Results of Base-Line Sampling of Freshwater Mussel Communities for Long-Term Monitoring of the Saint Croix National Scenic Riverway, Minnesota and Wisconsin.

By

David J. Heath and Paul W. Rasmussen

Wisconsin Department of Natural Resources

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COVER

Clockwise From Upper Right

Quadrula fragosa (Conrad, 1835) winged mapleleaf
Cumberlandia monodonta (Say, 1829) spectaclecase
Simpsonaias ambigua (Say, 1825) salamander mussel
Lampsilis higginsi (Lea, 1857) Higgins eye

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Prepared by: David J. Heath and Paul W. Rasmussen

Wisconsin Department of Natural Resources

Madison, Wisconsin.

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ABSTRACT

Based on results of a 1987 survey of the Saint Croix National Scenic Riverway (Doolittle, 1988), five freshwater mussel long-term monitoring study areas were chosen in the Namekagon and Saint Croix rivers located in Wisconsin and Minnesota. This riverway contains some of the rarest mussel taxa (species and subspecies) in North America including *Lampsilis higginsi* **(Lea, 1857),** *Cumberlandia monodonta* **(Say, 1829),** *Quadrula fragosa* **(Conrad, 1835), and** *Simpsonaias ambigua* **(Say, 1825). Samples to determine several population characteristics were taken using SCUBA from June through September, 1988, and April through August, 1989. Randomly chosen one m^2 quadrat samples from which all living and dead mussels were collected were used to determine population density, community composition, age and total length distributions, living/dead and sex ratios. Supplemental collections not involving quadrats were made using stratified random diver searches to provide additional information on all but population density. A total of 38 taxa was found at the monitoring sites. Greatest taxa richness was found in downstream study areas. Of taxa known to be present in the study areas, an average of 5 taxa per study area were not found in quadrat samples. Mean population densities of total mussels (#/m^2) were highest in upstream study areas (13.1. 16.9, 9.4) and lowest in downstream study areas (5.1, 4.2).** *Actinonaias ligamentina carinata* **(Barnes, 1823) at the upstream most study area had the highest species population density (7.65/m^2). Coefficients of variation of mean total mussel density were as high as 65%. The number of quadrat samples needed in a repeated study to determine changes in mean population density varied greatly among taxa and study areas. At one study area, an estimated 401 quadrat samples were needed to detect a 10% change in total mussel population density and 16 were needed to detect a 50% change. For most individual taxa at most sites, over 300 samples were required to detect a 50% change. Two groups of taxa, one judged to be sensitive to and one exploitive of riverine degradation, required fewer samples per study to detect a change in mean population density than any of their individual members. Living/dead ratios varied from 0 to 20 for individual taxa. The lowest ratios were found in the study area with the lowest total mussel population density. Sex ratio expressed as # females/# males was 0.86. Gravid** *C. monodonta* **were found from 5 May to 23 June 1989 and not found gravid during April 1989 and from 1 July to 15 August 1988. No** *Q. fragosa* **were collected gravid although 22 specimens were collected during the time period that** *Quadrula* **spp. have been found gravid in Wisconsin. Marked and recaptured** *C. monodonta* **annual growth was dependent on size at time of initial tagging and mean annual growth varied from 11 to one mm in total length. The first quartile from population length distributions was computed as a method of comparing relative recruitment rates. For population monitoring through time, it was suggested that mussel samples be taken during the same seasons within a study area to avoid difficulties in interpreting shifts in relative recruitment caused by seasonally associated juvenile recruitment events.**

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INTRODUCTION

North American freshwater bivalve populations, particularly unionids, have undergone rapid changes since the appearance of Europeans. Stansbery (1964) reported over half the unionid species historically recorded from Mussel Shoals of the Tennessee River lost by 1963. In the Ohio River System, 11 mussel species are apparently recently extinct and 33 others are considered endangered (Stansbery, 1971). Freshwater mussels constitute the largest group of federally listed endangered or threatened invertebrates. The United State Fish and Wildlife Service lists 33 North American mussel species as endangered (United States Fish and Wildlife Service, 1989). From the upper Mississippi River, Fuller (1980) lists 23 mussel taxa as jeopardized or endangered. These post european settlement changes in freshwater mussel populations are attributed to sedimentation (Ellis, 1936), water pollution from municipal and industrial discharges (Starrett, 1971), effects of navigational and hydropower dam construction (Bates, 1962; Coker, 1930), commercial barge fleeting (Sparks and Blodgett, 1985), navigation channel maintenance (Havlik and Marking, 1980), introduction of exotic species and commercial mussel harvest (Gardner, et. al, 1976; Heath et. al., 1988).

Historically, malacologists were only able to use the presence or absence of taxa to determine the status of populations. Also, many recent investigations have employed collection techniques that have minimal reliability and are not adequately repeatable. Collection techniques such as brailing, wading, timed searches, shore collections and non-statistical choice of sampling locations all have substantial limitations, particularly for population monitoring. In an attempt to describe mussel population and community changes, some recent investigators have conducted detailed quantitative studies using repeatable methods (Miller and Payne, 1988, 1991; Miller ***et. al.***, 1990). These quantitative studies not only consider the presence or absence of taxa but also relative abundance, population shell length frequencies, population densities, and biomass.

The Saint Croix National Scenic Riverway (SCNSR) is a refuge for several globally and regionally rare mussel species (Doolittle, 1988). These globally rare taxa include *Cumberlandia monodonta* (Say, 1829), *Simpsonaias ambigua* (Say, 1825), *Quadrula fragosa* (Conrad, 1835), and *Lampsilis higginsi* (Lea, 1857). Regionally rare taxa include *Tritogonia verrucosa* (Rafinesque, 1820), *Quadrula metanevra* (Rafinesque, 1820), *Fusconaia*

ebena (Lea, 1831), *Cyclonaias tuberculata* (Rafinesque, 1820), *Elliptio c. crassidens* (Lamarck, 1819), *Ellipsaria lineolata* (Rafinesque, 1820) and *Epioblasma triquetra* (Rafinesque, 1820) (Doolittle, 1988; Heath, 1989; Wisconsin Department of Natural Resources, 1988).

Of these globally rare species, *L. higginsi* is listed as federally endangered (Federal Register 41FR24064, 14 June 1976). *C. monodonta*, *S. ambigua,* and *Q. fragosa* are presently undergoing federal review for listing. The population of *Q. fragosa* in the SCNSR is believed to be the only extant one remaining globally.

The purpose of this investigation was to collect descriptive information on freshwater mussel populations and communities within the SCNSR. The objectives were to provide base-line information for future monitoring of mussel communities and populations, with emphasis on rare taxa. An equally important objective was to gather biological and demographic information on the globally rare taxa. The descriptive information collected included population density, recruitment, living / dead and sex ratios, species richness, relative abundance, habitat descriptions and reproductive period.

STUDY AREAS

The Saint Croix River is located in northwestern Wisconsin and east central Minnesota. It drains an area of 22,196 km^2 (Graczyk, 1986) (Figure 1) and forms a portion of the border between the states of Minnesota and Wisconsin. From its confluence with the Mississippi River upstream 45 km, the Saint Croix River is known as Lake Saint Croix. This riverine lake was formed over the last several thousand years by alluvial deposits from the Mississippi River which increased its water level. Several tributaries enter the Saint Croix River. One of the largest is the Namekagon River. The Namekagon River drains an area of 2595 km^2 (Smith, 1908). The majority of the Saint Croix and Namekagon rivers are within the SCNSR which is administered by the United States Department of Interior National Park Service.

Data on mean annual flow, in cubic feet per second, is available for only 3 of the 5 study areas. At CTH K, from 1927 to 1970, mean annual flow was 472. At Narrows study area, from 1914 to 1979, flow was 1300. At Interstate study area, from 1910 to 1979, flow was 4200 (Smith, 1908).

Graczyk (1986) concluded that water quality was good in the SCNSR. Concentrations of selected water quality characteristics were better than in most other streams within the State of Wisconsin. For example, dissolved oxygen ranged from 9.4 to 11.0 mg/l, mean suspended sediment from 3.0 to 15.0 mg/l, mean total phosphorus from 0.02 to 0.08 mg/l, and total nitrogen from 0.42 to 1.3 mg/l. Major ion concentrations were low except for iron and manganese.

Five areas were chosen in the SCNSR for this mussel study (Figure 1). Results of a river-wide mussel survey conducted by Doolittle (1988) were used to identify study areas locations that met four criteria. The first criteria was that study area locations had to be distributed throughout the riverway. Where possible locations were selected that contained rare mussel taxa and had a high and ostensibly uniform population density based on cursory inspections using SCUBA. Finally, each area had to have comparatively easy accessibility. Of the five study areas selected, four were located on the Saint Croix River and one was located on the Namekagon River.

The following are location and size descriptions of each of the five study areas. River km are the

upstream distance from the mouth of the stream. Topographic maps with river distances are on file at the Wisconsin Department of Natural Resources (WDNR) and the Water Milage System has been described by Fago (1988).

CTH K

Namekagon River km 48.99 to 49.49. T-40-N, R-12-W, section 18 NE quarter, Washburn County, Wisconsin. Dunn Lake, Wis. United States Geological Survey 7.5' quadrangle, 1982. Upstream boundary located 430 m downstream of the Trego Lake dam on the upstream margin of a wooded unnamed island. Downstream study area boundary on the upstream margin of the first wooded island downstream of County Trunk Highway K. Surface area and mean width were approximately 19,870 m^2 and 40 m, respectively (Figure 2).

NARROWS

Saint Croix River km 190.47 to 190.61. T-41-N, R-17-W, section 35 SE quarter of SW quarter of NE quarter, Burnett Co., Wisconsin. Yellow Lake, Wis.-Minn. United States Geological Survey 7.5' quadrangle, 1982. On left descending bank. Upstream boundary 98 m upstream of center of protruding rocky point. Downstream boundary 38 m downstream of center of protruding rocky point. Surface area and mean width were approximately 2230 m^2 and 16.4 m, respectively (Figure 3).

INTERSTATE

Saint Croix River km 83.23 to 84.97. T-34-N, R-19-W, section 35 SE quarter of SE quarter, and section 36, Chisago County, Minnesota and Polk County, Wisconsin. St. Croix Dalles, Wis.-Minn. United States Geological Survey 7.5' quadrangle, 1978. Upstream boundary is perpendicular to the river flow extending out from the boat ramp within Interstate Park on the Wisconsin side. The downstream boundary is a line perpendicular to the river flow extending through the downstream margin of a wooded island locally known as Blast Island. This island is located largely in section 35 NE quarter of SE quarter of SE quarter. Surface area and mean width were approximately 315,286 m^2 and 181 m, respectively (Figure 4).

MARINE 2

Study area located between Saint Croix River km 58.97 and 59.50. T-32-N, R-19-W, section 31 SE quarter of SE quarter of SE quarter, section 31 SW quarter of SE quarter of SE quarter, Polk County, Wisconsin. T-31-N, R-19-W, section 6 NW quarter of NE quarter of NE quarter, section 6 NE quarter of NW quarter of NE quarter, section 6 SE quarter of NW quarter of NE quarter, St. Croix Co., Wisconsin. Marine on St. Croix, Minn.-Wis. United States Geological Survey 7.5' quadrangle, 1967. On left descending bank. The upstream boundary was 200 m upstream of the point where the Polk and St. Croix county lines meet the waterline. The downstream boundary was 330 m downstream of the point where the county lines meet the waterline. Several other landmarks are given in Figure 6. Mean width was 8.7 m with a maximum of 13 m and a minimum of 4 m. Surface area was approximately 4609 m^2.

Supplemental collection sites located at Saint Croix River km 57.88, T-31-N, R-19-W, section 6 SW quarter of NE quarter of SW quarter, and km 58.47, T-31-N, R-19-W, section 6 NE quarter of SE quarter of NW quarter. Both in Washington County, Minnesota. Marine on St. Croix, Minn.-Wis. United States Geological Survey 7.5' quadrangle, 1967. Both near right descending bank (Figure 6).

HUDSON

Study area located between Saint Croix River km 26.71 and 29.17 (to obtain U. S. Government river distances subtract 0.88 km) in Lake Saint Croix. T-29-N, R-20-W, section 23, 26 and 35, Washington County, Minnesota. Hudson, Minn.-Wis. United States Geological Survey 7.5' quadrangle, 1967. The upstream boundary is perpendicular to the river flow and is located 370 m upstream of the railroad bridge. The downstream boundary is parallel to and beneath the downstream Interstate 94 bridge. The portion between the railroad bridge and a point 290 m upstream of the southern study area boundary are coterminous with the designated *L. higginsi* (Lea, 1857) essential habitat (Higgins' Eye Mussel Recovery Plan). The study area portion upstream and downstream of these two points is within the designated essential habitat but includes a smaller area. Surface area and mean width were approximately 125,435 m^2 and 51 m, respectivley (Figure 5).

