A SURVEY OF THE MUSSELS OF THE MINNESOTA RIVER, 1989

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ABSTRACT

A survey of the Mussels of the Minnesota River of southern Minnesota was made during the summer of 1989. Fifty-nine sites were studied and 1268 live specimens representing 20 species were examined for size, condition, and abundance. The distribution of both live and dead species was determined from the site analysis. Both quadrats and timed searches were employed to gather the data.

Forty native species have been reported to have occurred in the river since the late 1800's, but one of them, *Anodonta grandis corpulenta*, was not distinguished from *Anodonta grandis grandis* for the purposes of this study. Of the 39 taxa recognized, only 20 were found to be living in the Minnesota River now, l7 others apparently have been extirpated, and two species are extralimital. *Corbicula fluminea*, the introduced Asiatic Clam, was found in the lowermost part of the river in 1978, but has not been found live there since.

Many of the extant species are considered to be in some degree of trouble. No signs of reproduction or recruitment were found at many sites, and at others they ranged from poor to good. Both reproduction and recruitment success differed among the species.

Density was found to be low at most sites and no mussels were found at a few others. Both density and diversity (as number of species) were highest just below dams as the result of fish congregating there and the reasonably stable habitat provided by the dam.

Among the variety of limiting factors affecting the mussels of the Minnesota River, drought, unstable substrates, excessive siltation, and perhaps chemical pollution emerge as the most important ones.

In its present condition, the Minnesota River mussel fauna cannot tolerate commercial harvesting.

INTRODUCTION

Although mussels have been periodically recorded from the Minnesota River since the early 1800's and their shells were eagerly sought by the button industry a century later, there has never been a systematic study to determine either their distribution or abundance in the entire river. Recognizing a need for such information, the Minnesota Department of Natural Resources Nongame Wildlife Division sponsored a comprehensive survey of the mussel fauna in the summer of l989 that is reported herein.

Fossil mussel shells from Holocene floodplain deposits along the river indicate that a diverse fauna existed in the Minnesota long before the area was settled by Europeans, and that mussels were abundant in some stretches.

Early Americans used mussels for food and tools along the Minnesota River as evidenced by shells found in some archaeological sites (Guy Gibbon, personal communication), but they were not particularly exploited until the peak years of the button industry in the early 1900's. During those years, mussels were commercially harvested as far up the river as Montevideo, as well as in some of the major tributaries. Nachtrieb (1908) found during his survey of the Minnesota River, "...three beds in the course of half a mile which yielded about 30 tons of shells during the summer" at Bristol's Ferry (a few miles below Belle Plaine). In l917, 2054 tons of shells were harvested from the Minnesota River and almost five tons were taken from the Pomme de Terre (DeLestry, l918). It has proved impossible to determine precisely how many years harvesting took place on the Minnesota River, but in all likelihood it was not a profitable venture by the mid 1920's because the entire industry was in a state of collapse due mainly to overharvesting.

The purpose of this study was to determine the diversity, distribution, and abundance of mussels in the Minnesota River and also to evaluate reproductive success at as many places as possible. It is intended that the data reported here may serve as a basis for ascertaining future changes in the river's mussel populations.

THE STUDY AREA

The Minnesota River heads in Big Stone Lake on the Minnesota-South Dakota border near the town of Ortonville. From there it flows southeasterly for about 140 miles, its canyon being cut in a series of Precambrian granitic and metamorphic rocks, Cretaceous shale and sandstone, and Pleistocene glacial deposits of various sorts. At Mankato, in the south-central part of the state, the river abruptly turns and from there flows northeasterly about l00 miles to its confluence with the Mississippi River at St. Paul. Meandering of the Minnesota River adds to its total length, which is about 333 river miles. The lower part of its canyon is cut in lower Paleozoic sandstone, shale, dolomite, and limestone, and overlying glacial deposits. Dissection of the canyon mostly took place during the period when glacial River Warren flowed from the outlet of glacial Lake Agassiz at Browns Valley about 12,000 to 9,000 years ago. The present Minnesota River is but a small version of that ancient one.

The river drains about l6,900 square miles, l4,920 square miles being in Minnesota. The original vegetation in the western two-thirds of the basin was prairie,whereas the eastern third was in the Big Woods, and almost all the watershed is now devoted to agriculture. The rolling to flat uplands are covered with a variety of glacial deposits and some lake beds, many of which are readily eroded during periods of high runoff. 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 just under one foot per mile. The steepest natural gradients are between Granite Falls and Redwood Falls, where they can be about 10 feet per mile. Excellent descriptions of the characteristics of the river and its basin can be found in Kirsch *et. al.* (1985), Waters (1977), and the Hydrologic Atlas of Minnesota (1959), but a few features need to be mentioned that are important to the mussel fauna.

The flow rate of the Minnesota River varies seasonally, the lowest flows generally occurring August through February and the highest flows during the period March through June. Such a flow regime creates a seasonal cycle of turbidity of highest values during spring and lowest values in late summer and early fall, although, in the summer of 1989 turbidity was high into September as indicated by visibilities of only a few inches at the bottom of the river. Flooding is common along the river because of the low gradient and characteristics of the watershed and channel. The flow averaged 107.6 cfs at Ortonville between 1939 and 1980, and 3403.1 cfs at Jordan between 1935 and 1980. The river is also prone to periodic low-water levels and has dried along many stretches above Mankato (the point of confluence of its major tributary, the Blue Earth River). The river bottom was supposedly farmed in places during the drought of the late 1930's (Kennneth Bonema, personal communication). As of 1959 (19 years of record), the lowest flow recorded at Jordan was 85 cfs (Hydrologic Atlas of Minnesota, 1959). In September of 1976 the flow at New Ulm was but 29 cfs (Water Resources Data for Minnesota) and the river was but a series of separate pools connected by a small stream.

Kirsch *et. al.* (1985) characterized the river "... as a fertile, hard-water and moderately turbid stream". They also pointed out that turbidity, nitrate-nitrogen, and total phosphorus exhibit moderate increases downstream and that "... turbidity and nitrate-nitrogen average a two- to three-fold increase between the source and the mouth" between June and August. Secchi disk transparencies reported by them "...ranged from 0.3 to 5.6 feet," the highest readings being "...downstream of reservoirs in the upper 40 mi of river". Below that point they found secchi disc values "...typically less than 2.0 ft.". Waters (1977) noted that "Alkalinities are generally high, about 200 ppm, at most points in the river and tributaries draining lands that are covered by calcareous glacial sediments. Except in low-water conditions, the Minnesota is a muddy stream. Of the major rivers in the state, often it carries the most sulfates and carbonates and is the most turbid, with great quantities of clay and silt".

Additional information about the river is provided by Nachtrieb (1908). He found that: "The river bottom [below Minnesota Falls] is generally firm, being muddy in only a few places. Usually the bottom is sandy, tho it is frequently also gravelly and in places rocky." As regards water temperature, he noted that when the temperature in the boat was 26-28 C, that of the bottom water in places 7-10 ft. deep was 18-21 C°.

He was impressed with the turbulence of the river and said: "Besides tending to equalize temperature of the surface and bottom waters the continued boiling keeps the water laden with dirt, so that the water is at no time clear. This condition no doubt also effects the temperature".

At the time of settlement there were three natural fan-dammed lakes on the Minnesota in its upper reaches - Big Stone Lake, Marsh Lake, and Lac Qui Parle. However, Keating, in 1823, viewed the first two as mere expansions of the river and not properly called lakes. The natural dams were rebuilt or replaced after settlement for the purposes of flood control, lake-level control, and improvement of the recreational value of the lakes. The dam at Granite Falls and the one 2.5 miles below Granite Falls (Pete's Point) were originally built for the production of hydroelectric power, the latter now being used mainly for control of the river level. Another dam impounds the river at Odessa and was built to improve waterfowl habitat. According to Kirsch *et. al.* (1985) the six artificial dams on the upper Minnesota River now "... effectively block fish movements except during times of exceptionally high water." However, the natural pre-settlement dams probably did not impede fish movement. Dams that restrict fish movement are important to mussels because they are dispersed by fish, a point considered later in the discussions of mussel species.

Deducing the condition of the river as regards its turbidity in pre-settlement time has almost entirely revolved around the correct definition and translation of the Dakota word "sota". In recent literature the word has been translated as "cloudy" (Kirsch *et. al.*, 1985) as well as "sky-tinted" or "... a more accurate translation is whitish or sky-clouded" (Waters, l977). According to Carrie Schomer (instructor of the Dakota language, Univeristy of Minnesota, personal communication) the word "sota" means "clear"; moreover, there is no such word as "turbid" in the Dakota language. However, Elsie Cavender, an elder in the Dakota community of Granite Falls, claims that "sota" means "cloudy" (personal communication), but that it does not mean "whitish". Folwell (1922) thoroughly reviewed the meaning of the word "Minnesota" and its Dakota roots noting serious inconsistencies in its translation and a host of meanings. He then said: "Without presuming to challenge the high authorities, the writer ventures to raise the question whether in fact the water of the Minnesota was or is any more clear, or imperfectly clear, or slightly turbid, or non-transparent, or whitish, or bluish, or sky-tinted, or sky-colored, or whitishly clouded than that of the Mississippi or of other streams in the Northwest." His conclusion from observations and inquiries is that there "... is little or no difference". Because of those diverse opinions an attempt was made to find descriptions of the river water itself.

The only first-hand description of the Minnesota River water found from pre-settlement time and far enough above the mouth as not to be affected by high water of the Mississippi is that of Featherstonhaugh (1835). During his ascent of the Minnesota, as he came to the mouth of the Blue Earth River on 22 Sep 1834, he wrote, "This was a bold stream [Blue Earth], about eighty yards wide, loaded with mud of a blueish color, evidently the cause of the St. Peter's [Minnesota] being so muddy". He then took a side trip up the Blue Earth and when he re-entered the Minnesota, he noted, "... where it [the Minnesota] is not mixed with that of the Makatoh [Blue Earth River], we found it [the Minnesota] exceedingly limpid and altogether distinct from the turbid state of its tributary". Those statements certainly indicate that the Blue Earth was more turbid than the Minnesota at their confluence and that the Minnesota was more turbid downstream from the confluence than upstream. On his return trip to Fort Snelling, on l3 Oct 1834, he said, "... getting our paddles in motion again passed the Makatoh about a half an hour after noon: we found the water diminished in quantity, and the current comparatively gentle to what we experienced on our ascent of the St. Peter's [Minnesota]; neither was the river [Minnesota], after passing the junction much discoloured; tending, I think, to prove that its muddiness at other times commences near its sources, which, like those of all other streams, at this moment were very low." Thus, as he ascended the Minnesota River in mid-September the river was higher and more turbid below the mouth of the Blue Earth than when he returned to the same place a month later. Moreover, that description suggests that as the discharge decreased, the turbidity decreased and the Minnesota River was fairly clear in mid-October.

From the foregoing it is concluded that in pre-settlement time the Minnesota River was turbid during runoff, the turbidity varying in intensity in different stretches depending upon the contribution from tributaries, and visibly clearer in the fall. In other words it was a perfectly normal stream in Minnesota until its watershed became seriously affected by the activities of settlers. Kirsch *et. al.* (1985) summarized it best of all when they said, "... it stretches the imagination to think that pre-settlement man gazed upon the same brown ribbon of water that characterizes the Minnesota River of today. While the river has been meandering through the typically fine soil bed of glacial River Warren for thousands of years the breaking of the prairie sod, removal of forest groves, and the extensive drainage network have certainly been major contributors to the ambient 'muddiness' of the stream".

In 1958 the U. S. Army Corps of Engineers was authorized to dredge a channel nine feet deep in the lower Minnesota River from its mouth to near Savage, a distance of about 14.7 miles, to accomodate barges, and was also authorized to dredge a four foot channel from mile 14.7 upstream to Shakopee. The nine-foot channel is currently maintained by the Corps but the four-foot one is not.

PREVIOUS WORK

Mussels have been known from the Minnesota River since 1823, when Thomas Say, a biologist with the Long Expedition, first waded the stream (Keating, 1959). Most of the collections made after about 1880 are housed in the Bell Museum of Natural History, University of Minnesota.

Table 1a, with its annotated explanation, provides a historical record of mussel species observed or collected from the Minnesota River between 1823 and 1989 based both on a literature review and the Bell Museum's collections. Table 1b is a list of the specimens housed at the Bell Museum from the Minnesota River, including the date of collection, the collector, and the locality.

The only known major survey of the mussels of the Minnesota River was done by Henry Nachtrieb during July and August in the summer of 1908. A copy of his typed, unpublished, 1908 report was recently found among historical documents of the Animal Biology Department of the University of Minnesota. The study was undertaken for the U. S. Bureau of Fisheries. His survey covered the river from Minnesota Falls, just below Granite Falls, to Fort Snelling, and the purpose was to evaluate potential and existent mussel harvesting in the river. His sampling technique was to tow a "...crowfoot— a bar carrying a number of series of 'clam hooks'..." behind a launch. Apparently both his field notes and one collection of shells were sent to the Bureau of Fisheries, but they have not yet been located. Because his study is so important to later discussions it is quoted extensively as follows:

"The river bottom is generally firm, being muddy in only a few places. Usually the bottom is sandy, tho it is frequently also gravelly and in places rocky.

...Regular clamming has thus far been confined to a few places between Belle Plaine and Fort Snelling. So far as the location of clam beds is concerned the Minnesota River has been unknown above Bristol's Ferry, a private ferry a few miles below Belle Plaine.

...All along the river, excepting the region near Minnesota Falls, acres upon acres of excellent soil were being undermined and dropt into the river during the stage of moderately high water; and some bars were being shifted and washt away while others were being built up. This has a direct bearing on the clam problem. Whole clam beds have been washt up and deposited upon high banks and others have undoubtedly been buried. Places pointed out as good clam beds did not yield a clam after most thoro and repeated dragging. This insecurity of clam beds is most markt in about the middle two fourths of the course...

The tributaries are all torrents after heavy or continued rains and spring thaws, and nearly all of them are dry runs late in the summer. Only the Blue Earth at Mankato, the Cottonwood at New Ulm and the Redwood farther west cont[a]ined enough water late in the summer to justify an inspection. By the middle of August none of these could be navigated with the launch...

It will be noticed that according to the field notes the muckets [*A. carinata*] are almost twice as numerous as the threeridges [*A. plicata*] and the threeridges are a little more than twice as numerous as the pocketbooks [*L. ventricosa*]. The other commercially important species are not as abundant. This generalization is supported by the summer's harvest of clammers at Bristol's ferry. Here three beds in the course of half a mile yielded thirty tons of shells during the summer. Of these about twelve tons were muckets, eight tons threeridges and only about one ton niggerheads [*P. sintoxia*]. Mr. C. L. Appel, who was directing the clammimg at Bristol's Ferry [d]id not consider these shells of first quality. They all, or nearly all, have a black or darkened layer near the umbone. This is also true of the shells we collected in other parts of the river.

When we came by Bristol's ferry in August a days catch or haul indicated that the beds were nearly exhausted.

The distribution of the clam beds in the Minnesota between Minnesota Falls and Fort Snelling is very irregular. The great majority of our collection came from the upper fourth of the course. For a number of miles below Minnesota Falls the clam beds follow each other in rather close succession. They are not always densely populated and did not yield very large shells. Indeed the entire collection was composed of shells of medium and small size. The beds at Bristol's ferry yielded a much larger proportion of large shells than any of our drags did. This may be partly due to the fact that we made but one haul over a bed and may not always have dragged the best part of the bed. It is also possible, even probable, that we may have mist some beds altogether. Making due allowance for all this the evidence is still strong that clam beds are not easily establisht and maintained in the middle and lower portion of the course investigated. This is probably largely if not wholly determined by the conditions obtaining in the spring, the floods washing out and covering up the young clams and at times well establisht mature forms. If the river course could be given a greater permanency clam beds would be establisht all along the course.

Some of the clam beds in the upper portion of the course yielded almost nothing but threeridges, some others almost nothing but muckets and one or two largely pocketbooks. Whether a thoro dragging of these beds would have changed the character of the collection can not be said, but the testimony of clammers favors the view that the collections represent the conditions as they are. Why there should be this isolation and segregation could not be determined. Conditions appeared to be the same..."

On l8 Sep 1908, Nachtrieb sent a letter to B. W. Everman, Department of Commerce and Labor, Bureau of Fisheries, Washington D. C., summarizing the results of the summer's work. Some of his comments follow:

"...In general the river can be divided into three regions in reference to clamming - - the upper portion of the course between New Ulm and Minnesota Falls, the lower portion from Belle Plaine to the mouth and the intervening portion. The upper portion presents a series of clam beds following each other closely. The lower portion presents little more than above indicated, and the middle portion is relatively without beds of commercial value. The physical - - physiographic - - conditions I think explain this.. The shells dragged in the upper portion were all of moderate size, with only an occasional large one. Three-ridges are most abundant and next the Muckets and Pocketbooks. [Notice that comment does not contradict his statement in the report where he listsproportions for the river in general] As a rule these are found together in varying proportions. In a few instances one or the other was strikingly predominant. Niggerheads are everywhere scarce. In the upper portion we never got more than four in one dragging. Mr. Appel had only five or six gunny sacks full of niggerheads. None of the other species are found in commercial abundance."

Fuller (1978) surveyed the lower 15 miles of the Minnesota River for mussels in conjunction with his major survey of the Upper Mississippi River for the U. S. Army Corps of Engineers.

MATERIALS AND METHODS

Mussels were examined and voucher specimens collected at 59 sites (Pl. 1) on the Minnesota River; the vouchers were deposited in the collection at the Bell Museum of Natural History, University of Minnesota. The distance between sites averaged 5.6 miles (9 km) and ranged from 11 to 0.15 miles. The distance between sites is least downstream from Mankato because of the difficulty in locating mussels. Most of the sites correspond to the Minnesota Department of Natural Resources stream-survey sampling stations as given in Kirsch *et. al.* (1985).

Each site was examined either by SCUBA , snorkeling, wading or combinations thereof.

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. 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 5 inches (wrist depth). That operation was repeated at least once at each place so that the minimum quadrat area sampled was $1/8m^2$. The distance between the rows of quadrats was determined by the width of the river. In the upper part of the river, where it was small, rows of quadrats were spaced 4 - 10 m apart (about 10 percent of the river's width) and the total number of quadrats searched ranged from 20 - 40. except for Site 4, where 72 quadrants were sampled. Beginning with Site 23, where the river was widening, and thence downstream, the distance between the quadrats was established at 20 percent of the river's width and rows of quadrats were 10 m apart, 20 quadrats being searched at each site. Because of the paucity of mussels the size of the quadrats searched was increased to 1/4 m^2 at Site 40. Thus the area searched at each site ranged from 2.63 m^2 to 7.50 m^2.

After the quadrats were examined at each site a timed search was conducted that took one hour with three people doing the search. During this procedure the three people separated and investigated as many habitats as possible by wading, snorkeling, or using SCUBA.

Measurements of mussels were made by means of a caliper to the nearest tenth of a millimeter. Length was measured parallel to the hinge, and height was taken as the maximum distance perpendicular to the length. Width was measured perpendicular to the commisure.

Identifications were made in the field with the aid of a "mobile" reference collection provided by the Bell Museum of Natural History, University of Minnesota.

Water temperature was taken with a high-quality thermometer and was recorded to the nearest F° (Appendix 1). The thermometer was normally immersed to a depth of about 10 cm.

"Age" was determined by counting the annuli on each shell.

Gravidity was established by opening the shells with a pair of sharpened carpet pliers and then sampling marsupia for glochidia with a tiny glass pipette.

Each specimen observed was categorized as being in one of the following three conditions based on a set of specific criteria:

Live.

Recently Dead. Nacre has some luster. Body parts still clinging to the shell. Periostracum not much deteriorated or peeling. Shell not chalky. Such shells probably represent individuals that have been dead less than two to three years.

Dead. Nacre has no luster. No body parts clinging to the shell. Periostracum deteriorated and peeling or missing on many parts of the shell. Shell chalky. Dead more than 2 -3 years. Such shells sometimes cannot be distinguished from fossils several thousand years old.

Substrate particle sizes are given in the standard Wentworth system. Sizes finer than very coarse sand were determined by means of a grain-size pocket guide produced by geology students at Kent State University.

RESULTS

Mussel Distribution

The distribution of both live and dead specimens found during the 1989 season is shown in Plates 2 -38. In general the maps show patterns of extirpation, formerly wider distributions, as well as restricted distributions within the Minnesota River. Further interpretation of each map follows in the species accounts (including the introduced Asiatic clam, *Corbicula fluminea*).

Mussel Diversity

Live mussel diversity (as number of species) at each of the 59 sites ranged from none to a maximum of nine (Fig. 1), the average being 3.5. At 13 sites no live mussels were found. The maximum number of live plus dead (= "dead" + "recently dead") species found at a single site was 27 (Site 50).

Figure 1 shows changes of diversity from site to site along the Minnesota River from Big Stone Lake to it's mouth ("grid" refers to the quadrats sampled). No trend is obvious in the number of live species found by all methods along the river, but it appears that more species were consistently found from site to site in the stretch between river-mile 225 and 125. As has been found elsewhere (Bright *et. al.*, 1989), the number of live species is slightly higher below dams (see Fig. 4 for their location) than in stretches above them. In contrast, the number of dead species (live and dead all methods minus live all methods) is consistently high between river-mile 290 and Mankato, where the numbers decline markedly and then build up towards the mouth of the river.

The proportions of live species based on the 1268 live specimens found are shown in Figs. 2a and 2b. Figure 2a includes Site 7, which contained abnormally dense *Anodonta grandis grandis*, and which rather biases the data in favor of that species. Figure 2b is a plot of the same data without Site 7. If the river is considered as a whole it is apparent that *Truncilla truncata*, *Quadrula quadrula*, *Anodonta grandis grandis*, and *Amblema plicata* are the most abundant species.

It is recognized, however, that the species composition of a stream may differ markedly from stretch to stretch or even change systematically downstream. Figures 3a and 3b were constructed to show any such changes (3a and 3b can be pasted together). The most ubiquitous live taxa in the river are *Truncilla truncata* and *Anodonta grandis grandis*. *Leptodea fragilis* occurs in the upper part of the river but becomes more important downstream from New Ulm. Below Granite Falls *Potamilus ohioensis* is common, but it drops out of the fauna at river mile 22.2. Between New Ulm and the mouth of the river there are large gaps in the occurrence of species, for example *Quadrula quadrula* and *Amblema plicata*. *Lampsilis radiata luteola* was found live only above Granite Falls, where it is common in the fauna. *Lampsilis ventricosa* occurs most commonly from Mankato to about river mile 231, and *Quadrula pustulosa* occurs most commonly from New Ulm to Granite Falls. *Truncilla donaciformis* occurs only below river mile 56.4. Thus, the live species found in 1989 are roughly divided into upstream, midstream, and downstream groups.

Mussel Density

Density at each site is presented in two ways in Fig. 4 — mussels/m^2 in the quadrats and mussels/hr in the timed searches. Quadrat mussel densities ranged from 0 to 8.38/m^2 (Site 7) and averaged 0.65/m^2. Timed searches produced densities ranging from 0 to 94.33 mussels per hour, the highest being at Site 6. The mean for the timed search was 6.69 mussels per hour. The mean density in the quadrats is similar to those found in pools in the Cannon (Davis, 1988) and Zumbro systems (Bright *et. al.*, 1989):

Cannon + Straight Rivers = 0.55 mussels/m^2
(less Faribault bed)

Zumbro River	= 0.48 mussels/m^2
Minnesota River	= 0.65 mussels /m^2

The density of mussels in the Minnesota River, overall, was found to be very low. In 55 days of searching at 59 different sites, only 1268 live mussels were found using both timed-search and quadrat methods. .

Figure 4 shows that mussel densities are on average higher in the Minnesota River between the dam at the Big Stone Wildlife Refuge and the lower dam at Granite Falls (Pete's Point). In fact the highest densities recorded were just below five of the dams in the upper reaches of the river; however, for the most part, low densities were found in three of the lakes investigated. Densities decrease markedly at about river mile 240 , increase slightly in the stretch to New Ulm, and then drop to low levels below New Ulm (averaging about 0.2 mussels/m^2 in the latter stretch). If the data just below dams is eliminated from Fig. 4, the average density above the lower dam at Granite Falls becomes less than 0.5 mussels/m^2, or about the same as below Mankato. The timed searches produced an average of 4.4 mussels/hr above Granite Falls (excluding sites just below dams) whereas only 1.8 mussels/hr were found in the stretch below Mankato.

Substrate Preference

Substrate was recorded for 1098 live mussels. Figure 5 compares the abundance of mussels to the substrate in which they were found. It shows that the vast majority occurred in the finer grained substrates, especially those that were rich in sand or silt.

Although gravel bars and flat gravelly bedload deposits occurred at many sites, few live mussels were found in those substrates. However, dead shells were commonly found there.

Causes of Mortality

A variety of factors cause the death of mussels on the Minnesota River. The most obvious and unequivocal one is predation by racoons and muskrats. Midden shell-piles were noted here and there along the river, but were not noticeably common. The effect of fish predation in the river is unknown. Predation by shore birds is probably unimportant overall.

Low water levels are lethal to mussels in situations where they cannot escape to deeper water, most succumbing to dessication. There are numerous historical records of zero flow in the river, particularly upstream from New Ulm, the drought of the 1930's being a good example. Such conditions have no doubt caused massive mortality in stretches of the Minnesota throughout its history and will continue to do so in the future.

Fuller (1974) reviewed the effects of low concentrations of dissolved oxygen on mussels. He found that the effects varied between species and that one (*Amblema plicata*) is able to survive up to ten weeks without dissolved oxygen. Most species, however, seem to require a minimum range of 2.5 - 5 ppm for optimal survival and reproduction. Dissolved oxygen levels less than 2.5 ppm have been recorded at various depths in Big Stone Lake, Big Stone National Wildlife Refuge, Marsh Lake, Lac Qui Parle, and at several sites on the river itself in the same area (Zappetillo and Pierzina, written communication). Various DNR reports record DO's ranging from 7.4 - l4 ppm in the stretch below New Ulm, but presumably those are all from surface or near surface samples. It would seem, then, that the mussels in at least the upper part of the Minnesota River are routinely stressed by low oxygen levels that may increase mortality rates.

During winters with low water levels the river can freeze to the bottom in places and that creates both oxygen and temperature problems for mussels that cannot escape to deeper water or are unable to burrow in difficult substrates such as cobbles and boulders. This factor is likely a problem mostly above New Ulm.

Excessive siltation is common in the river year around, but is most serious during periods of runoff in spring and early summer (see Nachtrieb's statement above). Silt can clog the gills of mussels, cause the mussel to close its shell for extended periods of time, interfere with phototactic responses because of low light penetration, and create substrates so unstable that some species cannot survive there. Excessive silt loads no doubt adversly effect mussels over the entire length of the Minnesota River. Note that most of the mussels examined in 1989 were found in substrates that contained particles coarser than silt (Fig. 5).

Chemical pollution from various sources is probably a problem in the river and has most likely contributed in various ways to the demise of many mussels. Many of the chemicals that have been found toxic to mussels are known to occur in the river (see the review of contaminants and their effects by Havlik and Marking, 1987) but no direct evidence was found that indicacted which one(s) is the most serious in the Minnesota.

DISCUSSION

Mussel Species of the Minnesota River

Actinonaias ligamentina carinata (Mucket)

Not a single live specimen of *A. l. carinata* was found in the Minnesota River during this study. Dead shell records (Pl. 2) are common and indicate that it has occurred throughout the river in the recent past.

All twelve of the Mucket's fish hosts exist in the river, and nine of them occur above the dams at Granite Falls. Therefore, fish host availability does not appear to limit its distribution.

The Mucket has been noted or collected in the Minnesota River at various places since 1835 (Table 1a), but little information exists about its abundance. Grant (1886) noted that it was "... common in the River at Granite Falls." Dawley (1947) considered *A. l. carinata* "... widely distributed in medium and large rivers [in Minnesota], but not present in large numbers." Nachtrieb (1908) reported that of the commercial species it was second in abundance to Threeridge between Minnesota

Falls (Pete's Point) and New Ulm and that it was the most abundant species in the river overall. Baker (1928) and Mathiak (1979) indicated that its favorite habitat is shallow swift water with a stable sand, gravel or cobbly substrate. Such substrates are more common above Redwood Falls than downstream, where silt is predominant.

The absence of live specimens of the Mucket coupled with the ubiquitous and abundant finds of dead shells (Pl. 2;) indicates that some unknown factor(s) has apparently extirpated the species throughout the entire Minnesota River in the recent past — certainly since 1908. Recent studies in Minnesota have shown *A. l. carinata* to be in serious trouble in the Cannon (Davis, 1988) and Zumbro (Bright *et. al.*) Rivers.

Alasmidonta marginata (Elktoe)

Grant (1886) first reported the presence of Elktoe in the Minnesota River at Granite Falls, but it is uncertain if he found it live or dead (Tables 1a and 1b). During this study only one specimen was found live at Site 22 (Pl. 3), where it occurred in sandy cobbly substrate. It is now (Figs 3a and 3b), and probably always has been, a minor component of the Minnesota River fauna. Dawley (1947) considered it as "not common, but found in both small and large rivers in Minnesota." It was more widely distributed in the river in the recent past than it is now (Pl.3).

All five of the fish hosts listed by Fuller (1978) occur in the Minnesota — three of them occur above the dams at Granite Falls.

A. marginata is so rare in the river at the present time that it is likely in risk of extirpation.

Amblema plicata (Threeridge)

Threeridge is widely distributed in both small and large streams in Minnesota (Dawley, 1947) and even now can be abundant in places. It was found live at nine sites in the Minnesota River between Lac Qui Parle and New Ulm and at Site 50 (3 specimens) just upstream from Shakopee (Pl. 4). It was found recently dead at three sites between New Ulm and Le Sueur (Pl. 4). Dead shells were found at numerous localities all along the river indicating that it was formerly more widespread than now (Pl. 4). Grant (1886) reported that it was "rather common" in the river at Granite Falls and at Fort Snelling. Nachtrieb (1908) found it to be common between Minnesota Falls and New Ulm and in places downstream from Belle Plaine. It was most commonly found in silty sand and pebbly sand substrates in the Minnesota River (Fig.5) and is a significant component of the fauna at some sites (Figs 3a and 3b).

Fifteen of its fish hosts are known from the river and eleven occur above the dams at Granite Falls.

About nine percent of all the live specimens found in the river were less than three years old, indicating that some recruitment is taking place. The population at Site 15 (Fig. 6) appears to be healthy in that young age classes are common. Recent recruitment is indicated at Site 20 (Fig. 6), but several length classes smaller than 95 mm are absent. The species appears to be holding its own upstream from New Ulm. However, downstream from that point Threeridge is rare and likely in trouble. Certainly it is far less common now than during Nachtrieb's 1908 survey, but still proportionally high (Figs. 2a and 2b), and the population at Fort Snelling observed by Grant in 1885 is gone.

Anodonta grandis grandis (Floater)

The Floater is one of the most widespread mussels in the Minnesota River (Pl. 5) and is a major component of the fauna (Figs. 2a and 2b). It occurs live all the way from Ortonville to the mouth of the river at Ft. Snelling. Although It was not found live in either Lac Qui Parle or Big Stone Lake it is expected to be living in both lakes. Its favorite substrates in the Minnesota seem to be silt, sandy silt, granular silt, and silty sand (Fig.5). It is a common and widespread species in the state (Dawley, 1947; Bright *et. al.*, in preparation). It was extremely common at Site 7 below the Big Stone Refuge dike (Pl. 1 and 5) where 226 live specimens were found during the timed search.

Nineteen of its 22 fish hosts occur in the river and seventeen of those are known above the dams at Granite Falls.

Although widespread in the river, the Floater is not abundant everywhere. Only two sites produced enough live material to construct histograms of length classes (Fig. 7). Recruitment appears to be taking place at both Sites 7 and 9 and some gravid females were found there. Overall, about 16% of all the live *A. g. grandis* found were three years old or younger (as estimated by annuli) and only 7% were two years old or younger. At many sites only adults were found, some occassional females being gravid. It is likely, then, that the Floater is surviving reasonably well in the Minnesota River and is extremely successful in at least two places.

Anodonta grandis corpulenta (Stout Floater)

Because the Stout Floater is normally found in backwaters, impoundments, bayous, large rivers with low gradients, and in mud and mud-gravel bottoms it was not expected in the Minnesota, except perhaps near the mouth.

Initially, the *Anodonta grandis* from the Minnesota River were identified in the field (based on shell characters) as the subspecies *grandis* . Later, however, when all the voucher specimens were reviewed together, it became apparent that some of them were shorter and appeared slightly more inflated than usual and might represent the subspecies *corpulenta*. Consequently, the 1989 Minnesota River material was restudied both qualitatively and quantitatively to determine if *corpulenta* is recognizable. All the shell characters that have been used by previous workers to separate the two subspecies were analyzed and the conclusion was reached that the two cannot be reliably distinguished. Moreover, some statistical data from the review strongly indicate that there is but one population of *A. grandis* in the Minnesota River. Thus, we are reporting all specimens from the Minnesota River as the subspecies *grandis* and question the validity of the records of Grant (1886) and Havlik (1977, 1989) .

If the glochidia of *A. g. grandis* and *A. g. corpulenta* are truly different, as summarized by Baker (1928) and Oesch (1984), then they must be studied to determine if *corpulenta* actually lives in the Minnesota River, as well as elsewhere in

Minnesota.

Anodonta imbecilis (Paper Floater)

Grant (1885) said that *A. imbecilis* was "very abundant in the Minnesota River at Fort Snelling." Dawley (1947) also recorded its presence in the river. No one else had found it until this study. At Site 50 (Pl. 6) one dead shell was found.

Both its fish hosts (Creek Chub and Pumkinseed) occur throughout the river.

Even though the Paper Floater is hermaphroditic it has not been successful, and probably was always rare. It most likely has been extirpated in the Minnesota River.

Anodontoides ferussaciana (Cylinder)

The Cylinder is primarily confined to small- and medium-sized streams in Minnesota (Dawley,1947; Bright *et. al.*, 1989: Bright *et. al.*, in preparation). Consequently, it is no surprise that it is scarce in the Minnesota River (Pl. 7).

At Site 7, where one live specimen was found there is no evidence for either reproduction or recruitment. Its occurrence below Ortonville is most likely accidental.

Arcidens confragosus (Rockshell)

Plate 8 shows that at some time in the recent past *A. confragosus* occurred from the mouth of the Minnesota River to just below Granite Falls. Grant (1886) noted that it lived in the river only at Fort Snelling and Dawley (1947) noted its presence in the river. Nachtrieb found it during his 1908 survey.

All five of its fish hosts are known in the Minnesota so that factor cannot account for its apparent extirpation. It probably was always uncommon.

Ellipsaria lineolata (Butterfly)

The Butterfly was first reported in the river by Grant (1886) at Fort Snelling, where it was "not common". It has been found several times since (Table 1a), but not during this study. Dawley (1944) stated that "It is widely distributed in the Mississippi R. below Minneapolis, but it is not abundant anywhere. It is also found in the Minnesota River." It is apparenly extirpated in the Minnesota now.

cf. *Elliptio crassidens* (Elephant Ear)

This study produced only one dead shell that is hesitantly referred to as *E. crassidens* (Pl. 9). Prior to now only Nachtrieb and Havlik (Table 1a) had found the species in the Minnesota River and only dead shells. It most likely only occurred in the lower stretch of the river and was always scarce.

Elephant Ear was once more common in the Mississippi River, although always rare (Dawley, 1947). It is rarely found in the Mississippi River today and is certainly extirpated in the Minnesota. In fact it is listed as "endangered" in both the state and federal registries. Its major problem has been the near elimination of its only known fish host (Skipjack Herring) from the Mississippi drainage above Keokuk dam in Iowa.

Elliptio dilatatus (Spike)

Grant (1886) reported the Spike from the Minnesota River at Fort Snelling and dead shells have been collected at various places since (Table 1a, Pl. 10). At some time in the past, it occurred as far upstream as Montevideo (Pl. 10).

It is apparently extirpated in the Minnesota in spite of ample habitat and the presence of all five of its fish hosts.

Fusconaia ebena (Ebony shell)

Prior to this study, the Ebony Shell had only been collected once in the Minnesota River. Havlik (1977) collected dead shells from a dredge pile at river-mile 14.7. This study produced dead shells at five sites downstream from LeSueur (Pl. 11). Havlik also found dead shells near highway I-35W in the fall of 1989 (Table 1a).

F. ebena was once common in the Mississippi River, but is now scarce most likely because of overharvesting by the pearl button industry and river pollution. Dawley (1947) noted that it occurred in the Mississippi River below St. Anthony Falls and that it "...has not been seen for some years and may be extinct in Minnesota". It is certainly extirpated in the Minnesota River, although most of its fish hosts still occur there.

Fusconaia flava (Pigtoe)

The Pigtoe was common in the Minnesota River at Fort Snelling in 1885 (Grant, 1886)), and it has been found elsewhere since that time (Table 1a). Dawley (1947) indicated that it occurred in the Red, St. Croix, Minnesota, and Mississippi systems in Minnesota. Plate 12 shows that *F. flava* was found live in 1989 only above New Ulm, where it can be a major proportion of the fauna (Figs. 3a and 3b). One recently dead specimen was discovered at site 57, indicating that it had been living there or had been washed downstream within the past year or so. It occurred in a wide range of substrates from silt to sandy granular pebbles (Fig. 5).

Three fish are hosts to *F. flava* glochidia — the Bluegill, the White Crappie, and the Black Crappie — and all three occur throughout the Minnesota river.

Density of the species was high enough only at Site 21 to construct a histogram of length-classes (Fig. 8) and it suggests that recruitment there is adequate. In the river as a whole, however, only five specimens three years or younger were found. The distribution data (Pl 12) suggest that the species is not doing well downstream from New Ulm.

Lampsilis higginsi (Higgins Eye)

The Higgins Eye mussel, a federally and state endangered species, has never been found live in the Minnesota River. Dawley (1947) claimed that it occurred in the

Minnesota, but that conclusion was based on a misidentified *Obovaria olivaria* (Bell MNH #2455). The only other records are of dead shells (Havlik, 1977 and 1989, vouchers not available in Minnesota). This study produced one dead shell just above Shakopee (Pl. 13, Bell MNH # 6396) that was considered a probable *L. higginsi.* Those three records indicate that it has lived in the lower Minnesota, but that it probably was rare (as elsewhere) and that it is most likely extirpated.

Both of its fish hosts (Sauger and Freshwater drum) occur in the Minnesota, the Sauger being known only below the dams at Granite Falls.

Lampsilis radiata luteola (Fat Mucket)

Dawley (1947) viewed the Fat Mucket widespread in all parts of Minnesota and not restricted to any stream type. Grant (1886) noted that it occurred in the Minnesota and that "This is our most common species and is usually found very abundantly... The heaviest and largest yet found are at Fort Snelling; some of these are 5 inches long." Nachtrieb (1908) also found it durng his survey. It was surprising, then, to find *L. r. luteola* live at only 7 of the 59 sites during this study of the Minnesota River, and to find them live only upstream from Lac Qui Parle River (Plate 14). In the upstream stretch it comprised a major proportion of the fauna at some sites (Figs. 3a and 3b) and in the river as a whole was about fifth in abundance (Fig. 2a). It occurred most commonly in silt, silty sand, and sand (Fig. 5).

