live)

Anodonta grandis grandis (dead)