Supplemental collection site located at Saint Croix River km 27.79 (to obtain U. S. Government river

distances subtract 0.88 km). T-29-N, R-20-W, section 26 SE quarter of SW quarter of NE quarter, St. Croix County, Wisconsin. Hudson, Minn.-Wis. United States Geological Survey 7.5' quadrangle, 1967. Directly out from west end of causeway near left descending bank (Figure 5).

METHODS AND MATERIALS

The groups of bivalve mollusks studied included *Corbicula fluminea* and members of the families Margaritiferidae and Unionidae. Several bivalve collection methods were used depending on the type and amount of population and community information needed.

The dates sampled at each of the 5 study areas are given below.

CTH K: 29 August 1988 - 2 September 1988.

Narrows: 22 August 1988 - 24 August 1988; 12, 13 September 1988.

Interstate: 27 June 1988 - 21 July 1988; 21 April 1989; 5, 23, May 1989; 8, 9, 23 June 1989; 27, 28 July 1989; 16 - 18 August 1989.

Marine 2: 25 - 28 July 1988; 1 - 4 August 1988; 26 July 1989.

Hudson: 8 - 11 August 1988; 14 September 1988; 6 July 1989; 14, 16 August 1989.

To determine population densities, living / dead ratios, and community composition, a one m^2 quadrat was placed at randomly located stations within each of the five study areas. Station locations were selected by randomly choosing two-dimensional coordinates on a grid overlaid on an enlarged study area map. Where practical, stations were located in the field by measuring distances from identifiable points. When measuring was impractical, stations were located by estimating distances and directions visually. At each station, one quadrat was placed on the substrate and all living bivalves and empty shells were removed by hand by a diver equipped with self contained underwater breathing apparatus (SCUBA) and brought to the surface in a 3 mm mesh-sized bag. Substrate within each quadrat was excavated to a depth at which no additional bivalves were found. A total of 286 quadrat samples were divided amoung study areas such that the coefficients of variation of total mean mussel population density were roughly equivelent.

The second collection method, relative abundance collection, involved the procurement of additional numbers of living mussels without the use of quadrats. This method was used where mussel numbers from quadrat samples were low. As many as three stratified random stations were selected in each study

area within which all living bivalves encountered by random diver searches were collected. Stations were stratified by choosing evenly spaced stations along the length of the study area. These data were used for all population and community descriptors except density and living / dead ratios.

The third collection method was similar to the second except that it was directed at target taxa, not at the entire mussel community. Taxa (species, subspecies and forms) of special concern were collected when total numbers were inadequate from other methods. At the Marine 2 and Hudson study areas, it was necessary to establish supplemental collection sites to procure larger numbers of target taxa that were microhabitat specific. Data from target taxa collections were used only to estimate aspects of target taxa populations, including living / dead and sex ratios, and population total length and age distributions.

In addition, any rare living or empty mussels observed incidentally during all collection procedures were recorded to supplement taxa richness information. Unidentifiable empty shells and empty shell fragments collected using any method were not recorded. Only living and identifiable empty shells or shell fragments were recorded.

Living specimens obtained from all collection methods were measured using a vernier calipers for total length and total height. Total length is defined as the maximum total shell distance approximately parallel to the hinge line from the anterior to posterior margins. Total height is the maximum shell distance from the dorsal to ventral margins approximately perpendicular to the total length. Age in years was estimated by counting the total number of growth rings on the exterior surface of the shell. Most specimens were examined to determine whether or not they were gravid. This determination was done by the examination of the marsupia and excurrent aperture for the presence of either eggs or glochidia. For sexually dimorphic taxa, sex was identified based on external shell characteristics. Sex was not recorded for taxa that did not exhibit conchological sexual dimorphism. Sex was not recorded for individuals thought to be sexually immature. Substrate particle size was estimated visually and tactilely at each sampling station for each collection method. Particle size definitions approximated those

of Fago (1988). Bedrock was defined as solid rock forming a continuous surface. Sizes of the following categories in mm were 300 or greater for boulder, 76 to 299.9 for rubble, 3 to 75.9 for gravel, 1.0 to 1.9 for coarse sand, 0.06 to 0.99 for fine sand, 0.004 to 0.059 for muck and silt, and less than 0.004 for clay. Detritus was defined as dead organic material covering the bottom. Water current was estimated visually and tactilely as fast, moderate, slow or no perceivable current.

Initial examinations of mussel population density distributions suggested that they were skewed, and that the standard deviation increased with the mean. We used the logarithmic transformation ($\log_e$(density + 1)) to make the population density distributions more nearly normal and to stabilize the variance. The logarithmic transformation was also suggested because collections of many taxa appeared to follow a negative binomial distribution. Mean population densites were back-transformed yeilding geometric means.

All statistical comparisons and sample size calculations were carried ou on the log scale since it is on this scale that the assumptions of these procedures were best satisfied. The geometric mean, which is the back-transformed mean of the log transformed observations, is presented along with the arithemitc mean in Tables 3-7. Because of the skewed nature of the data the arithmetic mean may not be a good summary measure of population denisty, but it is useful of comparison with other studies.

Coefficients of variation and 95% confidence intervals were calculated for the log transformed data. On the log scale the 95% confidence interval is symmetric about the mean, while it is asymmetric when back-transformed to the original scale. Mussel population densities were compared among sites using one way ANOVA on the log transformed data, with comparisons between pairs of sites carried out using Tukey's studentized range test as modified by Kramer for unequal sample sizes (Sokal and Rohlf, 1981).

Means and variances (log scale) of the population density from the current study were used to estimate the sample sizes necessary to detect differences of a given size between two monitoring studies. The results are presented in terms of % change from current means population densities for each taxon. The formula used is given below (see Sokal and Rohlf, 1981).

$$N = 2(Z_\alpha + Z_\beta)^2 s^2 / \delta^2$$

where N = number of samples needed in each study

α = significance level (we used $\alpha = 0.05$)

$1 - \beta$ = the power of the test, that is, the probability of rejecting the null hypothesis when it is not true (we used $1 - \beta = 0.8$)

Z_x = normal deviate corresponding to probability x

s^2 = variance of mussel population density

δ = the size of the difference between means, measured as a difference in densities, but presented as % change from the current mean

All computations were done using using Statistical Analysis System, version 5 (SAS, 1985a, 1985b).

C. monodonta were marked by etching a unique number on the periostracum of both valves, measured for total length, and replaced to the microhabitat they were found in. Marked individuals were recaptured almost exactly a year after capture. Specimens were then remeasured and condition was noted as living, dead or moribund.

RESULTS AND DISCUSSION

TAXA RICHNESS

Taxa richness is one useful measure of changes in mussel populations. Living members of 39 taxa were collected from within the five study areas during 1987-1989 (Table 1). All taxa collected living were also represented by empty shells. Two taxa, *F. ebena* and *E. c. crassidens* were collected empty only during 1988-1989, but the latter was collected living during 1987. Taxa richness was greatest in downstream study areas (Table 2). CTH K study area contained the least number of taxa with 16. Narrows study area contained 22 taxa, Interstate had 33, Marine 2 had 29 and Hudson had 31.

The cumulative number of taxa collected using methods whose results are representative of the community (i.e. quadrat and relative abundance collection methods) was influenced by the total number of individuals collected. Figures 7 to 11 present evidence that all or nearly all taxa potentially present

were collected. Except for the Marine 2 study area which had a comparatively small sample size, significant taxa richness plateaus were reached which suggested that all or nearly all taxa present were sampled. But all taxa present were not sampled using methods representative of the community. There are two reasons for this.

Some taxa were extremely rare at a site or their spatial distribution was very clumped because they were found only within scarce circumscribed microhabitats. Collection methods used to describe the community rarely found these taxa. These taxa were found in target taxa collections or were incidentally collected while using other methods. For example *C. monodonta* was present in four study areas but was collected only in target taxa samples. At Interstate in a population sample size of 1788 mussels, 5 taxa were collected only incidentally or in target taxa collections. Relative abundance collections missed 6 taxa at Marine 2, 4 at Hudson, 3 at Narrows and none at CTH K. Therefore, these taxa richness curves have limited use in predicting the total numbers of taxa present but are good predictors of the number of taxa expected using collection methods that provide results representative of the mussel community.

The presence of empty shells may indicate the presence of taxa within a study area, particularly if their condition suggests recent death. At Hudson, the presence of freshly dead *Lasmigona costata* (Rafinesque, 1820) suggested that although it was not collected living, it may occur there. All other taxa collected dead only are given in Table 2. All those collected as empty shell only during 1988-1989 appeared to have died some time ago.

RELATIVE ABUNDANCE

Clear numerical dominance by a single taxon in mussel communities has been observed commonly by others. Thiel (1981) found *Amblema p. plicata* (Say, 1817) constituted 59.2% of the mussel community in the Mississippi River. Parmalee and Klippel (1984) found *Villosa vanuxemensis* (Lea, 1838) constituted nearly 50% of the fauna in the Tellico River, Tennessee and Williams and Schuster (1989) found *F. ebena* clearly dominant in the Ohio River. Numerical dominance by single taxon seemed to have occurred prehistorically as well. Theler (1987) found *F. ebena* constituted 58% of the subfossil assemblage at

several archeological sites in southwestern Wisconsin. Murry (1981) found *Cyrtonaias tampicoensis* (Lea, 1838) clearly dominant in the Frio River, Texas. Although dominance by a single taxon in unionid communities seems common, a cursory survey of the literature suggested that co-dominance or no dominance seems equally common. Reasons for single taxon dominance are unknown but could include competitive exclusion, availability of host organisms, physical and chemical factors, food availability and water temperature.

In the present study, a clear numerically dominant taxon was apparent at each of the 5 study areas. The dominant taxon varied between study areas with the two upstream areas having the same dominant. *Actinonaias ligamentina carinata* (Barnes, 1823) dominated the community at both CTH K (55.06% of total mussels) and Narrows (34.33%). *Truncilla truncata* Rafinesque, 1820 was dominant at Interstate (51.34%). *Fusconaia flava* (Rafinesque, 1820) dominated at Marine 2 (27.07%) and *A. p. plicata* was dominant at Hudson (37.18%). In each study area, the dominant was two to eight times more numerous than the subdominant. Of the remaining taxa, at least 72% comprised less than 5% of the community in each study area (Tables 3 to 7).

Shifts in relative abundance can be used as a tool to describe changes in mussel communities. In the Mississippi River, *F. ebena* may have constituted from 58% to 80% of the community (Coker, 1921; Theler, 1987) prior to 1930. Recent investigations all reported its rarity and replacement by the more environmentally tolerant *A. p. plicata* (Fuller, 1980; Thiel, 1981). The near extirpation of *F. ebena in the upper Mississippi River watershed* is due to the loss of its anadromous host fish after the construction of a dam (Coker, 1930).

POPULATION DENSITY

Relative abundance comparisons through time can indicate shifts in community composition but give no information about absolute abundances. Estimates of population and total mussel density do provide measures of absolute abundance by supplying information on numbers of individuals per unit area that can be compared through time. In addition, population density information can provide insight into

ecological questions such as minimum number of mussels required for successful reproduction, patchiness, and association between abundance and physical, chemical and biological factors.

In the present study, total mussel density was higher in the upstream study areas than the downstream areas (ANOVA, with Tukey's procedure). Mean of the log transformed density of total living mussels per m^2 (± STD) was 2.64 ± 1.04 (geometric mean = 13.07) at CTH K and was not significantly different ($p<0.05$) from either Narrows which was 2.89 ± 1.27 (geometric mean = 16.93) or Interstate which was 2.34 ± 1.19 (geometric mean = 9.42). Mean total mussel density at Marine 2 was 1.81 ± 0.62 (geometric mean = 5.13) and was not significantly different from Interstate or Hudson which was 1.65 ± 1.03 (geometric mean = 4.22) (Table 9). Raw data summaries of frequency of occurrence are given in Appendix A.

Mean of the natural logarithm transformed population density of individual taxa per m^2 varied between 0 and 2.16 (geometric mean = 7.65). Several taxa present in study areas were not collected during quadrat sampling and received an estimate of 0 (Tables 3 to 7). Mean estimates for two of the four globally rare unionids were not obtained. *C. monodonta* and *S. ambigua* were both present in each of the four downstream study areas but only *S. ambigua* was collected in quadrats at Narrows. Both these mussels had an extremely clumped distribution and occurred in microhabitat uncommon within the study areas. The probability of randomly selecting uncommon microhabitat was small given the total number of quadrats sampled. Even with a greater number of quadrat samples, an extremely clumped distribution would make the mean estimate very unreliable. *Q. fragosa,* which was found only at Interstate, had a mean population of 0.02 ± 0.11. *L. higginsi* was found at Interstate and Hudson had a mean of 0.02 ± 0.11 and 0.01 ± 0.08, respectively.

Coefficients of variation for mean log transformed population densities were high, probably as a result of random or clumped spatial distributions. The lowest coefficient of variation for total mussel density was 34.4% at Marine 2 followed by 39.3% at CTH K, 44.0% at Narrows, 50.6% at Interstate, and 65.2% at Hudson. Values for individual taxa were higher, often exceeding 300%. The large variances result in

relatively wide 95% confidence intervals for mean population density estimates (see Table 13).