Fuller (1978) listed 13 fish hosts for the Fat Mucket and all of them occur in the Minnesota River. Ten of them occur upstream from the dams at Granite Falls.

Recruitment appears unsatisfactory at Sites 7-9,as no specimens less than 65 mm (3 -5 years old) were found (Fig. 9). Only three percent of all the live specimens were judged to be two years old or less and only 11 percent were three years old or younger. Plate 14 shows that the Fat Mucket was once more widely distributed in the Minnesota River in the recent past. All evidence points to the conclusion that *L. r. luteola* is in trouble throughout most of the Minnesota River, as it may be in the Zumbro drainage (Bright *et. al*., 1989).

Lampsilis teres teres (Yellow Sandshell)

Grant (1886) reported the Yellow Sandshell to be "very abundant in the Minnesota River at Fort Snelling", but Nachtrieb reported none from the river in 1908. Havlik (1977, 1989) found only dead shells below Savage. This study found dead shells as far up the river as Granite Falls (Pl. 15), their being more common below about Belle Plaine.

Eight of its fish hosts live in the Minnesota River and five of them occur above the dams at Granite Falls.

L. t. teres is probably extirpated in the Minnesota River.

Lampsilis ventricosa (Pocket book)

The Pocketbook occurs in all parts of the state and is "... common in small, medium, and large rivers" (Dawley, 1947). Grant (1885) noted that "This is a very common species and widely distributed..." and occurs in the "... Minnesota River at Granite Falls and Fort Snelling". Nachtrieb (1908) declared it the third commonest of the commercial species in the Minnesota and that some mussel beds in the "upper course" (between New Ulm and Granite Falls) were largely *L. ventricosa*. Figure 16 shows that it is living thoroughout the river upstream from Shakopee, but that it is not known live downstream from there. It is most common in the stretch between about Granite Falls and Le Sueur (Figs. 3a and 3b) and is usually found in sand and silty sand (Fig 5).

All six of the Pocketbook's fish hosts occur in the Minnesota River, five of them below the dams at Granite Falls, and one (the Yellow Perch) known only above the dams.

Although the species now lives at many sites it is never abundant, and no sites were found where *L ventricosa* could be collected in sufficient quantities to construct length-frequency histograms. Considering the river as a whole, however, 22% of the live specimens were three years old or younger and 9 % were two years old or younger. A single gravid female was found at Site 25.

From the foregoing it is concluded that *L. ventricosa* has decreased considerably in abundance since the turn of the century, that reproduction is currently taking place, that recruitment is modest overall, and that it is perhaps safe between about Le Sueur and Redwood Falls. Downstream from a point a few miles below Le Sueur, however, the Pocketbook appears to be in trouble, as evidenced by its scarcity and lack of recruitment.

Lasmigona complanata (White Heel splitter)

The White Heelsplitter has been known to live in the Minnesota since Grant's report (1886) and has been recognized many times since (Table 1a). It is never abundant and occurs live at 10 sites and dead at 20 sites (Pl. 17). Silty sand and sand seem to be its favorite habitat (Fig. 5).

It has four fish hosts and all are known in the river both above and below the dam at Pete's Point below Granite Falls.

A length-frequency diagram for 27 specimens at Site 7 (Fig. 10) shows an absence of lengths less than 105 mm. This suggests that all the specimens are greater than about six years old and that recruitment is poor. Of all the specimens examined from the river about 12 % were two years old or younger, indicating that some reproduction and recruitment is taking place, but likely just enough to merely maintain some local populations. Its distribution in the Minnesota River appears diminished (Pl. 17), especially in the Granite Falls area.

In all likelihood this species is just hanging on in the Minnesota River as it is in the Zumbro River (Bright *et. al.*, 1989).

Lasmigona compressa (Creek Heelsplitter)

This study provides the first record of the Creek Heelsplitter in the Minnesota River - a dead shell from Site 17. Because it normally occurs in smaller creeks and streams throughout the state, this occurrence is considered accidental and it is unlikely that *L. compressa* was ever established in the Minnesota River.

Lasmigona costata (Fluted Shell)

The fluted shell was first recorded from the Minnesota River by Grant (1886) from Granite Falls and has been seen but three times since. Havlik found dead shells near Savage (1977) and Nachtrieb (1908) added a recently dead shell to the University of Minnesota collection (Bell MNH #3274) from his study between Fort Snelling and Minnesota Falls. Dead shells were found at 13 sites during this study (Pl. 19), primarily between Redwood Falls and the confluence with Lac Qui Parle River. Dead shells from so many sites coupled with Nachtrieb's record suggest that the species was once sparingly established in the Minnesota River, but that it is now most likely extirpated.

Leptodea fragilis (Fragile Papershell)

The Fragile Papershell is generally a large river species in Minnesota, known only from the Mississippi drainage. Its single fish host, the Freshwater Drum, lives both upstream and downstream from the dams at Granite Falls. Its proportion in the fauna increases markedly downstream (Figs 3a and 3b) and its favorite substrates are silt, sand, and granular sand (Fig. 5). Overall, it is one of the most ubiquitous species in the river (Pl. 20, Figs. 2a and 2b) but nowhere in high density. Grant (1886) noted that it was "abundant in the Minnesota River at Fort Snelling" and it has been noticed by many researchers since (Table 1a). The species is apparently tolerant "... of environmental alteration" (Fuller, 1985), is widespread in the upper Mississippi River, and appears to be exploiting impoundments there (Fuller;1978,1985).

L. fragilis is reproducing well in the Minnesota River below New Ulm as evidenced by gravid females and the fact that 29% of the 62 live specimens found were three years old or less (16% were 2 years old or less).

Plate 20 shows that it has been widely distributed throughout the Minnesota in the recent past. Live specimens were routinely found downstream from Site 32 (Pl 20, Figs. 3a and 3b), but were much less common above New Ulm. Apparently habitat conditions are more favorable for the species downstream, it has less competition for habitat, or perhaps its fish host is more common. Alternatively, its distribution and success below New Ulm may indicate that it is presently in a state of re-colonizing a formerly depleted range in an upstream direction.

Ligumia recta (Black Sandshell)

Dawley (1947) concluded that *L. recta* was "... in all drainages [in Minnesota], common in all but the smallest rivers." Grant (1885) noted that "this species is common [in Minnesota] and in some places abundant." He recorded it from the Minnesota River in general and at Granite Falls, and Nachtrieb found it during his 1908 survey.

Three of its five fish hosts in the river occur above the dams at Granite Falls.

It was formerly widespread in the Minnesota River as indicated by Plate 21, but probably never abundant. Only one live individual was found during the entire study (at Site 32), indicating the Black Sandshell is in risk of extirpation in the river.

Megalonaias gigantea (Washboard)

The first record of occurrence in the Minnesota River of Washboard was that of Nachtrieb (1908, Table 1a). It has been found only twice since and never alive. Dawley (1947) indicated that it occurred only "... in the lower Minnesota", and was otherwise restricted to the Mississippi and lower St. Croix.

Fuller (1978) listed 16 fish hosts for the Washboard and 15 of them occur in the Minnesota River.

Dead shells were found at two sites below Shakopee (Fig. 22). It was probably always rare in the river and is now most likely extirpated.

Obliquaria reflexa (Threehorn)

The Threehorn is confined to the Mississippi, Minnesota and lower St. Croix Rivers (Dawley, 1947). Grant (1886) found it in the Minnesota at Fort Snelling and it has been found several times since (Table 1a). This species is uncommon in the Mississippi River, probably always has been, and is considered "...as a persistent and stable, but not abundant member..." of the fauna" (Fuller, 1978).

There is no known fish host. In fact it might not need one because it might not have a parasitic stage (Fuller, 1978)

It was formerly widely distributed downstream from about Granite Falls (Pl 23) but probably was never abundant. Grant apparently did not find it at Granite Falls in 1885. Only five live specimens were found during this study (in silt and sandy silt,Fig. 5) and no evidence of reproduction was seen. This species is so rare in the Minnesota River that it might be in risk of extirpation in spite of the fact that it persists in low numbers in the Mississippi.

Obovaria olivaria (Hickorynut)

Dawley (1947) viewed *O. olivaria* as not common in the Mississippi, St. Croix and Minnesota Rivers. The only live record for the entire Minnesota is that of Olson from a site near New Ulm in 1934 (Table 1a). Thus, it has probably always been rare.

It formerly occurred as far up the river as about Montevideo (Pl. 24).

The dead shell at Site 17 is of interest because the Hickorynut's only fish host (the Shovelnose Sturgeon) is not known to occur above the dams at Granite Falls.

The species appears to be extirpated in the Minnesota River.

Plethobasus cyphyus (Bullhead)

The only record of the Bullhead from the Minnesota River is that of Dawley (1944). She noted that it had been found 16 miles above New Ulm, but no voucher can be found to verify her claim. It was not found during this study. If it did live in the river at one time, it is apparently extirpated now.

Pleurobema sintoxia (Ohio River Pigtoe)

The Ohio River Pigtoe is known only from the Minnesota, Mississippi and St. Croix Rivers in Minnesota (Bright *et. al*., in preparation), where it was formerly more abundant. Nachtrieb (1908), who listed it as *Quadrula coccinea* — the Niggerhead, indicated that one ton of a total 30 tons of shells harvested near Bristol's Ferry in the summer of 1908 were *P. sintoxia*. Thus, they were relatively common in at least that stretch of the Minnesota early in the century. Later, however, in a letter to the Bureau of Fisheries dated 18 Sep 1908, Nachtrieb said: "Niggerheads are everywhere scarce. In the upper portion we never got more than four in one dragging. Mr. Appel [the clammer at Bristol's Ferry] had only five or six gunny sacks full of niggerheads." Even that latter comment indicates a far greater abundance than now.

Its only fish host in Minnesota is the Bluegill, which occurs throughout the river.

The species was formerly distributed from near Montevideo to the mouth of the Minnesota (Pl. 25). The single recently dead specimen found at Site 32 suggests that it might still be living somewhere in the river, but, even if so, it is so rare that it is surely in danger of extirpation.

Potamilus alatus (Pink Heelsplitter)

The Pink Heelsplitter was formerly common throughout the Mississippi (below St. Anthony Falls) and Red River drainages in Minnesota (Bright et. al., in preparation). Grant (1885) noted that it was common in the Minnesota River at Fort Snelling and at Granite Falls. Its favorite substrates in the Minnesota River are sand, silty sand and granular sand (Fig. 5).

Its only fish host is the Freshwater Drum, which lives both upstream and downstream from the dams at Granite Falls.

Plate 26 shows that *P. alatus* was formerly widespread in the Minnesota River, but that it was found live at only nine sites during this study. It is a minor component of the overall fauna in the Minnesota (Figs. 2a and 2b), but is more significant in the upper reach and between Montevideo and Mankato (Figs. 3a and 3b). All but one of the specimens found were adults and no gravid females were found, suggesting poor reproduction and recruitment. Apparently the species is just hanging on in parts of the river, but it appears extirpated downstream from New Ulm.

Potamilus ohioensis (Pink Papershell)

The Pink Papershell was first recorded in the Minnesota River at Fort Snelling by Grant (1886), where he found it "common". Curiously, it has been rarely collected since. Dawley (1947) viewed it as "... a rare species limited to large rivers." Fuller (1978) found that it is prospering in the Mississippi River, but is a minor constituent (0.73%) of the fauna. It is also minor in the Minnesota River overall (Figs. 2a and 2b) but is proportionally important locally between about Granite Falls and Shakopee (Figs 3a and 3b).

Both its hosts (Freshwater Drum and White Crappie) occur throughout the

Minnesota River.

Although not abundant, *P. ohioensis*, occurs at many sites below Granite Falls (Pl. 27) and was more routinely encountered below new Ulm than above there. It is reproducing and recruiting very well in the river as evidenced by gravid females and the fact that about 67% of the specimens examined were three years old or less and 51 % were two years old or less (the highest of all species in the river).

Fuller explained its current success in the Mississippi River by its ability to live in "... soft and easily penetrable, but nonetheless stable substrates; typically, it lives deeply buried in mud or muddy sand... Its low density, great mobility, and lengthy pseudosiphons apparently allow the animal to survive in the upper layer of moving bedload - and, perhaps, even to exploit this habitat, which is ultimately lethal to other species." Figure 5 shows that it was found in silt, sandy silt, silty sand and sand in the Minnesota. In fact it was found in what was interpreted as "greasy black sludge" at two sites, one below New Ulm, and another at Le Sueur. Certainly the substrates described by Fuller (above) are abundant downstream from Mankato (the confluence of the Blue Earth River). Why it was so scarce below Shakopee is unknown. Alternative explanations for its success below New Ulm are the same as for *Leptodea fragilis*, it might be re-colonizing upstream.

Quadrula fragosa (Stranger)

The Stranger has rarely been collected in Minnesota (Bright *et. al*,. in preparation). In the Minnesota River a dead shell was found at Site 46 (Plate 28) and Havlik (1989) found another at Hwy I-35W. Fuller (1978) did not find it in his survey of the upper Mississippi River but Dave Heath (personal communication) has recently found it living there at several sites.

This is a difficult species to distinguish from *Q. quadrula*, and future work might prove it to be more common. On the face of this study, however, it appears to be extirpated in the Minnesota River.

Quadrula metanevra (Monkeyface)

The monkeyface was found in the Minnesota River in 1885 by Grant, by Nachtrieb in 1908, and has rarely been seen since (Table 1a). Dawley (1947) claimed that it lived only in the Mississippi River below St. Anthony Falls in Minnesota. Fuller (1978) considered that "... it is (or was) widely distributed in the larger streams of the Mississippi basin..." but one of the... less common mussels in most places where it occurs" and that it "... is highly characteristic of dense mussel populations on gravel bars or in stable mud areas."

Two of its fish hosts occur throughout the Minnesota River (Green Sunfish and Bluegill), but the third (Sauger) lives only below the dams at Granite Falls.

Only dead shells of *Q. metanevra* were found during this study (Pl. 29). At one time in the past it occurred as far upstream as Granite Falls. It is apparently extirpated in the Minesota River now.

Quadrula nodulata (Wartyback)

The Wartyback was first recorded in the Minnesota River by Havlik (1977), who found dead shells in a dredge pile near Savage (Table 1). It apparently has been scarce in the state wherever it occurred because Dawley (1947) did not even record its presence in Minnesota and it was an uncommon element of the Mississippi River fauna at the time of the Ellis survey (1931). Fuller (1978) indicated that it has recently increased in abundance (at least in proportion) in the Mississippi River because it "...tolerates broad habitat variety, including impoundment", and can tolerate rather fine sediment.

It currently lives in the Minnesota River at four sites above Mankato (Pl. 30), but only a total of seven individuals were found, including one two years old. At eight other sites only dead shells were found (Pl. 30). All but seven of the specimens were in a silt substrate (Fig. 5). It is certainly a minor element of the present fauna (Figs. 2a and 2b, Figs. 3a and 3b).

Five of its known fish hosts occur throughout the Minnesota River, and the sixth (Flathead Catfish) is known downstream from the dams at Granite Falls.

This species might be in serious trouble in the Minnesota River as suggested by scarcity of young, no gravid females, low numbers, and its restricted distribution (Pl. 30).

Quadrula pustulosa (Pimpleback)

The Pimpleback has been found in the Minnesota River by many researchers since the time of Grant's work (Table 1a). It is also known from the St. Croix and Mississippi Rivers (Dawley, 1947). Its proportion in the Mississippi fauna has risen from 4.98% to 8.86% between the early 1930's and 1977 according to Fuller (1978) because of its tolerance to substrates (sand, silt) "... that are unfavorable to most mussels", and commoness of its fish hosts.

All six of its fish hosts occur in the Minnesota River. Two of them (Black and Brown Bullheads) apparently live only above Granite Falls and two others (the Flathead Catfish and the Shovelnose Sturgeon) occur only below Granite Falls.

It comprises about 3% of the overall fauna of the Minnesota River (Figs. 2a and 2b) but is more important locally (Figs. 3a and 3b). It was found in a variety of substrates but was more common in sand (Fig. 5). In the past, *Q. pustulosa* has occurred widely in the Minnesota River as far upstream as Montevideo (Pl. 31). Although it was found at 24 sites during this study, it occurred live at only seven (all upsteam from New Ulm). Of the 35 individuals only one young was found, suggesting poor recruitment. Gravid females were rare.

The Pimpleback is obviously hanging on at some places above New Ulm, but appears to be in trouble below that point. Because of its wide substrate tolerance it is possible that chemical pollution may have the greatest affect on the distribution of this mussel species.

Quadrula quadrula (Mapleleaf)

The Mapleleaf was first recorded from the Minnesota River at Fort Snelling by

Grant in 1886 (Table 1a). It is also known from the Red, St. Croix and Mississippi Rivers (Dawley, 1947). Fuller (1978) noted that it is increasing as a proportion in the Mississippi River.

Both its fish hosts occur in the Minnesota, the Bluegill being everywhere, and the Flathead Catfish existing below the dams at Granite Falls.

This study found that the Mapleleaf constitutes a major proportion of the overall fauna, being about third in rank, (Figs. 2a and 2b) and that it can be extremely important locally (Figs. 3a and 3b). However, it was absent at many sites, even though it occurs as far upstream as the mouth of the Lac Qui Parle River (Pl. 32). Although 111 live specimens were found, only five of them were judged to be three years old or less based on annuli counts.

The Mapleleaf was sufficiently abundant at Sites 19 and 20 that length-frequency diagrams could be constructed (Fig. 11). That diagram shows good recruitment at Site 19 and acceptable (fair) recruitment at Site 20 (most of the young were found at these two sites). The species appears to be well established above New Ulm, but not everywhere. However, below New Ulm its range appears restricted (Pl. 32) and only 10 live specimens were found.

Simpsonaias ambigua (Salamander Mussel)

Only four dead specimens of the Salamander Mussel were found in the entire Minnesota River. These occurred near Granite Falls (Pl. 33) and represent the first records (Table 1a) in the entire drainage. Fuller observed that *S. ambigua* was once "...widely recorded in the Mississippi basin..." but now "... seems to be on the edge of extinction." The only live record of the species near Minnesota in many years is from the St. Croix River (Doolittle/Miller, personal communication). Its only known habitat is in interstices in rocky streambeds, which are uncommon in the Minnesota River.

Its only known host is the Mudpuppy (a salamander) that inhabits interstices in bouldery substrates and is itself reportedly in decline because of pollution and habitat destruction.

Although the Salamander Mussel's distribution (Pl. 33) suggests that it is most likely extirpated, there is a slight chance that it could turn up elsewhere if enough time were available for the meticulous search it takes to find the species. At best it is in serious trouble in the Minnesota River.

Strophitus undulatus (Strange Floater)

Strophitus undulatus was never known live in the Minnesota River until this study located one live individual at each of two sites (Pl. 34). In fact, few museum specimens exist to document its presence there (Table 1a). Dawley (1947) viewed it "... not common but found in both small and large rivers" in Minnesota. Fuller (1978) found that "...it has apparently never been common in the Upper Mississippi River; it is another characteristically small-stream animal." It has occurred more widely in the Minnesota in the past (Pl. 34), probably always in low numbers, and perhaps only became established now and then. In any case, it is so rare now that it might not survive because of the additional stress of pollution.

Three of its four fish hosts are known in the river, but it is reputed to have falcultative glochidial parasitism and therefore may not need to rely on fish for dispersal.

Both live specimens were found in sandy silt.

Toxolasma parvus (Lilliput)

Grant (1886) reported that "about a dozen specimens were found in the Minnesota River at Fort. Snelling.", but it has been found only dead since (Table 1a) until this study. It was previously known from southeastern Minnesota in the lower St. Croix, Mississippi, lower Minnesota, and Zumbro Rivers (Bright *et. al.*, in preparation). Fuller (1980) found it abundant in many pools in the Upper Mississippi River, but absent in the Twin Cities area.

Four of its five fish hosts occur throughout the Minnesota River. Its favorite substrate is "soft" silt or silty sand and that is where it was found in the upper Minnesota River (Fig. 5). Fuller (1978) noted it was most common in the Upper Mississippi River "on a substrate of muddy sand in shallow often slow-water areas close to shore.", which agrees with the findings of this study.

Plate 35 shows that *T. parvus* was previously more widespread in the river and that at present it lives only just below Ortonville in three places where 11 live specimens were found (no juveniles). It does not appear to be doing well in the Minnesota River at this time and might be in threat of extirpation — probably because suitable habitats are constantly being altered by siltation and spring floods and other less obvious factors (low DO's, chemical pollution, etc.).

Tritogonia verrucosa (Buckhorn, Pistolgrip)

Grant (1886) found Buckhorn to be uncommon at Granite Falls and at Fort. Snelling. Shells he collected that are at the Bell Museum are considered "recently dead", as are those collected by Nachtrieb (Tables 1a and 1b). Dawley (1947) listed it as occurring in the Mississippi, St. Croix, and Minnesota Rivers. Fuller (1978) viewed it as "formerly widespread and rather common in the Upper Mississippi basin..." and "... encountered alive only once during this survey" at Hudson on the St. Croix.

"It tolerates many types of streambed, though gravel is surely optimal" (Fuller, 1978). Gravel substrates are not so common in the Minnesota River.

It's fish hosts are unknown.

Tritogonia verrucosa once occurred in the Minnesota River as far upstream as Granite Falls (Pl. 36). Now, it is most likely extirpated.

Truncilla donaciformis (Fawnfoot)

Grant (1886) indicated that the Fawnfoot was "rather common in the Minnesota River at Ft. Snelling." Dawley (1947) listed it as occurring "in the Mississippi River at Red Wing and the Minnesota River at Fort Snelling, a rare species and limited to the largest rivers in the state." Fuller (1980) stated that it "is the most successful freshwater mussel in the modern impounded UMR" (Upper Mississippi River) and that it was the second most commonly encountered species in his (1978) study.

Both its hosts (Sauger and Freshwater Drum) are successful in the Minnesota River, although only the Drum occurs above the dams at Granite Falls.

The Fawnfoot was once a resident of the Minnesota River as far upstream as Montevideo (Pl. 37). Only three live specimens were found during this study, which suggests that — in contrast to the Mississippi River — it is in serious threat of extirpation in the Minnesota for some unknown reason.

Truncilla truncata (Deertoe)

Truncilla truncata was present in the Minnesota River in the late 1800's (Grant, 1886) and it has been found numerous times since (Table 1a).

Its fish hosts are the same as for *T. donaciformis*.

The Deertoe is certainly the most successful mussel species in the Minnesota River at this time. It is widespread (Pl. 38) and it often represents the highest proportion of the fauna at given sites (Pl. 3a and 3ab). It represents the highest proportion of the overall fauna (Pl. 2a and 2b). Recruitment is generally good where densities are high enough to observe same (Fig. 12). About 43% of the 257 live specimens were three years old or younger (indicating recruitment and reproduction). Gravid females were common. It is indeed a generalist as regards substrate preference (Fig. 5), which may partly account for its success. It must also be tolerant of chemical pollution and shifting substrates.

Introduced Species

The introduced and widespread Asiatic Clam (*Corbicula fluminea*) was first recognized in Minnesota by Cummings and Jones (1978). They collected dead shells and one live specimen from a small lake that receives the effluent of the Black Dog Power Plant in Burnsville. They also found dead shells in the Minnesota River just downstream from the outlet of the lake and its confluence with the river. No live specimens have been found in the Minnesota River since their study. Their collection is vouchered at the Bell Museum of Natural History , University of Minnesota. Subsequent to their discovery the species has been found living at several sites in the Mississippi and St. Croix Rivers (Bright, *et. al.*, in preparation).

General

Although there do not seem to be any clear-cut assemblages of mussels in the Minnesota River that can be related to distinct, systematic, natural habitat changes downstream, a few differences are apparent. *Truncilla truncata* is the most ubiquitous species (Figs. 3a and 3b) and occurs throughout the river below river-mile 305. *Toxolasma parvus* and *Lampsilis radiata luteola* exist only in the upper reaches of the river. Both are important proportionally at various sites (Figs. 3a and 3b), but neither are abundant. In the stretch between river-miles 290 and 70, there is a sort of "mid-stream" assemblage in which *Quadrula pustulosa, Lampsilis ventricosa*, and *Fusconaia flava* are most commonly encountered (Figs. 3a and 3b). Three other species, *Potamilus ohioensis, Leptodea fragilis*, and *Trunciilla donaciformis* are most abundant and highest proportionally in downstream sites (Figs. 3a and 3b). Downstream from Shakopee few species exist and abundance is low (Figs. 3a and 3b, Fig. 4). Suitable habitats occur for most species all along the river, so it is of interest whether or not the foregoing differences are natural or are partially and artifact of human-induced changes in the river since settlement.

Data from Featherstonhaugh (1835), Grant (1886) and Nachtrieb (1908a) fortunately lend some insight into historical changes in the Minnesot River's mussel fauna, even though Nachtriebs' study was biased toward commercial species.

Featherstonhaugh (1835), was impressed with the "great quantities" of shells on the beach of Big Stone Lake, as well as a "great profusion of *fasciatus* (presumably *Actinonaia ligamentina carinata*) at a site between the Blue Earth River and Swan Lakes. In neither of those areas did this study find mussels so abundant that they could be construed to fit his descriptions — now, at both places mussels are scarce.

The stretch of the Minnesota below Savage can conveniently be considered as a whole. Grant found 21 species live at Fort Snelling in 1885 (Grant, 1886) and, based on his descriptions, mussels were plentiful there then. Nachtrieb (1908a) reported that a clammer harvested 15 tons of live mussels at Savage in 1908. Fuller (1978) recorded no live mussels in the lower 15 miles of the river in 1977. However, he used a brail for sampling and might not have sampled all the best habitats (ie., just below the dredge shelf, next to the shoreline, especially in fallen trees, and in rocky places); moreover, the brail is notoriously inneficient in situations where mussel density is very low and distribution is patchy. Havlik (1977) reported 31 species represented by dead shells that she collected from dredge piles at Savage, some of which could have been buried in the stream bed for an extended period of time, and this study found 22 dead ones. Later (Havlik, 1989) found nine live ("alive" plus "fresh-dead") species near the I-35W bridge at Burnsville, including one she called *Anodonta grandis corpulenta*. This study found four additional live species, bringing the total live ones to 13 below Savage. Since Grant's time, then. the diversity of live species below Savage has dropped 38% and mussel abundance has decreased. Because the vast majority of the live specimens found in 1989 (Havlik, 1989; this study) were younger than 11 to 12 years old, it is obvious that the stretch below Savage has experienced recent colonization.

Grant (1886) found nine species live at Granite Falls and this study found seven, as well as four others dead (Site 19, Memorial Park), which represents a 22% decrease in the diversity of live species in the past hundred years. Moreover, from his descriptions, the abundance has decreased considerably.

Nachtrieb (1908a and b) found the abundance of the four most important commercial species as listed below:

RIVER OVERALL (mouth to Minnesota Falls)

Species	Relative Abundance
Mucket	4
Threeridge	2
Pocketbook	1

UPPER PORTION (New Ulm to Minnesota Falls
Species
Threeridge — most abundant
Mucket and Pocketbook — second in abundance, about equal
Niggerhead (Ohio River Pigtoe, but including a few *Obovaria*) —
"scarce", "no more than four per dragging"

MIDDLE PORTION (New Ulm to Bristol's Ferry)
"Relatively without beds of commercial value"

LOWER PORTION (Bristol's Ferry to mouth)
One-half mile stretch below Bristol's Ferry
30 Tons shells total harvest
12 Tons Mucket
8 Tons Threeridge
1 Ton "Niggerhead" (Ohio River Pigtoe)
9 Tons other species

Savage
15 Tons shells total harvest.

Compared to 1908, Threeridge (*Amblema plicata*) still constitutes a major proportion of the mussel fauna of the river as a whole (Figs. 2a and 2b), but may be less abundant and widespread in the stretch between New Ulm and Minnesota Falls (Nachtriebs "upper portion"). Unfortunately, Nachtrieb's study was unknown until long after the field season for this study, so the beds he mentiond just below Bristol's Ferry (about river-mile 47) were not examined. So all that can be said about his "lower portion" (indeed, all the way below New Ulm) as regards Threeridge is that it is now extremely scarce (Figs 3a and 3b, Pl. 4) and most likely less abundant than in 1908.

According to Nachtrieb's evidence (above) the Mucket (*Actinonaias ligamentina carinata*) was abundant and widespread in 1908. This study found no live specimens in the river, so it it is clear that the species was apparently extirpated after then.

The Pocketbook (*Lampsilis ventricosa*) is still important in the Minnesota River overall, but is by no means in contention for third place in abundance (Figs. 2a and 2b). Moreover, it is proportionally less important in the stretch between New Ulm and Minnesota Falls now than it was in 1908, and it is missing below river-mile 85 in contrast to 1908.

Pleurobema sintoxia (Ohio River Pigtoe; most of Nachtrieb's "Niggerhead") was far more abundant between Bristol's Ferry and Minnesota Falls and at Savage in 1908 than they are now — this study found but one "recently dead" specimen in the entire river.

Nachtrieb (1908a) listed the Deertoe (*Truncilla truncata)* as present in the river during his study. If his sampling method is assumed to be representative, it is probable that the Deertoe was uncommon then. Now, in marked contrast, it is the most widespread (Figs. 3a and 3b) and one of the proportionally important species in the stretch below Minnesota Falls. This change could have resulted from either a decrease in abundance of one or more of the other species or an actual increase in the abundance of Deertoe — it is impossible to determine which alternative is correct..

The stretch of the Minnesota River below Shakopee is now essentially devoid of mussels (Fig. 1). Based on the 15-ton harvest at Savage alone in 1908, one is drawn to the conclusion that mussel density is far less in that stretch than now.

Nachtrieb (1908a and b) generally characterized the mussels of the river in four ways, which can be compared with the results of this study.

(1) He noted (1908a) that beds were in close succession for a number of miles below Minnesota Falls, but that "...they are not always densely populated...". Data from this study certainly agrees with his observation.

(2) He found (1908a) that mussels were abundant in the upper one-fourth of the course (Minnesota Falls to about Franklin). That is certainly not the case today as densities are generally lower there than in the stretch just below (Fig. 4).

(3) He said (1908a) that the beds were most insecure (ie., subject to being washed away or buried) in the middle two-fourths of the river (about Franklin to about Belle Plaine). Although general observations in 1989 would agree that shifting substrate caused by excessive flooding are indeed a problem for most species, no one stretch below Granite Falls appeared much more threatened than another. However, the problem may be worse below the confluence with the Blue Earth River at Mankato.

(4) He observed (1908b) that the middle one-third of the stretch he studied was without beds of commercial value (about 10 miles above New Ulm to about Le Sueur). It is unclear if he meant that the mussels were of poor quality or were scarce, so it is difficult to compare results here with his. Suffice it to say that this study found found no beds containing commercial species that were either of the quantity or quality worthy of exploitation.

Apparently the commercial clammer's view of mussel abundance and quality in the river were a bit more optimistic than Nachtrieb's, as in 1917 they removed 2054 tons of mussels from the Minnesota (Delestry, 1918). Unless mussel abundance had increased since 1908, that harvest must have constituted a major set-back to the fauna, especially as regards overall production of glochidia and recruitment.

Based on studies of the Cannon (Davis, 1988), Zumbro (Bright *et. al.*, 1989), and Minnesota (this study) Rivers ;it is obvious that most dams are advantageous to the mussel fauna. The highest densities recorded on the Minnesota were just below dams (Fig. 4). Apparently congregating fish and a more or less staable habitat are conducive to locally enhanced mussel reproduction and recruitment, especially in streams where mussel density is low.

As best as can be determined from his list of mussels collected, Nachtrieb (1908a) found a total of 25 live species below Granite Falls (Table 1a). This study found but 20 live species in the entire river and dead shells of 17 others (Table 1a). Most of the species found in this study that were not found by Nachtrieb (Table 1a) were small or rare ones that are not readily caught by the crowfoot. All vagaries considered, it appears that live diversity (as number of species) of the river is now considerably lower than in 1908. A comparsison of previous studies (Table 1a) shows that at some time in the recent past there were 19 more live species in the Minnesota River than now, including two extralimital ones.

If the number of live species plus dead ones (all methods in Fig. 1) is taken as an indication of the river's diversity some time between 1908 and 1989, then two points of interest emerge. First, diversity was lowest above about mile 290 (Lac Qui Parle: also see Figs. 2a and 2b). Such is not surprising as that stretch of the river is mostly ponded (Pl. 1), and where free flowing it is small and shallow. Second, the diversity below Lac Qui Parle was generally high to New Ulm, decreased markedly to Mankato, and then increased downstream to the mouth. That trend below Lac Quie Parle is even now approximated by the diversity of live species (Fig. 1). Note also that mussel density drops at Mankato (Fig. 4). The question, then, is what factor(s) change between New Ulm and Mankato that affect the abundance and diversity of mussels and when did they change? Neither question can be resolved here, but the answers might be found in one or all of the following possible factors that can deleteriously affect mussels:

(1) Both New Ulm and Mankato have historically contributed the major inflow of sewage effluent and urban runoff, with their attendant pollutants, to the Minnesota River upstream from the Twin Cities.

(2) The Blue Earth River, the major tributary, delivers large quantities of silt and a varietry of chemical pollutants annually to the Minnesota at Mankato, and the Cottonwood does likewise at New Ulm. The Blue Earth has always contributed large quantities of silt according to Featherstonhaugh (1835) but it has only contributed a high unnatural chemical load since the advent of artificial fertilizers, herbicides, and pesticides.

(3) Groundwater that is polluted with agricultural fertilizers, herbicides, and pesticides might contribute extra contaminants to the river downstream from New Ulm and Mankato because it is east of that stretch where Cambrian and Ordovician sediments provide important aquifers that in places drain into the Minnesota River.

One point of interest is that the mussel beds at the majority of sites in 1989 were composed of individuals that were less than 10 to 12 years old (eg. Site 20, Appendix 1). Such an age configuration shows that many sites were populated 10 to 12 years ago and later. The summer of 1976 was one of severe drought. During that year J. C. Underhill (University of Minnesota) was surveying the fish in the river, most of which were concentrated in small pools. He recalls (personal communication) that many stretches of the river between pools was but a "trickle" as compared to normal, and that many of the small and shallow pools were dry. The following low water-flow records for 1976 (Water Resource Data for Minnesota, 1976) indicate more precisely the severity of that drought:

Lac Qui Parle — 6.5 cfs, 30 August
Redwood Falls — 0.06 cfs, 29 August
New Ulm — 29 cfs, 12 September
Mankato — 58 cfs, 12 September
Jordon — 195 cfs, 30 August.

Water temperatures late that summer and early fall were commonly in the 25 to 30 C°

range. The above mentioned age structure is probably related to the drought, the implication being that it caused increased mussel mortality along the river in 1976.

In contrast, at Site 29 (Appendix 1), for example, the *Amblema plicata* ranged from 14 to 18 years old, which indicates that they colonized the site before the drought of 1976 and were able to survive its effects.

Dead shells were found everywhere in the river and outnumbered live mussels at most sites. For the entire survey (both methods), 6475 dead shells were examined compared to only 1268 live mussels, and the largest proportion of the dead ones were *Actinonaias ligamentina carinata* (25%). So many dead shells (in a variety of stages of deterioration) indicate a lot of mussel mortality in the recent past. It is suspected that the life of a shell in the Minnesota River might be as high as 30 to 40 years unless it is quickly and permanently buried, but no evidence is available to confirm such a suspicion.

There was an uneven distribution of live mussels and dead shells between the timed-search and quadrat sampling methods. Most of the live mussels were found during the timed-search (965 out of 1068), whereas most of the dead shells were found in the quadrat studies. This came as a surprise as data were initially analyzed, but there are good reasons for the differences. The timed-search is a stratified sampling method in which a person purposely seeks the best live mussel habitats and samples the productive ones thoroughly for both live and dead specimens. Thus, that method is biased toward habitats with living mussels. The sites for the quadrats, on the other hand, are established to reflect the density and distribution of both live and dead mussels in a more random way. The fact that more dead shells were found using that method reflects their abundance in and on the stream bed as well as the very patchy and clumped nature of the living mussels.

The Minnesota River is the major instate tributary of the Upper Mississippi River and the mussel faunas of the two streams are quite similar in compostion. It is of interest, therefore, to compare the status of the species common to both. Fuller (1978, 1980, 1985) developed a set of terms to describe the Upper Mississippi fauna and they are used here with minor modification.

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 Upper Mississippi or Minnesota 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.

Extralimital: Species that normally inhabit smaller tributary streams, but that can occassionaly colonize larger ones.

The following list compares the status of of the species in the two streams:

SPECIES	UPPER MISSISSIPPI RIVER	MINNESOTA RIVER
Actinonaias ligamentina carinata	Jeopardized	Apparently extirpated

Alasmidonta marginata	Extralimital	Jeopardized
Amblema plicata	Healthy	In trouble below New Ulm
Anodonta grandis grandis	Healthy	Healthy
Anodonta imbecilis	Healthy	Apparently extirpated
Anodontoides ferussacianus	Extralimital	Extralimital
Arcidens confragosus	Troubled	Apparently extirpated
Ellipsaria lineolata	Troubled	Apparently extirpated
cf. *Elliptio crassidens*	Jeopardized	Apparently extirpated
Elliptio dilatatus	Troubled	Apparently extirpated
Fusconaia ebena	Jeopardized	Apparently extirpated
Fusconaia flava	Healthy	In trouble below New Ulm
Lampsilis higginsi	Endangered	Apparently extirpated
Lampsilis radiata luteola	Troubled	Jeopardized below Lac Qui Parle River
Lampsilis teres teres	Troubled	Apparently extirpated
Lampsilis ventricosa	Healthy	Troubled
Lasmigona complanata	Troubled	Troubled
Lasmigona compressa	Extralimital	Extralimital
Lasmigona costata	Extralimital	Extralimital or apparently extirpated
Leptodea fragilis	Healthy	Healthy below New Ulm, troubled above?
Ligumia recta	Troubled	Jeopardized
Megalonaias gigantea	Troubled	Apparently extirpated

Obliquaria reflexa	Healthy	Troubled - jeopardized
Obovaria olivaria	Healthy	Apparently extirpated
Plethobasus cyphyus	Jeopardized	Apparently extirpated
Pleurobema sintoxia	Jeopardized	Jeopardized at best
Potamilus alatus	Troubled	Troubled at best
Potamilus ohioensis	Healthy	Healthy below New Ulm
? *Quadrula fragosa*		Apparently extirpated
Quadrula metanevra	Troubled	Apparently extirpated
Quadrula nodulata	Healthy	Troubled ?
Quadrula pustulosa	Healthy	Troubled below New Ulm
Quadrula quadrula	Healthy	Troubled below New Ulm
Simpsonaias ambigua	Jeopardized or apparently extirpated	Apparently extirpated?
Strophitus undulatus	Troubled	Jeopardized or extralimital
Toxolasma parvus	Jeopardized	Jeopardized ?
Tritogonia verrucosa	Jeopardized	Apparently extirpated
Truncilla donaciformis	Healthy	Jeopardized
Truncilla truncata	Healthy	Healthy

The above comparison shows that the mussel fauna of the Minnesota River is in far worse condition than that of the Mississippi. Seventeen of the 37 species known to have occurred in the Minnesota River, excluding extralimital ones, are apparently extirpated (with the qualification that absence is difficult to prove), whereas Fuller (1985) lists only one for the Mississippi. Only two of the Minnesota River mussels are viewed as healthy everywhere in the river, and five more appear healthy in part of their range.

