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THE QUALITATIVE ANALYSIS, RELATIVE ABUNDANCE, AND DISTRIBUTION OF FRESHWATER UNIONID MUSSELS IN THE ST. CROIX AND NAMEKAGON RIVERS

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Abstract

Eighty-four 60m2 belt line transects using S.C.U.B.A. and 35 midden pile searches conducted over the contiguous portions of the St. Croix and Namekagon Rivers (405 km) proved effective as a qualitative survey technique but was inadequate quantitatively in the assessment of rare species. Thirty-eight species of freshwater unionid mussels live and/or dead were identified in the St. Croix River. 16 species were identified live in the Namekagon River. *Anodontoides ferusassaianus* was the only species that was unique to the Namekagon River and a total of 39 species were documented in the complete river survey. Range extensions were documented for *Cumberlandia monodonta*, *Simpsonaias ambigua*, *Quadrula fragrosa*, *Truncilla truncata*, *Epioblasma triquetra*, *Quadrula quadrula*, *Truncilla donaciformis*, *Tritigonia verrucosa*, *Quadrula metanevra*, *Lampsilis higginsi*, *Elliptio crassidens*, and *Ellipsaria lineolata*. Live shell and dead shell means indicate that the mussel populations in the riverway are generally healthy. Island distributions and species clustering were exhibited throughout the river system. Cluster analysis by species indicates that less common species were more likely to be found with other uncommon species. Common species were found with other common species. Locations with the greatest species diversity were usually the locations where the least common species occurred. Ninety-six percent of all the mussels were collected when river depths were 0.5-3.5m. Sixty-four percent of all the mussels collected occurred in sand, gravel, and rock bottom substrates in varying combinations.

Introduction

The unionid mussel survey of the St. Croix and Namekagon Rivers, from their respective headwaters to the St. Croix Rivers confluence with the Mississippi River (405 km) was conducted from June 15th through August 18th, 1987 for the National Park Service, St. Croix National Riverway and Wisconsin's Bureau of Endangered Resources.

In previous studies Fuller (1978) reported 28 species on the St. Croix River near Hudson, Wisconsin. Stern (1983) and Baker (1928) found 14, and 15 species respectively in the St. Croix River. Mathiak (1979) identified 19 species, and

Dawley (1947) found 25 species. Only Mathiak (1979) had surveyed the Namekagon River previously finding 8 species in comparison to the 16 species found in this study.

The purpose of the study was to qualitatively analyze the freshwater unionid mussels in the St. Croix and Namekagon river system and to determine their relative abundance and distribution. Data on substrate, depth, distribution, and relative abundance were collected. In conducting a complete qualitative survey in the complete riverway, the survey noted specifically the distribution and diversity of each species within all habitats encountered. This information is imperative for the development of recommendations on population and habitat which will enhance or maintain populations, emphasizing federal and/or state listed, and other rare species.

The methods utilized in this survey recommend a monitoring program for mussels in the contiguous portions of the National Riverway indicating what regular measurements should be taken, frequency with which measurements are made, and information on how measurements are to be interpreted.

This paper is a synopsis of the first field season's data on the St. Croix and Namekagon Rivers' mussel populations. There needs to be considerably more field work in order to obtain quantitative life table data, including recruitment and mortality rates for selected key species and population density estimates.

Study Area

The 400+ km St. Croix National Scenic Riverway extends from the Great Lakes Basin to the Mississippi River draining a 22,200 km2 basin about equally divided between the State's of Minnesota and Wisconsin (Figure 1). The St. Croix begins as a cold water stream from a height of land, where at extremely high water it provides a tenuous connection to Lake Superior through the Bois Brule River. As the St. Croix and its tributaries coalesce in their southward flow concomitant physical changes occur in velocity, depth, width, temperature, siltation, and related attributes. Three major continental biomes, boreal forest, northern hardwood forest, and central grasslands each with its attendant riparian wetland communities, contribute further to changes in stream characteristics. Virtually all of the aquatic and riparian biological communities have their origins in, or are shaped by the flowing waters of the St. Croix and Namekagon Rivers, and by their tributaries or their fluvial antecendents of the Wisconsin glaciation. The present rivers are dynamic ecological systems constantly shifting with seasonal and annual instream variation in both physical and biotic traits (Andersen, 1987).

Average annual precipitation within the St. Croix River Basin is 74 cm/yr. (range = 71 cm - 79 cm) (Wisconsin Department of Natural Resources, 1972). The average gradient for the St. Croix River (275 km in length) is 38 cm/km. The average discharge at St. Croix Falls, which includes 80% of the drainage area, is 119 m3/sec (U.S. Geol. Surv., 1982).