Large variances not only decrease the precision of point estimates, but also increase the sample sizes needed to detect population density changes through time. For example, the estimated number of m^2 samples per time period necessary to detect a 10% change in mean total mussel density at Interstate was 401. To detect a change of 20% required 100 samples, 30% required 45, 40% required 25 and 50% required 16. Estimated samples sizes for total mussels for each study area are given in Figure 12. For individual taxa the number of samples required to detect changes in mean population densities were larger, particularly for the rarest mussels. For both *L. higginsi* and *Q. fragosa* at Interstate, we estimated that over 55,000 samples would be required to detect a 10% change in mean population density and over 2,200 samples to detect a 50% change (Appendix B). For *L. higginsi* at Hudson, over 108,000 samples are required to detect a 10% change and over 4,300 for a 50% change. For the majority of individual taxa, the number of samples required to detect even a 50% change in mean population density varied from between 11 for the most abundant taxa to 6774 for the rarest with the majority greater than 300. Because quantitative samples of more than about 150 per site are impractical, it is useful to consider monitoring taxa groups rather than individual taxa for population density changes.

The largest grouping possible is all taxa. In each of the five study areas a 20% to 30% change in total mussel population density can be detected with less than 100 samples in each area. Although such overall comparisons are useful, they give limited information on the globally rare and environmentally sensitive taxa which are a primary focus of monitoring efforts. This same drawback applies to comparisons between time periods of only the dominant taxa. An intermediate approach is to group taxa on the basis of their ecological or management characteristics. If taxa can be grouped in useful ways, this approach has the advantage that fewer samples will be required to detect changes that would be necessary for individual taxa.

We assigned taxa to one of three groups based on their apparent tolerance to degraded environmental conditions expressed as geographic range reductions in the upper midwest. For example, the loss of *L.*

higginsi from 52.5% of its original range (Havlik, 1980) indicated that it would be best placed in the group of environmentally sensitive taxa. This group includes only taxa that appear to be very sensitive to human-caused disturbances. Recent laboratory and field investigations indicate that *A. p. plicata* is quite tolerant to environmental degradation and has increased in abundance so it was placed in the exploitive group (Starrett, 1971). Taxa placed in the indifferent group were those that did not seem to fit easily into the other two groups or whose populations did not seem to have changed perceivably in degraded streams. Members of the three groups and group means of the natural logarithm transformed population densities are given in Table 8.

As long as taxa groups contain more that one member, samples sizes required to detect a change of a given size will be generally smaller for the group than for its individual members. For example, detecting a 30% change in mean population density requires between 312 and 6155 one m^2 samples for the members of the sensitive taxa group individually, but for the group as a whole only 112 samples are required. At Marine 2, detecting a 30% change requires 725 to 7317 samples for the sensitive taxa individually, but requires only 218 samples for the group.

LIVING/DEAD AND SEX RATIOS

The total mussel living / dead ratio was highest at CTH K (2.81) followed by Interstate (2.28), Marine 2 (1.73), Narrows (1.36) and Hudson (0.52) (Tables 3 to 7). Living / dead ratios had a maximum of 20 and a minimum of 0.0 for individual mussel taxa. The six lowest ratios for individual taxa were found at Hudson. These were *Truncilla donaciformis* (Lea, 1827) (0.02), *L. higginsi* (0.04), *Corbicula fluminea* (Muller, 1774) (0.05), *Ligumia recta* (Lamarck, 1819) and *Actinonaias ligamentina carinata* (Barnes, 1823) (both 0.06), and *Lampsilis radiata luteola* (Lamarck, 1819) (0.09). Reasons for these low ratios at Hudson are unknown. They may include high recent mortality or weak recent recruitment, either of which may explain the low value for *T. donaciformis*. This short-lived mussel's abundance could potentially change dramatically from the appearance of a single poor year class thus affecting the living / dead ratio. These ratios are probably best interpreted relative to base-line living / dead data and in combination with population and

age class information. Degree of shell preservation may also affect living / dead ratios between study areas.

We were only able to calculate sex ratio (# of females / # of males) for six taxa. These taxa were *E. lineolata, E. triquetra, L. higginsi, L. r. luteola, Lampsilis ventricosa* (Barnes, 1823), *L. recta,* and *T. verrucosa.* Most ratios were less than 1.0 which indicated more males than females. The sex ratio for all 5 study areas combined was 0.67. Total ratios by site varied from 0.57 at Narrows to 0.84 at Interstate. The cause of more than the expect one-half of living mussels manifesting male conchology is unknown. It is possible that sexually immature individuals were identified as males. It is probably more likely that there were reproductively sterile females identified as males. A third possibility is that a segment of the population is hermaphroditic and that male conchological characteristics are expressed by them.

GRAVID PERIODS OF *C. monodonta* AND *Q. fragosa*

Gravid *C. monodonta* were found from 5 May to 23 June 1989 (Figure 18). They were not found gravid during April 1989 and from 1 July to 16 August 1988. The highest percentage of the population found gravid was observed on 8 June 1989 (38.2%, N=34). Based on this evidence and assuming one brooding period per calendar year, *C. monodonta* is a summer brooder (tachytictic), although we have no samples from September through March. Howard (1915) found a single gravid specimen on 2 May 1912. Because its ovaries were full of mature eggs he concluded that there are two broods produced in a season. However, the presence of mature eggs in a gravid individual does not necessarily indicate the production of multiple broods. Transfer of eggs from the gonads to marsupia could occur over several weeks in a single brooding season. Of the 26 *C. monodonta* specimens found gravid during spring 1989, the smallest in total length was 58 mm and was estimated, based on external annuli counts, to be 3 years of age.

No gravid *Q. fragosa* were collected during 1988 and 1989. A total of 22 of the 49 specimens examined in the two years were collected at the time of the year when *Quadrula* spp. were found gravid in Wisconsin. Figure 19 summarizes combined brooding periods for four members of *Quadrula* collected from Wisconsin. These four members are *Quadrula quadrula* (Rafinesque, 1820), *Quadrula metanevra*

(Rafinesque, 1820), *Quadrula p. pustulosa* (Lea, 1831) and *Quadrula nodulata* (Rafinesque, 1820). The sample of 861 *Quadrula* individuals was collected from the end of May to mid-October and gravid *Quadrula* were found from late May to the third week of July. Within this time period, we had examined 22 *Q. fragosa* and none were found gravid (Table 10). During this time period, and assuming *Q. fragosa* has the same brooding period as *Quadrula* spp., we would have expected to find about 20% of the *Q. fragosa* (4 specimens) gravid. Although this is a low expected number gravid, in combination with the absence of individuals less than 4 years of age, it may indicate the lack of any young-of-the-year recruitment into the *Q. fragosa* population.

C. monodonta GROWTH AND MORTALITY

A total of 164 *C. monodonta* were tagged during 1988. A total of 135 of these were recaptured during 1989 (=82%). Of the 135 specimens recaptured, 6 (=4.4%) were found dead. This annual total mortality rate of 4.4% is probably natural and expected for a long-lived organism.

C. monodonta annual growth in total length varied with size at time of capture during 1988. Figure 20 presents a Walford Plot (Worthy, 1978) of recaptures. Mean annual growth in mm for specimens 20 to 60 mm in length was 11. Specimens 60 to 100 mm grew 6 mm on average and those between 100 to 150 mm grew one mm. Since this data is restricted to only to one year's growth, data from additional years is needed to construct a more useful relationship between age and total length using a Walford plot representing multiple years of growth.

SUBSTRATE DESCRIPTIONS

Visually determined substrate composition varied between sites (Table 11). At CTH K study area, rubble dominated 45% of the bottom followed by gravel and coarse sand. The only study area dominated by boulder was Narrows (30%) which explained why it was the only study area that *S. ambigua* occured in randomly selected quadrat samples. Coarse sand was dominant at Interstate (33%) and rubble at Marine 2 (38%). The substrate at Hudson was primarily fine sand (48%).

POPULATION LENGTH AND AGE STRUCTURES

Absence of small mussels in samples is a historic problem for most investigators. This problem probably stems from relatively few small individuals present because of fast growth rates during juvenile life stages. A second possible cause is the use of collection methods that under-sample small mussels.

In the present study, very small (<10 mm length) mussels were frequently collected, although probably under-represented (Appendix C). Because of underwater visibility exceeding 0.75 m at all 5 study areas, divers were able to see small mussels easily. In this study, the under-representation of small specimens was due to unnoticed specimen drift from substrate disturbance caused by the diver. In addition, specimens less than 3.1 mm were lost through the mesh collecting bags. The smallest specimen found was a *Potamilus alatus* (Say, 1817) at Interstate study area which was 3 mm in total length. For taxa with greater than 29 individuals measured by total length at a site, relatively small individuals were always observed. Therefore, recent recruitment occurred for these species at these study areas. For taxa with very large samples (N> 300), the age class presumed to be 0 or 1 was represented in the length distributions as a distinct peak.

Although a sampling bias towards size was present, for monitoring purposes this bias does not reduce the ability to compare recent recruitment through time. Assuming the same sampling methods are used in the future, biases would be similar to the present study. If sampling techniques were used that provided a different bias, data could be compared for selected size classes. Therefore, the use of population length distributions to measure relative young-of-the-year recruitment should allow comparisons through time. Difficulties would arise only if comparisons were attempted for absolute recruitment.

We are using the first quartile (Q_1) of the length distribution as a measure of relative recruitment. The first quartile is that length below which the lowest 25% of the lenths lie. In a yer of good youg-of-th-year recruitmentt, the Q_1 should be small because of the large proportion of small individuals; in a year of low recruitment, on the other hand, the Q_1 should be larger because of the small proportion of small individuals.

The first quartile of the length distribution was calculated for all taxa that had 30 or more individuals represented in the population samples. These quartiles are presented in Table 12. Q_1 values for each taxon differed between study areas. For example, values for *Elliptio dilatata* (Rafinesque, 1820) varied from 15.5 mm at Interstate to 93.7 mm at Hudson. These between study area differences could be caused by different growth rates and time of year sampled as well as by different recruitment rates.

Growth rates are likely to differ between study areas because of differences in food availability, quality and other factors. The calendar dates of samples may explain different Q_1's from 1988 and 1989 observed for two species. Different Q_1's were noted for the two taxa for which we had sufficient data from both 1988 and 1989. These were *C. monodonta* at Interstate (49.8 mm in 1988, 69.3 mm in 1989) and *S. ambigua* at Interstate (26.2 mm in 1988, 21.2 mm in 1989) and at Marine 2 (29.0 mm in 1988 , 32.0 mm in 1989). These differences could be due to the time of year the samples were taken and do not necessarily reflect different relative recruitment rates. During 1988, nearly all *C. monodonta* from Interstate were collected during July immediately after adults ceased being gravid and presumably when juveniles first appeared. During 1989, however, the majority of the sample was taken prior to July. As expected, the 1989 sample contained fewer small individuals. The different months in which the 1988 and 1989 samples were taken may explain the 20 mm difference in Q_1's between these two years for *C. monodonta*. The same may be true of *S. ambigua*, although the differences were smaller. We conclude that comparisons of length distributions to estimate changes in relative recruitment is useful. These comparisons should not use data collected during different times of the year in order to avoid complicaitons caused by seasonal juvenile mussel deposition.

FUTURE MONITORING PROTOCOL

This report presents results from a base-line study of freshwater mussel populations. The goal of the study was to determine, as far as was possible during one sampling point, some population characteristics that could be used for monitoring. To ensure that results of future monitoring efforts are comparable to results of the present investigation, some suggestions concerning study design and effort

for future investigations are given here.

1) Monitoring should continue annually for five consecutive years after which it should be done about once every five years. Annual monitoring for the first five years is intended to establish larger and more accurate base-line information and to determine if there are any short term changes in endangered species populations. Some populations may be prone to annual or multi-year changes in population density, age and length structures, living / dead ratios and community composition. These population changes can be caused by natural mortality events and natural variations in young-of-the-year recruitment and survival. After the sixth sampling year, trend analysis can be done.

2) Sampling methods used here should be duplicated. Population density samples should be taken and information on age, height, length, habitat, gravid condition, sex and living / dead ratios and community composition should be collected. Quadrat samples using seiving instead of hand collecting can be used and compared with caution to results given here. We recommend when comparing data between these two methods, that all speicimens less than 20 mm in total length be elimiated from the analysis.

3) The total number of quadrat samples for all study areas and each study area to be taken in future monitoring depends on the desired level of statistical certainty. We would suggest as a balance between field effort and statistical reliability, that a number of samples be taken to detect a 30% change in the geometric mean at each site. This would include a total of about 575 quadrat samples distributed among study areas as indicated in Figures 13 through 17.

4) Temporal data comparison should be done for population length, height and age distributions, population densties, sex ratios, living / dead ratios, gravid conditiona and community composition. For those taxa that were underrepresented in quadrat samples, target taxa collections should be made to obtain sufficient specimens for comparisons of length, height and age distributions, sex and livng / dead ratios, and gravid condition.