CONCLUSIONS

A quadrat method for assessing mussel density was assessed during this survery. It proved effective in determining the abundance of both live and dead mussels, but proved less effective in determining diversity at most sites than a timed search. The timed search has the advantage of being a stratified technique that leads to the discovery of live mussels with a very patchy distribution. Both methods should be used together in future studies.

Some previous studies were available for comparison with the present one and they allowed some conclusions to be drawn about past and present distributions and changes in the abundance of mussels in the Minnesota River. Those comparisons, limited as they are, point out the importance of having base data for assessing the current status of organisms and their habitat. Based on those comparisons, it was possible to demonstrate that 46% of the species of mussels in the Minnesota River (excluding the two extralimital ones) have been extirpated some time since 1908, that many others appear to be in various degrees of trouble, that overall mussel abundance has decreased since the turn of the century, and that the composition of local communities has changed.

The foregoing discussions suggest a scenario that reasonably explains the current distribution and abundance of mussels in the Minnesota River. Extreme natural events have always caused periodically high mussel mortality, but the fauna has recovered. These include such phenomena as periodic droughts that restrict or eliminate habitat and permit abnormally high water temperature, periodic low DO's induced by algal blooms, and cyclic spring floods that create high turbidity. Human alteration of the river from various chemical additives, increased runoff and siltation caused by the spread of agriculture in the basin, and commercial clamming have all contributed additional stress to the system in historical times. This combination of natural and human effects has suppressed the abundance of mussels in the Minnesota River and therefore has increased their chance of extirpation to the point that many local communities are continually prohibited from complete recovery. The Minnesota River fauna is in even worse condition than that of the Mississippi. However, two species that are apparently able to tolerate environmental alteration (*Leptodea fragilis* and *Potamilus ohioensis*) appear to be successful (re-colonizing?) in the lower part of the Minnesota River. Based on this study, it is impossible to separate all the effects of natural and unnatural factors that stress the mussels in the Minnesota, but the suspicion is growing that periodic droughts are far more significant to mortality than was previously expected.

It is the opinion here, that the mussel fauna of the Minnesota River cannot withstand commercial harvesting without further adverse impact.

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EXPLANATION OF TABLE 1a
Historical Record of Mussels in the Minnesota River

This table presents a summary of all the available records of species that have been found in the Minnesota River as well as a record of voucher specimens housed at the Bell Museum of Natural History, University of Minnesota. Voucher specimens at the Museum were re-examined to determine their status at the time of collection. Based on criteria presented in the materials and methods section, each specimen was categorized as follows:

L = found live
RD = found recently dead
D = found dead

Species not represented by specimens in the Bell Museum's collection are designated by an **"X"**. They may be either literature citations or represented by collections housed elsewhere.

I The first record found is a drawing in the "Narrative of the Long Expedition" by William Keating. The drawing was based on a specimen collected by Thomas Say in 1823 and is labeled *Anodonta gibbosus*. It appears to be a specimen of what we might now call *Anodonta grandis grandis*. Say no doubt collected more material on the Minnesota but it was impossible to check for this report as his writings are missing from the university library. Moreover, his Minnesota River collections were not found.

II In 1835, George W. Featherstonhaugh led an expedition known as "A canoe voyage up the Minnay Sotor". In the written account of the voyage, Featherstonhaugh first notes mussels in the Minnesota River between the Blue Earth River and Swan Lakes. He said, "A great profusion of unios were lying in the sandy bottom, buried to their umbones; the species called *fasciatus*" (presumably *Actinonaias ligamentina carinata*). Later in the journey, after departure from Lac Qui Parle, he discusses a five hour march to a stream called *Wahboptah* ". . .which may be translated *Ground Nut River* after the species *Psoralea esculenta*, a bulbous root which grows here" (he was referring to the Pomme de Terre River). He ". . .strolled up the stream and collected some very fine unios. . .". Featherstonhaugh's final reference to collecting mussels is upon reaching Big Stone Lake. "Here on the beach, I found great quantities of unios and anadontas [most likely *grandis grandis*]; and whilst I was engaged in opening some of them, a beautiful large black marten came towards me, but ran off as soon as I stirred". The disposition of his specimens is as yet unknown.

III Uly S. Grant was a geologist with the Minnesota Geological and Natural History Survey and, among his other duties, was in charge of collecting and curating mollusks. His report of 1886 not only lists mussels in the old Natural

History Survey collection, but also mentions abundance. Most of his specimens are in the collection of the Bell Museum of Natural History.

IV According to an old, inactive Bell Museum catalog, C. W. Hall collected several species in the late 1800's at Granite Falls. These specimens were lost sometime between 1900 and 1933 as their records were not transferred to the catalog begun in 1933.

V Collector unknown. 1900. The Bell Museum has one specimen of *L. fragilis* collected from the mouth of the Chippewa River

VI Henry Nachtrieb, former head of the Department of Zoology, University of Minnesota, was hired to survey the mussels of the Minnesota River. A recently discovered unpublished report by Nachtrieb indicates that he collected during the summer of 1908. The Bell Musum has many specimens collected from the Minnesota River during that time for which the collector is not listed, and it is most likely that they were collected by him. Because he collected with a crowfoot and boiled the specimens he sent to the Bureau of Fisheries, it is concluded that the mussels listed in his report represent live ones.

VII Collector unknown. 1930. A single specimen of *A. grandis grandis*. Location given only as "Minnesota River".

VIII Theodore A. Olson, formerly professor in the School of Public Health, University of Minnesota. He collected many specimens in the mid 1930's.

1-- A live specimen (Bell MNH XXXX) collected near New Ulm in 1934, but no collector is recorded in Bell Museum records. C. Dawley (1944) recorded a specimen collected near New Ulm in 1934 by T. A. Olson. They are probably the same.

2-- C. Dawley (1944) recorded that P. cyphyus was collected in 1934 16 miles above New Ulm, but she did not indicate the collector. It is likely that her record is one of Olson's.

3-- C. Dawley (1944) recorded that T. truncata was collected in 1934 16 miles above New Ulm, but she did not indicate the collector. It is likely that her record is one of Olson's.

IX Charlotte Dawley's works (1944, 1947) contain records of mussels known from the Minnesota River prior to 1944. She based her distribution records on the literature and specimens that are now at the Bell Museum. There is no record to show that she ever collected the Minnesota River.

X Collector unknown. 1963.

XI Marion E. Havlik. 1977. All specimens were collected dead in dredge spoil at the head of the 9-foot channel at river-mile 14.7 near Savage.

XII Bob Belligh. 1985.

XIII Wallmow and McCormack. 1985.

XIV John Schladweiler. 1985.
XVI John Moriarity. 1988.

XVII John Enblom. 1988.

XVIII Gerda Nordquist. 1988.

XIX Marion E. Havlik. 1989

XX This study.

	Species	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
1	A. lig. carinata		XL	XL	X		RD		D	X		XD				D			D		D	D
2	Al. marginata			X	X		L			X				D					D			L
3	Am. plicata			L	X		X		D	X		XD		D		D		D			D	L
4	An. corpulenta			L								XD									L	
5	An. grandis	X	XL				RD	D	D	X					L			RD				L
6	An. imbecilus			L						X												D
7	An. ferussaciana								D	X												L
8	Ar. confragosus			L			D			X		XD									D	D
9	E. crassidens						D			X		XD									XD	D
10	E. dilatatus			L			RD		D	X		XD						D			D	D
11	E. lineolata			D			D			X		XD									D	
12	F. ebena											XD									D	D
13	F. flava			L			X		L1	X		XD		D		D		D			L	L
14	L. higginsi									X		XD									XD	D
15	L. r. luteola			L			D		D	X		XD								L	D	L
16	L. teres teres			L						X		XD									D	D
17	L. ventricosa			L	X		L		L	X		XD		D		D	L	D			L	L
18	Las. complanata			L			RD		L	X		XD		RD		D	D	D			L	L
19	Las. compressa																					D
20	Las. costata			X	X		RD			X		XD										D
21	Le. fragilis			L		RD	RD		L	X		XD		RD		D	D	RD	D	D	L	L
22	Li. recta			X	X		D			X		XD				D		D				L

Table 1a

	Species	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
23	M. gigantea						X		D	X												D
24	O. reflexa			L			X		RD	X		XD					D	D			D	L
25	Ob. olivaria						X		L	X		XD									D	D
26	P. sintoxia						X			X		XD				D		D	D		XD	D
27	P. cyphyus								X2	X												
28	Po. alatus			L	X		RD		D	X		XD				D		RD		D	L	L
29	Po. ohioensis			L						X									D		L	L
30	Q. fragosa																				D	D
31	Q. metanevra			L			X			X												D
32	Q. nodulata											XD				D		D			D	L
33	Q. pustulosa			L			L		L	X		XD		D		D		D			D	L
34	Q. quadrula			L			X			X		XD					D	RD			L	L
35	Sim. ambigua																					D
36	Str. undulatus			X	X							XD									XL	L
37	T. parvus			L						X	D	XD			RD						XD	L
38	Tri. verrucosa			RD	X		RD			X		XD				D					D	D
39	Tru. donaciformis			L						X		XD		D				D			XD	L
40	Tru. truncata			RD			RD		X3	X		XD		RD			RD	RD	D		D	L
41	Cor. fluminea												XD									

TABLE 1b

Minnesota River vouchers at the Bell Museum of Natural History, University of Minnesota

	Species	Date	Collector	Location
1	A. lig. carinata	1835	G. W. Featherstonhaugh	upstream Blue Earth River and downstream Swan Lakes
2	A. lig. carinata	1835	G. W. Featherstonhaugh	near Patterson Rapids
3	A. lig. carinata	1885	C. W. Hall (or Grant)	Granite Falls
4	A. lig. carinata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
5	A. lig. carinata	1934	T. A. Olson	16 milles above New Ulm
6	A. lig. carinata	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
7	A. lig. carinata	1985	J. Schladweiler	near Judson
8	A. lig. carinata	1988	J. Enblom	near Patterson Rapids
9	Al. marginata	1885	C. W. Hall(or Grant)	Granite Falls
10	Al. marginata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
11	Al. marginata	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
12	Al. marginata	1988	J. Enblom	near Patterson Rapids
13	Al. marginata	1988	J. Enblom	near Shakopee
14	Am. plicata	1885	C. W. Hall (or Grant)	Granite Falls
15	Am. plicata	1885	U. S. Grant	Fort Snelling
16	Am. plicata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
17	Am. plicata	1934	T. A. Olson	16 miles above New Ulm
18	Am. plicata	1977	M. E. Havlik	head of the 9 mile navigation channel, Savage, MN
19	Am. plicata	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
20	Am. plicata	1985	J. Schladweiler	near Judson
21	Am. plicata	1988	J. Moriarity	near Upper Sioux State Park
22	Am. plicata	1988	J.Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
23	Am. plicata	1989	M. E. Havlik	I-35W bridge
24	An. corpulenta	1822	T. Say	Unknown
25	An. corpulenta	1885	U. S. Grant	Fort Snelling
26	An. corpulenta	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
27	An. corpulenta	1989	M. E. Havlik	I-35W bridge
28	An. grandis	1835	G. W. Featherstonhaugh	"on the beach...great quantities" Big Stone Lake

Table 1b

	Species	Date	Collector	Location
29	An. grandis	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
30	An. grandis	1930		MN River- exact location in unknown
31	An. grandis	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
32	An. grandis	1985	Wallmow & McCormack	confluence of Pomme de Terre River with Marsh Lake
33	An. grandis	1985	Wallmow & McCormack	mouth of Lac Qui Parle River, T115N,R44W,Sec 10
34	An. grandis	1988	J. Moriarity	between Odessa & Ortonville, T121N, R46W, Sec 26
35	An. grandis	1988	J. Moriarity	below Lac Qui Parle Dam, T118N, R42W, Sec 24
36	An. grandis	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
37	An. imbecillus	1885	U. S. Grant	Fort Snelling
38	An. ferussaciana	1934	T. A. Olson	16 miles above New Ulm
39	Ar. confragosus	1885	U. S. Grant	Fort Snelling
40	Ar. confragosus	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
41	Ar. confragosus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
42	Ar. confragosus	1989	M. E. Havlik	I-35W bridge
43	Cor. manilensis	1978	Cummings & Jones	near Blackdog electric generating plant,Burnsville,MN
44	E. crassidens	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
45	E. crassidens	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
46	E. crassidens	1989	M. E. Havlik	I-35W bridge
47	E. dilatatus	1885	U. S. Grant	Fort Snelling
48	E. dilatatus	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
49	E. dilatatus	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
50	E. dilatatus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
51	E. dilatatus	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
52	E. dilatatus	1989	M. E. Havlik	I-35W bridge
53	E. lineolata	1885	U. S. Grant	Fort Snelling
54	E. lineolata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
55	E. lineolata	1989	M. E. Havlik	I-35W bridge
56	E. lineolatus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN

	Species	Date	Collector	Location
57	F. ebena	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
58	F. ebena	1989	M. E. Havlik	I-35W bridge
59	F. flava	1885	U. S. Grant	Fort Snelling
60	F. flava	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
61	F. flava	1934	T. A. Olson	16 miles above New Ulm
62	F. flava	1934	T. A. Olson per Dawley	3.5 miles below New Ulm
63	F. flava	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
64	F. flava	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
65	F. flava	1985	J. Schladweiler	near Judson
66	F. flava	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
67	F. flava	1988	J. Moriarity	mouth of the Yellow River, T115n, R38W, Sec 28
68	F. flava	1989	M. E. Havlik	I-35W bridge
69	Lam. higginsi	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
70	Lam. higginsi	1989	M. E. Havlik	I-35W bridge
71	Lam. r. luteola			Fort Snelling
72	Lam. r. luteola	1885	U. S. Grant	Fort Snelling
73	Lam. r. luteola	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
74	Lam. r. luteola	1934	T. A. Olson	near New Ulm
75	Lam. r. luteola	1977	M. E. Havlik	9-foot navigation channel
76	Lam. r. luteola	1988	G. Nordquist	Big Stone Lake, T122N, R47W, NE1/4,NW1/4.Sec 14
77	Lam. r. luteola	1989	M. E. Havlik	I-35W bridge
78	Lam. t. teres	1885	U. S. Grant	Fort Snelling
79	Lam. t. teres	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
80	Lam. t. teres	1989	M. E. Havlik	I-35W bridge
81	Lam. ventricosa	1885	C. W. Hall (or Grant)	Granite Falls
82	Lam. ventricosa	1885	U. S. Grant	Fort Snelling
83	Lam. ventricosa	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
84	Lam. ventricosa	1934	T. A. Olson	16 miles above New Ulm

85	Lam. ventricosa	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
86	Lam. ventricosa	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
87	Lam. ventricosa	1985	J. Schladweiler	near Judson
88	Lam. ventricosa	1988	J. Moriarity	mouth of the yellow River, T115N, R38W, Sec 28
89	Lam. ventricosa	1988	J. Schladweiler	at Pete's Point
90	Lam. ventricosa	1989	M. E. Havlik	I-35W bridge
91	Las. complanata	1885	U. S. Grant	Fort Snelling
92	Las. complanata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
93	Las. complanata	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
94	Las. complanata	1934	T. A. Olson	16 miles above New Ulm
95	Las. complanata	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
96	Las. complanata	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
97	Las. complanata	1985	J. Schladweiler	near Judson
98	Las. complanata	1988	J. Moriarity	mouth of the Yellow river, T115N, R38w, Sec 28
99	Las. complanata	1988	J. Schladweiler	Pete's Point
100	Las. complanata	1989	M. E. Havlik	I-35W bridge
101	Las. compressa	1989	Gatenby,Olson,Plummer	See this report
102	Las. costata	1885	C. W. Hall (or Grant)	Granite Falls
103	Las. costata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
104	Las. costata	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
105	Le. fragilis	1885	U. S. Grant	Fort Snelling
106	Le. fragilis	1900		mouth of the Chippewa River,MN
107	Le. fragilis	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
108	Le. fragilis	1934	T. A. Olson	below St. Peter
109	Le. fragilis	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
110	Le. fragilis	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
111	Le. fragilis	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
112	Le. fragilis	1985	J. Schladweiler	near Judson

	Species	Date	Collector	Location
113	Le. fragilis	1988	G. Nordquist	Big Stone Lake,T122N, R47W, NE1/4,NW1/4, Sec 14
114	Le. fragilis	1988	J. Enblom	near Patterson Rapids
115	Le. fragilis	1988	J. Moriarity	below Lac Qui Parle Dam, T118N, R42W, Sec 24
116	Le. fragilis	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
117	Le. fragilis	1988	J. Schladweiler	Pete's Point
118	Le. fragilis	1989	M. E. Havlik	I-35W bridge
119	Li. recta	1885	C. W. Hall (or Grant)	Granite Falls
120	Li. recta	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
121	Li. recta	1934	T. A. Olson	16 miles above New Ulm
122	Li. recta	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
123	Li. recta	1985	J. Schladweiler	near Judson
124	Li. recta	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
125	M. gigantea	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
126	M. gigantea	1932	T. A. Olson	Cedar Avenue in clammers waste of 1932
127	O. reflexa	1885	U. S. Grant	Fort Snelling
128	O. reflexa	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
129	O. reflexa	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
130	O. reflexa	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
131	O. reflexa	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
132	O. reflexa	1988	J. Schladweiler	Pete's Point
133	O. reflexa	1989	M. E. Havlik	I-35W bridge
134	Ob. olivaria	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
135	Ob. olivaria	1932	T. A. Olson	Cedar Avenue in clammers waste of 1932
136	Ob. olivaria	1934	T. A. Olson	New Ulm
137	Ob. olivaria	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
138	Ob. olivaria	1989	M. E. Havlik	I-35W bridge
139	P. cyphus	1934	T. A. Olson per Dawley	16 miles above New Ulm
140	P. sintoxia	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling

141	P. sintoxia	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
142	P. sintoxia	1985	J. Schladweiler	near Judson
143	P. sintoxia	1988	J. Enblom	near Patterson Rapids
144	P. sintoxia	1988	J. Moriarity	mouth of the Yellow River, T115n, R38W, Sec 28
145	P. sintoxia	1989	M. E. Havlik	I-35W bridge
146	Po. alatus	1885	C. W. Hall (or Grant)	Granite Falls
147	Po. alatus	1885	U. S. Grant	Fort Snelling
148	Po. alatus	1885	U. S. Grant	Fort Snelling
149	Po. alatus	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
150	Po. alatus	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
151	Po. alatus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
152	Po. alatus	1985	J. Schladweiler	near Judson
153	Po. alatus	1988	G. Nordquist	Big Stone Lake, T122N, R47W, NE1/4,NW1/4,Sec14
154	Po. alatus	1988	J. Moriarity	below Lac Qui Parle Dam,T118N, R42W, Sec24
155	Po. alatus	1989	M. E. Havlik	I-35W bridge
156	Po. ohioensis	1885	U. S. Grant	Fort Snelling
157	Po. ohioensis	1988	J. Enblom	near Patterson Rapids.
158	Po. ohioensis	1989	M. E. Havlik	I-35 W bridge
159	Q. fragosa	1989	M. E. Havlik	I-35W bridge
160	Q. metanevra	1885	U. S. Grant	confluence of the MN and MI Rivers,Fort Snelling
161	Q. metanevra	1908	Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
162	Q. nodulata	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
163	Q. nodulata	1985	J. Schladweiler	nearJudson
164	Q. nodulata	1988	J. Moriarity	mouth of the Yellow River, T115n, R38W, Sec 28
165	Q. nodulata	1989	M. E. Havlik	I-35W bridge
166	Q. pustulosa	1885	U. S. Grant	Fort Snelling
167	Q. pustulosa	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
168	Q. pustulosa	1934	T. A. Olson	16 miles above New Ulm

			Collector	Location
169	Q. pustulosa	1934	T. A. Olson	Cedar Avenue in clammers waste of 1932
170	Q. pustulosa	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
171	Q. pustulosa	1985	B. Belligh	near Franklin, Renville county, T122, R34W
172	Q. pustulosa	1985	J. Schladweiler	near Judson
173	Q. pustulosa	1988	J. Moriarity	mouth of the Yellow River, T115N, R38 W, Sec 28
174	Q. pustulosa	1989	M. E. Havlik	I-35W bridge
175	Q. quadrula	1885	U. S. Grant	FortSnelling
176	Q. quadrula	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
177	Q. quadrula	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
178	Q. quadrula	1988	J. Moriarity	mouth of the Yellow River, T115N, R38W, Sec 28
179	Q. quadrula	1988	J. Schladweiler	Pete's Point
180	Q. quadrula	1989	M. E. Havlik	I-35W bridge
181	S. ambigua	1989	Gatenby,Olson,Plummer	see this report
182	S. undulatus	1885	C. W. Hall (or Grant)	Granite Falls
183	S. undulatus	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
184	S. undulatus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
185	S. undulatus	1989	M. E. Havlik	I-35W bridge
186	To. parvus	1885	U. S. Grant	Fort Snelling
187	To. parvus	1963		Big Stone Lake - 8 miles above outlet
188	To. parvus	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
189	To. parvus	1985	Wallmow & McCormack	confluence of Pomme de Terre River with Marsh Lake
190	To. parvus	1989	M. E. Havlik	I-35W bridge
191	Tri. verrucosa	1885	C. W. Hall (or Grant)	Granite Falls
192	Tri. verrucosa	1885	C. W. Hall (or Grant)	Granite Falls
193	Tri. verrucosa	1885	U. S. Grant	Fort Snelling
194	Tri. verrucosa	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
195	Tri. verrucosa	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
196	Tri. verrucosa	1985	J. Schladweiler	near Judson

	Species	Date	Collector	Location
197	Tri. verrucosa	1989	M. E. Havlik	I-35W bridge
198	Tru. donaciformis	1885	U. S. Grant	Fort Snelling
199	Tru. donaciformis	1977	M. E. Havlik	head of the 9-foot navigation channel, Savage, MN
200	Tru. donaciformis	1985	B. Belligh	near Franklin, Renville County, T112N, R34W
201	Tru. donaciformis	1988	J. Moriarity	mouth of the Yellow river, T115N, R38W, Sec 28
202	Tru. donaciformis	1989	M. E. Havlik	I-35W bridge
203	Tru. truncata	1885	U. S. Grant	Fort Snelling
204	Tru. truncata	1908	H. Nachtrieb	MN River- between Minnesota Falls and Fort Snelling
205	Tru. truncata	1934	T. A. Olson per Dawley	16 miles above New Ulm
206	Tru. truncata	1977	M. E. Havlik	head of 9-foot navigation channel, Savage,MN
207	Tru. truncata	1985	B. Belligh	near Franklin,Renville County T112N, R34W
208	Tru. truncata	1988	J. Enblom	near Patterson Rapids
209	Tru. truncata	1988	J. Moriarity	below Lac Qui Parle Dam, T118N, R42W, Sec 24
210	Tru. truncata	1988	J. Moriarity	mouth of the yellow river, T115N, R38W, Sec 28
211	Tru. truncata	1988	J. Schladweiler	Pete's Point
212	Tru. truncata	1989	M. E. Havlik	I-35W bridge

Species Diversity, Minnesota River, 1989

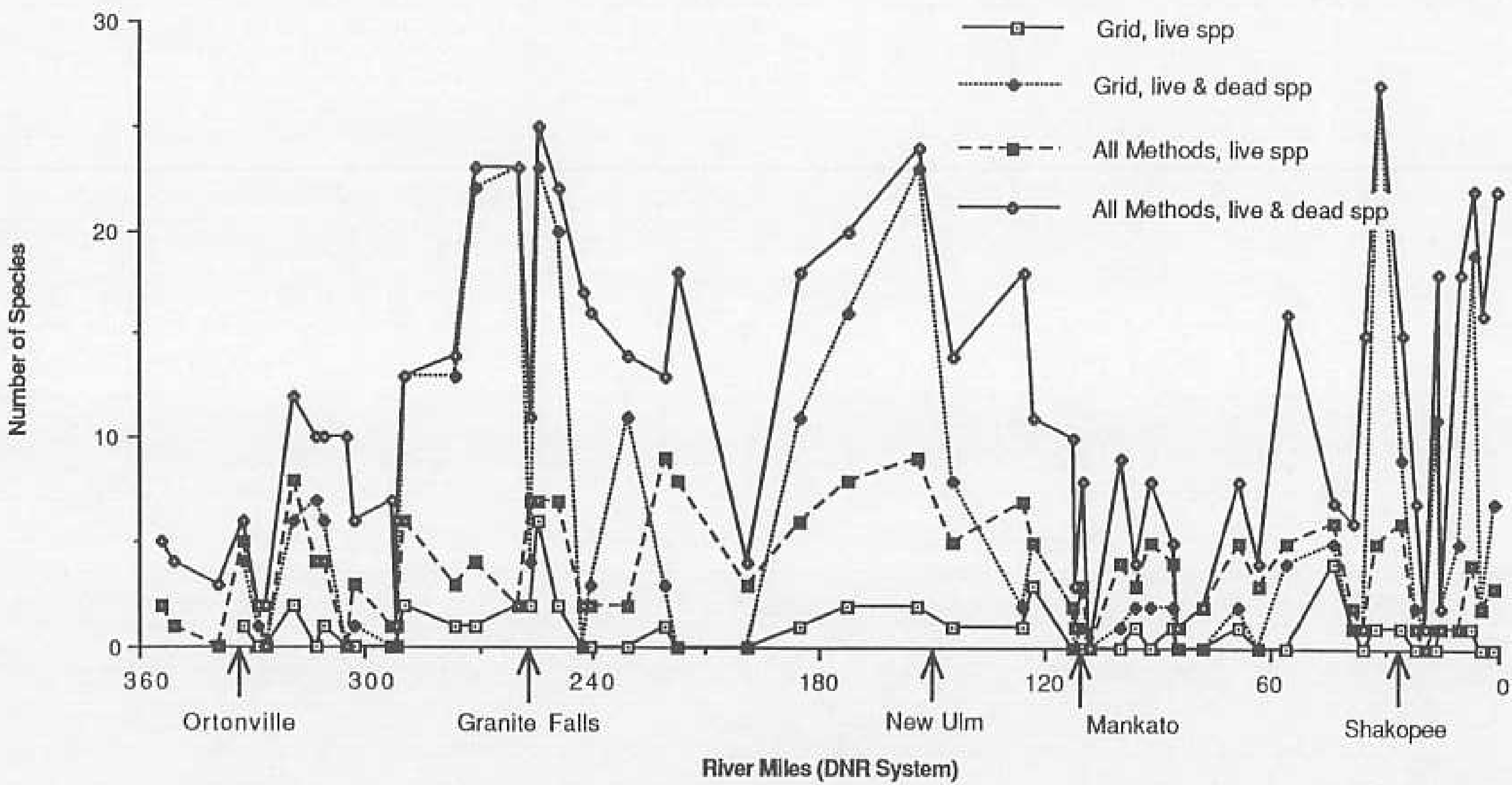


Figure 1

Proportions of Live Mussels Found.
Minnesota River, 1989

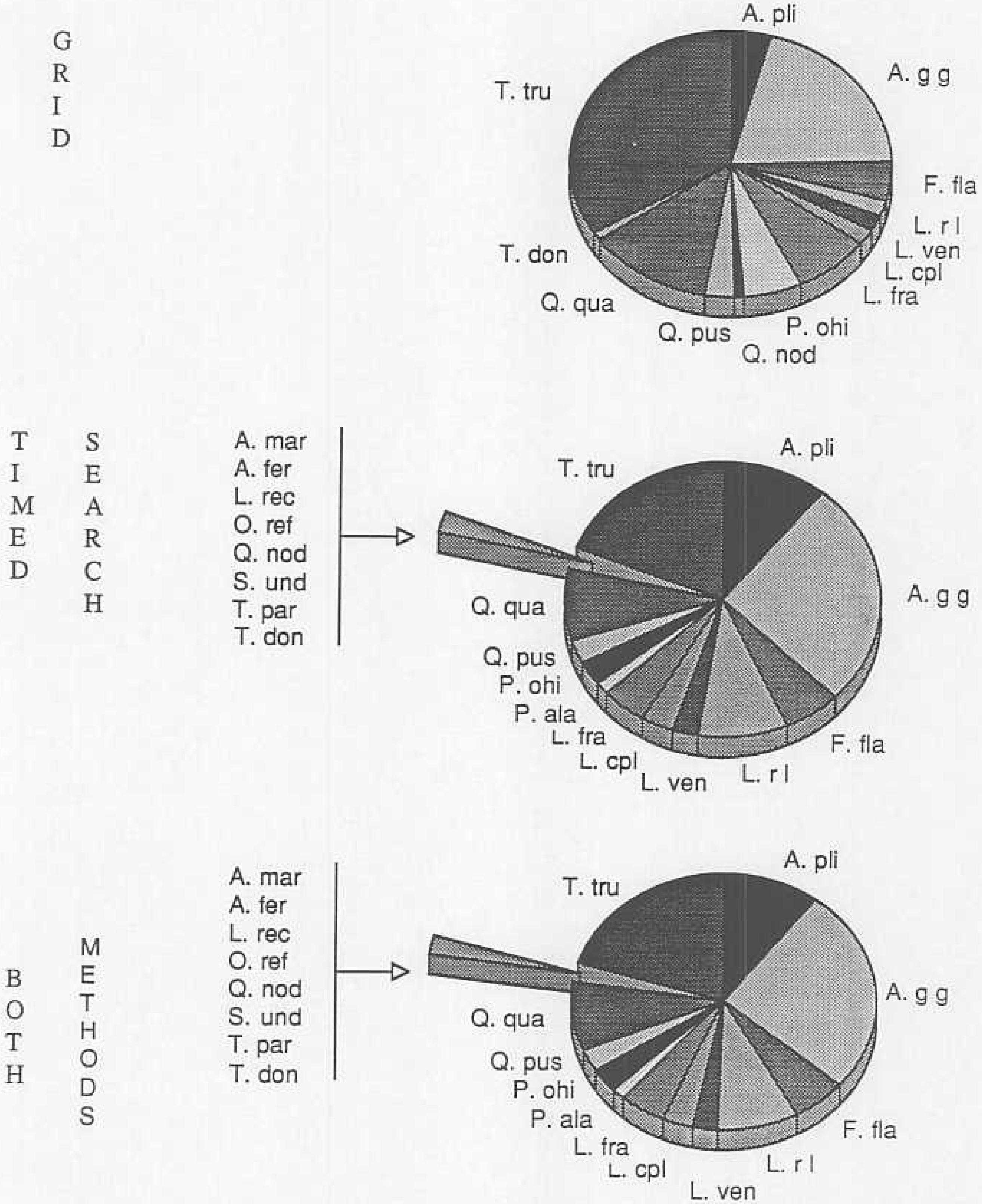
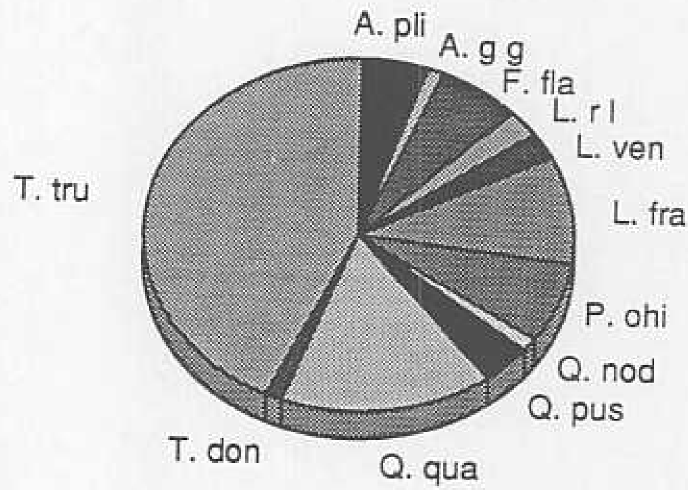


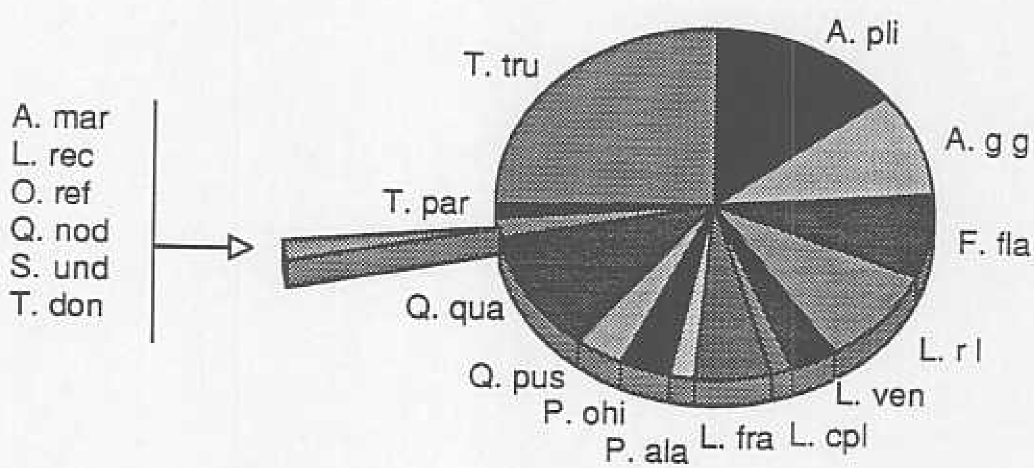
Figure 2a

Proportions of Live Mussels Found Omitting Site 7. Minnesota river, 1989

GRID



TIMED SEARCH



BOTH METHODS

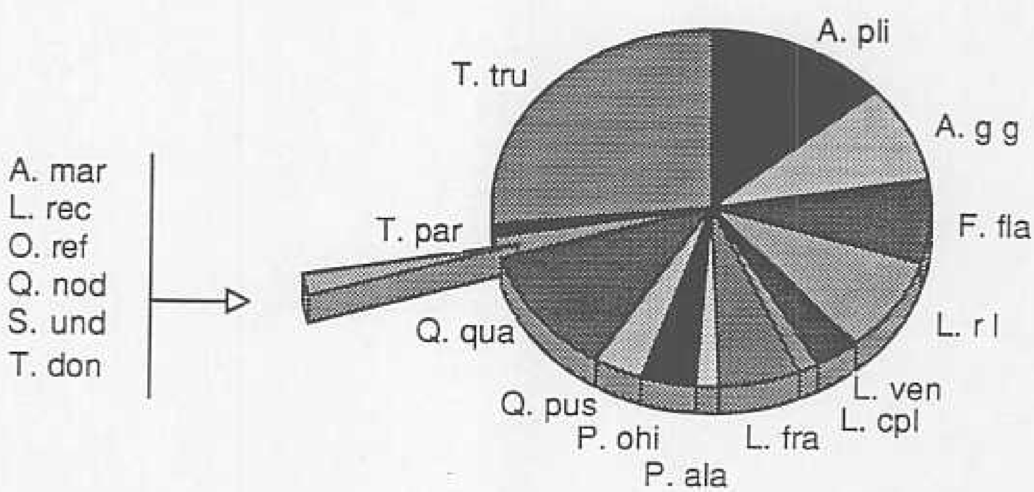


Figure 2b

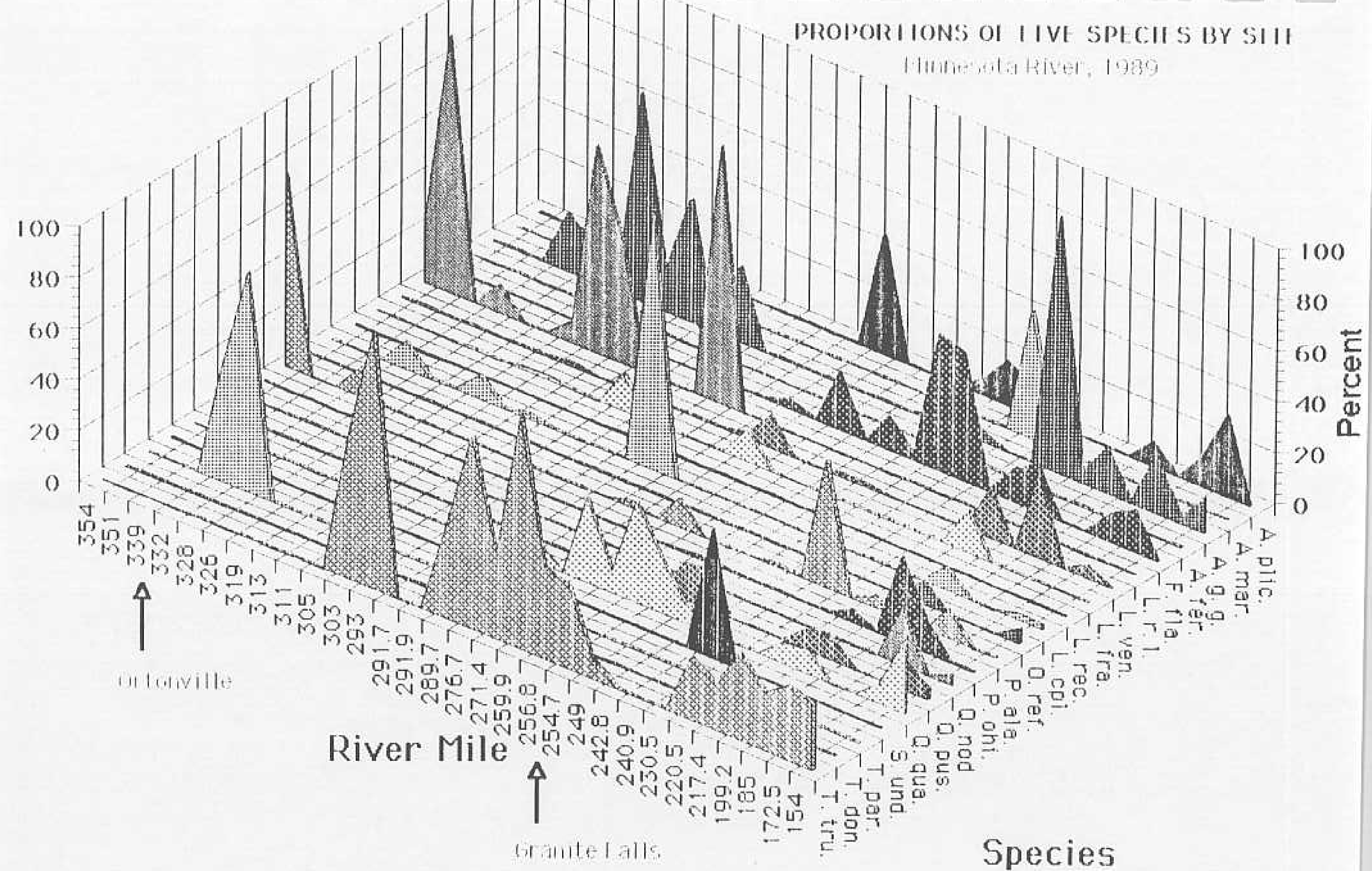
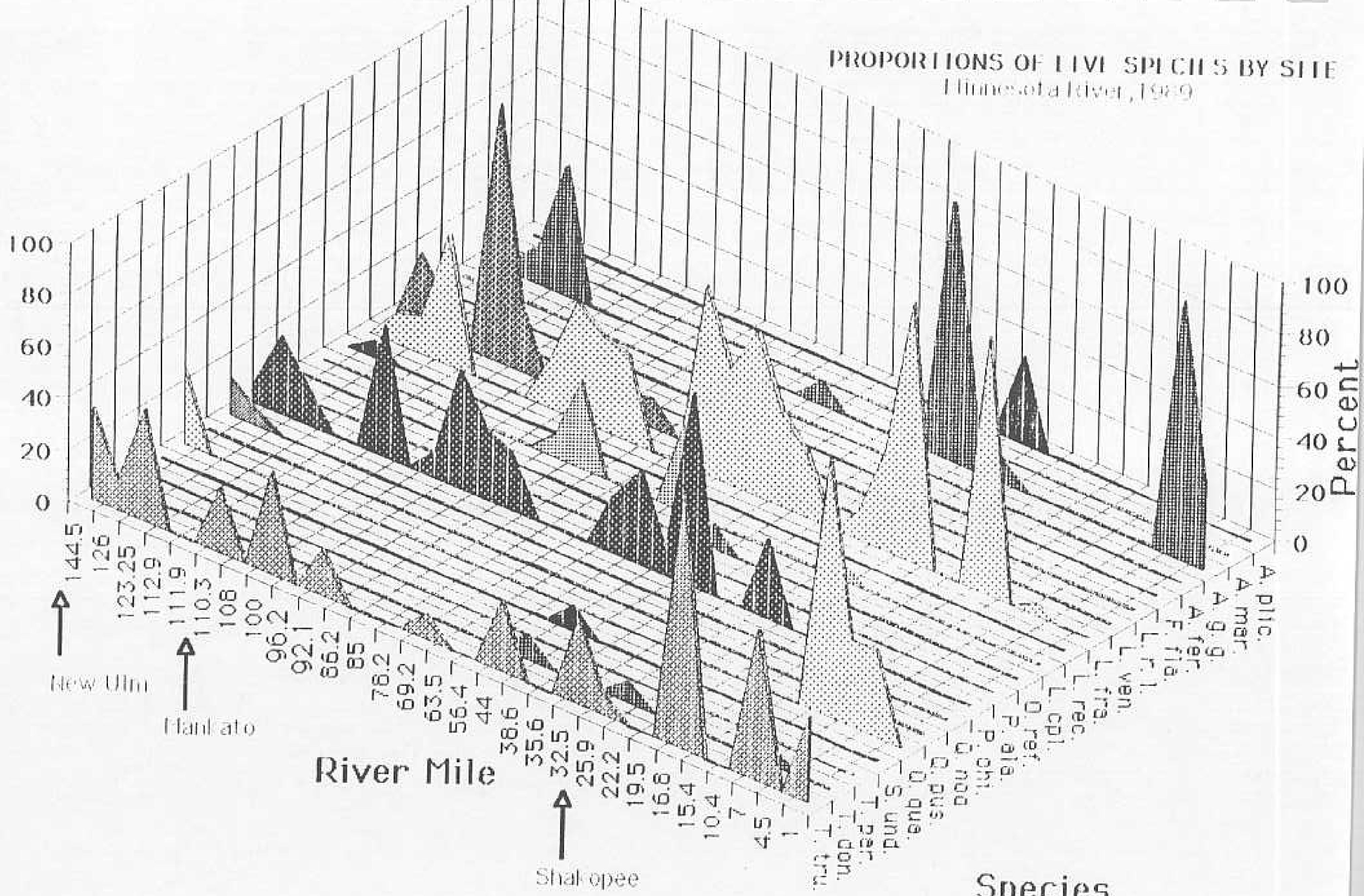

PROPORTIONS OF LIVE SPECIES BY SITE
Minnesota River, 1989
Percent
100
80
60
40
20
0
River Mile
354
351
339
332
328
326
319
313
311
305
303
293
291.7
291.9
289.7
276.7
271.4
259.9
256.8
254.7
249
242.8
240.9
230.5
220.5
217.4
199.2
185
172.5
154
Ortonville
Granite Falls
Species
A. plic.
A. mar.
A. g. g.
A. fer.
F. fla.
L. r. l.
L. ven.
L. fra.
L. rec.
L. cpi.
O. ref.
P. ala.
P. ohi.
Q. nod
Q. pus.
Q. qua.
S. und.
T. par.
T. don.
T. tru.

Figure 3a



PROPORTIONS OF LIVE SPECIES BY SITE
Percent
100
80
60
40
20
0
144.5
126
123.25
112.9
111.9
110.3
108
100
96.2
92.1
86.2
85
78.2
69.2
63.5
56.4
44
38.6
35.6
32.5
25.9
22.2
19.5
16.8
15.4
10.4
7
4.5
1
New Ulm
Mankato
Shakopee
River Mile
A. plic.
A. mar.
A. g. g.
A. fer.
F. fla.
L. r. l.
L. ven.
L. fra.
L. rec.
L. cpl.
O. ref.
P. ala.
P. ohi.
Q. nod
Q. pus.
Q. qua.
S. und.
T. per.
T. don.
T. tru.
Species

Figure 3b

Live Mussel Density, Minnesota River, 1989

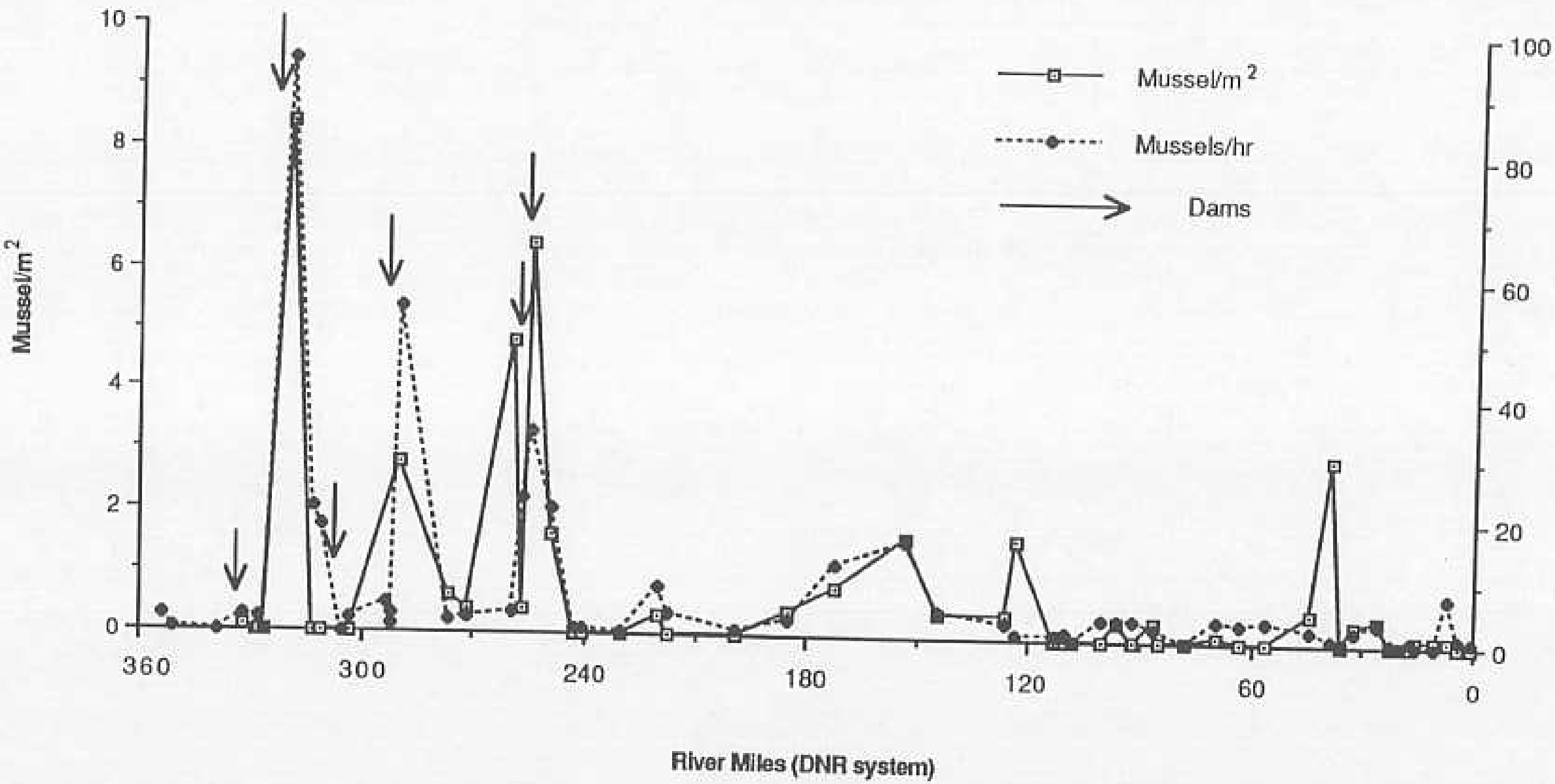


Figure 4

Explanation of Figure 5

MINNESOTA RIVER 1989 SUBSTRATE
listed in ascending order - fine material to coarse material

SILT
SANDY SILT=SaS
GRANULAR SILT = GS
SILTY BOULDERS = SBo
SILTY SAND = SSa
SAND
GRANULAR SAND = GSa
PEBBLY, SILTY SAND = PSSa
PEBBLY, GRANULAR SAND = PGSa
GRANULAR, PEBBLY SAND = GPSa
PEBBLY SAND = PSa
COBBLY, PEBBLY SAND = CPSa
PEBBLY, COBBLY SAND = PCSa
COBBLY SAND = CSa
SANDY, ORGANIC DETRITUS = SaODetr
SANDY BOULDERS = SaBo
PEBBLY, SANDY BOULDERS = PSaBo
SILTY, SANDY GRANULES = SSaG
SANDY GRANULES = SaG
GRANULES
PEBBLY, SANDY GRANULES = PSaG
PEBBLY GRANULES = PG
SILTY, SANDY PEBBLES = SSaP
GRANULAR, SANDY PEBBLES = GSaP
SANDY, GRANULAR PEBBLES = SaGP
SANDY PEBBLES = SaP
COBBLY, SANDY PEBBLES = CSaP
PEBBLES
COBBLY PEBBLES = CP
SANDY COBBLES = SaC
COBBLES

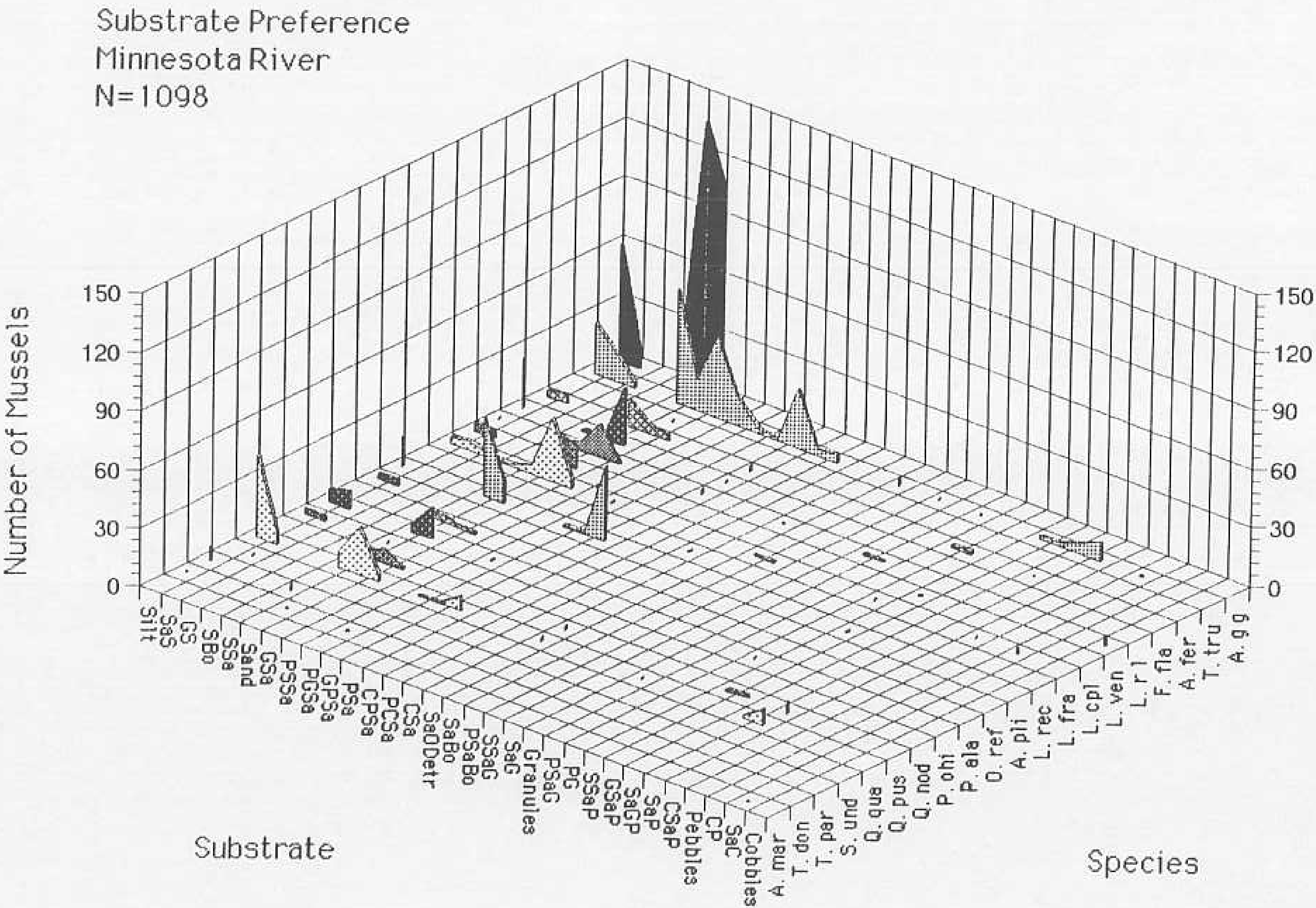
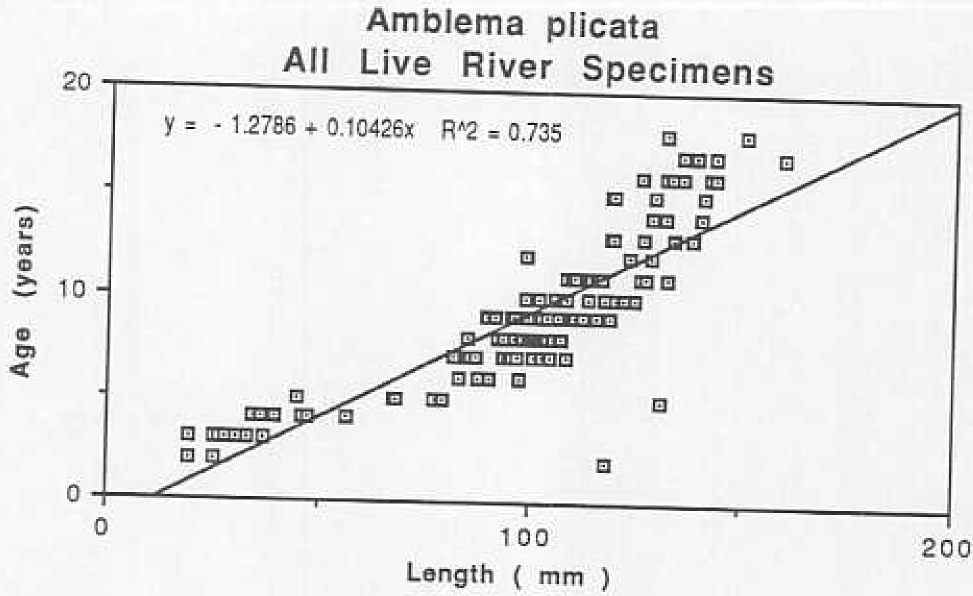
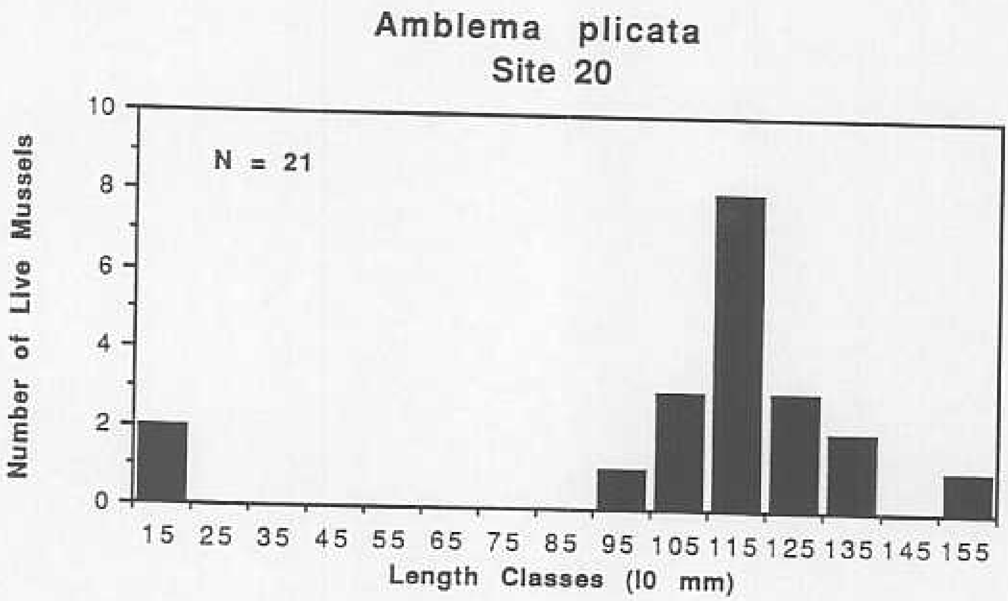

Substrate Preference
Minnesota River
N=1098
Number of Mussels
150
120
90
60
30
0
Silt
SaS
GS
SBo
SSa
Sand
GSa
PSSa
PGSa
GPSa
PSa
CPSa
PCSa
CSa
SaODetr
SaBo
PSaBo
SSaG
SaG
Granules
PSaG
PG
SSaP
GSaP
SaGP
SaP
CSaP
Pebbles
CP
SaC
Cobbles
A. mar
T. don
T. par
S. und
Q. qua
Q. pus
Q. nod
P. ohi
P. ala
O. ref
A. pli
L. rec
L. fra
L. cpl
L. ven
L. r l
F. fla
A. fer
T. tru
A. g g
Substrate
Species

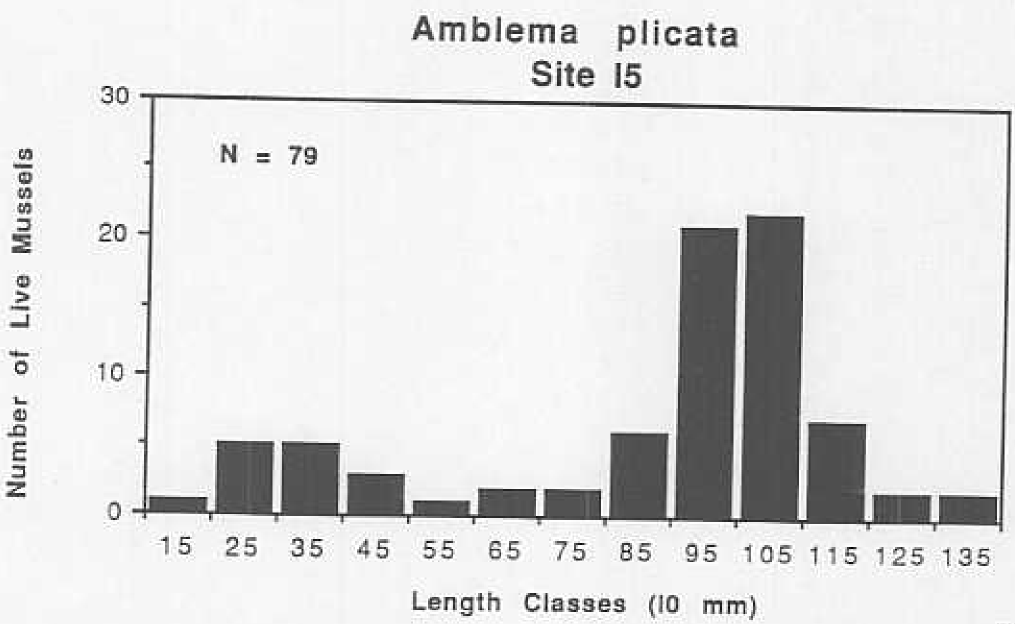
Figure 5



Amblema plicata
All Live River Specimens
y = - 1.2786 + 0.10426x R^2 = 0.735
Age (years)
Length (mm)
0
10
20
0
100
200



Amblema plicata
Site 20
N = 21
Number of Live Mussels
Length Classes (l0 mm)
0
2
4
6
8
10
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155



Amblema plicata
Site l5
N = 79
Number of Live Mussels
Length Classes (l0 mm)
0
10
20
30
15 25 35 45 55 65 75 85 95 105 115 125 135

Figure 6

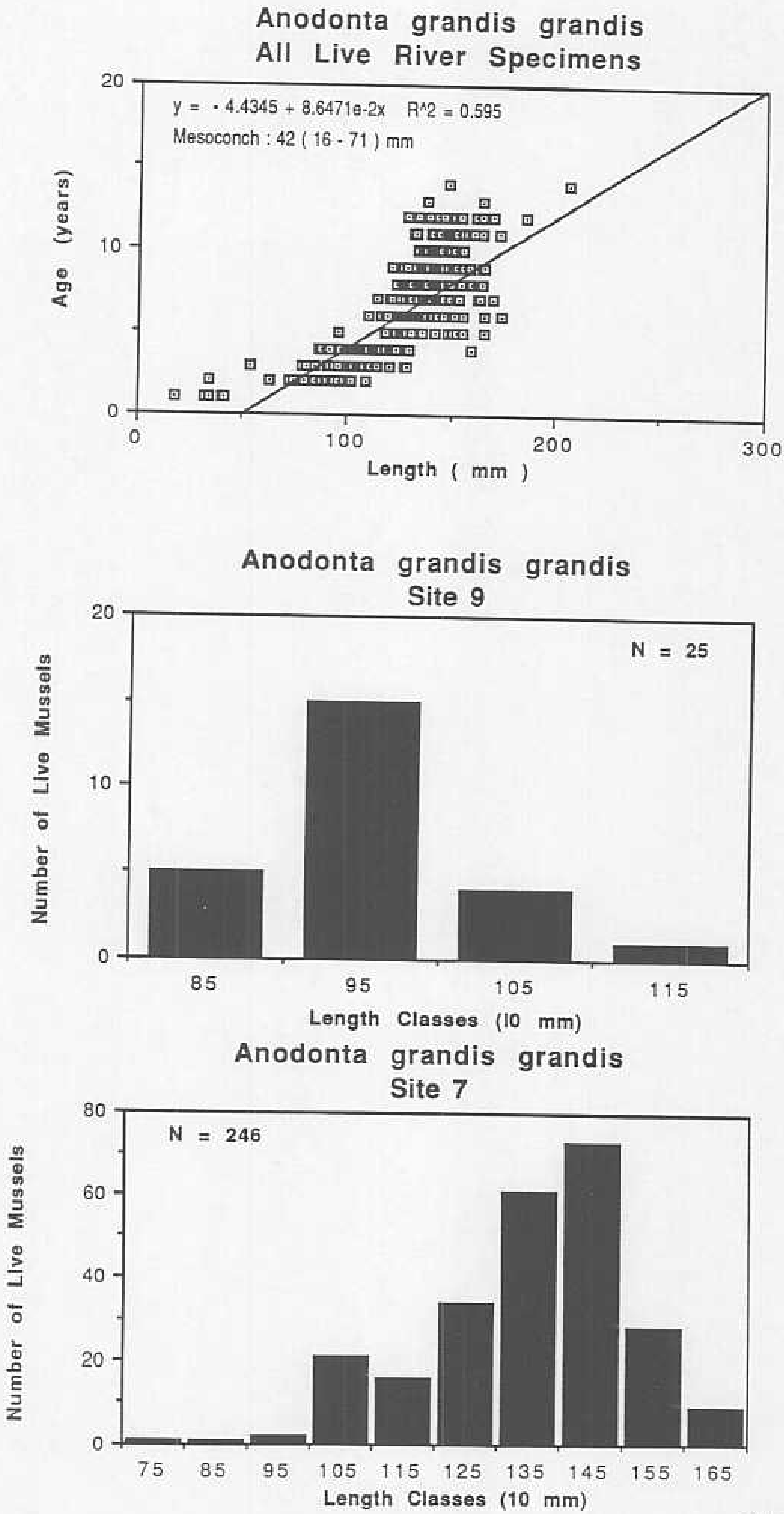
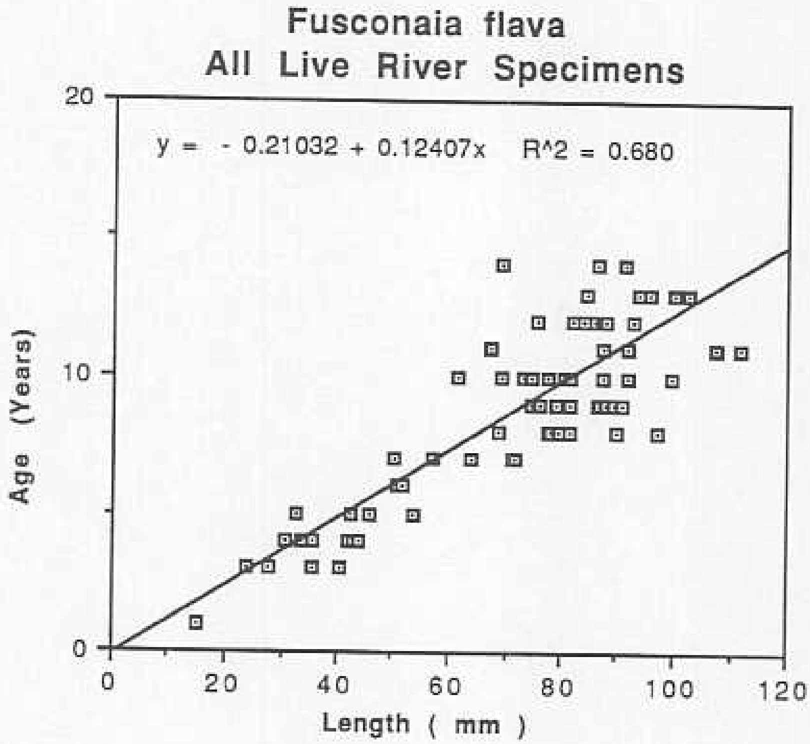

Anodonta grandis grandis
All Live River Specimens
y = - 4.4345 + 8.6471e-2x R^2 = 0.595
Mesoconch : 42 (16 - 71) mm
Age (years)
Length (mm)
0
10
20
0
100
200
300
Anodonta grandis grandis
Site 9
N = 25
Number of Live Mussels
Length Classes (10 mm)
0
10
20
85
95
105
115
Anodonta grandis grandis
Site 7
N = 246
Number of Live Mussels
Length Classes (10 mm)
0
20
40
60
80
75
85
95
105
115
125
135
145
155
165

Figure 7


Fusconaia flava
All Live River Specimens
y = - 0.21032 + 0.12407x R^2 = 0.680
Age (Years)
Length (mm)
0
10
20
0
20
40
60
80
100
120

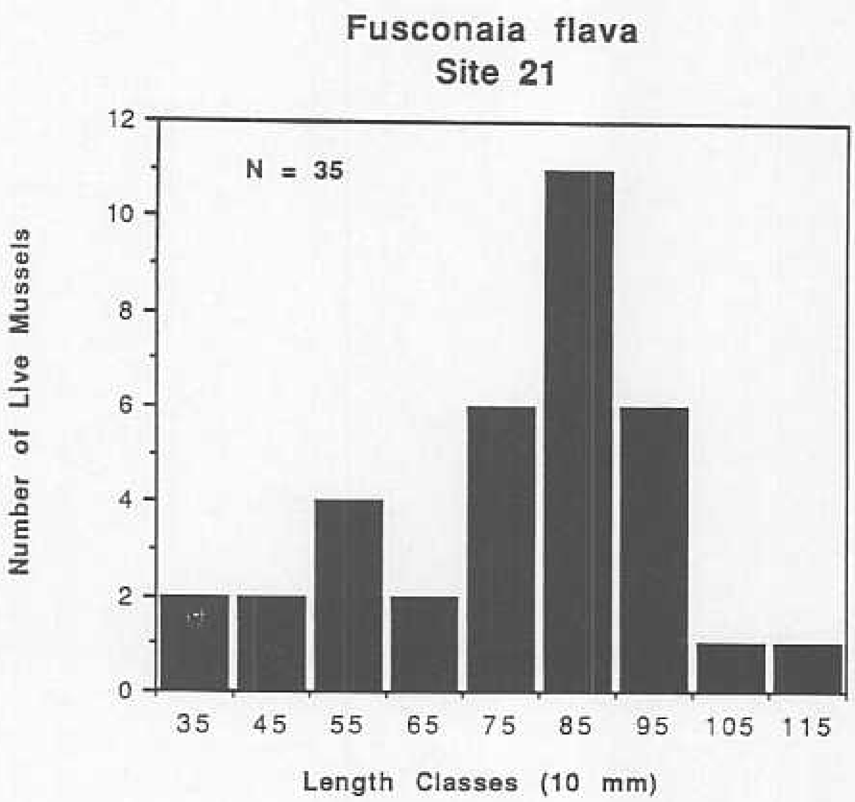
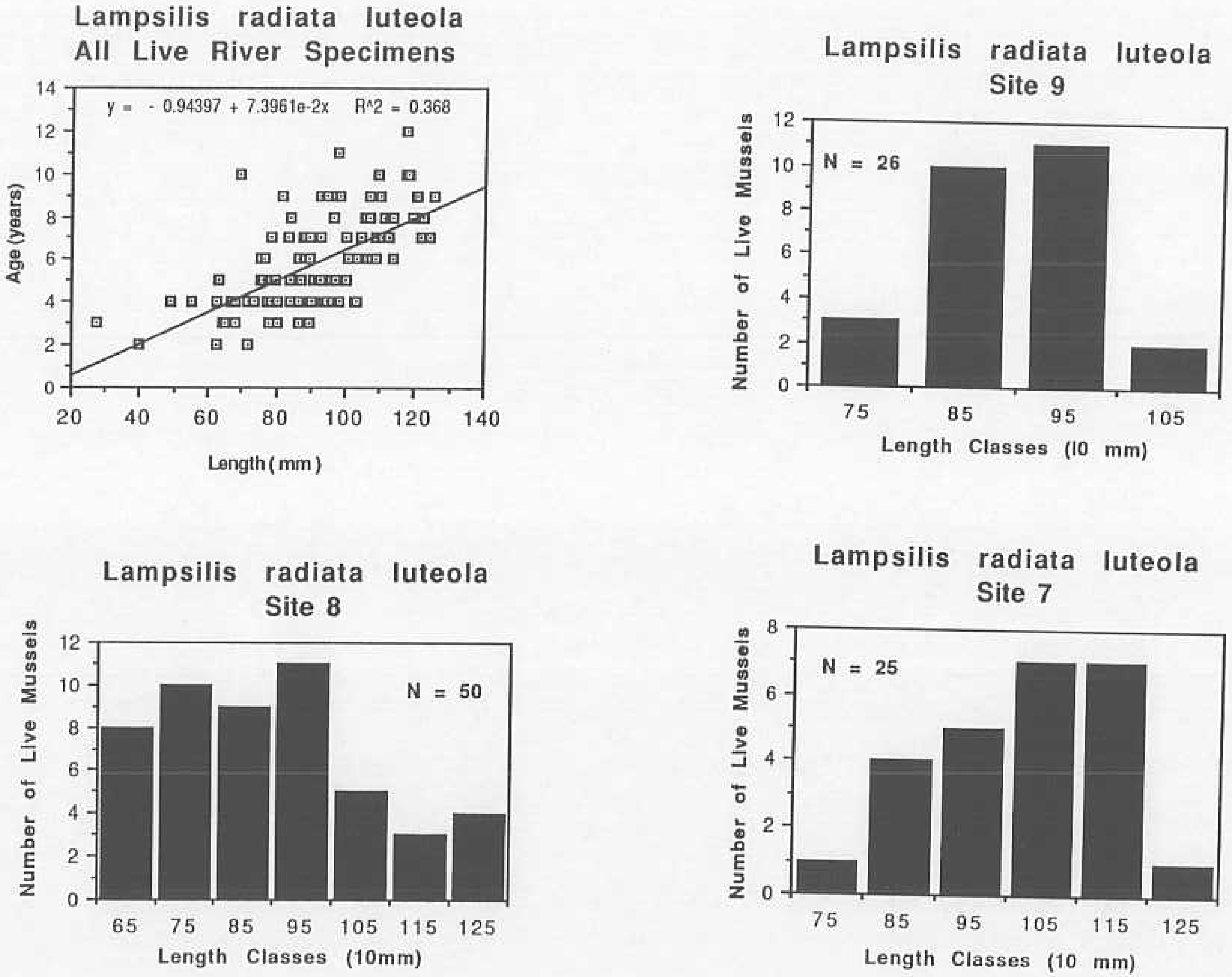
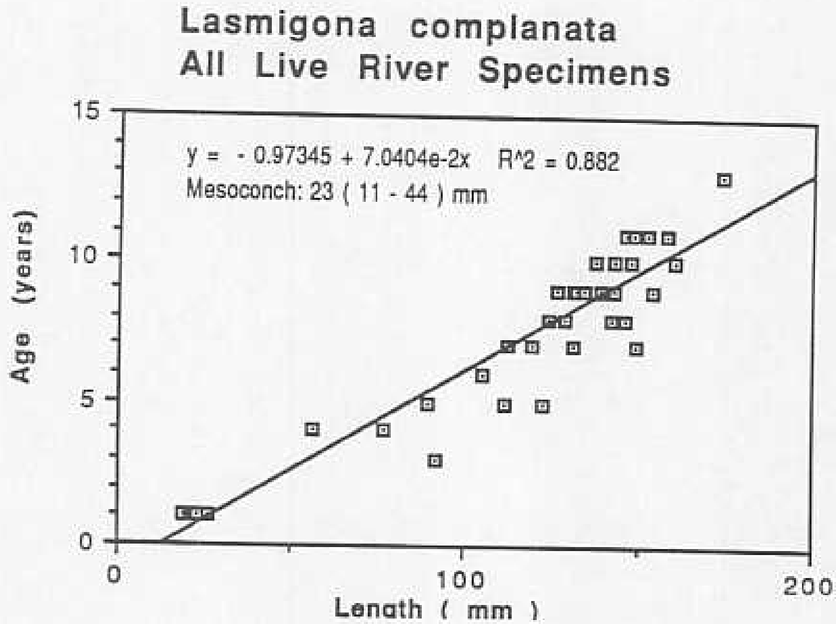

Fusconaia flava
Site 21
N = 35
Number of Live Mussels
Length Classes (10 mm)
0
2
4
6
8
10
12
35
45
55
65
75
85
95
105
115

Figure 8



Lampsilis radiata luteola
All Live River Specimens
y = - 0.94397 + 7.3961e-2x R^2 = 0.368
Age (years)
Length (mm)
Lampsilis radiata luteola
Site 9
N = 26
Number of Live Mussels
Length Classes (10 mm)
Lampsilis radiata luteola
Site 8
N = 50
Number of Live Mussels
Length Classes (10mm)
Lampsilis radiata luteola
Site 7
N = 25
Number of Live Mussels
Length Classes (10 mm)

Figure 9


Lasmigona complanata
All Live River Specimens
y = - 0.97345 + 7.0404e-2x R^2 = 0.882
Mesoconch: 23 (11 - 44) mm
Age (years)
15
10
5
0
0
100
200
Lenath (mm)

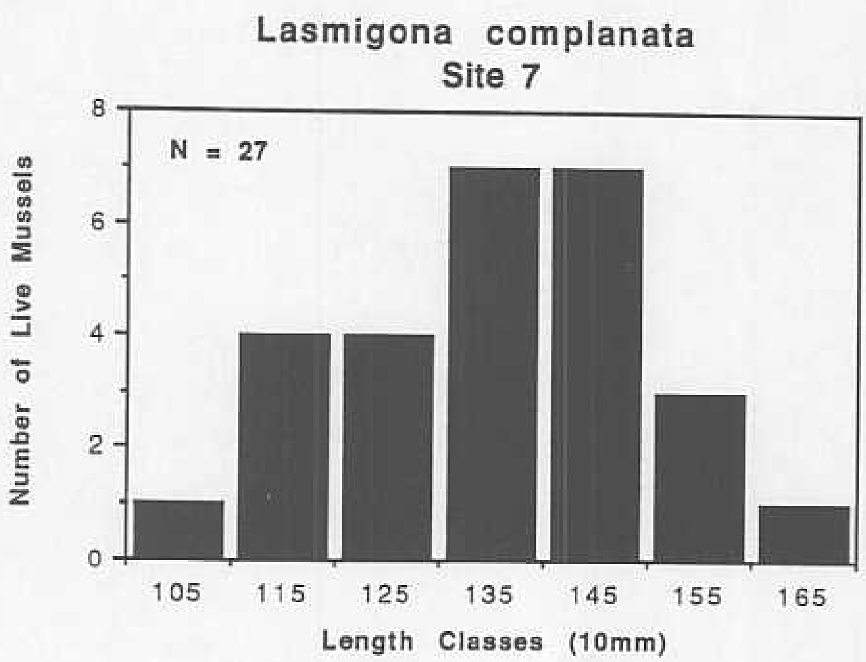
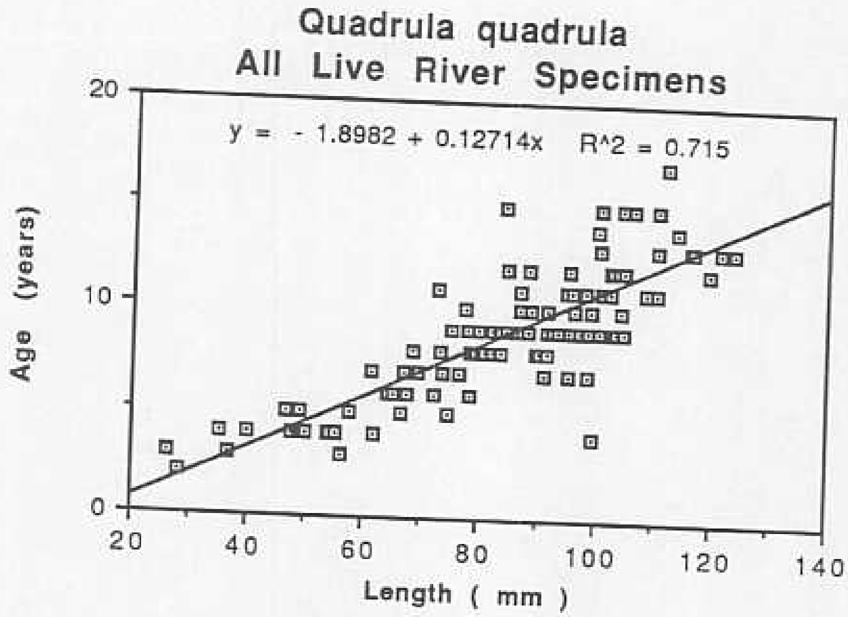
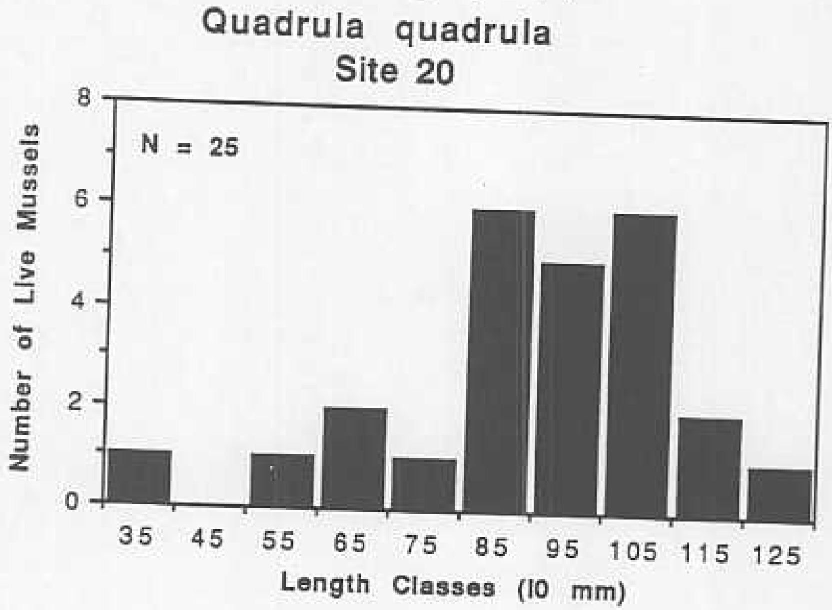