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Figure 1. General location of five study areas sampled for freshwater bivalves in the Saint Croix and Namekagon rivers, Minnesota and Wisconsin during 1988.

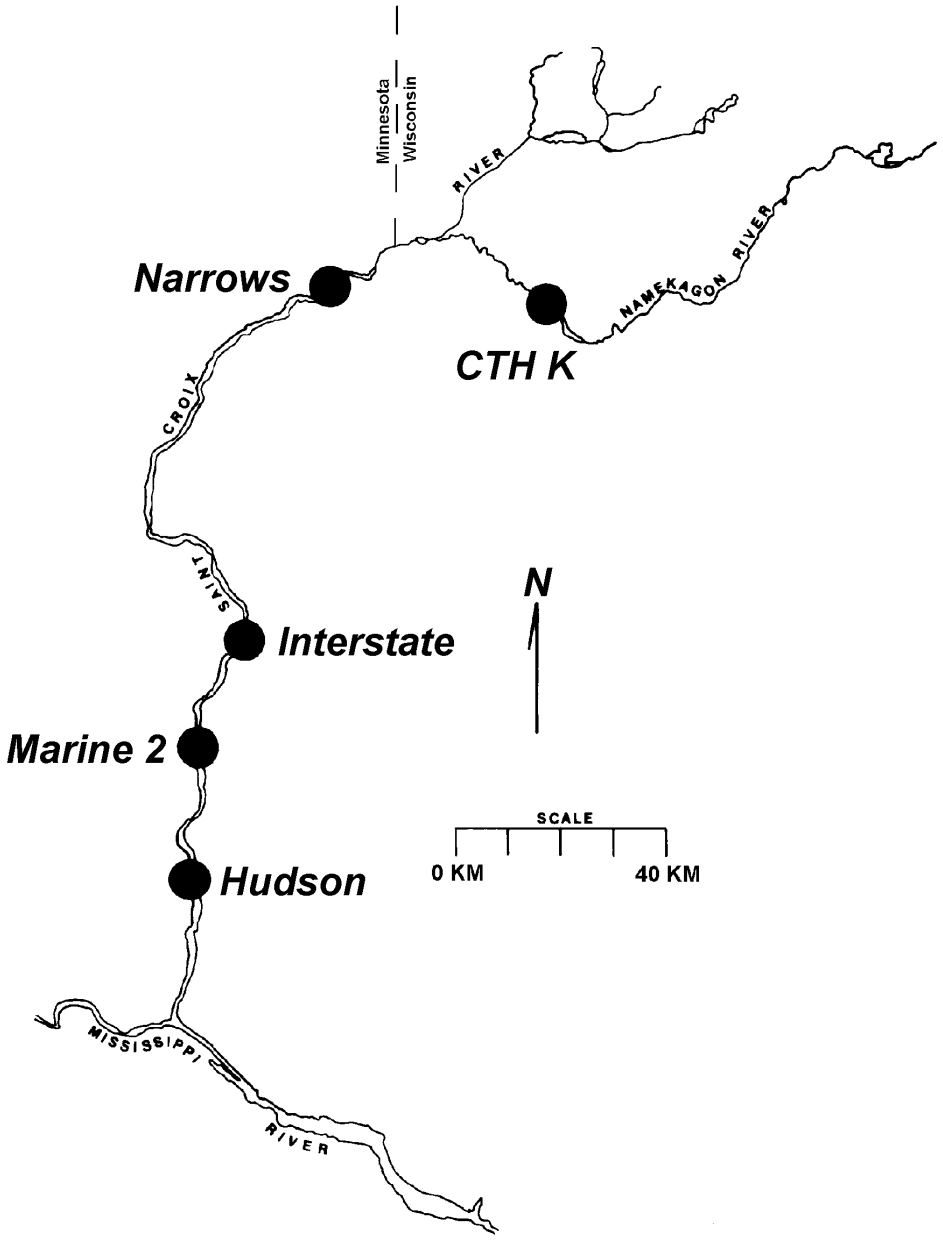

Figure 2. Location of the CTH K study area on the Namekagon River. Namekagon River km 48.99 to 49.49. T-40-N, R-12-W, section 18, Washburn Co., Wisconsin. Dunn Lake, Wis. U.S.G.S. 7.5' quadrangle, 1982.

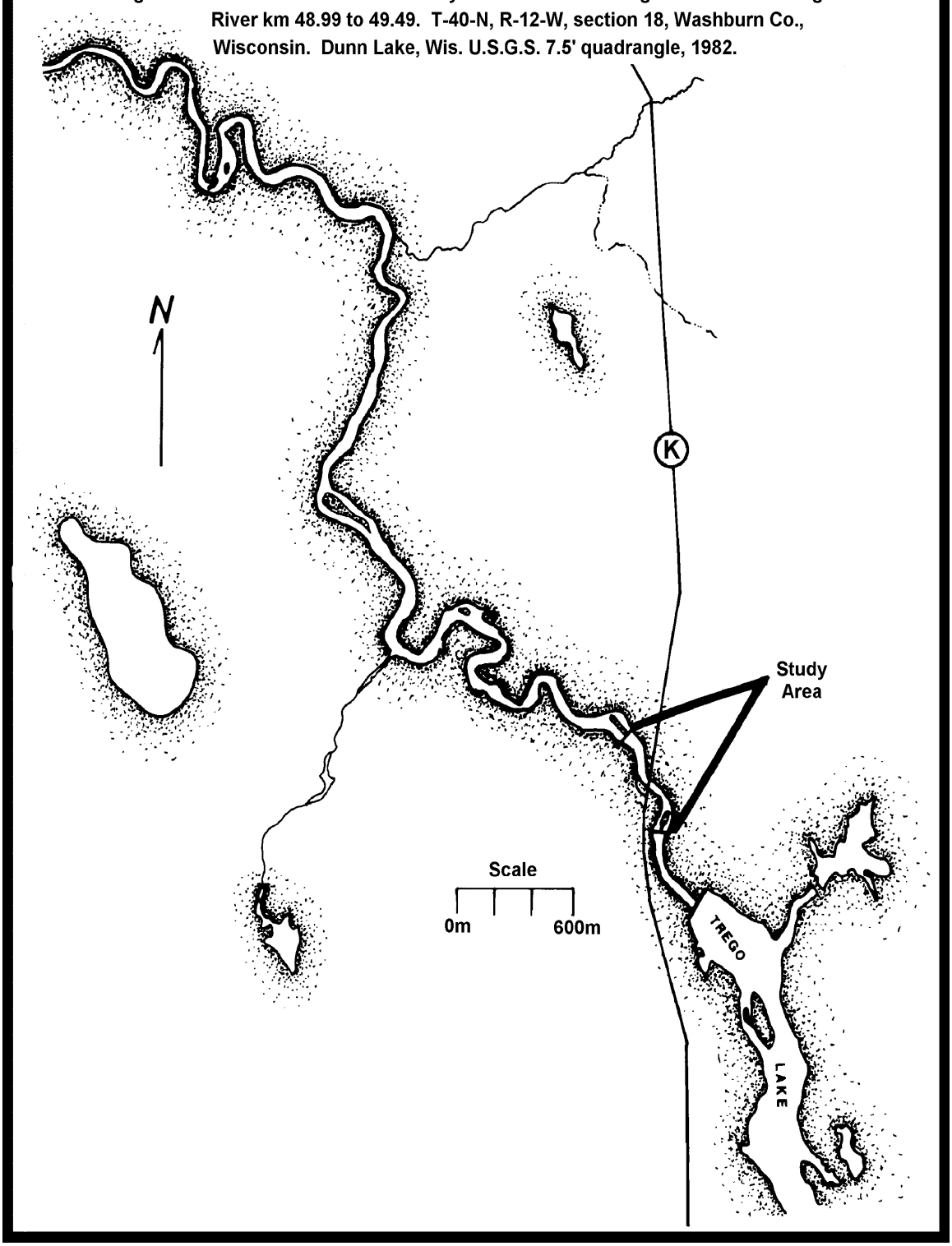

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Figure 3. General and detailed location of the Narrows study area on the Saint Croix River. Saint Croix River km 190.47 to 190.61. T-41-N, R-17-W, section 35, Burnett Co., Wisconsin. Yellow Lake, Wis.-Minn. U.S.G.S. 7.5' quadrangle, 1982.

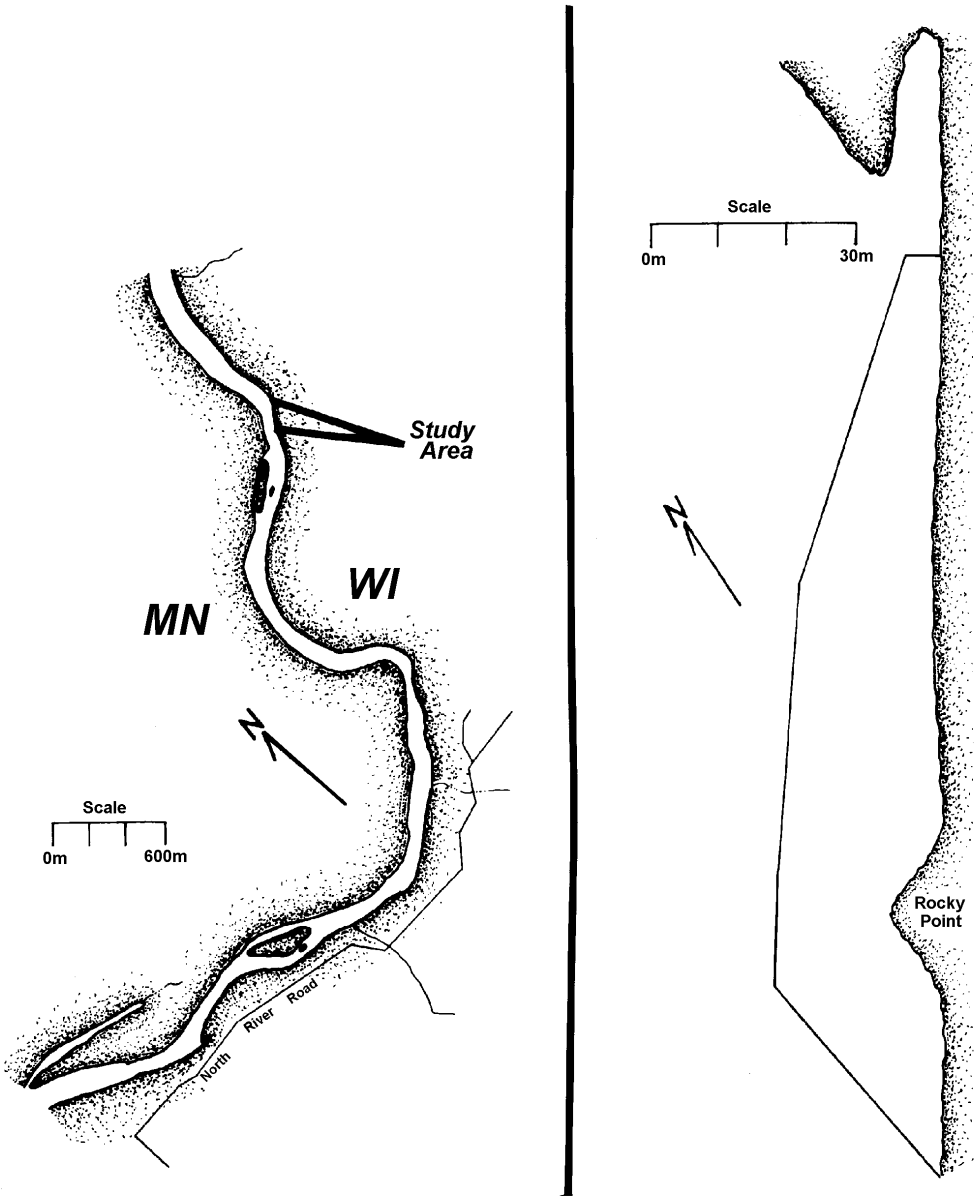

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Figure 4. Location of the Interstate study area on the Saint Croix River. Saint Croix River km 83.23 to 84.97. T-34-N, R-19-W, sections 35 & 36, Chisago Co., Minnesota and Polk Co., Wisconsin. St. Croix Dalles, Wis.-Minn. U.S.G.S. 7.5' quadrangle, 1978.