Lasmigona complanata
Site 7
N = 27
Number of Live Mussels
8
6
4
2
0
105
115
125
135
145
155
165
Length Classes (10mm)

Figure 10


Quadrula quadrula
All Live River Specimens
y = - 1.8982 + 0.12714x R^2 = 0.715
Age (years)
Length (mm)
0
10
20
20
40
60
80
100
120
140


Quadrula quadrula
Site 20
N = 25
Number of Live Mussels
Length Classes (l0 mm)
0
2
4
6
8
35
45
55
65
75
85
95
105
115
125

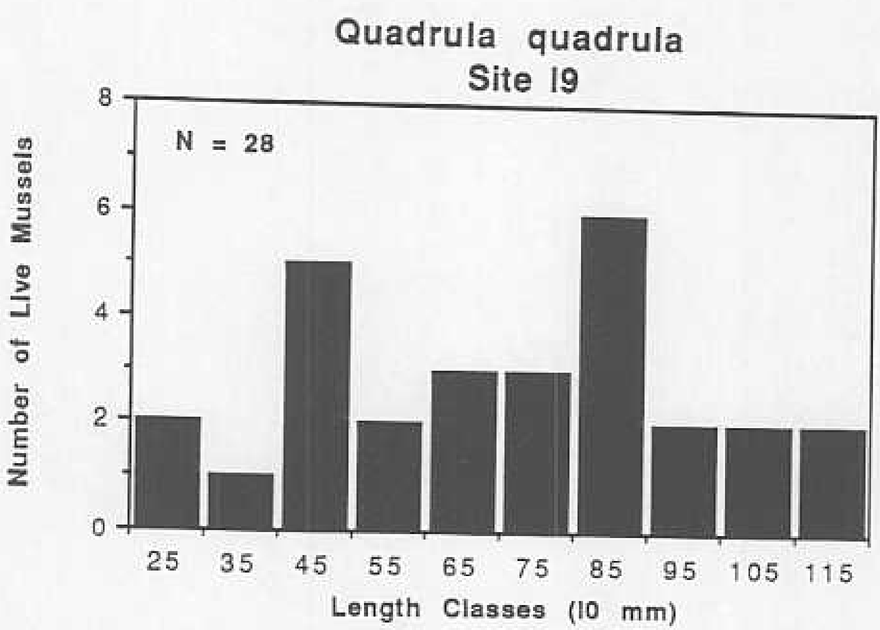

Quadrula quadrula
Site l9
N = 28
Number of Live Mussels
Length Classes (l0 mm)
0
2
4
6
8
25
35
45
55
65
75
85
95
105
115

Figure 11

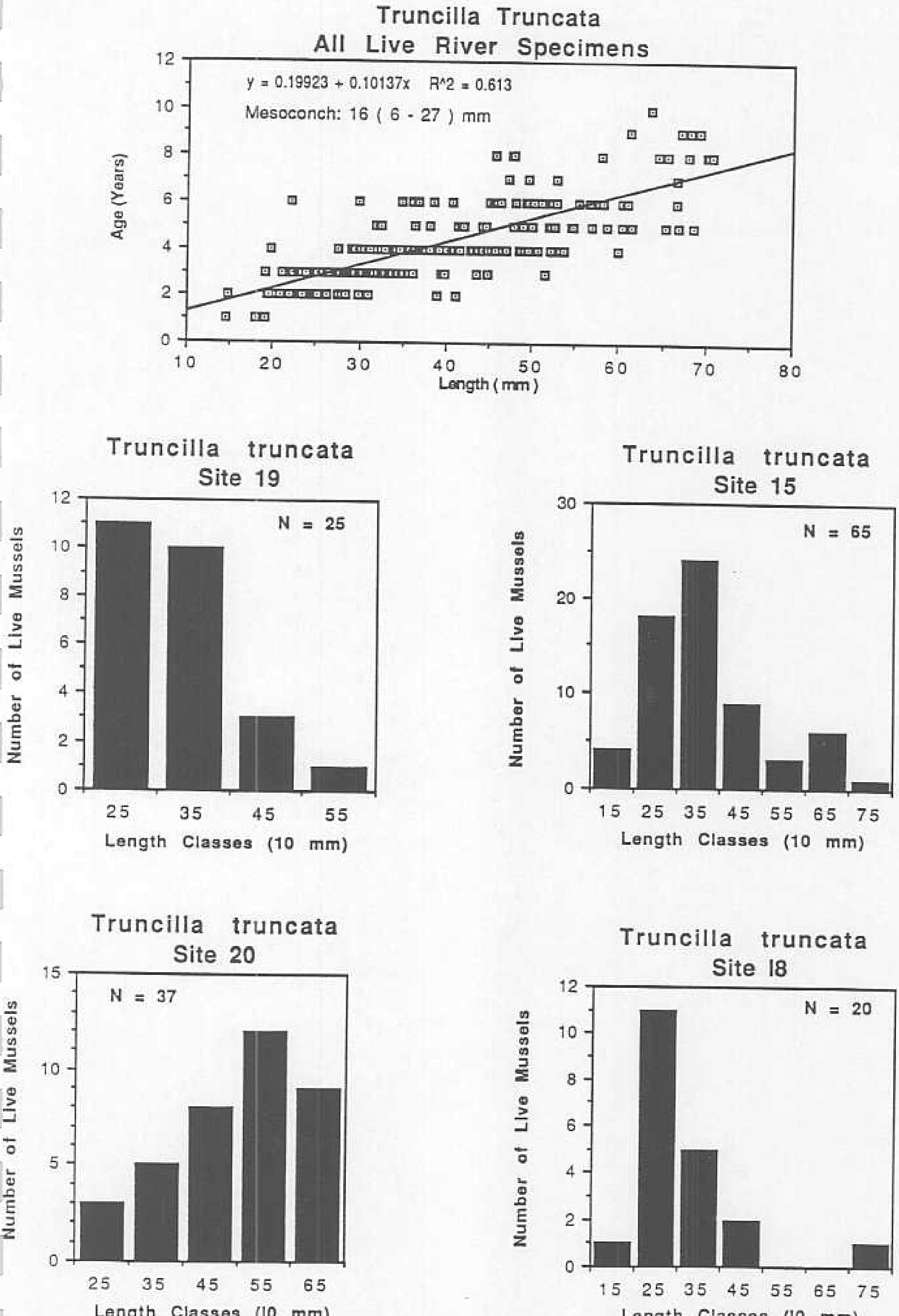

Truncilla Truncata
All Live River Specimens
y = 0.19923 + 0.10137x R^2 = 0.613
Mesoconch: 16 (6 - 27) mm
Age (Years)
Length (mm)
Truncilla truncata
Site 19
N = 25
Number of Live Mussels
Length Classes (10 mm)
Truncilla truncata
Site 15
N = 65
Number of Live Mussels
Length Classes (10 mm)
Truncilla truncata
Site 20
N = 37
Number of Live Mussels
Length Classes (10 mm)
Truncilla truncata
Site 18
N = 20
Number of Live Mussels
Length Classes (10 mm)