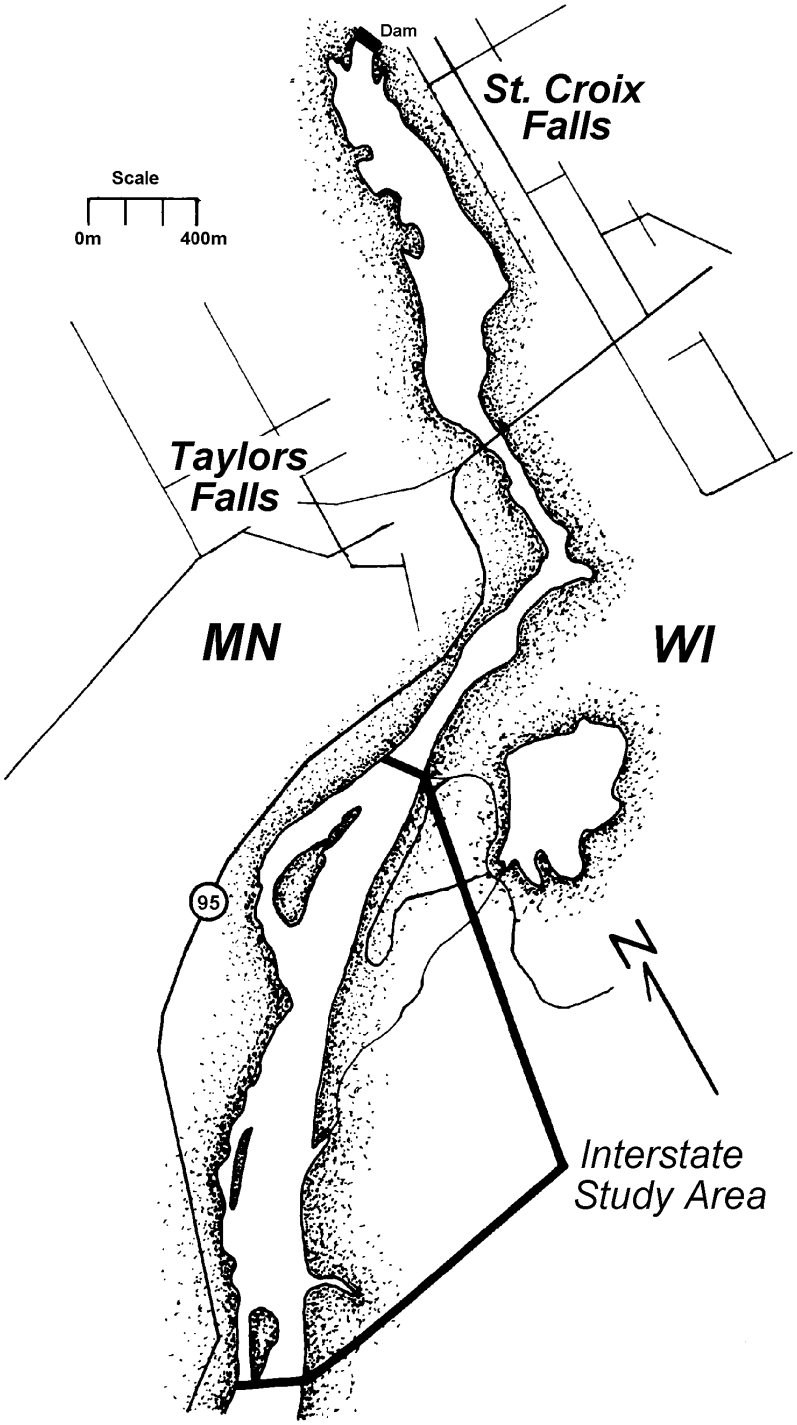

Figure 5. General and detailed location of the Marine 2 study area and supplemental collection sites on the Saint Croix River. Study area located between Saint Croix River km 58.97 and 59.50. T-32-N, R-19-W, section 31, Polk Co., Wisconsin. T-31-N, R-19-W, section 6, St. Croix Co., Wisconsin. Supplemental collection sites located at Saint Croix River km 57.88 and 58.47. T-31-N, R-19-W, section 6, Washington Co., Minnesota. Marine on St. Croix, Minn.-Wis. U.S.G.S. 7.5' quadrangle, 1967.

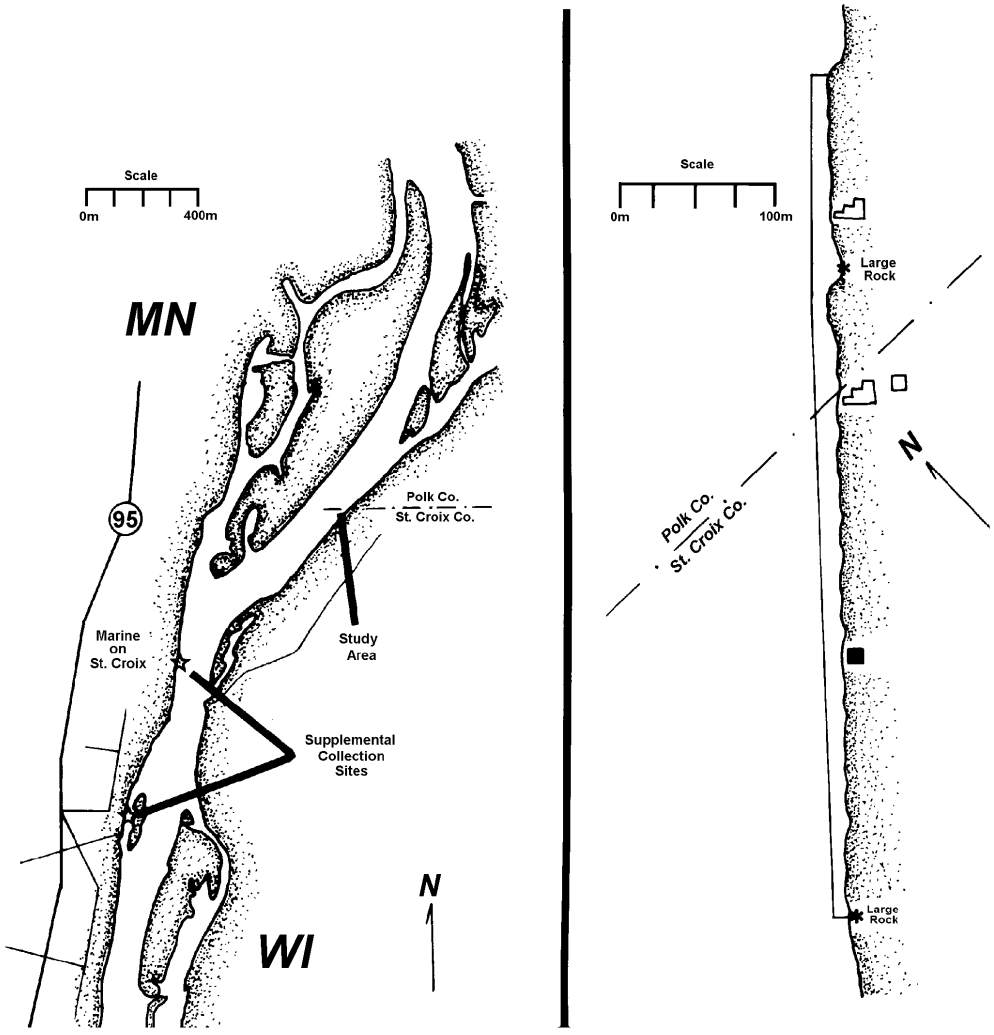

Figure 6. Location of the Hudson study area and supplemental collection site on the Saint Croix River. Study area located between Saint Croix River km 26.71 and 29.17. T-29-N, R-20-W, section 23, 26 and 35, Washington Co., Minnesota. Supplemental collection site located at Saint Croix River km 27.79. T-29-N, R-20-W, section 26, St. Croix Co., Wisconsin. Hudson, Minn.-Wis. U.S.G.S. 7.5' quadrangle, 1967. To obtain U. S. Government river distances subtract 0.88 km.

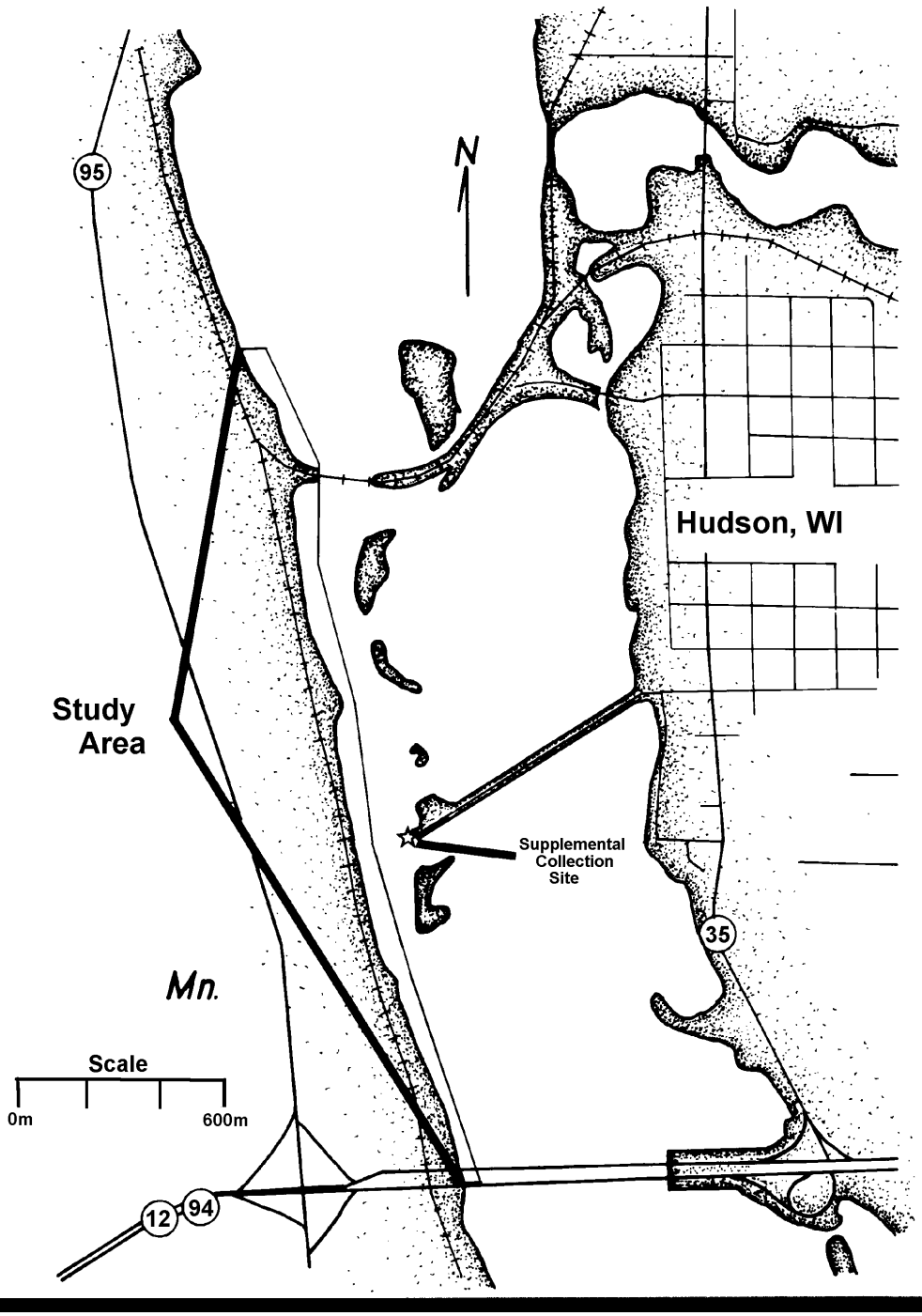

Table 1. Taxonomic list of the freshwater mussels and clams collected in the five study areas of the Saint Croix and Namekagon rivers, 1988-1989 (= collected as shells only).*

PHYLUM MOLLUSCA (Linne, 1758) Cuvier, 1797
CLASS BIVALVIA Linne, 1758 (after Bonnani, 1681)
ORDER UNIONOIDA Stoliczka, 1871
FAMILY MARGARITIFERIDAE Haas, 1940
Cumberlandia monodonta (Say, 1829)
FAMILY UNIONIDAE (Fleming, 1828) Ortmann, 1911
Anodonta imbecillis Say, 1829
Anodonta grandis form *grandis* Say, 1829
Anodonta grandis form *corpulenta* Cooper, 1834
Anodontoides ferussacianus (Lea, 1834)
Strophitus undulatus undulatus (Say, 1817)
Alasmidonta marginata Say, 1818
Simpsonaias ambigua (Say, 1825)
Lasmigona complanata complanata (Barnes, 1823)
Lasmigona costata (Rafinesque, 1820)
Lasmigona compressa (Lea, 1829)
Magnonaias nervosa (Rafinesque, 1820)
Tritogonia verrucosa (Rafinesque, 1820)
Quadrula quadrula (Rafinesque, 1820)
Quadrula fragosa (Conrad, 1835)
Quadrula metanevra (Rafinesque, 1820)
Quadrula pustulosa pustulosa (Lea, 1831)
Amblema plicata plicata (Say, 1817)
**Fusconaia ebena* (Lea, 1831)
Fusconaia flava (Rafinesque, 1820)
Cyclonaias tuberculata (Rafinesque, 1820)
Pleurobema sintoxia (Rafinesque, 1820)
**Elliptio crassidens crassidens* (Lamarck, 1819)
Elliptio dilatata (Rafinesque, 1820)
Obliquaria reflexa Rafinesque, 1820
Actinonaias ligamentina carinata (Barnes, 1823)
Ellipsaria lineolata (Rafinesque, 1820)
Obovaria olivaria (Rafinesque, 1820)
Truncilla truncata Rafinesque, 1820
Truncilla donaciformis (Lea, 1827)
Leptodea fragilis (Rafinesque, 1820)
Potamilus alatus (Say, 1817)
Potamilus ohiensis (Rafinesque, 1820)
Toxolasma parvus (Barnes, 1823)
Ligumia recta (Lamarck, 1819)
Lampsilis radiata luteola (Lamarck, 1819)
Lampsilis higginsi (Lea, 1857)
Lampsilis ventricosa (Barnes, 1823)
Epioblasma triquetra (Rafinesque, 1820)
ORDER VENEROIDA H. and A. Adams, 1856
FAMILY CORBICULIDAE Gray, 1847
Corbicula fluminea (Muller, 1774)

Table 2. Freshwater mussel and clam taxa found using all collection methods at each of the five study areas in the Saint Croix and Namekagon rivers, 1987-1989 (X = found living and dead, D = Found empty shells only).