Figure 12

MUSSEL SURVEY: MINNESOTA RIVER, 1989

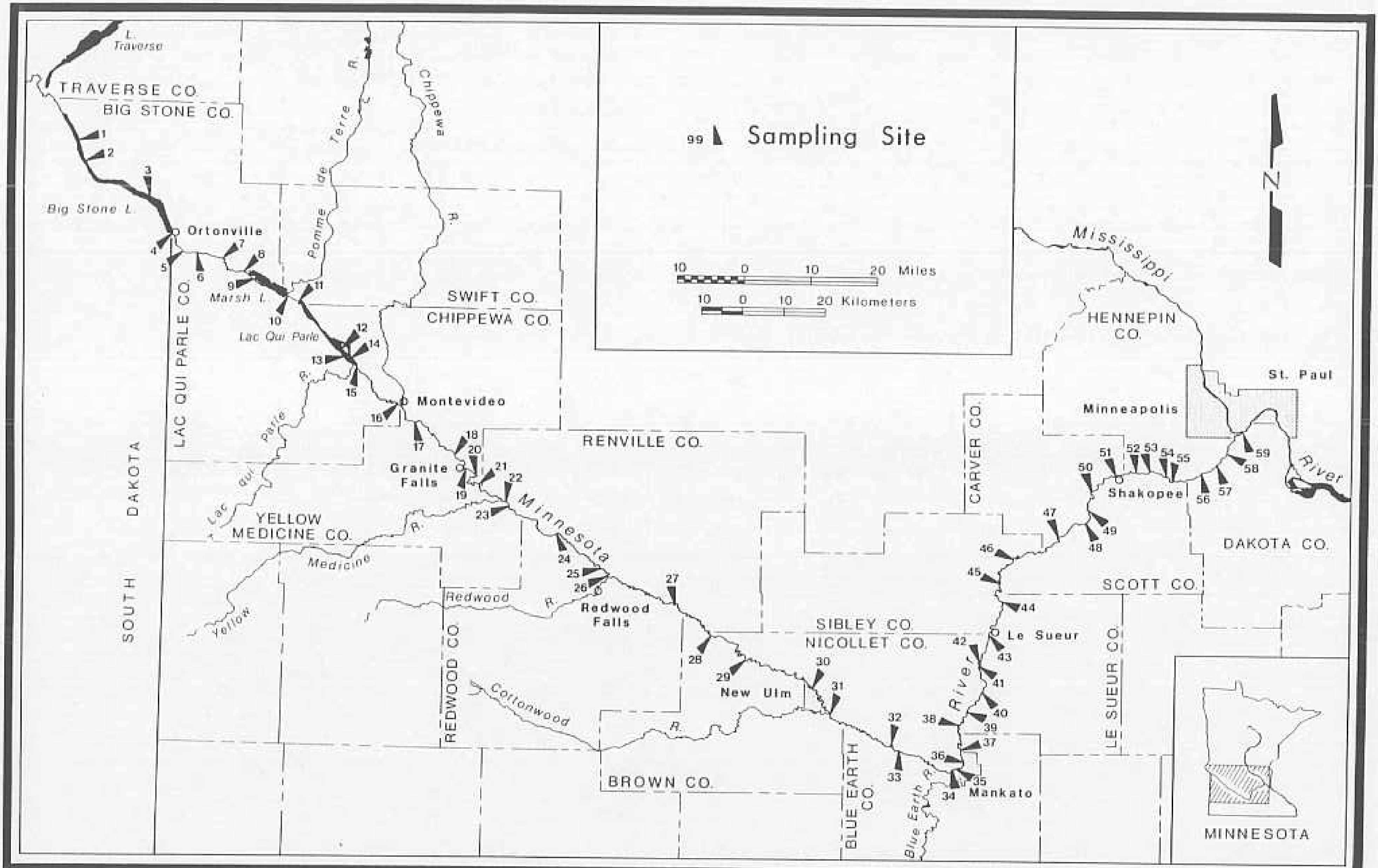


Plate 1

MUSSEL SURVEY: MINNESOTA RIVER, 1989

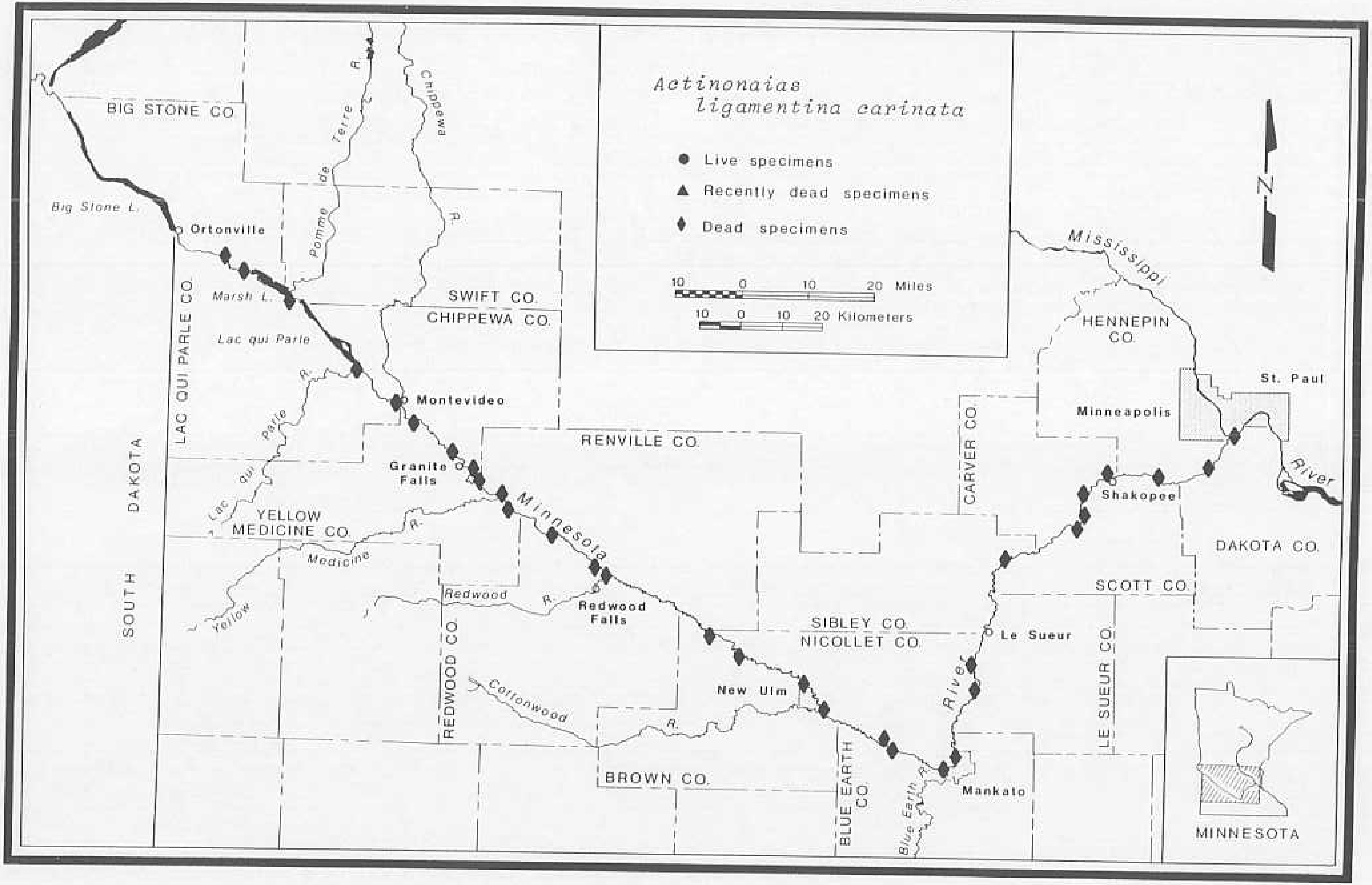


Plate 2

MUSSEL SURVEY: MINNESOTA RIVER, 1989

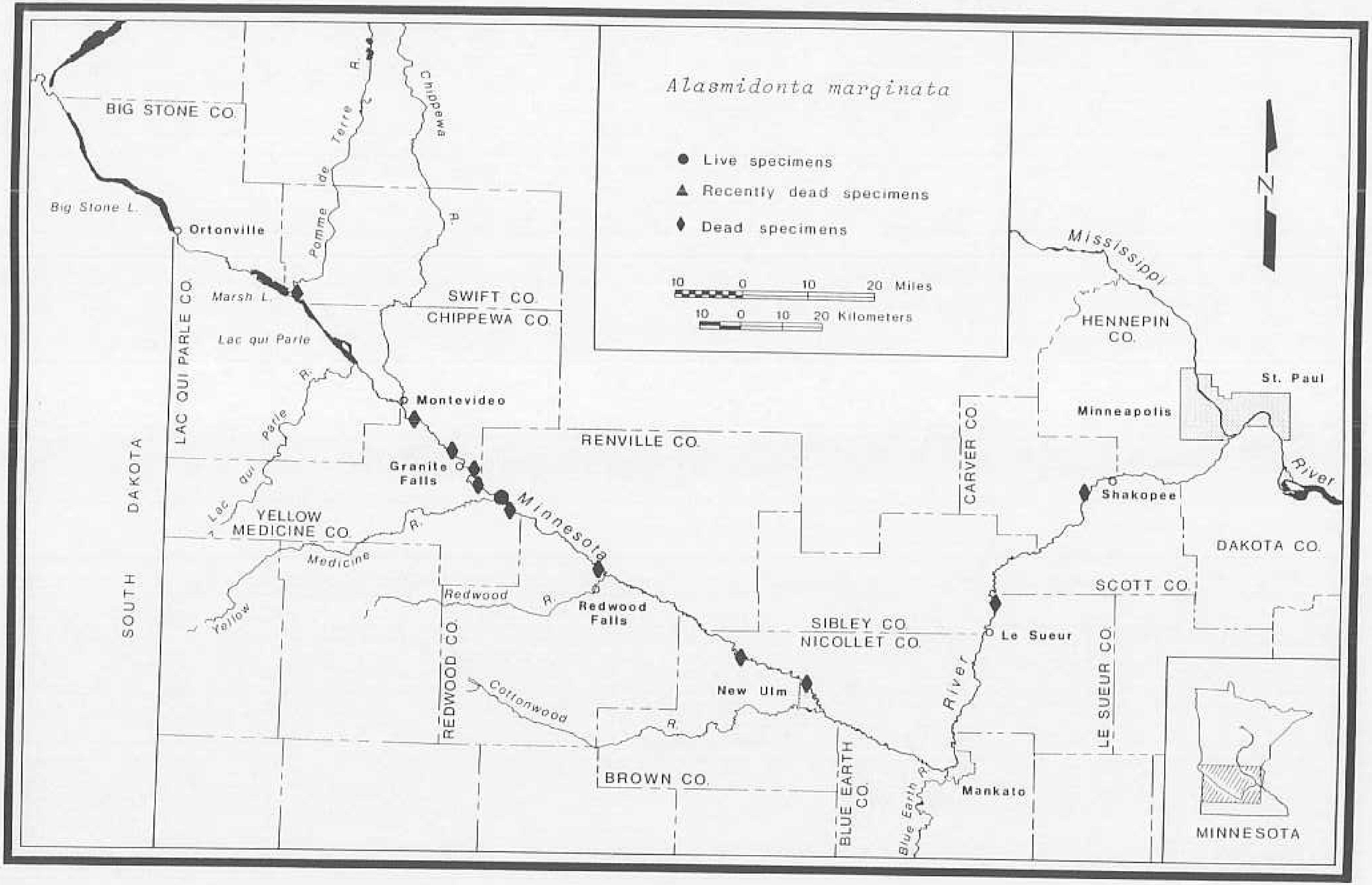


Plate 3

MUSSEL SURVEY: MINNESOTA RIVER, 1989

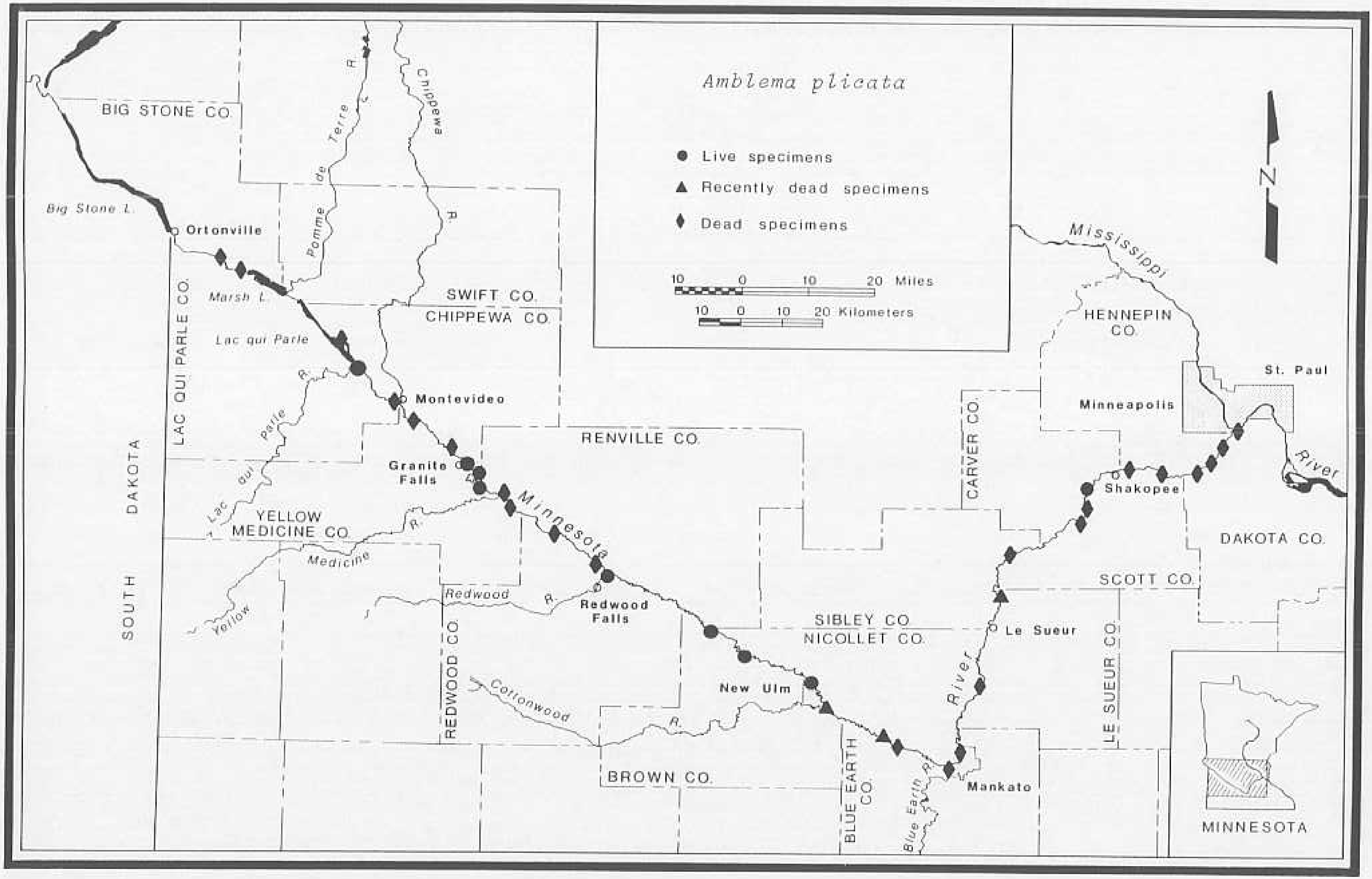


Plate 4

MUSSEL SURVEY: MINNESOTA RIVER, 1989

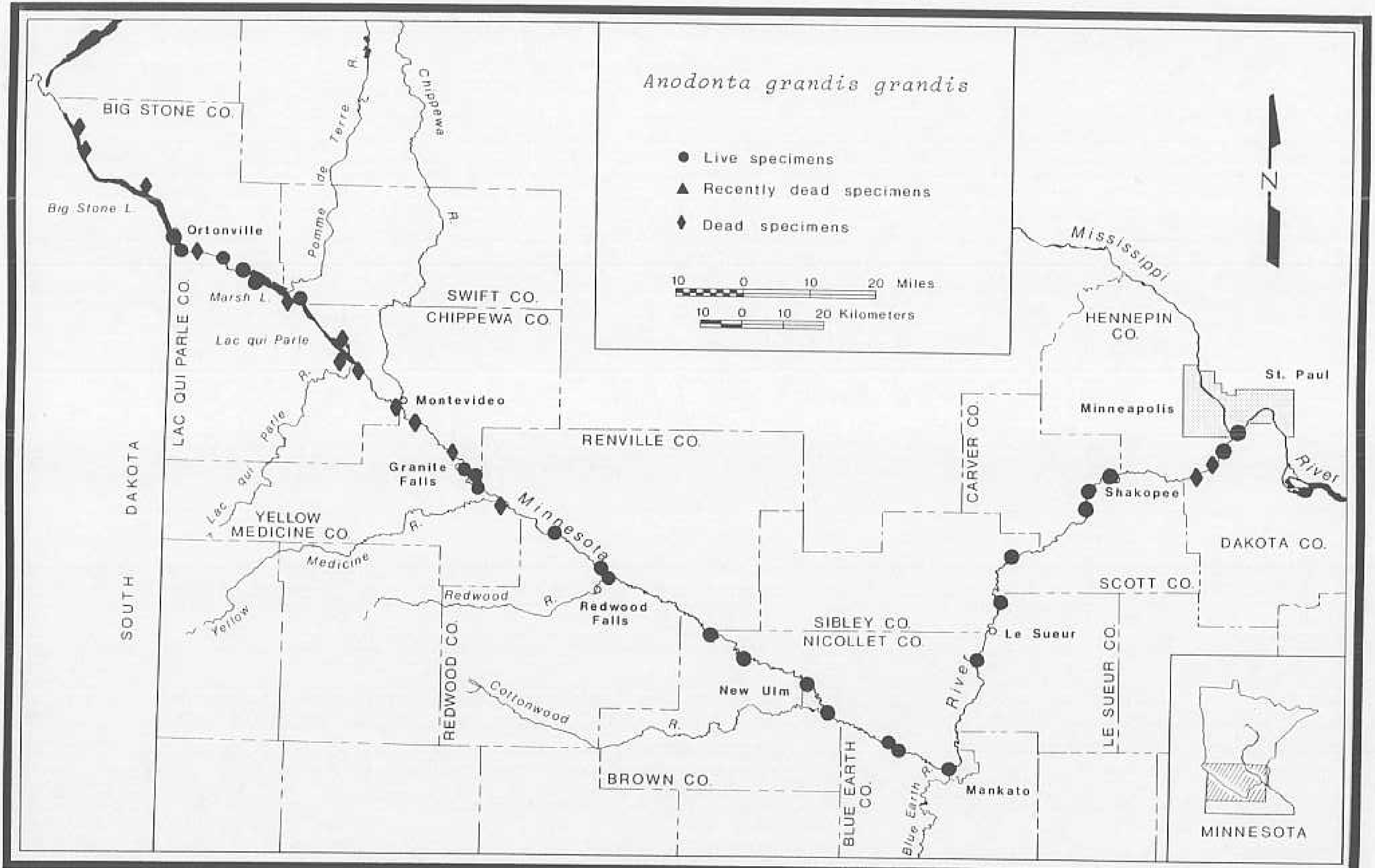


Plate 5

MUSSEL SURVEY: MINNESOTA RIVER, 1989

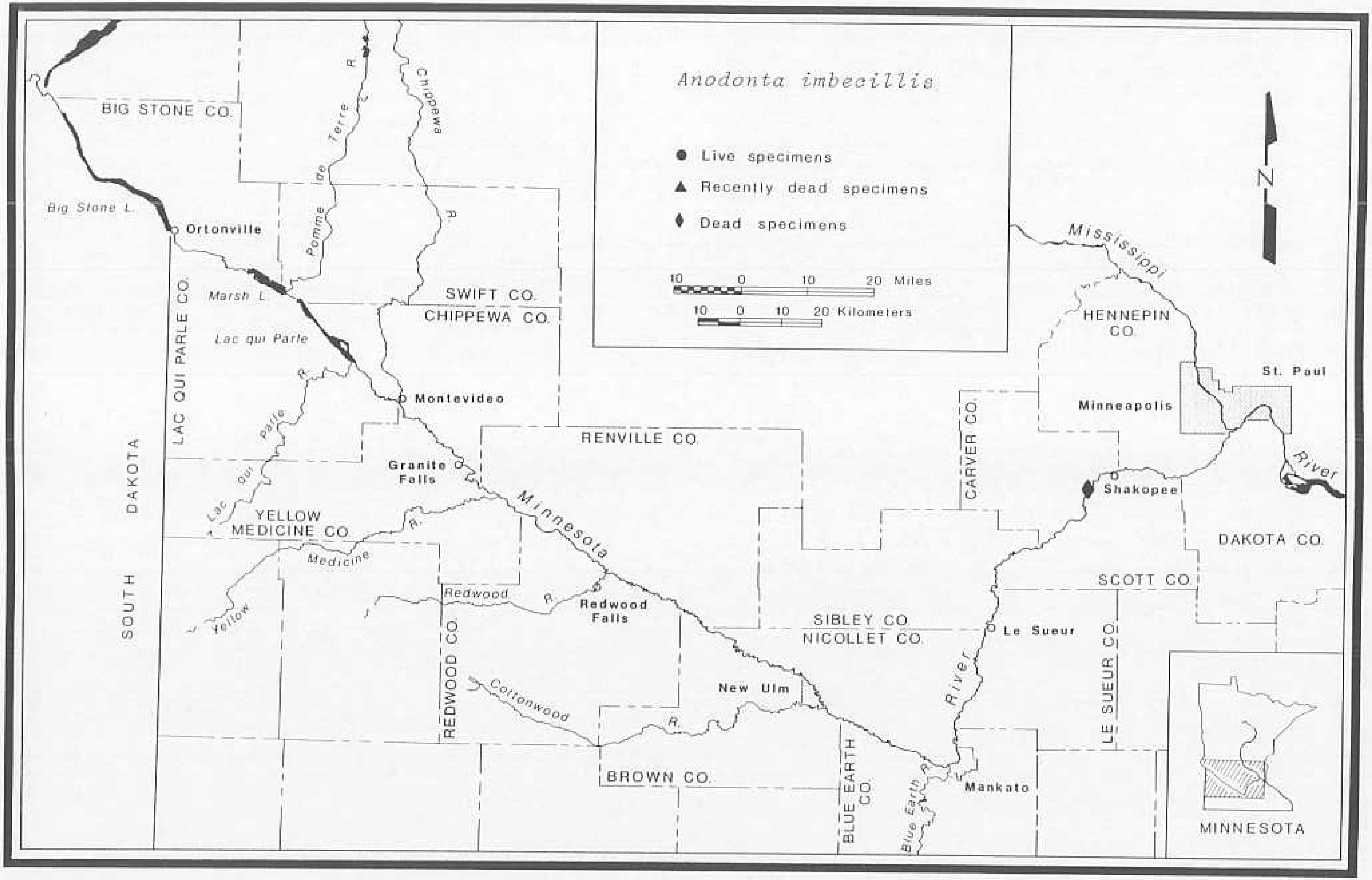


Plate 6

MUSSEL SURVEY: MINNESOTA RIVER, 1989

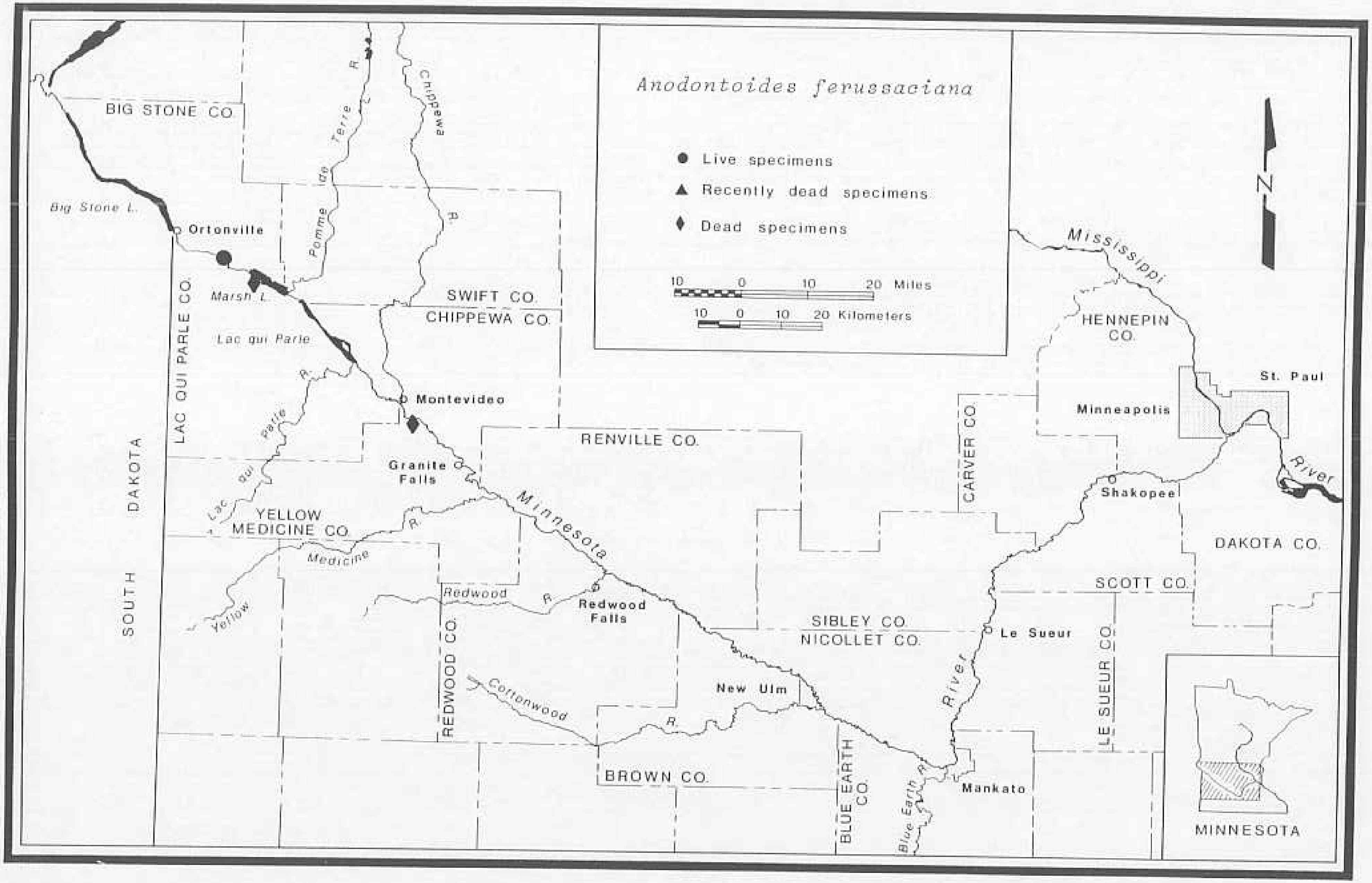


Plate 7

MUSSEL SURVEY: MINNESOTA RIVER, 1989

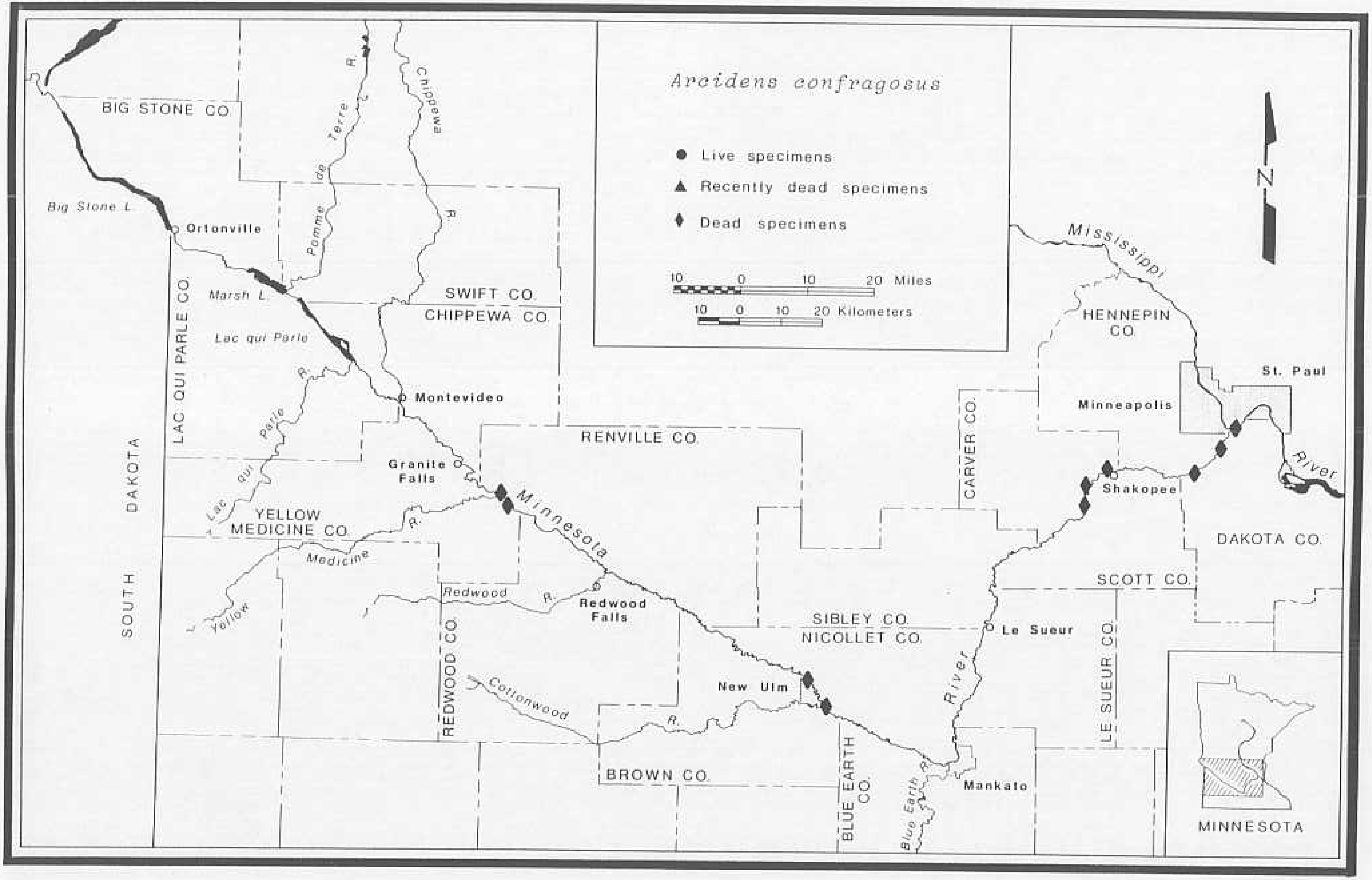


Plate 8

MUSSEL SURVEY: MINNESOTA RIVER, 1989

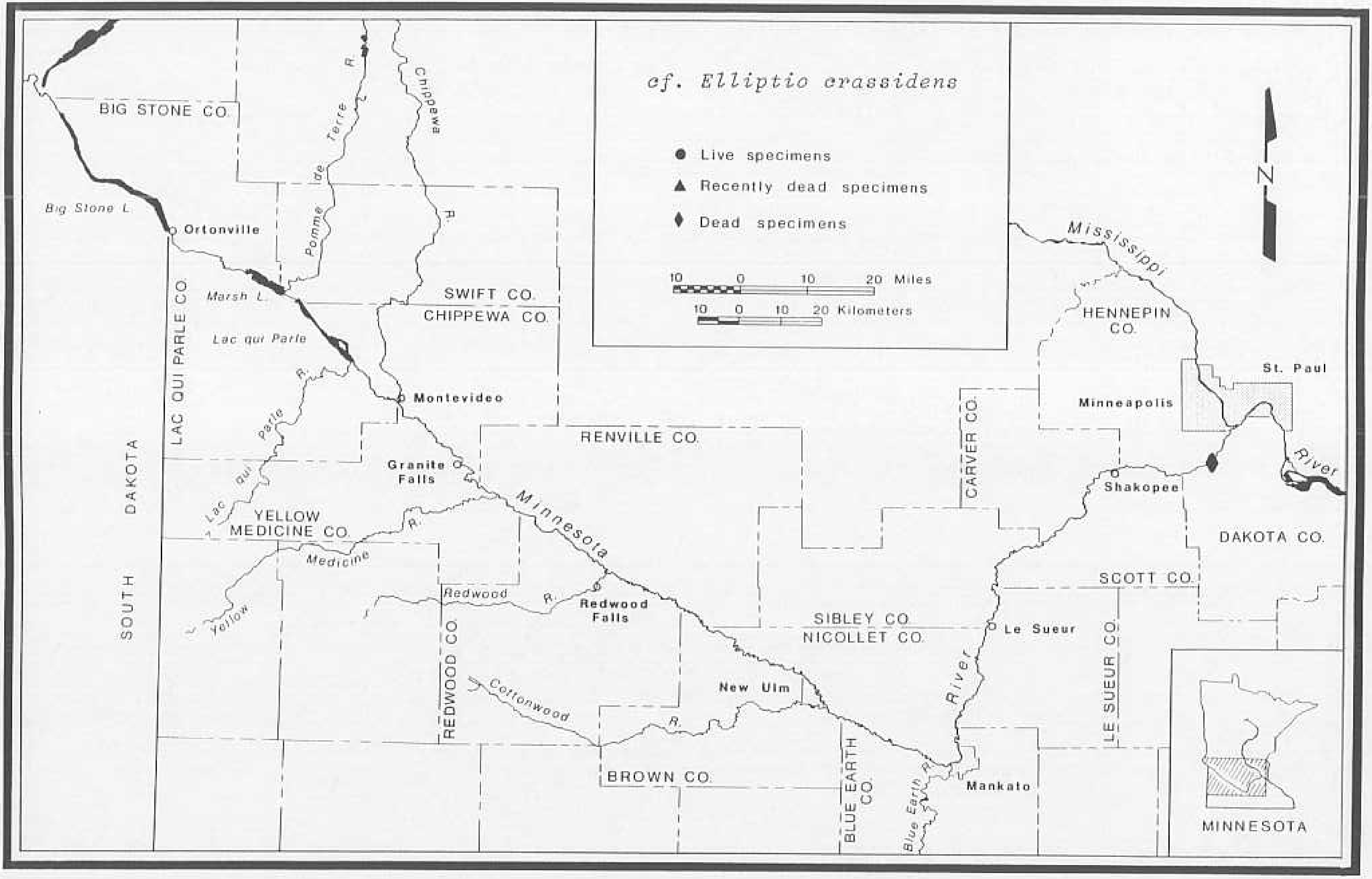


Plate 9

MUSSEL SURVEY: MINNESOTA RIVER, 1989

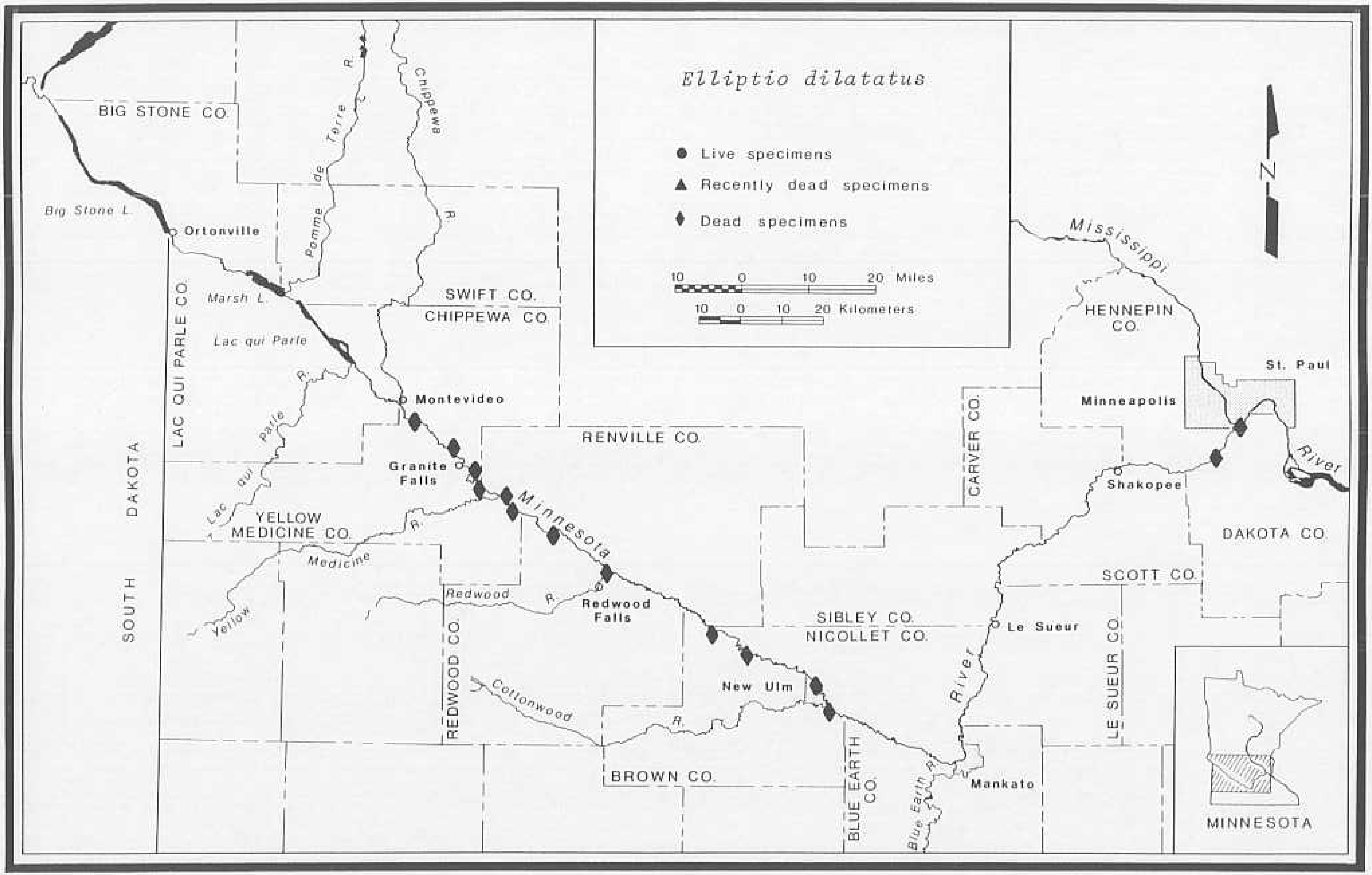


Plate 10

MUSSEL SURVEY: MINNESOTA RIVER, 1989

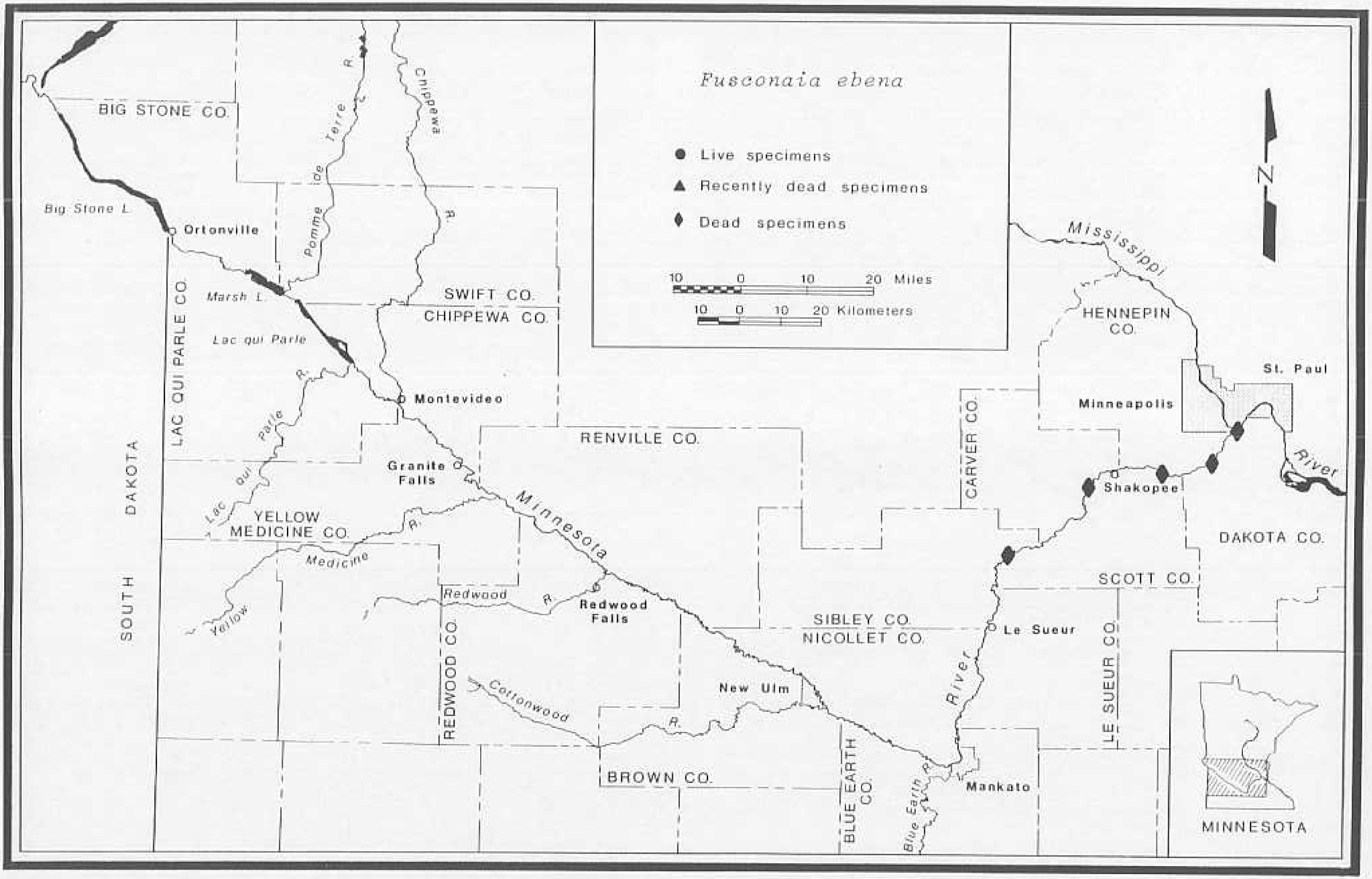


Plate 11

MUSSEL SURVEY: MINNESOTA RIVER, 1989

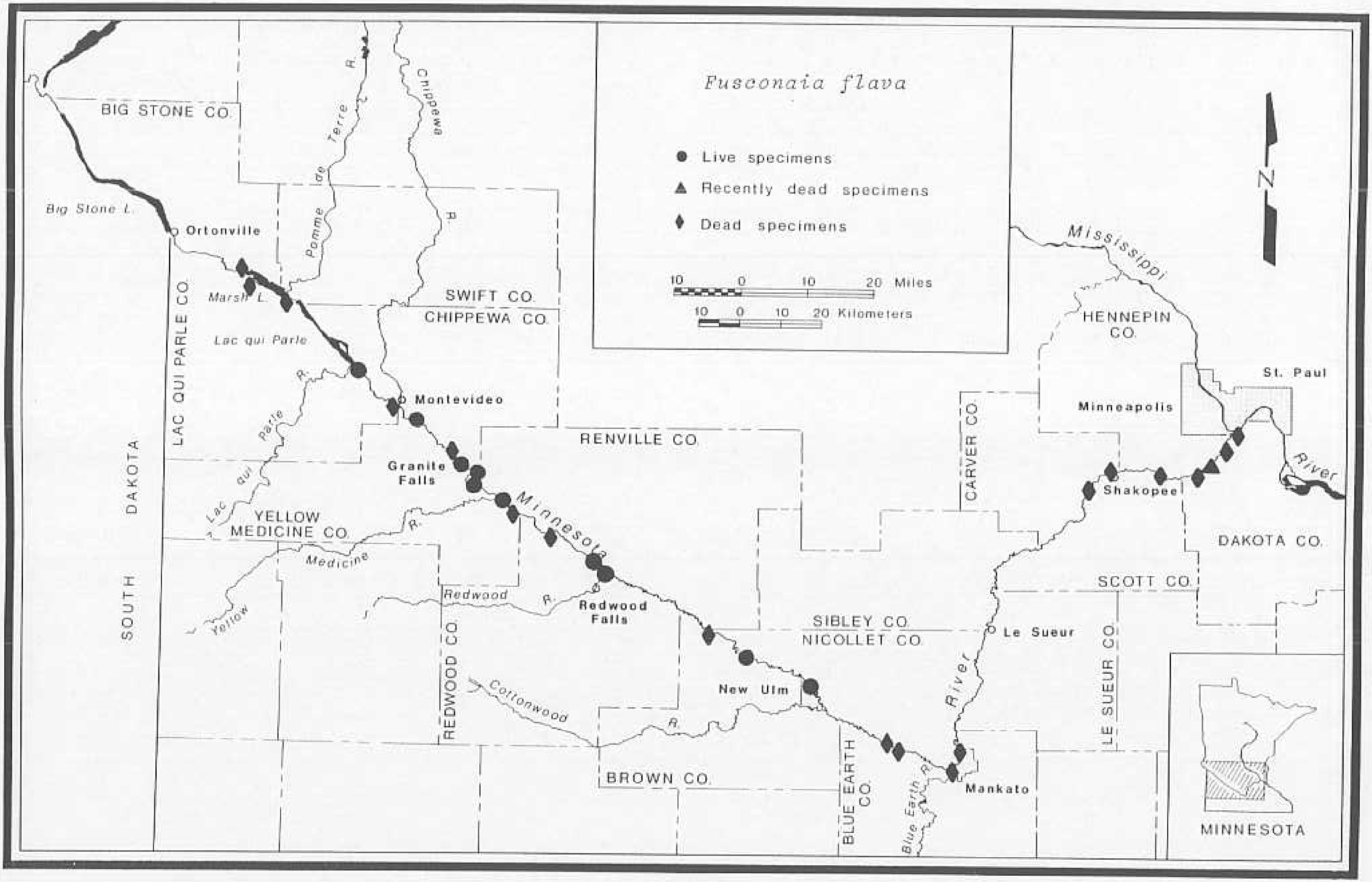


Plate 12

MUSSEL SURVEY: MINNESOTA RIVER, 1989

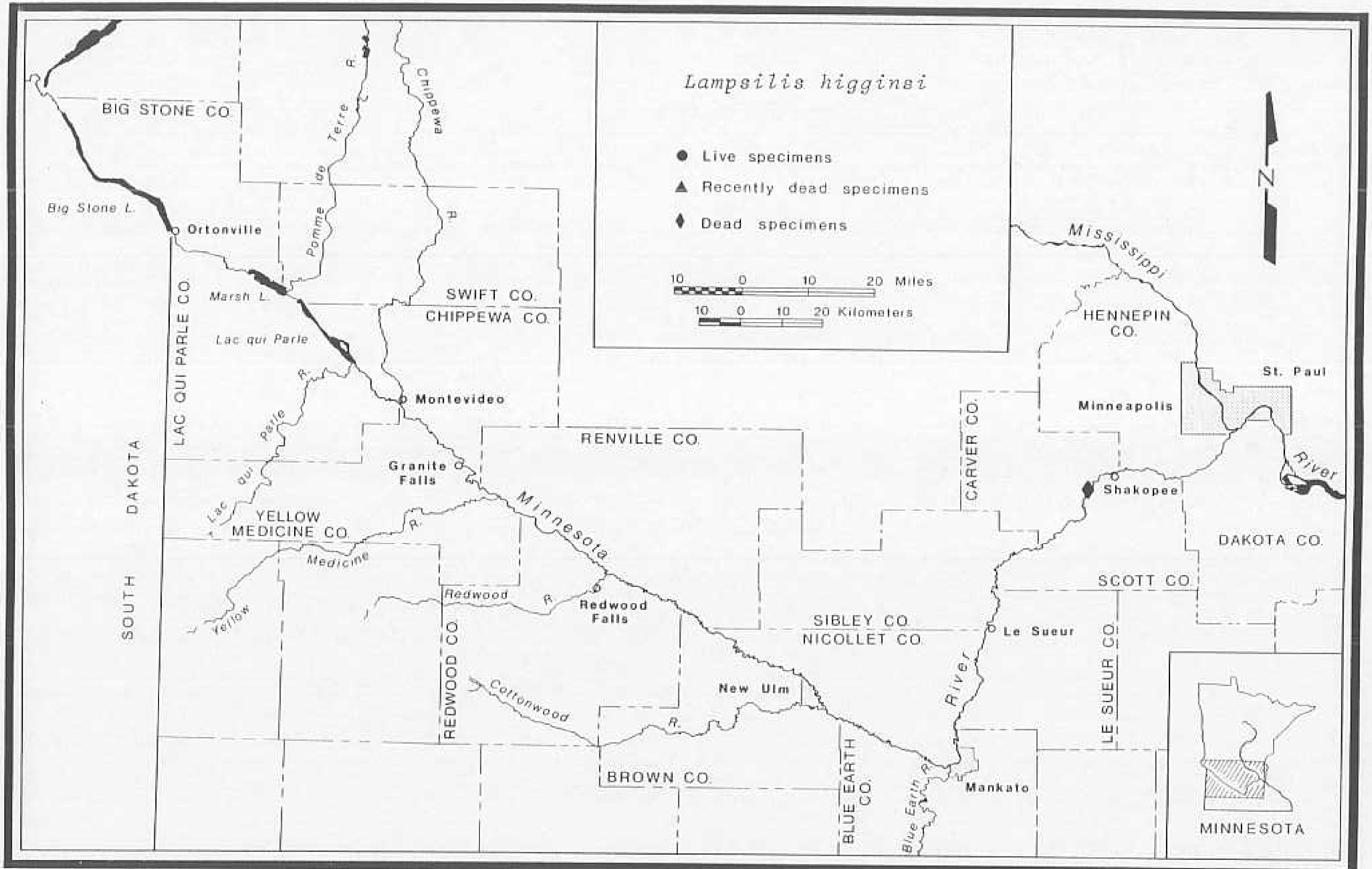


Plate 13

MUSSEL SURVEY: MINNESOTA RIVER, 1989

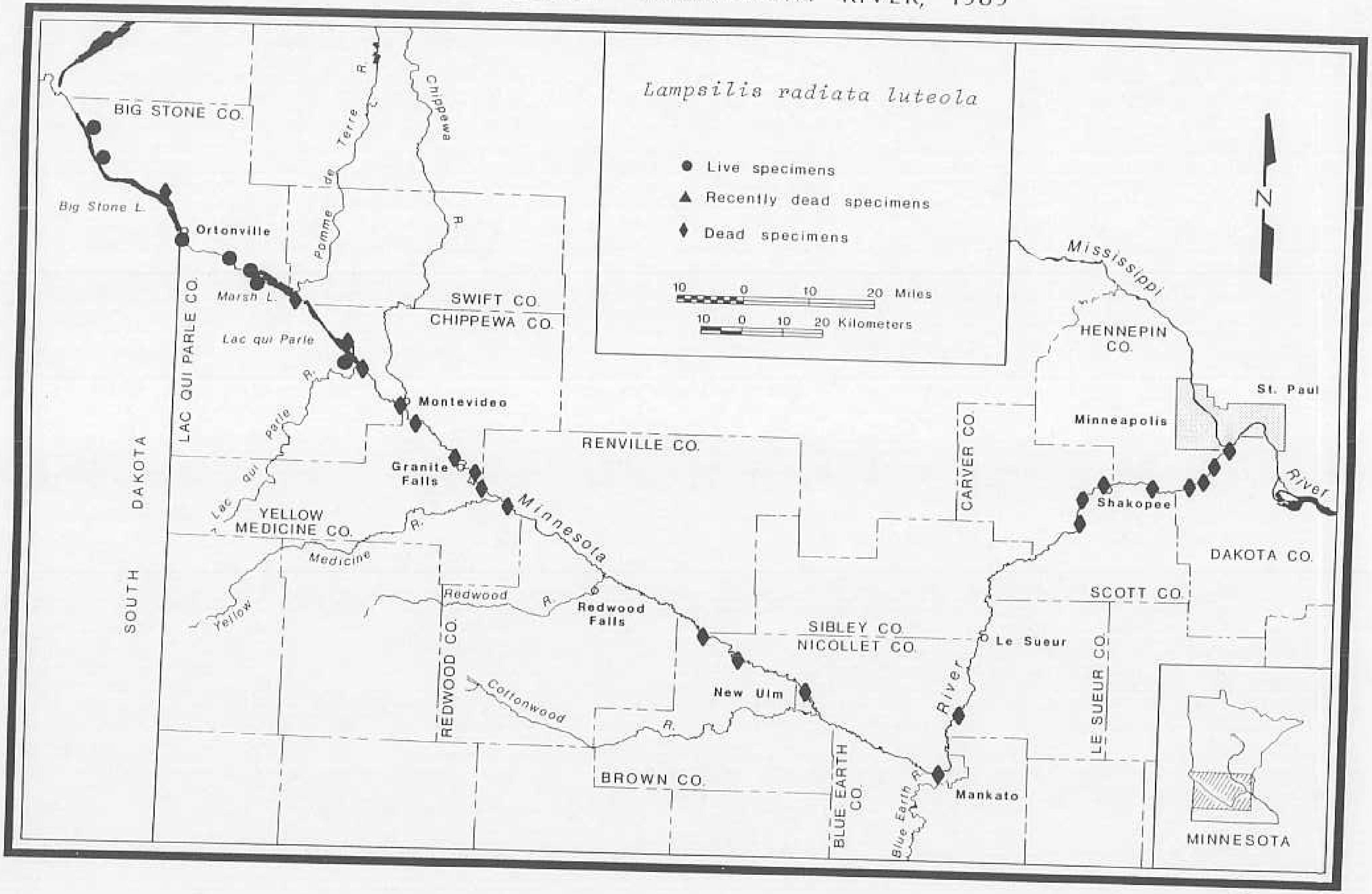


Plate 14

MUSSEL SURVEY: MINNESOTA RIVER, 1989

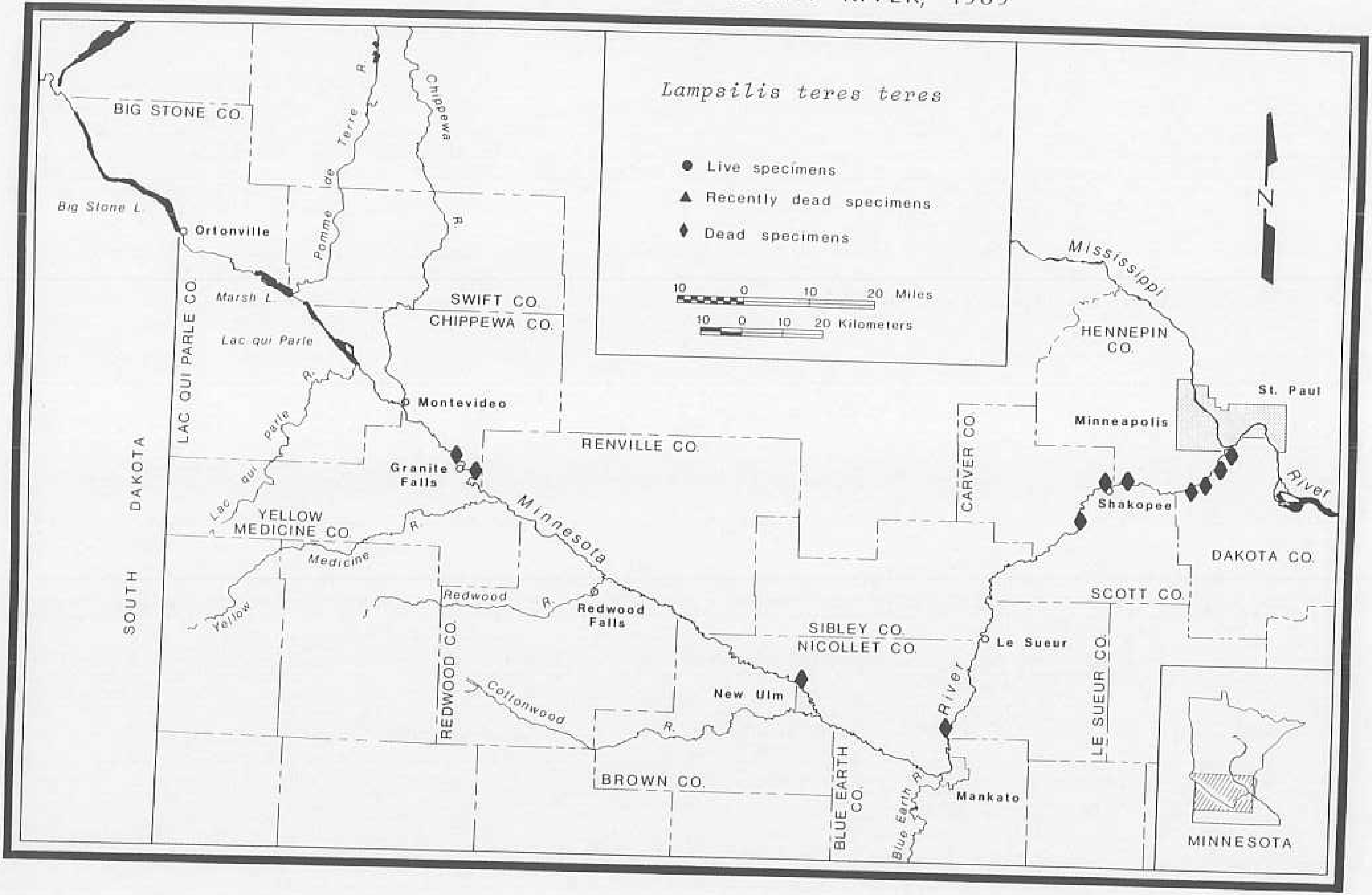


Plate 15

MUSSEL SURVEY: MINNESOTA RIVER, 1989

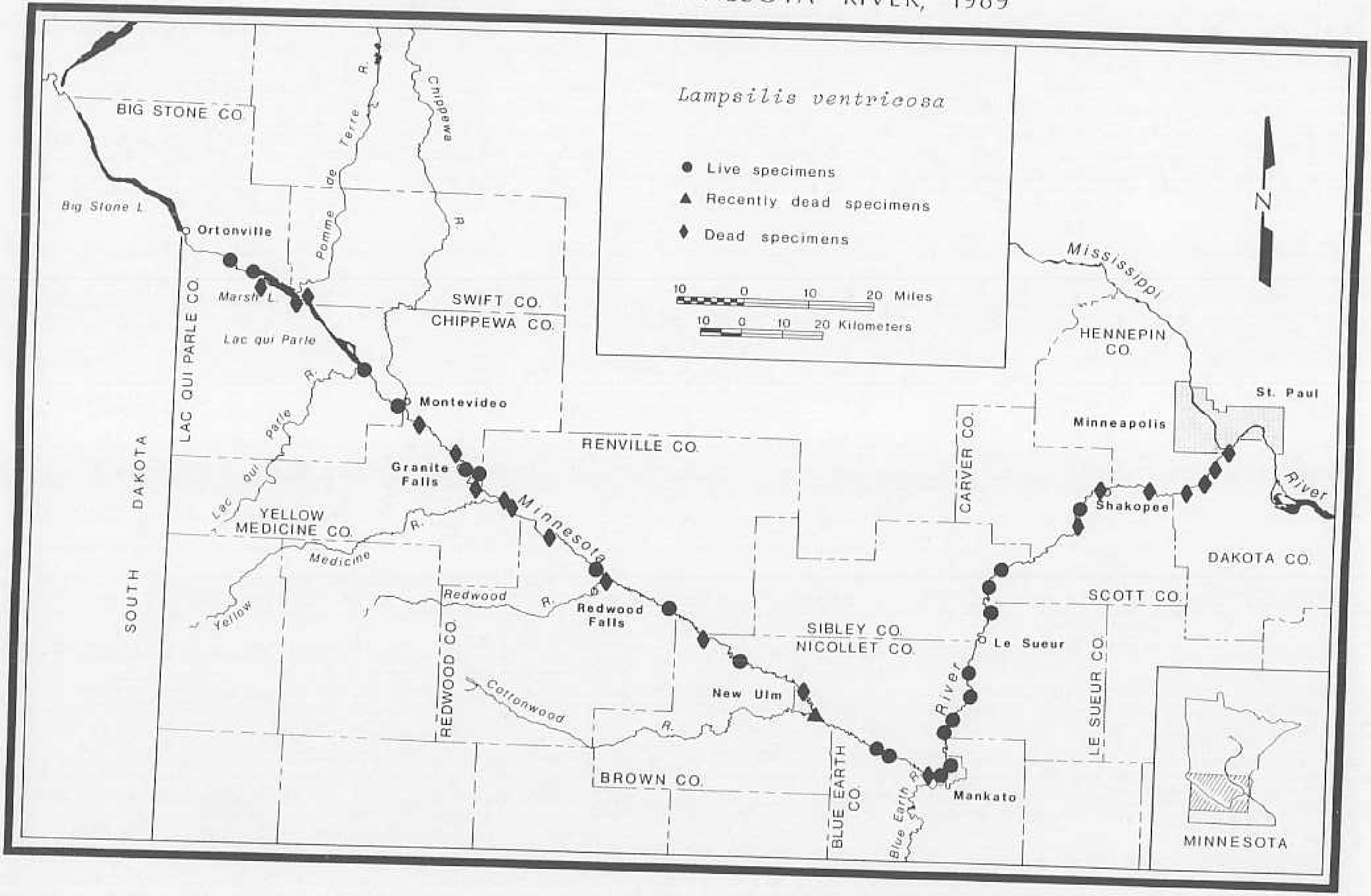
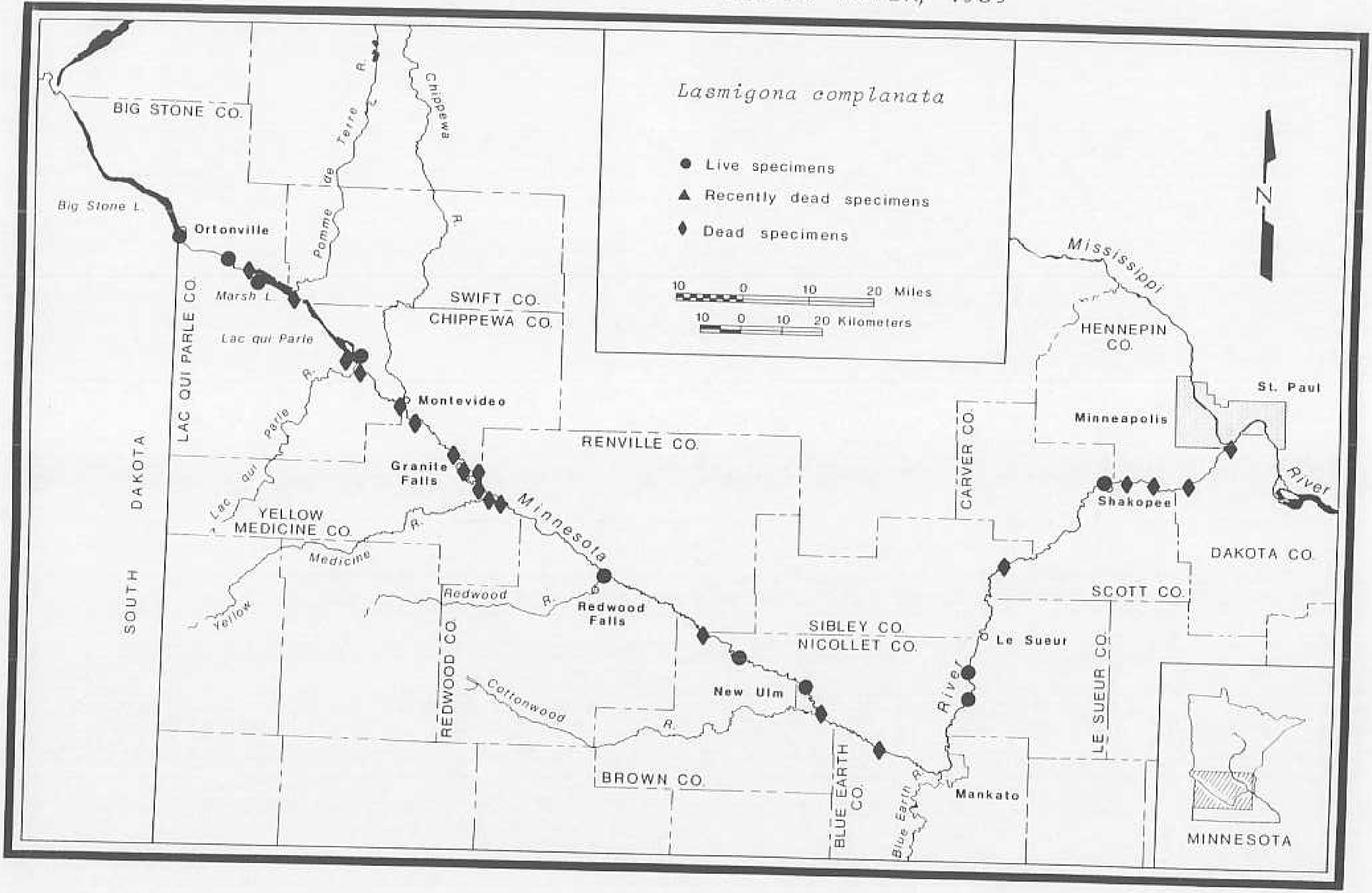


Plate 16


Lasmigona complanata
Live specimens
Recently dead specimens
Dead specimens
10 0 10 20 Miles
10 0 10 20 Kilometers
N
BIG STONE CO.
Big Stone L.
Ortonville
Marsh L.
Lac qui Parle
LAC QUI PARLE CO.
SOUTH DAKOTA
Pomme de Terre R.
Chippewa R.
SWIFT CO.
CHIPPEWA CO.
Montevideo
Granite Falls
Lac qui Parle R.
YELLOW MEDICINE CO.
Yellow Medicine R.
RENVILLE CO.
Minnesota
Redwood R.
Redwood Falls
REDWOOD CO.
Cottonwood R.
BROWN CO.
New Ulm
SIBLEY CO.
NICOLLET CO.
BLUE EARTH CO.
Blue Earth R.
Mankato
River
Le Sueur
LE SUEUR CO.
CARVER CO.
SCOTT CO.
Shakopee
HENNEPIN CO.
Minneapolis
St. Paul
Mississippi
River
DAKOTA CO.
MINNESOTA

MUSSEL SURVEY: MINNESOTA RIVER, 1989

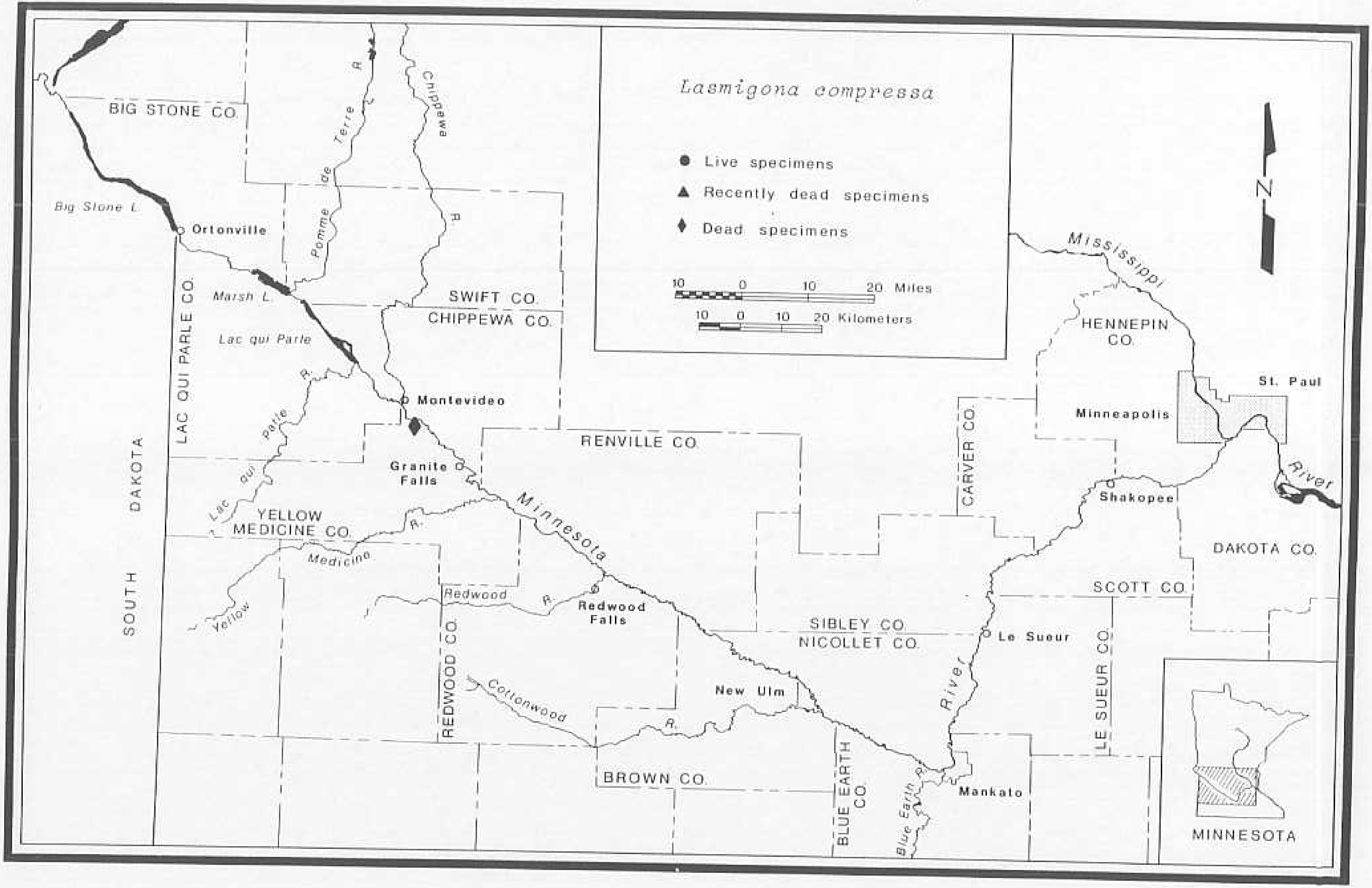


Plate 18

MUSSEL SURVEY: MINNESOTA RIVER, 1989

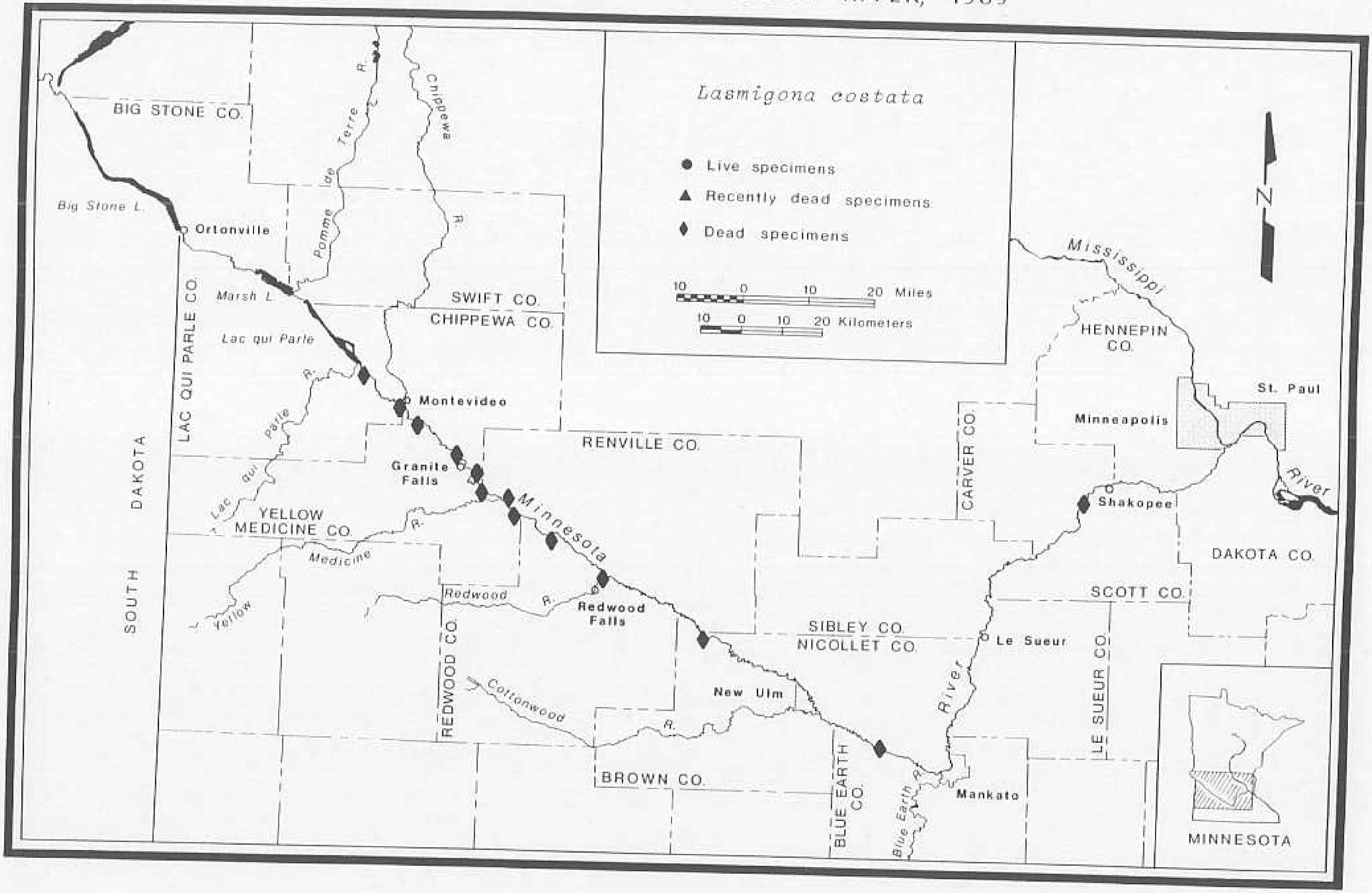


Plate 19

MUSSEL SURVEY: MINNESOTA RIVER, 1989

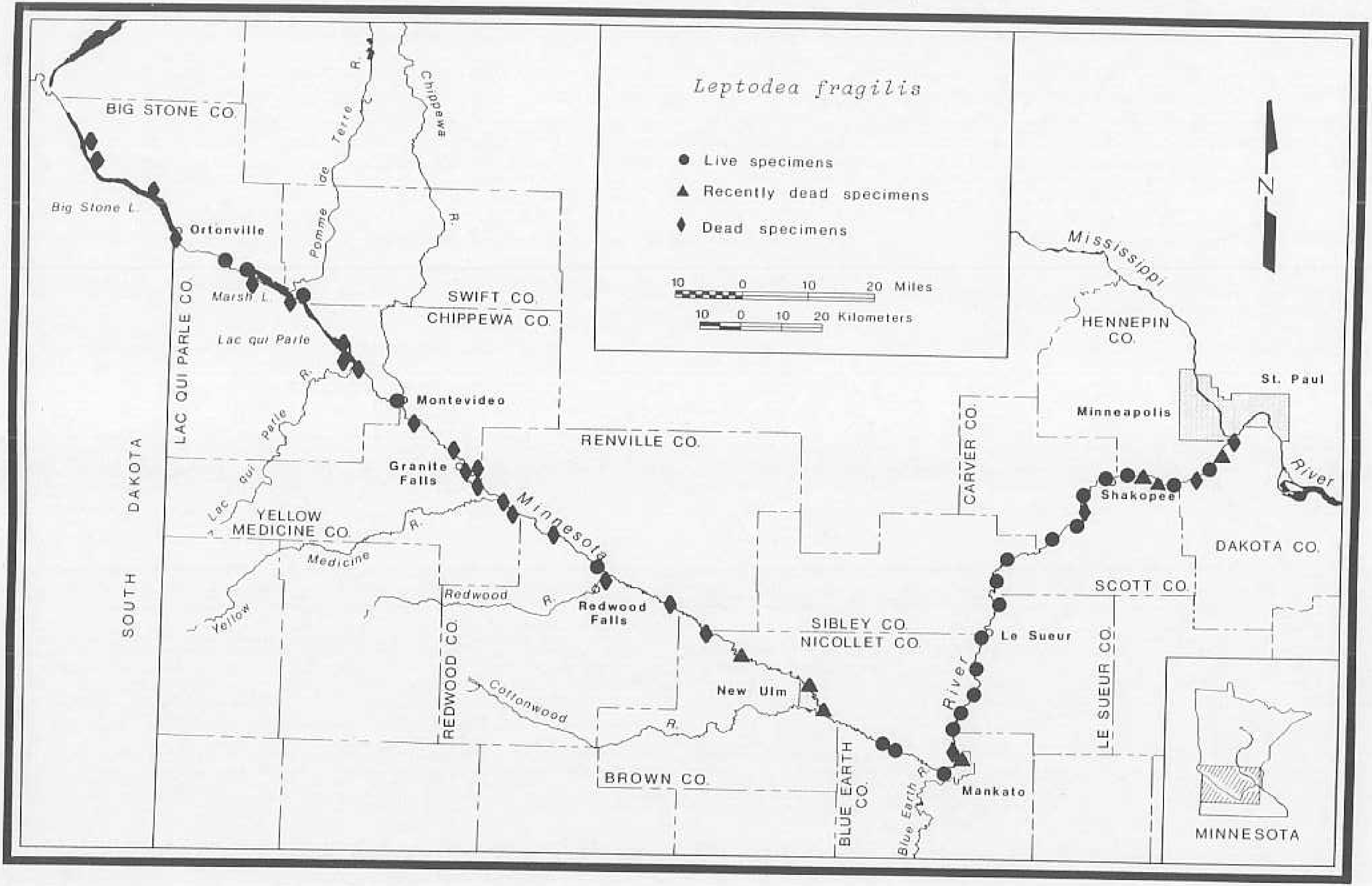


Plate 20

MUSSEL SURVEY: MINNESOTA RIVER, 1989

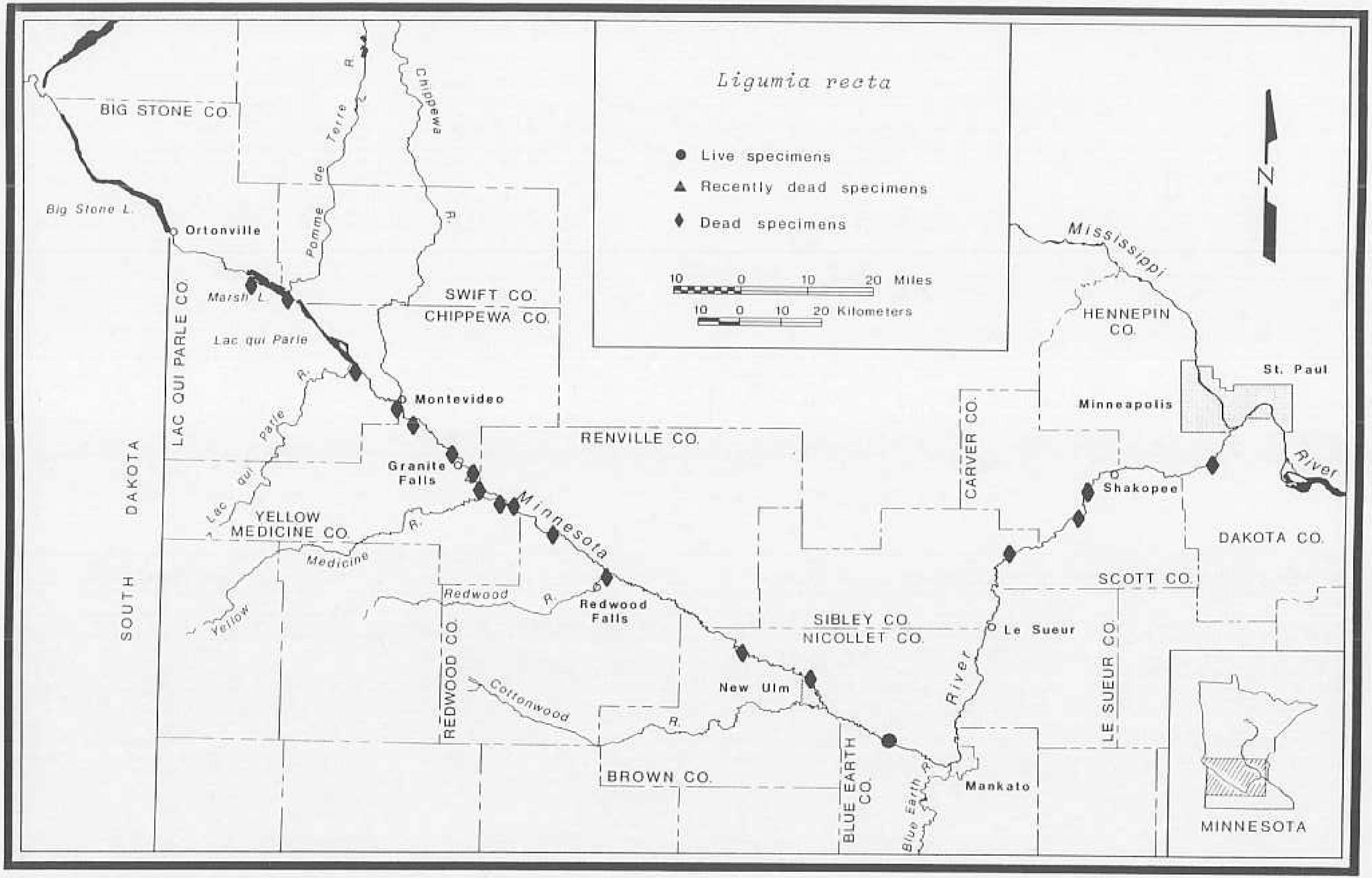


Plate 21

MUSSEL SURVEY: MINNESOTA RIVER, 1989

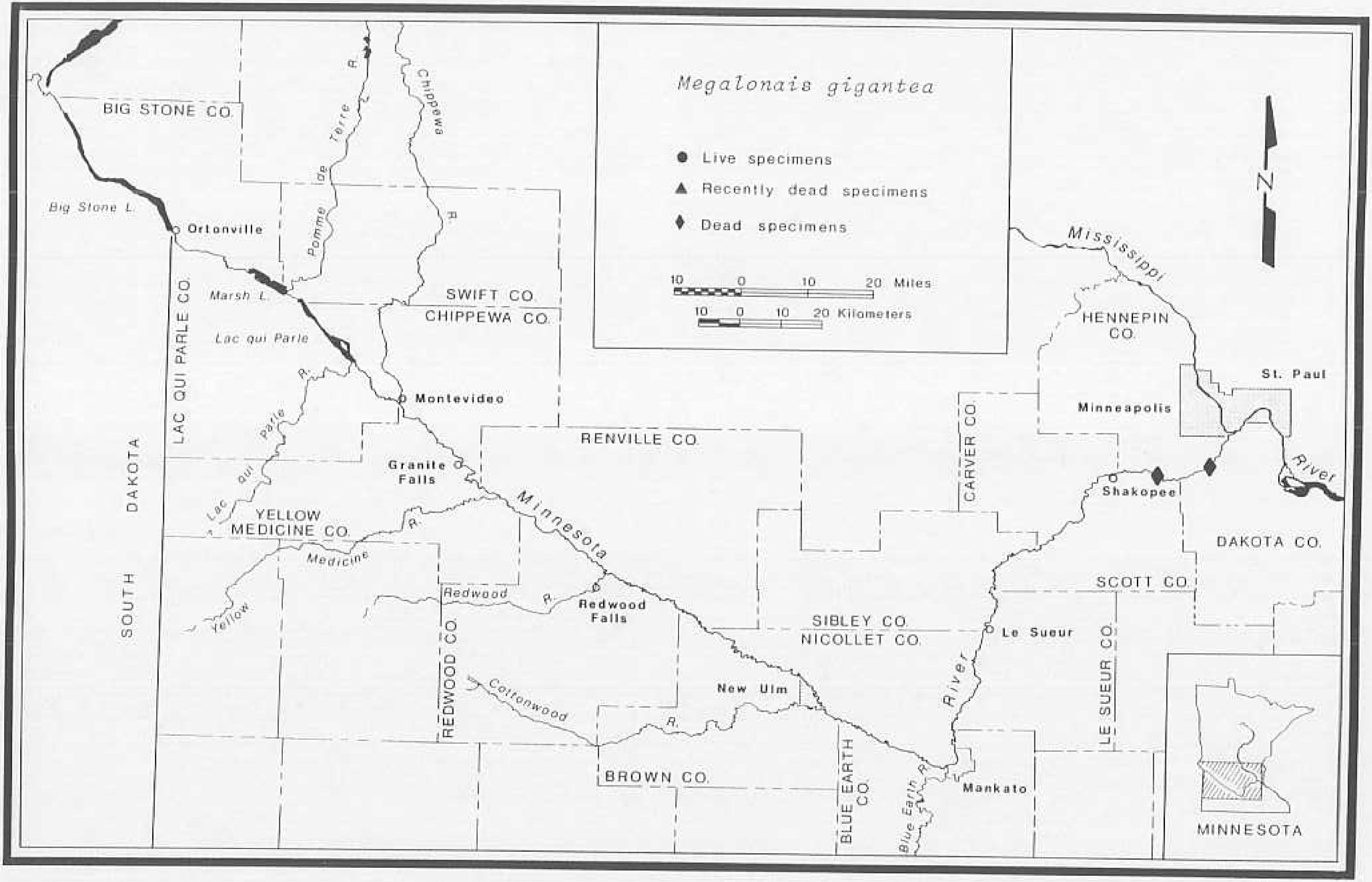


Plate 22

MUSSEL SURVEY: MINNESOTA RIVER, 1989

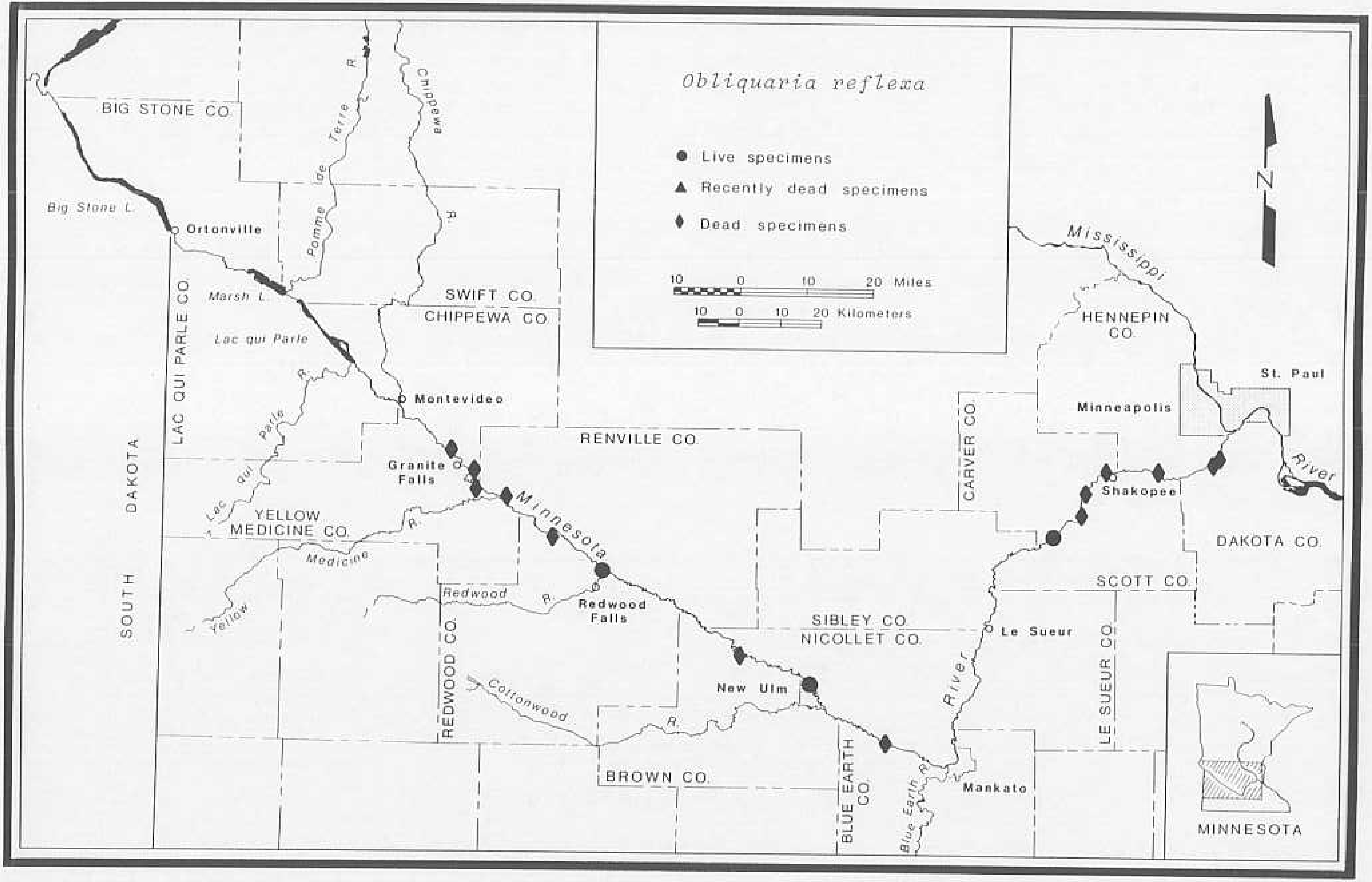


Plate 23

MUSSEL SURVEY: MINNESOTA RIVER, 1989

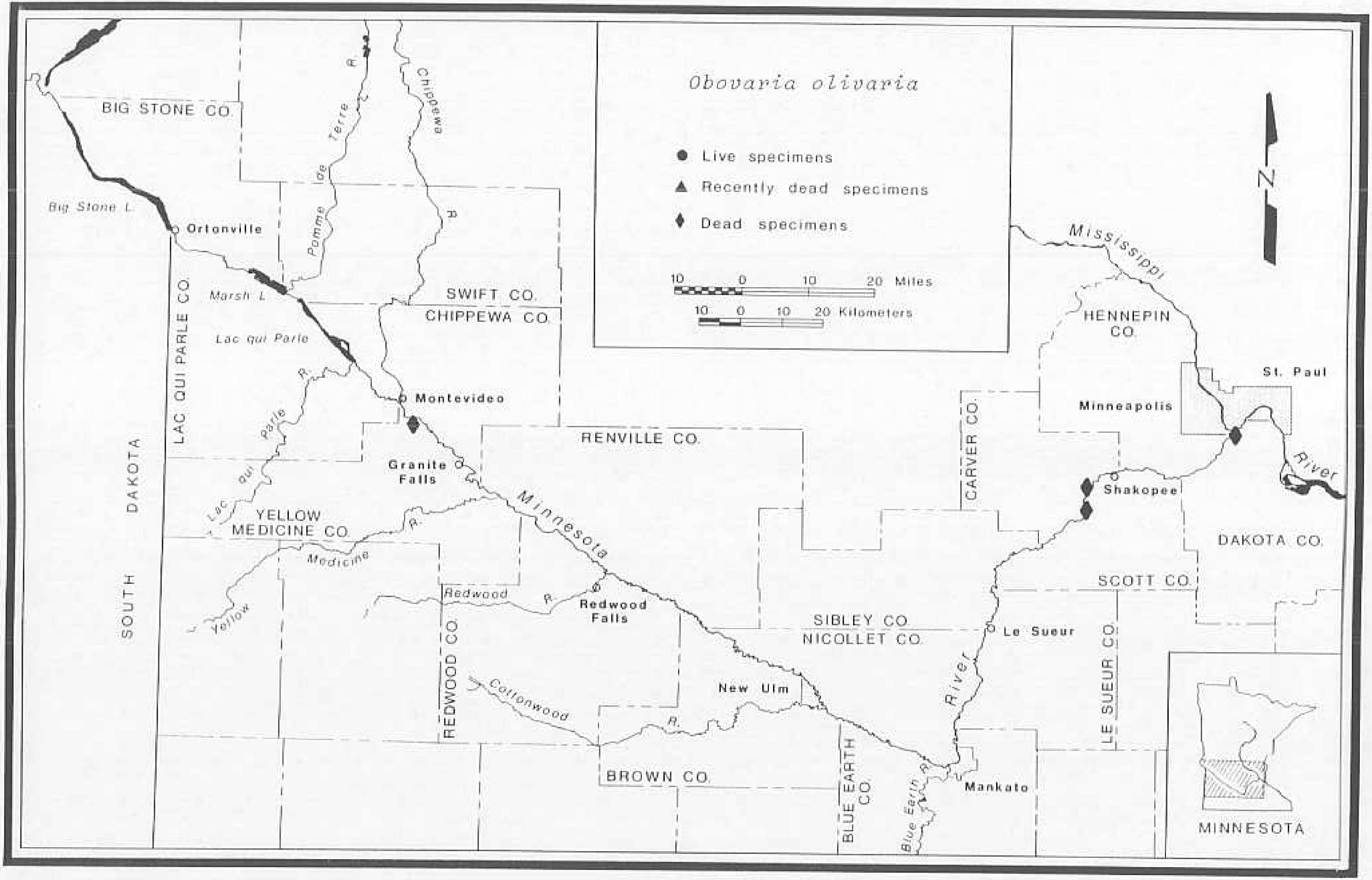


Plate 24

MUSSEL SURVEY: MINNESOTA RIVER, 1989

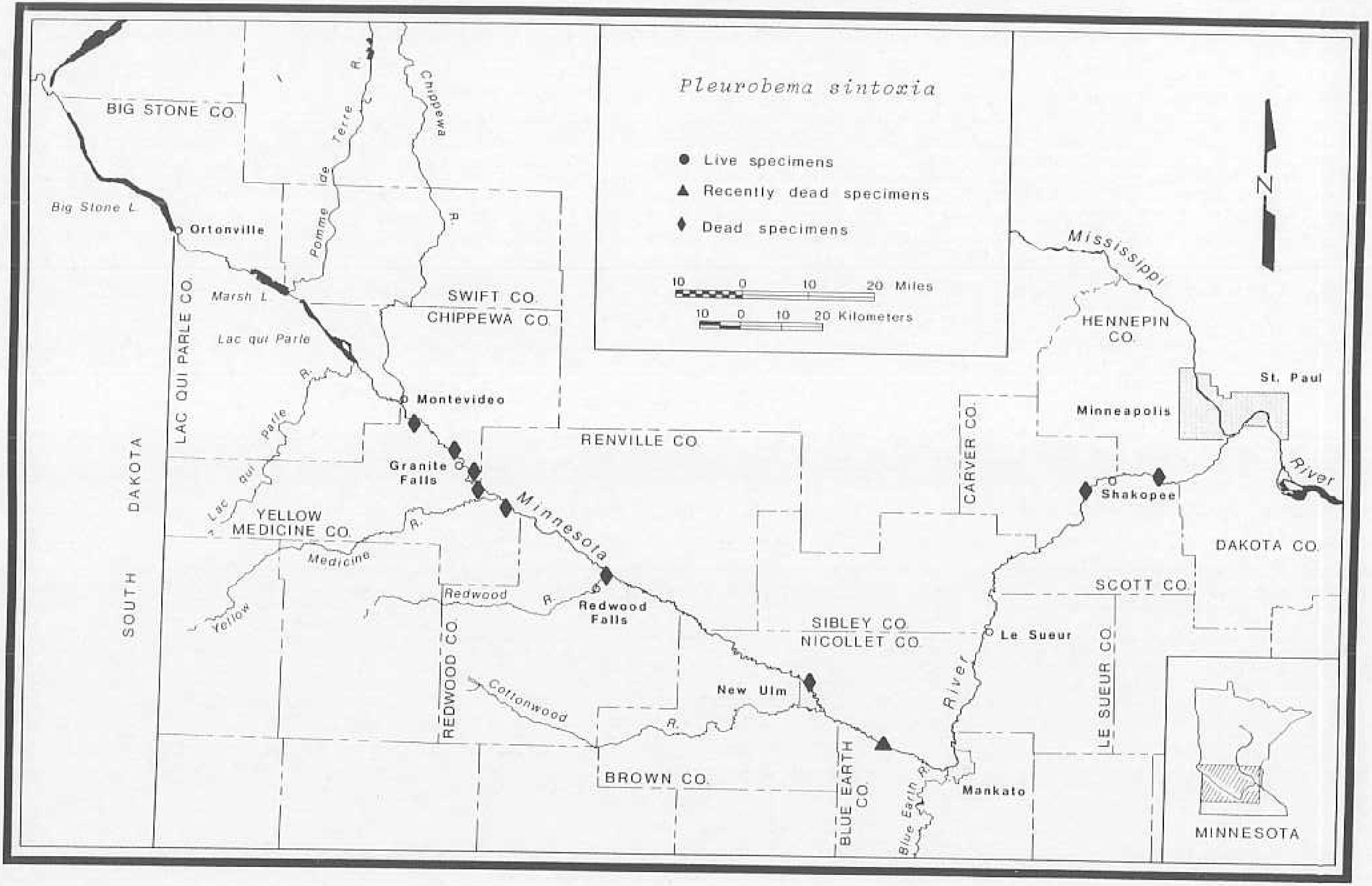


Plate 25

MUSSEL SURVEY: MINNESOTA RIVER, 1989

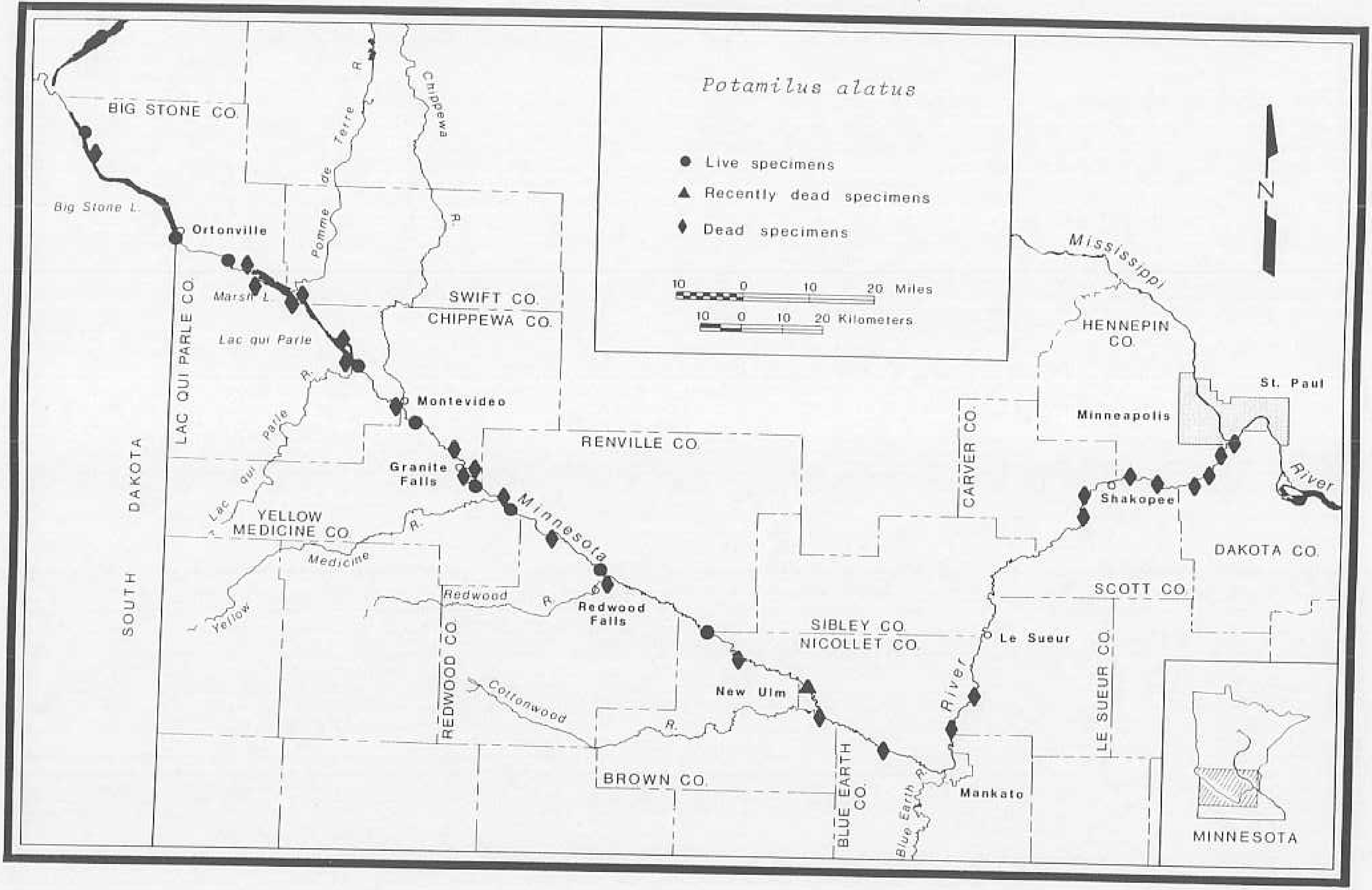


Plate 26

MUSSEL SURVEY: MINNESOTA RIVER, 1989

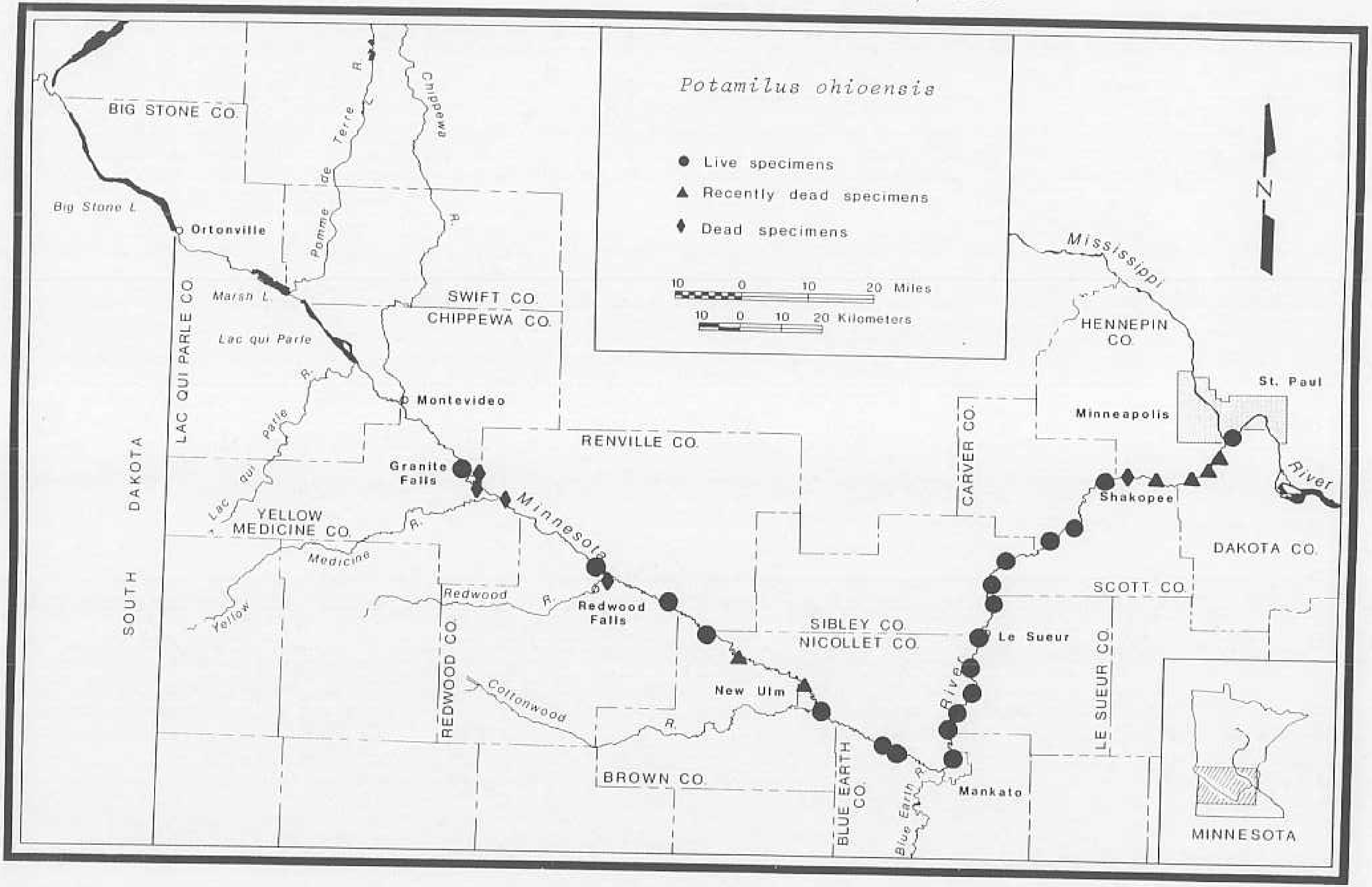


Plate 27

MUSSEL SURVEY: MINNESOTA RIVER, 1989