TAXON	STUDY AREA				
	CTH K	**Narrows**	**Interstate**	**Marine 2**	**Hudson**
A. l. carinata	*X*	*X*	*X*	*X*	*X*
A. marginata	*X*	*X*	*X*	*X*	*X*
A. p. plicata	*X*	*X*	*X*	*X*	*X*
A. g. f. *corpulenta*		*X*	*X*	*X*	*X*
A. g. f. *grandis*	*X*				
A. imbecillis		*X*	*X*	*X**	*X*
A. ferussacianus	*X*				
C. fluminea					*X*
C. monodonta		*X*	*X*	*X*	*X*
C. tuberculata	*X*	*X*	*X*	*X*	*X*
E. lineolata			*X*	*X*	*X*
E. c. crassidens			*X**		*D*
E. dilatata	*X*	*X*	*X*	*X*	*X*
E. triquetra			*X*	*X*	
F. ebena				*D*	*D*
F. flava	*X*	*X*	*X*	*X*	*X*
L. higginsi			*X*	*D**	*X*
L. r. luteola	*X*	*X*	*X*	*X*	*X*
L. ventricosa	*X*	*X*	*X*	*X*	*X*
L. c. complanata			*X*	*X*	*X*
L. compressa	*X*				
L. costata	*X*	*X*	*X*	*X*	*D*
L. fragilis		*X*	*X*	*X*	*X*
L. recta	*X*	*X*	*X*	*X*	*X*
M. nervosa					*X*
O. reflexa			*X*	*X*	*X*
O. olivaria	*D*	*X*	*X*	*X*	*D*
P. sintoxia	*X*	*X*	*X*	*X*	*X*
P. alatus		*X*	*X*	*X*	*X*
P. ohiensis			*X*	*X*	*X***
Q. fragosa			*X*	*D**	
Q. metanevra			*X*	*X*	*X*
Q. p. pustulosa	*X*	*X*	*X*	*X*	*X*
Q. quadrula			*X**		*X*
S. ambigua		*X*	*X*	*X*	*X*
S. u. undulatus	*X*	*X*	*X*	*X*	*X*
T. parvus		*X*	*D**	*D*	*X***
T. verrucosa			*X*	*X*	*X*
T. donaciformis			*X*	*X*	*X*
T. truncata		*X*	*X*	*X*	*X*
total number of taxa, living	**16**	**22**	**33**	**29**	**31**

*** = found by WDNR during 1987 and not in present study.**
**** = found during 1985 by author and not in present study.**

Table 3. Relative abundance, live/ dead and female/male sex ratios and means of the population density of living mussels in number per m^2 found at the CTH K study area (N = 37). Densities calculated from quadrat samples; living/dead and female/male ratios calculated from quadrat, relative abundance and target taxa collections; number collected and % relative abundance calculated from quadrat samples and relative abundance collections.

Taxon	mean (log scale)	STD (log scale)	mean (geo-metric)	#live / #dead		#Fem. / #Male		# Coll.	% Rel. Abun.	mean (arithmetic)
A. l. carinata	2.1579	0.8930	7.6527	416/112=	3.71	-------	-----	898	55.06	11.24
A. marginata	0.5335	0.6167	0.7048	40/4=	10.00	-------	-----	73	4.48	1.08
A. p. plicata	0.0187	0.1140	0.0189	1/0=	-----	-------	-----	3	0.18	0.03
A. g. f. *corpulenta*	-------	-------	-------	-------	-----	-------	-----	----	------	-------
A. g. f. *grandis*	0.0484	0.2109	0.0496	3/9=	0.33	-------	-----	9	0.55	0.08
A. imbecillis	-------	-------	-------	-------	-----	-------	-----	----	------	-------
A. ferussacianus	0.0297	0.1806	0.0301	2/2=	1.00	-------	-----	2	0.12	0.05
C. fluminea	-------	-------	-------	-------	-----	-------	-----	----	------	-------
C. monodonta	-------	-------	-------	-------	-----	-------	-----	----	------	-------
C. tuberculata	0.0187	0.1140	0.0189	1/0=	-----	-------	-----	1	0.06	0.03
E. lineolata	-------	-------	-------	-------	-----	-------	-----	----	------	-------
E. dilatata	0.3167	0.6023	0.3726	27/17=	1.59	-------	-----	51	3.13	0.73
E. c. crassidens	-------	-------	-------	-------	-----	-------	-----	----	------	-------
E. triquetra	-------	-------	-------	-------	-----	-------	-----	----	------	-------
F. ebena	-------	-------	-------	-------	-----	-------	-----	----	------	-------
F. flava	0.1839	0.4952	0.2018	16/2=	8.00	-------	-----	27	1.66	0.43
L. higginsi	-------	-------	-------	-------	-----	-------	-----	----	------	-------
L. r. luteola	0.8463	0.8065	1.3310	84/41=	2.05	41/88=	0.47	152	9.32	2.27
L. ventricosa	0.5804	0.5280	0.7868	39/36=	1.08	38/52=	0.73	111	6.81	1.05
L. c. complanata	-------	-------	-------	-------	-----	-------	-----	----	------	-------
L. compressa	0.0562	0.1918	0.0578	3/0=	-----	-------	-----	10	0.61	0.08
L. costata	0.5256	0.7221	0.6914	47/10=	4.70	-------	-----	131	8.03	1.27
L. fragilis	-------	-------	-------	-------	-----	-------	-----	----	------	-------
L. recta	0.1046	0.2751	0.1103	6/23=	0.26	9/13=	0.69	26	1.59	0.16
M. nervosa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
O. reflexa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
O. olivaria	-------	-------	-------	0/1=	0.00	-------	-----	----	------	-------
P. sintoxia	0.0562	0.1918	0.0578	3/0=	-----	-------	-----	5	0.31	0.08
P. alatus	-------	-------	-------	-------	-----	-------	-----	----	------	-------
P. ohiensis	-------	-------	-------	-------	-----	-------	-----	----	------	-------
Q. fragosa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
Q. metanevra	-------	-------	-------	-------	-----	-------	-----	----	------	-------
Q. p. pustulosa	0.0187	0.1140	0.0189	1/0=	-----	-------	-----	2	0.12	0.03
Q. quadrula	-------	-------	-------	-------	-----	-------	-----	----	------	-------
S. ambigua	-------	-------	-------	-------	-----	-------	-----	----	------	-------
S. u. undulatus	0.5407	0.8696	0.7172	66/11=	6.00	-------	-----	130	7.97	1.78
T. parvus	-------	-------	-------	-------	-----	-------	-----	----	------	-------
T. verrucosa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
T. donaciformis	-------	-------	-------	-------	-----	-------	-----	----	------	-------
T. truncata	-------	-------	-------	-------	-----	-------	-----	----	------	-------
All taxa	2.6442	1.0392	13.073	755/268=	2.82	88/153=	0.58	1631	100.00	20.41

Table 4. Relative abundance, live/ dead and female/male sex ratios and means of the population density of living mussels in number per m^2 found at the Narrows study area (N = 30). Densities calculated from quadrat samples; living/dead and female/male ratios calculated from quadrat, relative abundance and target taxa collections; number collected and % relative abundance calculated from quadrat samples and relative abundance collections.

Taxon	mean (log scale)	STD (log scale)	mean (geo-metric)	#live #dead		#Fem. #Male		# Coll.	% Rel. Abun.	mean (arithmetic)
A. l. carinata	1.7507	1.3947	4.7584	332/336=	0.99	-------	-----	332	34.33	11.07
A. marginata	0.3423	0.5383	0.4081	20/1=	20.00	-------	-----	20	2.07	0.67
A. p. plicata	0.6160	0.7943	0.8515	51/58=	0.88	-------	-----	51	5.27	1.7
A. g. f. *corpulenta*	0.0000	-------	0.0000	-------	------	-------	-----	0	0.00	0.00
A. g. f. *grandis*	-------	-------	-------	-------	------	-------	-----	----	------	-------
A. imbecillis	0.0000	-------	0.0000	-------	------	-------	-----	0	0.00	0.00
A. ferussacianus	-------	-------	-------	-------	------	-------	-----	----	------	-------
C. fluminea	-------	-------	-------	-------	------	-------	-----	----	------	-------
C. monodonta	0.0000	-------	0.0000	3/3=	1.00	-------	-----	0	0.00	0.00
C. tuberculata	0.4181	0.6875	0.5191	30/25=	1.20	-------	-----	30	3.10	1.00
E. lineolata	-------	-------	-------	-------	------	-------	-----	----	-----	-------
E. dilatata	1.2400	1.0716	2.4558	145/109=	1.33	-------	-----	145	14.99	4.83
E. c. crassidens	-------	-------	-------	-------	------	-------	-----	----	-----	-------
E. triquetra	-------	-------	-------	-------	------	-------	-----	----	-----	-------
F. ebena	-------	-------	-------	-------	------	-------	-----	----	-----	-------
F. flava	1.0388	0.9828	1.8257	106/39=	2.72	-------	-----	106	10.96	3.53
L. higginsi	-------	-------	-------	-------	------	-------	-----	----	-----	-------
L. r. luteola	0.8801	0.7662	1.4111	67/33=	2.03	20/33=	0.61	72	7.45	2.23
L. ventricosa	0.4373	0.5403	0.5485	24/11=	2.18	11/9=	1.22	24	2.48	0.80
L. c. complanata	-------	-------	-------	-------	------	-------	-----	----	-----	-------
L. compressa	-------	-------	-------	-------	------	-------	-----	----	-----	-------
L. costata	0.5908	0.7057	0.8054	40/22=	1.82	-------	-----	40	4.14	1.33
L. fragilis	0.2350	0.4412	0.2649	13/2=	6.50	-------	-----	13	1.34	0.43
L. recta	0.5021	0.5996	0.6522	30/33=	0.91	8/26=	0.31	30	3.10	1.00
M. nervosa	-------	-------	-------	-------	------	-------	-----	----	-----	-------
O. reflexa	-------	-------	-------	-------	------	-------	-----	----	-----	-------
O. olivaria	0.1290	0.3011	0.1377	6/7=	0.86	-------	-----	6	0.62	0.20
P. sintoxia	0.4006	0.5311	0.4928	23/7=	3.29	-------	-----	23	2.38	0.77
P. alatus	0.0231	0.1266	0.0234	1/0=	------	-------	-----	1	0.10	0.03
P. ohiensis	-------	-------	-------	-------	------	-------	-----	----	-----	-------
Q. fragosa	-------	-------	-------	-------	------	-------	-----	----	-----	-------
Q. metanevra	-------	-------	-------	-------	------	-------	-----	----	-----	-------
Q. p. pustulosa	0.6708	0.7864	0.9557	50/13=	3.85	-------	-----	50	5.17	1.67
Q. quadrula	-------	-------	-------	-------	------	-------	-----	----	-----	-------
S. ambigua	0.1195	0.3671	0.1269	29/26=	1.12	-------	-----	7	0.72	0.23
S. u. undulatus	0.1465	0.3798	0.1578	8/1=	8.00	-------	-----	8	0.83	0.27
T. parvus	0.0000	-------	0.0000	-------	------	-------	-----	1	0.10	0.00
T. verrucosa	-------	-------	-------	-------	------	-------	-----	----	------	-------
T. donaciformis	-------	-------	-------	-------	------	-------	-----	----	------	-------
T. truncata	0.1657	0.3480	0.1802	8/0=	------	-------	-----	8	0.83	0.27
All taxa	2.8865	1.2707	16.93	986/726=	1.36	39/68=	0.57	967	99.98	32.03

Table 5. Relative abundance, live/ dead and female/male sex ratios and means of the population density of living mussels in number per m^2 found at the Interstate study area (N = 108). Densities calculated from quadrat samples; living/dead and female/male ratios calculated from quadrat, relative abundance and target taxa collections; number collected and % relative abundance calculated from quadrat samples and relative abundance collections.

Taxon	mean (log scale)	STD (log scale)	mean (geo-metric)	#live #dead		#Fem. #Male		# Coll.	% Rel. Abun.	mean (arithmetic)
A. l. carinata	*0.1833*	*0.4069*	*0.2011*	*37/30=*	*1.23*	-------	-----	*37*	*2.07*	*0.34*
A. marginata	*0.1370*	*0.3058*	*0.1468*	*23/8=*	*2.88*	-------	-----	*23*	*1.29*	*0.21*
A. p. plicata	*0.1252*	*0.3111*	*0.1334*	*22/12=*	*1.83*	-------	-----	*22*	*1.23*	*0.20*
A. g. f. *corpulenta*	*0.0064*	*0.0667*	*0.0064*	*1/1=*	*1.00*	-------	-----	*1*	*0.06*	*0.01*
A. g. f. *grandis*	-------	-------	-------	-------	------	-------	-----	----	------	-------
A. imbecillis	*0.0064*	*0.0667*	*0.0064*	*1/0=*	------	-------	-----	*1*	*0.06*	*0.01*
A. ferussacianus	-------	-------	-------	-------	------	-------	-----	----	------	-------
C. fluminea	-------	-------	-------	-------	------	-------	-----	----	------	-------
C. monodonta	*0.0000*	-------	*0.0000*	*568/42=13.53*		-------	-----	*0*	*0.00*	*0.00*
C. tuberculata	*0.1411*	*0.3312*	*0.1515*	*26/6=*	*4.33*	-------	-----	*26*	*1.45*	*0.24*
E. lineolata	*0.1423*	*0.3246*	*0.1529*	*25/3=*	*8.33*	*42/26=*	*1.62*	*25*	*1.40*	*0.23*
E. dilatata	*0.4147*	*0.5558*	*0.5139*	*90/40=*	*2.25*	-------	-----	*90*	*5.03*	*0.83*
E. c. crassidens	*0.0000*	-------	*0.0000*	-------	------	-------	-----	*0*	*0.00*	*0.00*
E. triquetra	*0.3606*	*0.4829*	*0.4342*	*68/17=*	*4.00*	*49/75=*	*0.65*	*68*	*3.80*	*0.63*
F. ebena	-------	-------	-------	-------	------	-------	-----	----	-----	------
F. flava	*0.3592*	*0.5055*	*0.4321*	*72/26=*	*2.77*	-------	-----	*72*	*4.03*	*0.67*
L. higginsi	*0.0193*	*0.1144*	*0.0194*	*3/0=*	------	*11/16=*	*0.69*	*3*	*0.17*	*0.03*
L. r. luteola	*0.0000*	-------	*0.0000*	*0/2=*	*0.00*	*2/2=*	*1.00*	*0*	*0.00*	*0.00*
L. ventricosa	*0.0872*	*0.2398*	*0.0911*	*14/20=*	*0.70*	*3/5=*	*0.6*	*14*	*0.78*	*0.13*
L. c. complanata	*0.0000*	-------	*0.0000*	-------	-------	-------	-----	*0*	*0.00*	*0.00*
L. compressa	-------	-------	-------	-------	-------	-------	-----	----	-----	-------
L. costata	*0.0193*	*0.1144*	*0.0194*	*3/0=*	-------	-------	-----	*3*	*0.17*	*0.03*
L. fragilis	*0.0845*	*0.2455*	*0.0882*	*14/11=*	*1.27*	-------	-----	*14*	*0.78*	*0.13*
L. recta	*0.0128*	*0.0939*	*0.0129*	*2/5=*	*0.40*	*1/5=*	*0.2*	*2*	*0.11*	*0.02*
M. nervosa	-------	-------	-------	-------	-------	-------	-----	----	-----	-------
O. reflexa	*0.2498*	*0.3880*	*0.2838*	*43/12=*	*3.58*	-------	-----	*43*	*2.40*	*0.40*
O. olivaria	*0.1883*	*0.3487*	*0.2072*	*32/20=*	*1.60*	-------	-----	*32*	*1.79*	*0.30*
P. sintoxia	*0.2615*	*0.4445*	*0.2988*	*50/21=*	*2.38*	-------	-----	*50*	*2.80*	*0.46*
P. alatus	*0.1359*	*0.3205*	*0.1455*	*24/12=*	*2.00*	-------	-----	*24*	*1.34*	*0.22*
P. ohiensis	*0.0064*	*0.0667*	*0.0064*	*1/0=*	-------	-------	-----	*1*	*0.06*	*0.01*
Q. fragosa	*0.0193*	*0.1144*	*0.0194*	*3/7=*	*0.43*	-------	-----	*3*	*0.17*	*0.03*
Q. metanevra	*0.2817*	*0.4440*	*0.3254*	*53/10=*	*5.30*	-------	-----	*53*	*2.96*	*0.49*
Q. p. pustulosa	*0.5362*	*0.6076*	*0.7094*	*117/29=4.03*		-------	-----	*117*	*6.54*	*1.08*
Q. quadrula	*0.0000*	-------	*0.0000*	-------	-------	-------	-----	*0*	*0.00*	*0.00*
S. ambigua	*0.0000*	-------	*0.0000*	*152/14=10.86*		-------	-----	*0*	*0.00*	*0.00*
S. u. undulatus	*0.0321*	*0.1463*	*0.0326*	*5/5=*	*1.00*	-------	-----	*5*	*0.28*	*0.05*
T. parvus	-------	-------	-------	-------	-------	-------	-----	----	-----	-------
T. verrucosa	*0.1856*	*0.3405*	*0.2040*	*31/10=*	*3.10*	*9/10=*	*0.90*	*31*	*1.73*	*0.29*
T. donaciformis	*0.5154*	*0.5838*	*0.6743*	*110/68=1.62*		-------	-----	*110*	*6.15*	*1.02*
T. truncata	*1.6088*	*1.2476*	*3.9970*	*918/671=1.37*		-------	-----	*918*	*51.34*	*8.50*
All taxa	*2.3436*	*1.1857*	*9.4191*	*2508/1102=2.28*		*117/139=0.84*		*1788*	*99.99*	*16.56*

Table 6. Relative abundance, live/ dead and female/male sex ratios and means of the population density of living mussels in number per m^2 found at the Marine 2 study area (N = 42). Densities calculated from quadrat samples; living/dead and female/male ratios calculated from quadrat, relative abundance and target taxa collections; number collected and % relative abundance calculated from quadrat samples and relative abundance collections.

Taxon	**mean** (log scale)	**STD** (log scale)	**mean** (geo-metric)	**#live #dead**		**#Fem. #Male**		**# Coll.**	**% Rel. Abun.**	**mean** (arithmetic)
A. l. carinata	*0.1747*	*0.3565*	*0.1909*	*12/15=*	*0.80*	-------	-----	*29*	*4.91*	*0.29*
A. marginata	*0.0495*	*0.1807*	*0.0508*	*3/3=*	*1.00*	-------	-----	*4*	*0.68*	*0.07*
A. p. plicata	*0.1980*	*0.3169*	*0.2190*	*12/8=*	*1.50*	-------	-----	*35*	*5.92*	*0.29*
A. g. f. *corpulenta*	*0.0165*	*0.1070*	*0.0166*	*1/1=*	*1.00*	-------	-----	*2*	*0.34*	*0.02*
A. g. f. *grandis*	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
A. imbecillis	*0.0000*	-------	*0.0000*	-------	-----	-------	-----	*0*	*0.00*	*0.00*
A. ferussacianus	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
C. fluminea	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
C. monodonta	*0.0000*	-------	*0.0000*	*87/41=*	*2.12*	-------	-----	*0*	*0.00*	*0.00*
C. tuberculata	*0.0000*	-------	*0.0000*	-------	-----	-------	-----	*1*	*0.17*	*0.00*
E. lineolata	*0.0165*	*0.1070*	*0.0166*	*1/0=*	-----	*1/0=*	-----	*1*	*0.17*	*0.02*
E. dilatata	*0.3425*	*0.4895*	*0.4085*	*26/30=*	*0.87*	-------	-----	*71*	*12.01*	*0.62*
E. c. crassidens	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
E. triquetra	*0.0000*	-------	*0.0000*	-------	-----	*0/1=*	*1*	*1*	*0.17*	*0.00*
F. ebena	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
F. flava	*1.0173*	*0.5381*	*1.7658*	*90/68=*	*1.32*	-------	-----	*160*	*27.07*	*2.14*
L. higginsi	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
L. r. luteola	*0.0000*	-------	*0.0000*	*0/1=*	*0.00*	-------	-----	*0*	*0.00*	*0.00*
L. ventricosa	*0.0660*	*0.2059*	*0.0682*	*4/4=*	*1.00*	*2/5=*	*0.40*	*8*	*1.35*	*0.10*
L. c. complanata	*0.0330*	*0.1494*	*0.0336*	*2/1=*	*2.00*	-------	-----	*6*	*1.02*	*0.05*
L. compressa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
L. costata	*0.0000*	-------	*0.0000*	*0/1=*	*0.00*	-------	-----	*0*	*0.00*	*0.00*
L. fragilis	*0.3550*	*0.4338*	*0.4262*	*24/12=*	*2.00*	-------	-----	*59*	*9.98*	*0.57*
L. recta	*0.0330*	*0.1494*	*0.0336*	*2/1=*	*2.00*	*1/3=*	*0.33*	*2*	*0.34*	*0.05*
M. nervosa	-------	-------	-------	-------	-----	-------	-----	----	------	-------
O. reflexa	*0.0592*	*0.2220*	*0.0610*	*4/5=*	*0.80*	-------	-----	*4*	*0.68*	*0.10*
O. olivaria	*0.0000*	-------	*0.0000*	*0/1=*	*0.00*	-------	-----	*0*	*0.00*	*0.00*
P. sintoxia	*0.0330*	*0.1494*	*0.0336*	*2/3=*	*0.67*	-------	-----	*6*	*1.02*	*0.05*
P. alatus	*0.0922*	*0.2600*	*0.0966*	*6/3=*	*2.00*	-------	-----	*27*	*4.57*	*0.14*
P. ohiensis	*0.0165*	*0.1070*	*0.0166*	*1/0=*	*1.00*	-------	-----	*1*	*0.17*	*0.02*
Q. fragosa	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
Q. metanevra	*0.0922*	*0.2600*	*0.0966*	*6/1=*	*6.00*	-------	-----	*12*	*2.03*	*0.14*
Q. p. pustulosa	*0.0990*	*0.2455*	*0.1041*	*6/5=*	*1.20*	-------	-----	*21*	*3.55*	*0.14*
Q. quadrula	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
S. ambigua	*0.0000*	-------	*0.0000*	*181/40=4.53*		-------	-----	*0*	*0.00*	*0.00*
S. u. undulatus	*0.1320*	*0.2755*	*0.1411*	*8/4 =*	*2.00*	-------	-----	*19*	*3.21*	*0.19*
T. parvus	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
T. verrucosa	*0.1775*	*0.3555*	*0.1942*	*12/0=*	-----	*10/12=*	*0.83*	*26*	*4.40*	*0.29*
T. donaciformis	*0.1582*	*0.3800*	*0.1714*	*12/25=*	*0.48*	-------	-----	*21*	*3.55*	*0.29*
T. truncata	*0.3848*	*0.4962*	*0.4693*	*29/34=*	*0.85*	-------	-----	*75*	*12.69*	*0.69*
All taxa	*1.8125*	*0.6241*	*5.126*	*531/307=1.73*		*14/21=*	*0.67*	*591*	*100.00*	*6.26*

Table 7. Relative abundance, live/ dead and female/male sex ratios and means of the population density of living mussels in number per m^2 found at the Hudson study area (N = 69). Densities calculated from quadrat samples; living/dead and female/male ratios calculated from quadrat, relative abundance and target taxa collections; number collected and % relative abundance calculated from quadrat samples and relative abundance collections.