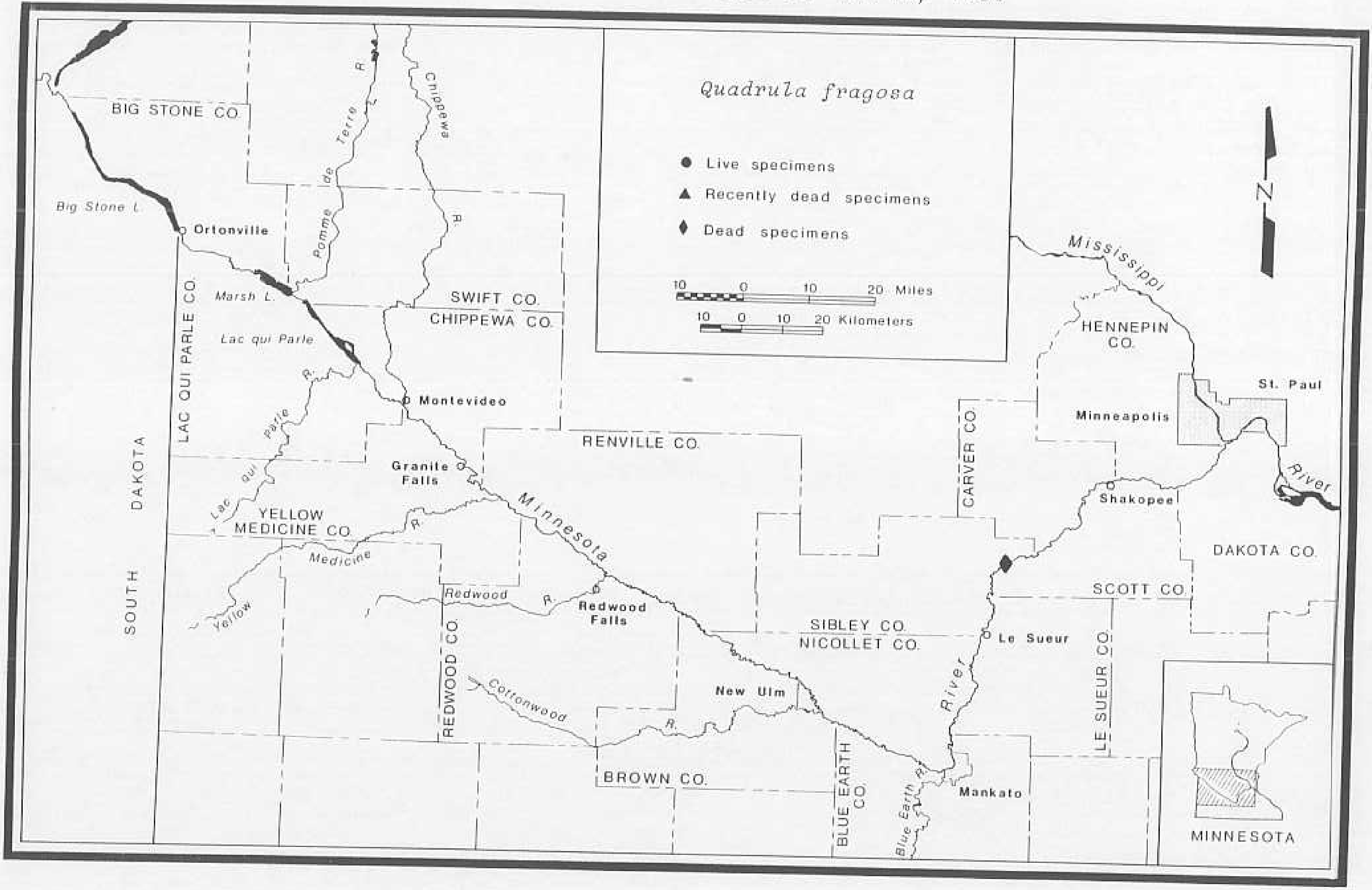


Plate 28

MUSSEL SURVEY: MINNESOTA RIVER, 1989

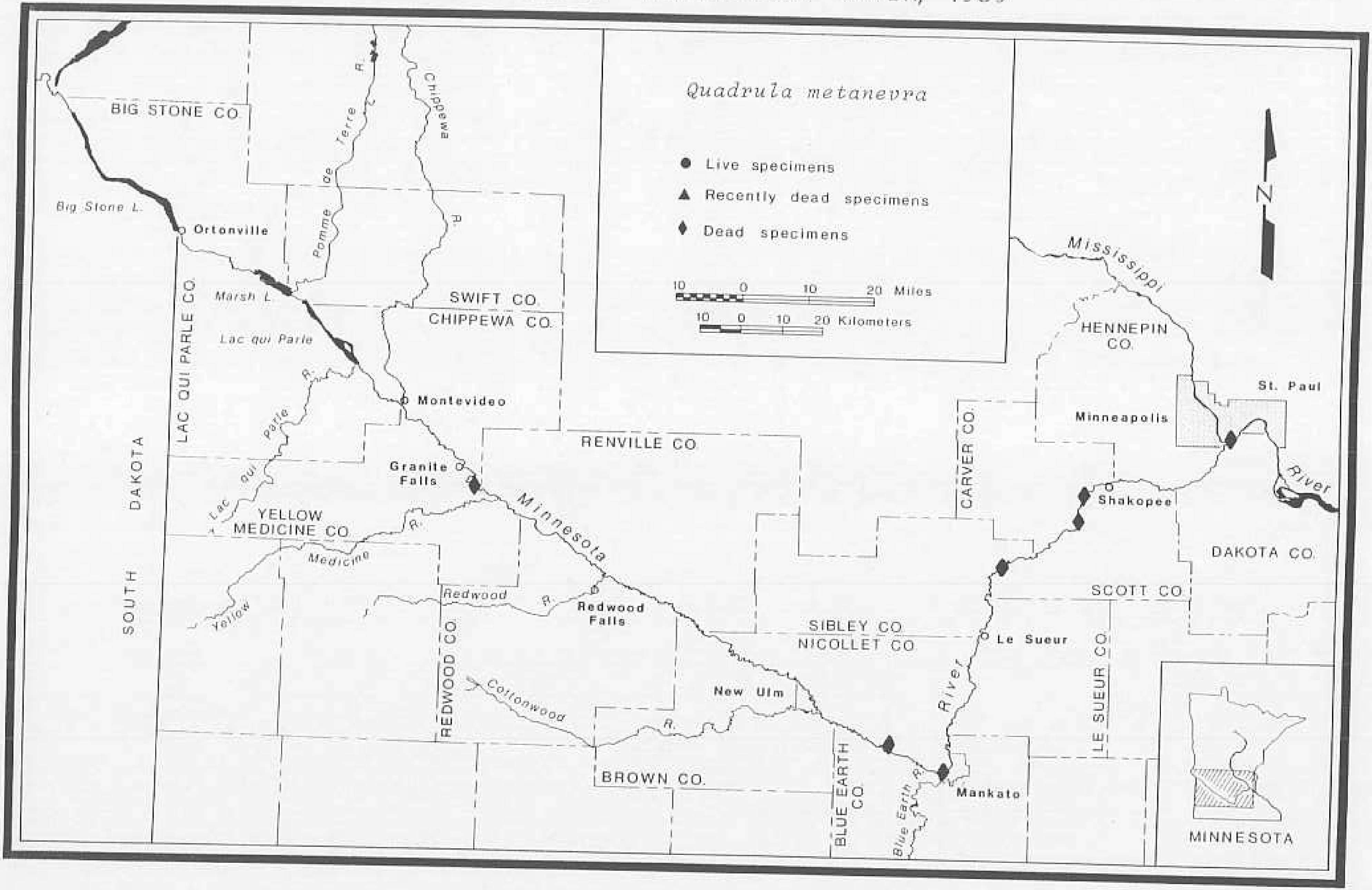


Plate 29

MUSSEL SURVEY: MINNESOTA RIVER, 1989

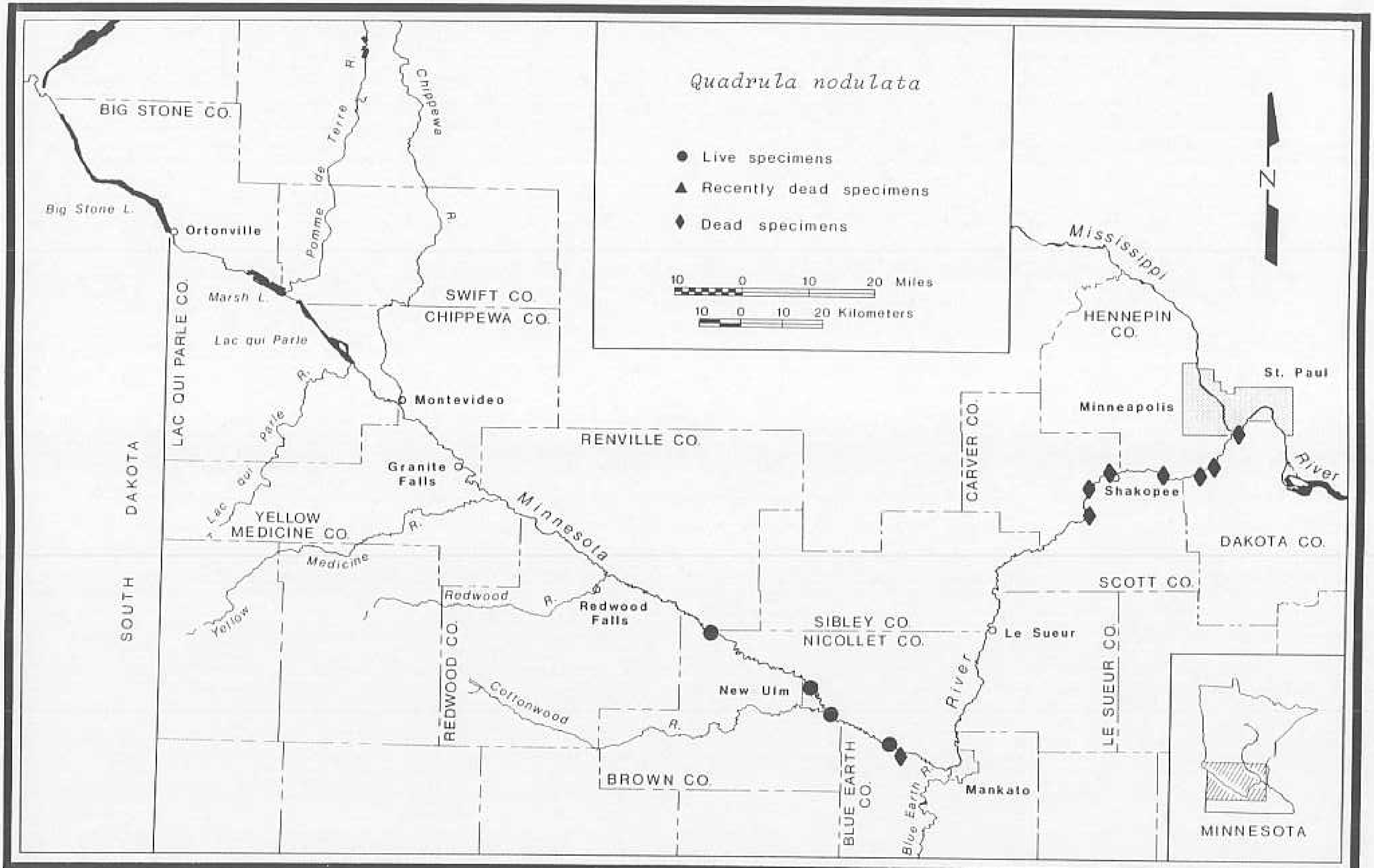


Plate 30

MUSSEL SURVEY: MINNESOTA RIVER, 1989

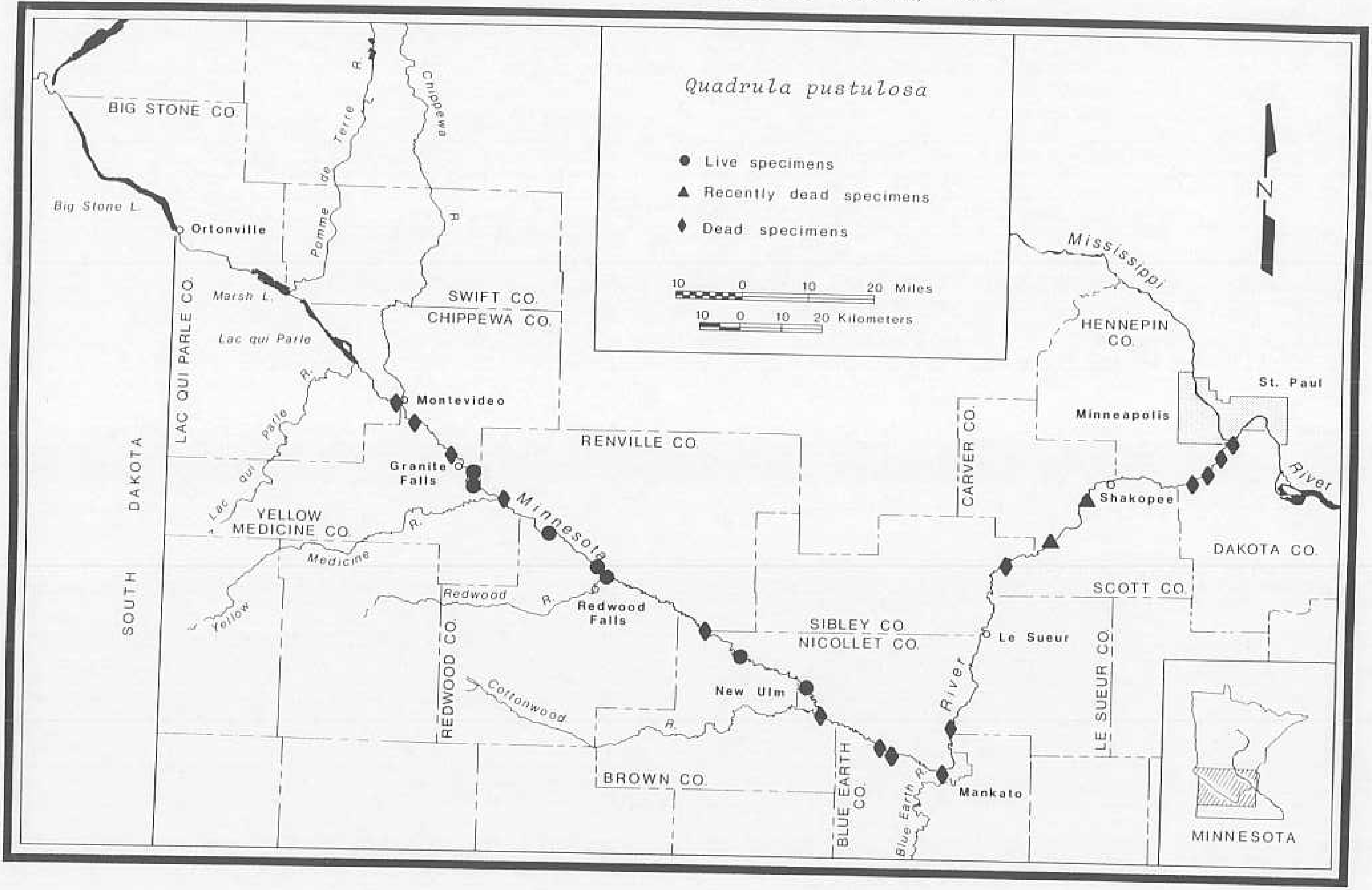


Plate 31

MUSSEL SURVEY: MINNESOTA RIVER, 1989

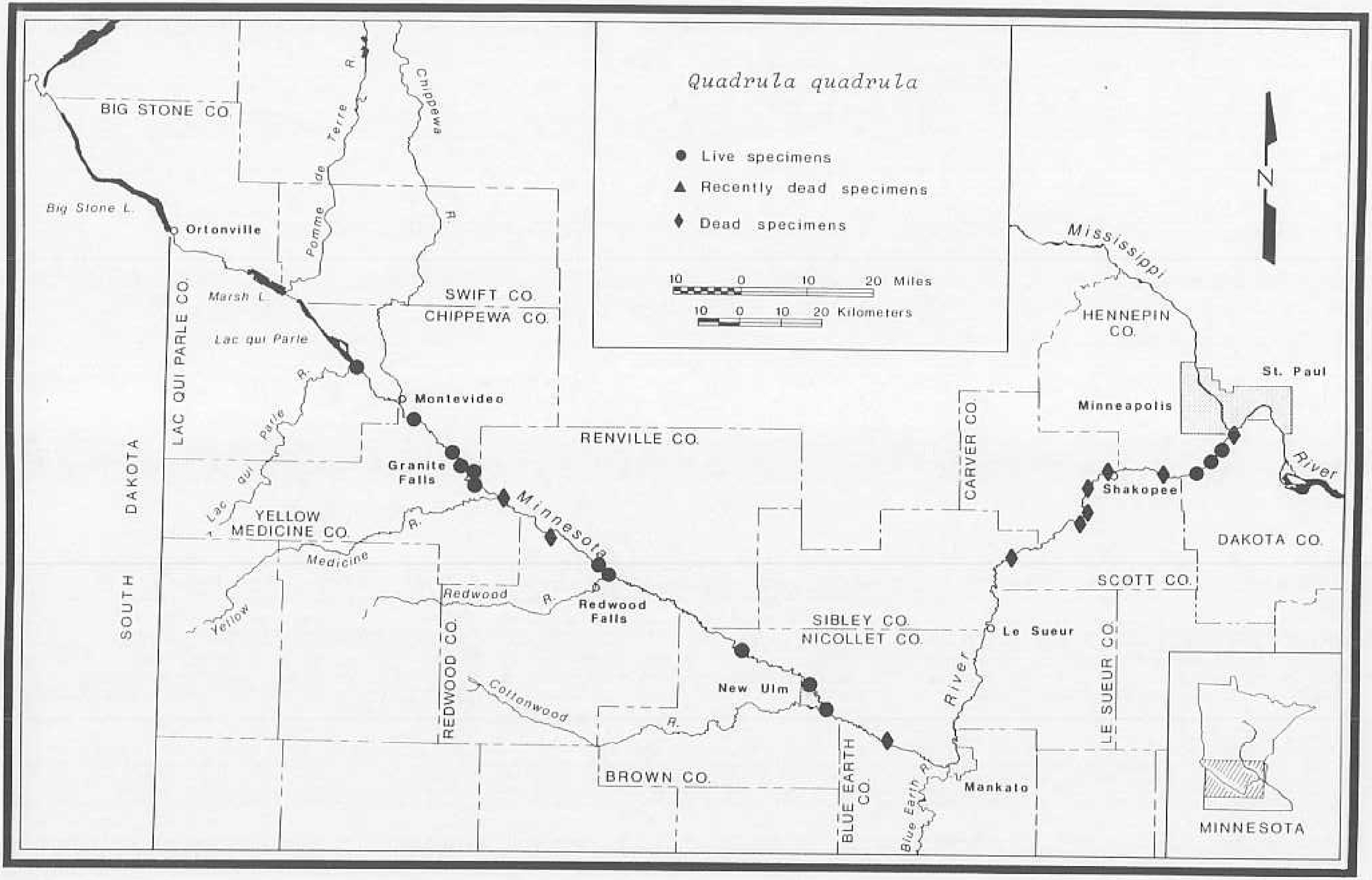


Plate 32

MUSSEL SURVEY: MINNESOTA RIVER, 1989

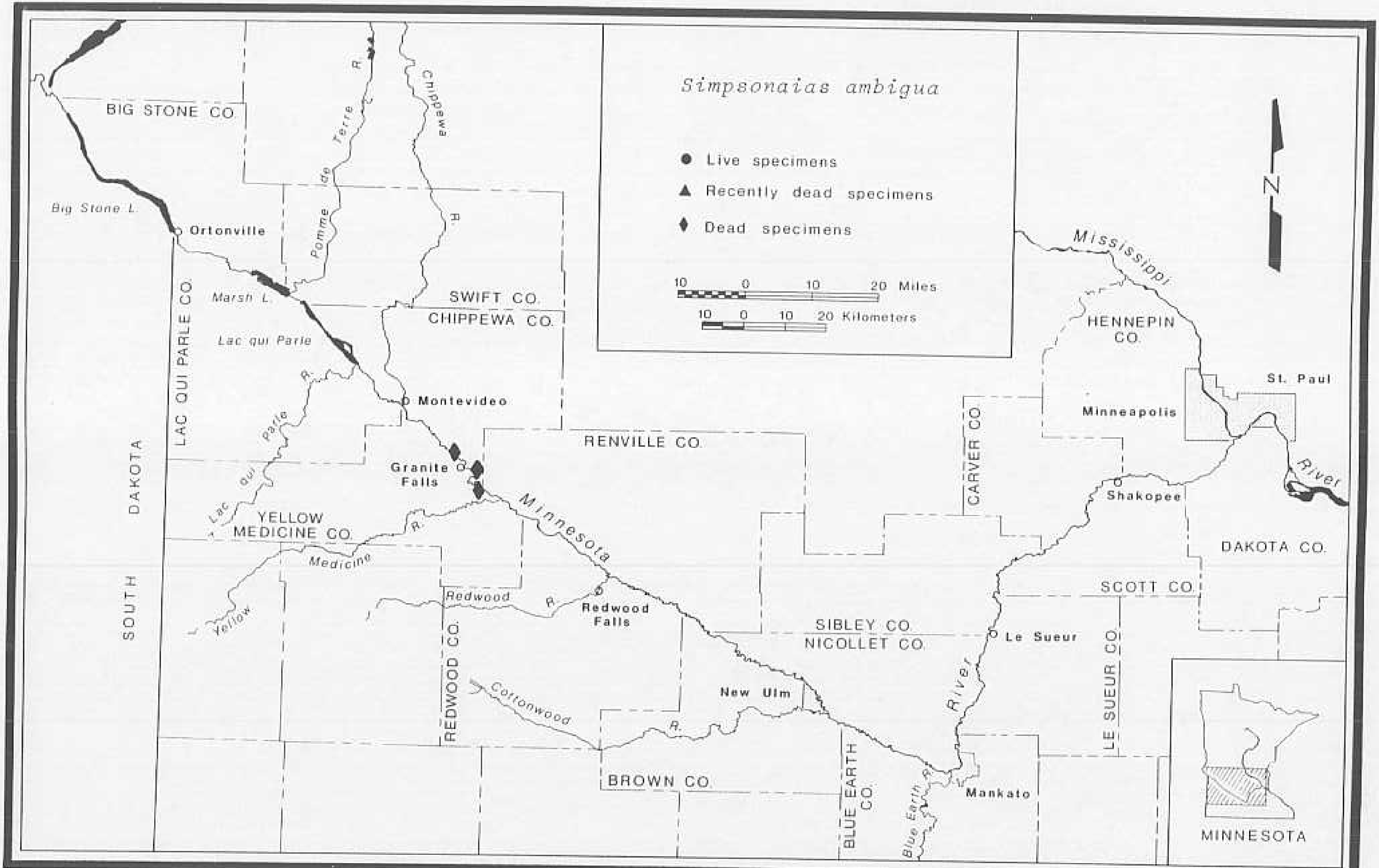
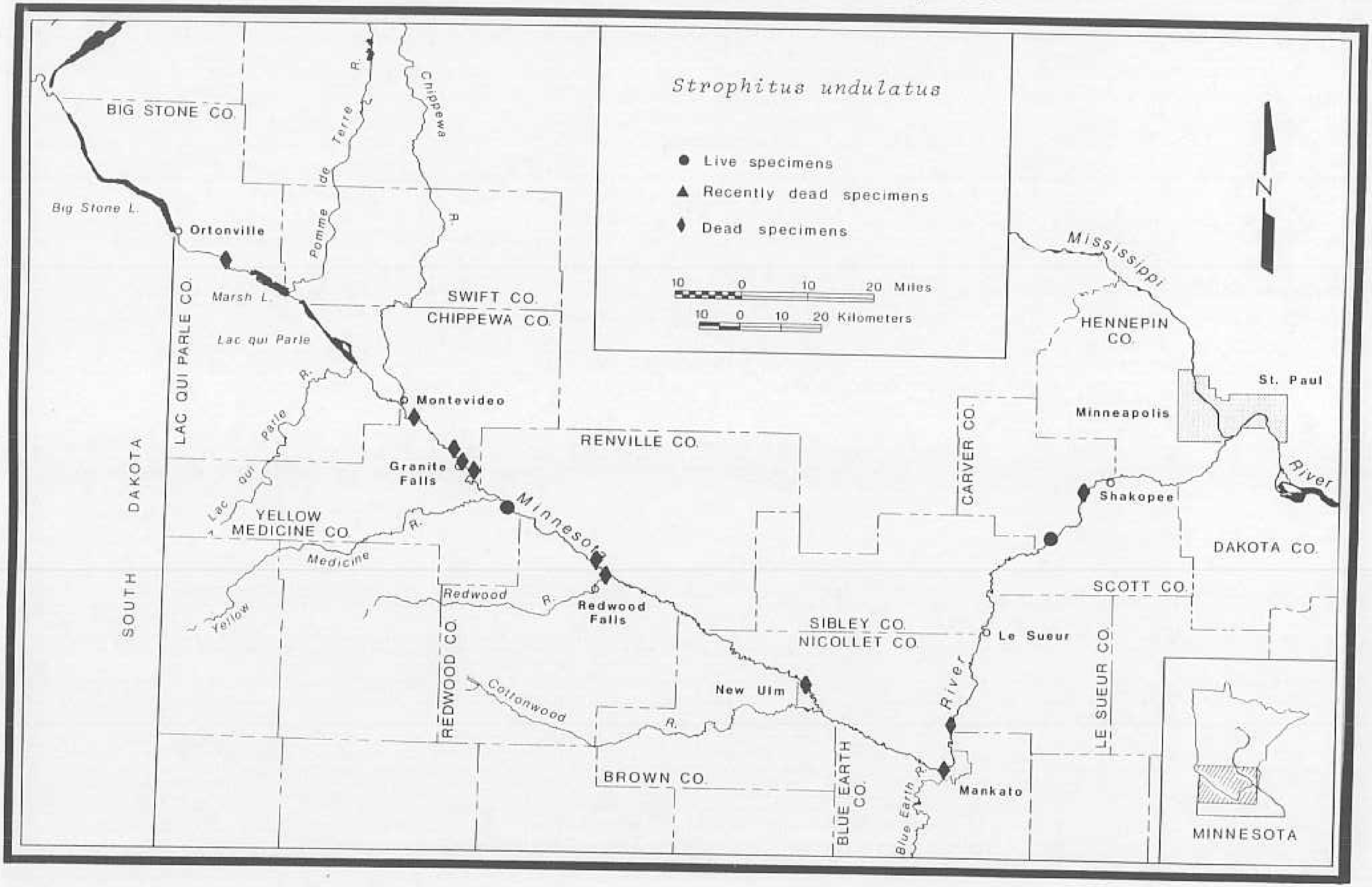


Plate 33

MUSSEL SURVEY: MINNESOTA RIVER, 1989



MUSSEL SURVEY: MINNESOTA RIVER, 1989

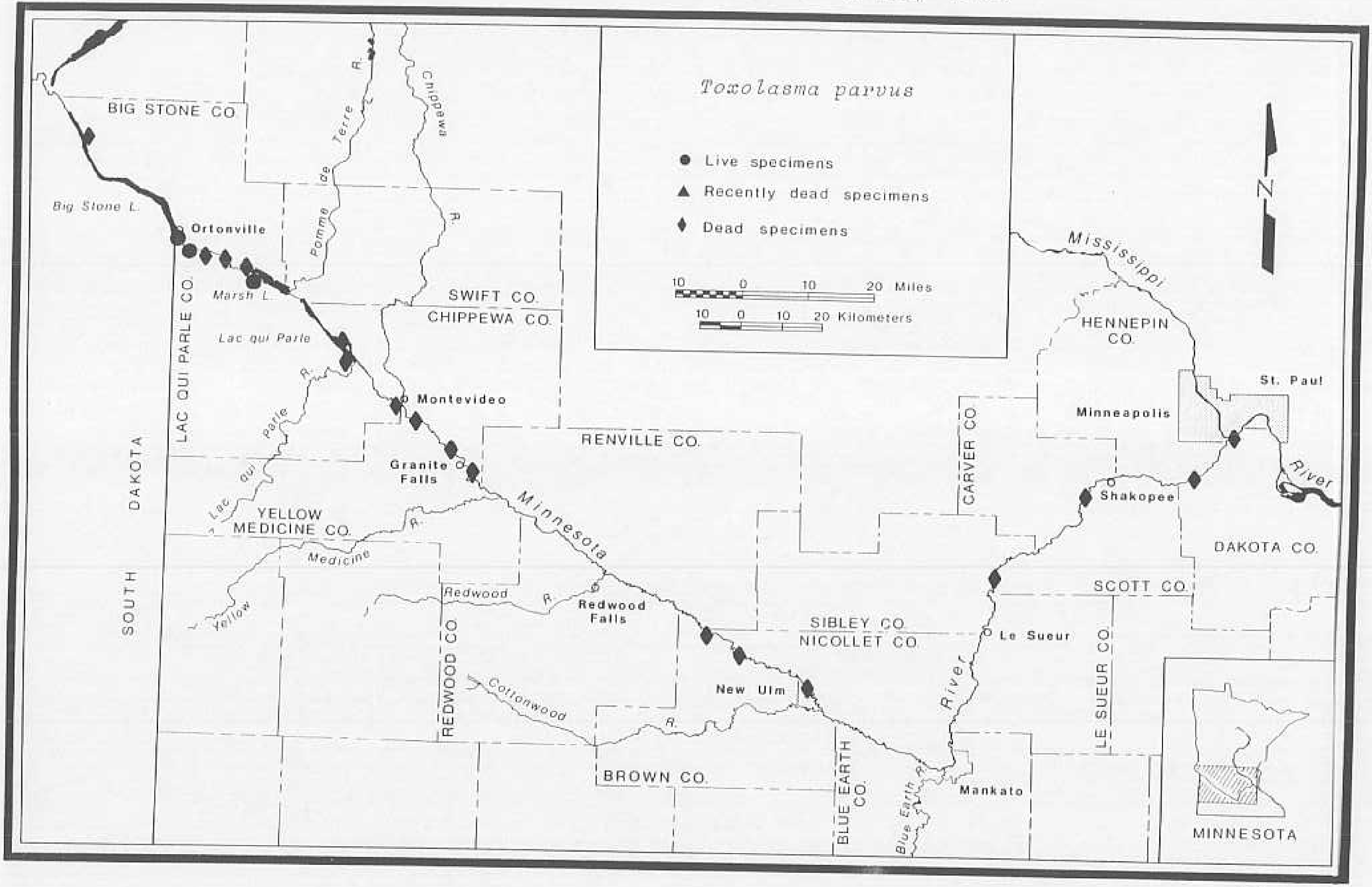


Plate 35

MUSSEL SURVEY: MINNESOTA RIVER, 1989

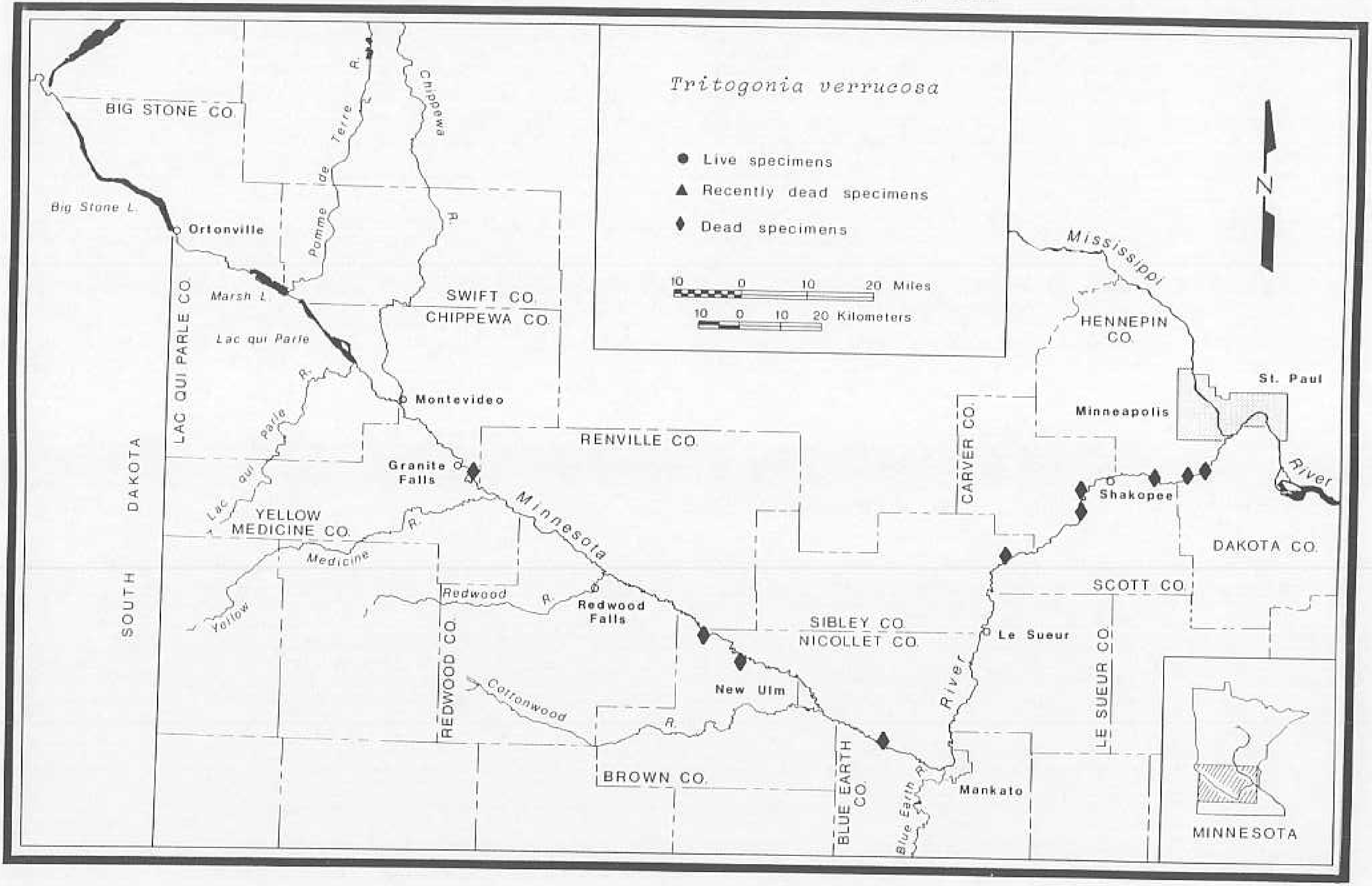


Plate 36

MUSSEL SURVEY: MINNESOTA RIVER, 1989

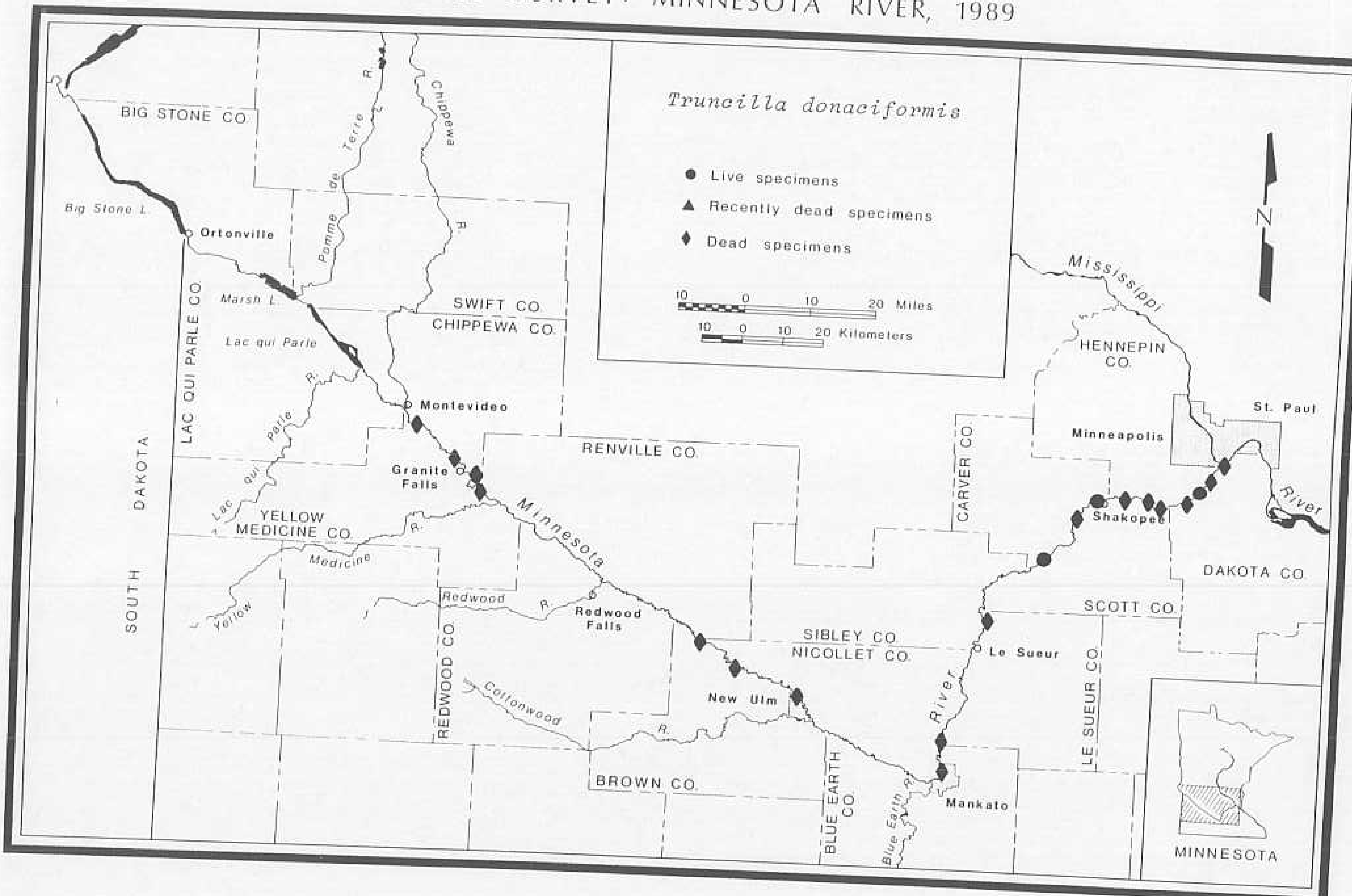


Plate 37

MUSSEL SURVEY: MINNESOTA RIVER, 1989

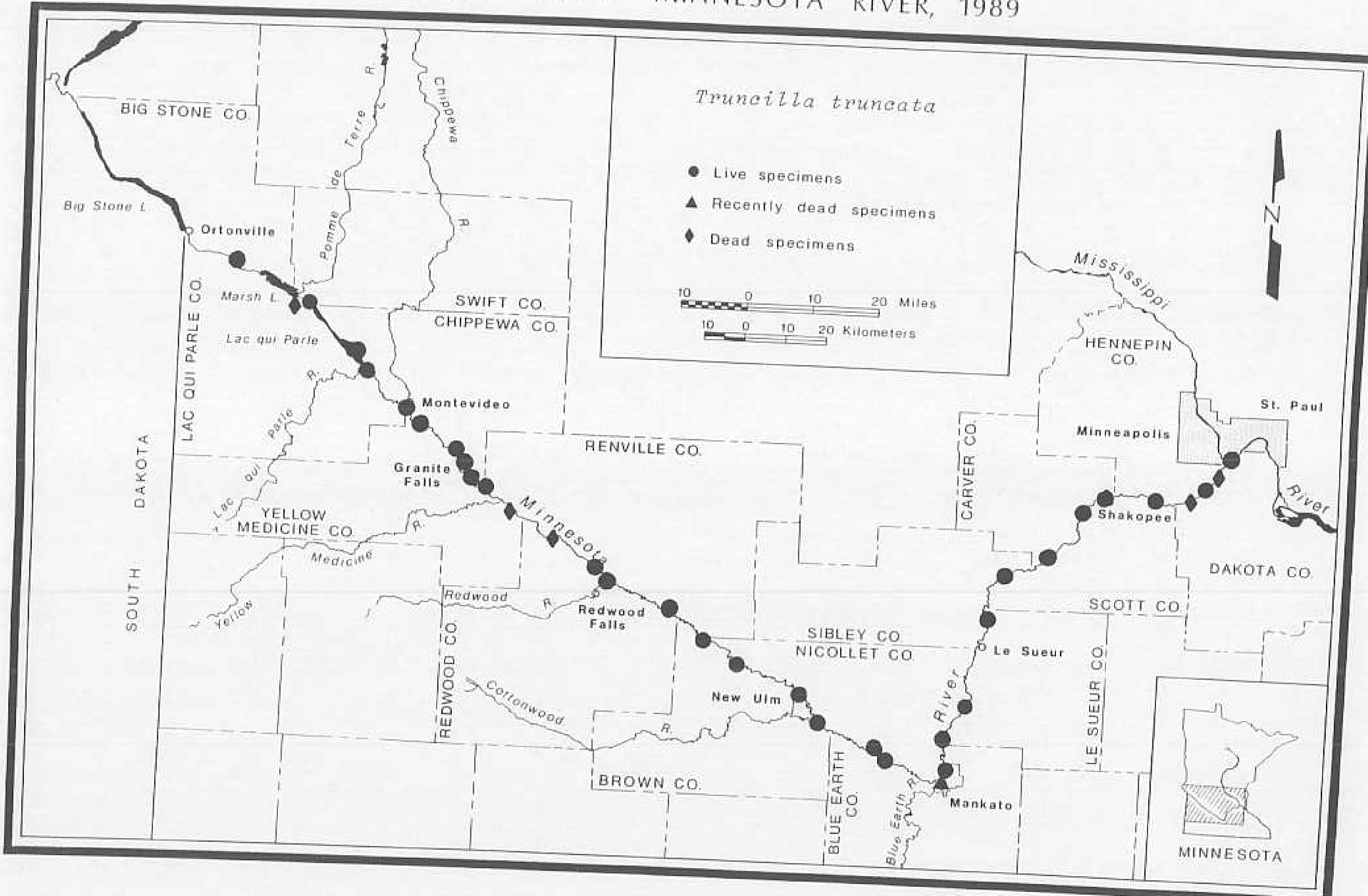


Plate 38