Taxon	mean (log scale)	STD (log scale)	mean (geo-metric)	#live / #dead		#Fem. / #Male		# Coll.	% Rel. Abun.	mean (arithmetic)
A. l. carinata	0.0200	0.1171	0.0203	2/35=	0.06	-------	-----	3	0.21	0.03
A. marginata	0.0000	-------	0.0000	0/1=	0.00	-------	-----	0	0.00	0.00
A. p. plicata	0.8079	0.7834	1.2431	142/108=	1.32	-------	-----	532	37.18	2.06
A. g. f. *corpulenta*	0.0561	0.2069	0.0577	6/3=	2.00	-------	-----	20	1.40	0.09
A. g. f. *grandis*	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
A. imbecillis	0.0201	0.1171	0.0203	2/0=	-----	-------	-----	5	0.35	0.03
A. ferussacianus	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
C. fluminea	0.0519	0.4572	0.3294	6/120=	0.05	-------	-----	6	0.42	0.09
C. monodonta	0.0000	-------	0.0000	56/14=	4.00	-------	-----	0	0.00	0.00
C. tuberculata	0.0100	0.0834	0.0101	1/3=	0.33	-------	-----	5	0.35	0.01
E. lineolata	0.0301	0.1424	0.0306	3/7=	0.43	19/18	1.06	10	0.70	0.04
E. dilatata	0.4623	0.7968	0.5876	103/256=	0.40	-------	-----	200	13.98	1.49
E. c. crassidens	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
E. triquetra	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
F. ebena	-------	-------	-------	0/17=	0.00	-------	-----	----	-----	-------
F. flava	0.3842	0.5038	0.4685	48/82=	0.59	-------	-----	162	11.32	0.70
L. higginsi	0.0100	0.0834	0.0101	1/25=	0.04	26/46=	0.57	17	1.19	0.01
L. r. luteola	0.0603	0.1967	0.0621	6/68=	0.09	1/12=	0.08	8	0.56	0.09
L. ventricosa	0.0561	0.2069	0.0577	6/14=	0.43	3/3=	1.0	8	0.56	0.09
L. c. complanata	0.0000	-------	0.0000	0/2=	0.00	-------	-----	1	0.07	0.00
L. compressa	-------	-------	-------	-------	-----	-------	-----	----	-----	-------
L. costata	-------	-------	-------	0/2=	0.00	-------	-----	----	-----	-------
L. fragilis	0.0779	0.2613	0.0810	9/21=	0.43	-------	-----	11	0.77	0.13
L. recta	0.0100	0.0834	0.0101	1/18=	0.06	0/1=	0.00	3	0.21	0.01
M. nervosa	0.0000	-------	0.0000	-------	-----	-------	-----	2	0.14	0.00
O. reflexa	0.3973	0.5431	0.4878	53/51=	1.04	-------	-----	164	11.46	0.77
O. olivaria	-------	-------	-------	0/3=	0.00	-------	-----	----	-----	-------
P. sintoxia	0.2294	0.4110	0.2578	27/48=	0.56	-------	-----	72	5.03	0.39
P. alatus	0.0779	0.2613	0.0810	9/2=	4.50	-------	-----	18	1.26	0.13
P. ohiensis	0.0000	-------	0.0000	0/2=	0.00	-------	-----	0	0.00	0.00
Q. fragosa	-------	-------	-------	-------	-----	-------	-----	----	-----	0.00
Q. metanevra	0.0502	0.1810	0.0515	5/4=	1.25	-------	-----	19	1.33	0.07
Q. p. pustulosa	0.1164	0.3208	0.1234	14/41=	0.34	-------	-----	57	3.98	0.20
Q. quadrula	0.0461	0.1918	0.0471	5/4=	1.25	-------	-----	9	0.63	0.07
S. ambigua	0.0000	-------	0.0000	83/33=	2.52	-------	-----	1	0.07	0.00
S. u. undulatus	0.0402	0.1632	0.0410	4/6=	0.67	-------	-----	13	0.91	0.06
T. parvus	0.0000	-------	0.0000	0/1=	0.00	-------	-----	0	0.00	0.00
T. verrucosa	0.0201	0.1171	0.0203	2/1=	2.00	4/1=	4.00	9	0.63	0.03
T. donaciformis	0.0201	0.1172	0.0203	2/108=	0.02	-------	-----	7	0.49	0.03
T. truncata	0.2847	0.4572	0.3294	35/125=	0.28	-------	-----	69	4.82	0.51
All taxa	1.6537	1.0285	4.2264	631/1225=	0.52	53/81=	0.65	1431	100.02	7.13

Table 8. Members of taxa groups and the group's living/dead ratio and mean of the natural log transformed population . Mean ± STD densities are only for those members found in quadrat samples.

Taxa Group	Mean (#/ m^2 on natural log scale) and living/dead ratio.				
	CTH K	**Narrows**	**Interstate**	**Marine 2**	**Hudson**
Sensitive Taxa					
A. l. carinata	*2.3124*	*1.9107*	*0.9734*	*0.4596*	*0.1281*
A. marginata	*±*	*±*	*±*	*±*	*±*
C. monodonta	*0.9449*	*1.4626*	*0.7798*	*0.5152*	*0.3051*
C. tuberculata	*(N=37)*	*(N=30)*	*(N=108)*	*(N=42)*	*(N=69)*
E. lineolata					
E. c. crassidens	*504*	*425*	*840*	*122*	*70*
E. triquetra	*126*	*387*	*133*	*64*	*109*
F. ebena	*=4.00*	*=1.10*	*=6.32*	*=1.9*	*=0.64*
L. higginsi					
L. costata					
Q. fragosa					
Q. metanevra					
T. verrucosa					
Indifferent Taxa					
A. imbecillis	*1.4802*	*2.3676*	*2.1667*	*1.6300*	*1.3061*
A. ferussacianus	*±*	*±*	*±*	*±*	*±*
E. dilatata	*1.0732*	*1.0686*	*1.1667*	*0.6567*	*0.9504*
F. flava	*(N=37)*	*(N=30)*	*(N=108)*	*(N=42)*	*(N=69)*
L. r. luteola					
L. ventricosa	*247*	*517*	*1645*	*385*	*402*
L. compressa	*133*	*300*	*959*	*265*	*878*
L. fragilis	*=1.86*	*=1.72*	*=1.72*	*=1.45*	*=0.458*
L. recta					
M. nervosa					
O. reflexa					
O. olivaria					
P. sintoxia					
P. alatus					
P. ohiensis					
Q. p. pustulosa					
S. ambigua					
S. u. undulatus					
T. donaciformis					
T. truncata					
Exploitive Taxa					
A. p. plicata	*0.0562*	*0.0616*	*0.1290*	*0.2407*	*0.8984*
A. g. f. corpulenta	*±*	*±*	*±*	*±*	*±*
A. g. f. grandis	*0.2520*	*0.7943*	*0.3203*	*0.3499*	*0.7744*
L. c. complanata	*(N=37)*	*(N=30)*	*(N=108)*	*(N=42)*	*(N=69)*
Q. quadrula					
T. parvus	*4*	*51*	*23*	*18*	*159*
C. fluminea	*9*	*58*	*13*	*12*	*238*
	=0.4	*=0.88*	*=1.8*	*=1.5*	*=0.668*

Table 9. Results of tests of significance for differences between mean of the natural logarithm transformed population between all of the 5 study areas on the Saint Croix and Namekagon rivers. Means with the same letter are not significantly different. Values of means on natural logarithm scale.

STUDY AREA	N	MEAN (Log Scale)	GROUPING		
CTH K	*37*	*2.6442*	*A*		
Narrows	*30*	*2.8865*	*A*		
Interstate	*108*	*2.3436*	*A*	*B*	
Marine 2	*42*	*1.8125*		*B*	*C*
Hudson	*69*	*1.6537*			*C*

Table 10. Number and date collected of Q. fragosa *from Interstate Study area, Saint Croix River, 1988 and 1989.*

DATE	WEEK	# COLLECTED	# GRAVID	
27 June 88	*26*	*2*		*0*
29 June 88	*26*	*1*		*0*
5 July 88	*27*	*2*	*0*	
7 July 88	*27*	*1*	*0*	
11 July 88	*28*	*1*	*0*	
12 July 88	*28*	*1*	*0*	
14 July 88	*28*	*1*	*0*	
21 July 88	*29*	*4*	*0*	
5 May 89	*19*	*1*	*0*	
9 June 89	*23*	*3*	*0*	
23 June 89	*25*	*9*	*0*	
28 July 89	*30*	*2*	*0*	
16 Aug. 89	*34*	*1*	*0*	
17 Aug. 89	*34*	*10*	*0*	
18 Aug. 89	*34*	*10*	*0*	
total	---	*49*	*0*	

Table 11. Percent substrate composition from randomly selected quadrat samples at the 5 study areas, Saint Croix and Namekagon rivers, 1988.

Substrate Type	Study Area				
	CTH K	**Narrows**	**Interstate**	**Marine 2**	**Hudson**
Boulder	5.81	29.84	3.60	8.21	0.72
Rubble	*45.27*	*14.83*	*10.94*	*38.10*	*7.32*
Gravel	*20.27*	*12.50*	*29.11*	*24.76*	*12.61*
Coarse Sand	*18.92*	*12.50*	*32.71*	*10.48*	*30.07*
Fine Sand	*7.70*	*22.17*	*20.42*	*18.45*	*47.54*
Muck & Silt	*2.03*	*7.33*	*1.87*	*0.00*	*0.87*
Clay	*0.00*	*0.00*	*1.12*	*0.00*	*0.00*
Detritus	*0.00*	*0.83*	*0.23*	*0.00*	*0.87*
Total	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

Table 12. First quartiles (Q_1) of population length distributions, in mm, for all taxa with N≥30 at each of the 5 study areas on the Saint Croix National Scenic Riverway, 1988 and 1989. ( ) = total number of mussels.

TAXON	STUDY AREA				
	CTH K	**Narrows**	**Interstate**	**Marine 2**	**Hudson**
A. l. carinata	*80.8(416)*	*57.7(335)*	*54.3(39)*	*62.5(32)*	---------
A. marginata	*52.6(73)*	---------	---------	---------	---------
A. p. plicata	---------	*51.3(51)*	---------	*103.5(36)*	*42.2(536)*
A g. f. *corpulenta*	----------	----------	----------	----------	----------
A. g. f. *grandis*	----------	----------	----------	----------	----------
A. imbecillis	----------	----------	----------	----------	----------
A. ferussacianus	----------	----------	----------	----------	----------
C. fluminea	----------	----------	----------	----------	----------
C. monodonta 1988	----------	----------	*49.8(141)*	*39.8(41)*	----------
C. monodonta 1989	----------	----------	*69.3(407)*	----------	----------
C. tuberculata	----------	*56.0(30)*	*50.8(30)*	----------	----------
E. lineolata	----------	----------	*40.6(37)*	----------	----------
E. c. crassidens	----------	----------	----------	----------	----------
E. dilatata	*78.3(51)*	*56.1(147)*	*15.5(96)*	*70.5(88)*	*93.7(204)*
E. triquetra	----------	----------	*19.1(109)*	----------	----------
F. ebena	----------	----------	----------	----------	----------
F. flava	----------	*33.9(107)*	*35.0(74)*	*35.44(163)*	*37.3(162)*
L. higginsi 1988	----------	----------	----------	----------	----------
L. higginsi 1989	----------	----------	----------	----------	*73.0(54)*
L. r. luteola	*52.5(152)*	*59.25(67)*	----------	----------	----------
L. ventricosa	*78.1(111)*	----------	----------	----------	----------
L. c. complanata	----------	----------	----------	----------	----------
L. compressa	----------	----------	----------	----------	----------
L. costata	*87.1(131)*	*72.0(40)*	----------	----------	----------
L. fragilis	----------	----------	----------	*58.8(74)*	----------
L. recta	----------	*82.3(30)*	----------	----------	----------
M. nervosa	----------	----------	----------	----------	----------
O. reflexa	----------	----------	*31.9(43)*	----------	*37.3(165)*
O. olivaria	----------	----------	*47.5(32)*	----------	----------
P. sintoxia	----------	----------	*45.0(50)*	----------	*42.5(72)*
P. alatus	----------	----------	----------	----------	----------
P. ohiensis	----------	----------	----------	----------	----------
Q. fragosa 1988	----------	----------	----------	----------	----------
Q. fragosa 1989	----------	----------	*44.3(33)*	----------	----------
Q. metanevra	----------	----------	*39.0(54)*	----------	----------
Q. p. pustulosa	----------	*40.3(50)*	*47.5(116)*	----------	*52.3(57)*
Q. quadrula	----------	----------	----------	----------	----------
S. ambigua 1988	----------	----------	*26.2(105)*	*29.0(96)*	*30.8(57)*
S. ambigua 1989	----------	----------	*21.8(49)*	*32.0(64)*	----------
S. u. undulatus	*65.3(130)*	----------	----------	*47.3(31)*	----------
T. parvus	----------	----------	----------	----------	----------
T. verrucosa	----------	----------	*51.4(31)*	----------	----------
T. donaciformis	----------	----------	*20.1(111)*	----------	----------
T. truncata	----------	----------	*27.8(496)*	*27.5(76)*	*24.9(70)*

Table 13. Total mussel and selected rare taxa means of the natural log transformed population density and 95% confidence intervals for the five study areas samples during 1988.

Taxon	Mean density (#/m^2 on log scale) and 95% confidence interval.				
	CTH K	**Narrows**	**Interstate**	**Marine 2**	**Hudson**
Total Mussels	*2.644 (2.302-2.986)*	*2.886 (2.422-3.350)*	*2.344 (2.115-2.572)*	*1.812 (1.620-2.005)*	*1.654 (1.406-1.901)*
L. higginsi			*0.0193 (-0.003-0.041)*		*0.010 (-0.010-0.030)*
Q. fragosa			*0.0193 (-0.003-0.041)*		

RESULTS OF BASE-LINE SAMPLING OF FRESHWATER MUSSEL COMMUNITIES FOR LONG-TERM MONITORING OF THE SAINT CROIX NATIONAL SCENIC RIVERWAY, MINNESOTA AND WISCONSIN.

APPENDICES

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