The major land uses in the St. Croix River Basin are woodland (57%) and cropland (22%) (Wisconsin Department of Natural Resources, 1987). The Wisconsin population within the Basin in 1978 was estimated at 112,703, which has increased 32% since 1950 (Fago, 1986).

The Upper Namekagon starts at Namekagon Lake Dam in Bayfield County. It is a fast, narrow, shallow, rocky warm water stream until it reaches County Trunk M. From County Trunk M, the Namekagon's water is cooled considerably from spring seepage and becomes a cold trout stream interrupted by four dams on its southwesterly flow. Upstream from each dam are four flowages that have warmer, slower water, with silt and muck bottoms. The dam's create the Pacwawong Flowage, Phipps Flowage, Lake Hayward, and Trego Flowage. The lower Namekagon from Trego Dam (Washurn County) south is wider, warmer, and slower passing through areas of high sandy banks, with many sharp bends. The Namekagon enters the St. Croix just north of Danbury, Wisconsin in Burnett County, completing a 158 km south and west journey.

The Upper St. Croix starts at a dam near Gordon, Wisconsin in Douglas County. It flows in a southerly direction for 164 km to the dam at St. Croix Falls in Polk County. The St. Croix lies in Wisconsin for its first 40 km, and then becomes a border river between Minnesota and Wisconsin, until it flows into the Mississippi River. Only the historic remnants of the Copper Mine Dam interrupts this narrow, small stream until it is joined with the Namekagon 32 km downstream. The St. Croix then becomes wider, deeper, and slower.

The Lower St. Croix covers a narrow river corridor for 84 km from St. Croix Falls Dam to Prescott, Wisconsin in Pierce County, where the river joins the Mississippi. The Lower St. Croix is wider, deeper, and slower than the Upper, its flow is controlled by the hydroelectric dam at its upstream end. Downstream of the dam are the high cliffs of the Dalles, which formed as meltwaters from the retreating glaciers cut a deep vertical walled gorge through the basaltic bedrock. In the Dalles, for approximately 3.2 km, the St. Croix, in places, is 21-30 m deep and its flow is the fastest. South of the Dalles, the river becomes wider, shallower, and passes between high banks for the next 32 km. About 35 km below the dam, the Apple River flows into the St. Croix. The river becomes deeper and slower moving. Approximately 43 km downstream the valley widens more. The last 40 km section of river is known as "Lake St. Croix." Near Hudson, Wisconsin, the St. Croix reaches a maximum width of 2,225m. A striking difference to the 12 m width of some sections of the Upper Namekagon River (Nat. Park Serv., 1987).

Methods

The rationale in the development of an overall sampling strategy was that sampling must not only emphasize data collection and analysis, but the data would also be used in making decisions on protection and management of aquatic ecosystems (Cairns et al., 1986). To be effective in a qualitative and quantitative survey of a river system, it is obvious that no single method or technique is adequate. It was noted by Gale (1975) that good quantitative estimates of mussel communities have been difficult to obtain using conventional survey techniques.

A reported disadvantage of brail efficiency is the clam bars' selectivity for larger mussels (Bridges, 1958). Considering the large proportion of rocky bottom substrate in the Namekagon and St. Croix Rivers and brail's overall inefficiencies, brail was not used in the study.

For qualitative and quantitative effectiveness, we felt that it was important to compare high mussel abundance areas to regular (random) chosen areas. Targeting only areas of known high mussel abundance creates a strong bias for specific species and habitats. It does not give a statistically accurate, or uniformly balanced assessment of a mussel population's diversity, distribution, or abundance. On the other hand, strict random sampling may not be the best way of determining species presence, abundance, or distribution, because mussel species exhibit clumped or island distribution, and all species in a community do not exhibit a high degree of spatial overlap (Kovalak et.al., 1987).

Considering the unique population parameters of mussels throughout a complete river system, we relied on three study methods and/or techniques to qualitatively analyze mussel populations and to quantify their abundance and distribution on the St. Croix and Namekagon Rivers. The river survey consisted of 50 60m2 belt line transects employing S.C.U.B.A. diving techniques at regular intervals (regular transects) every 8.2 km of river and 34 60m2 relative abundance transects conducted within each 10 km section of river in areas of known mussel populations. Also 36 midden piles were searched. The midden pile searches alluded to high mussel abundance areas in adjacent water, aided in qualitative indicators of species diversity, and indicated the presence of rare species. Isom et al. (1971) reported that midden pile searches have proven ineffective as a single sampling technique. Kovalek et.al. (1987) reported that dead shells do not accumulate in the same proportion to the occurrence of the live specimens in adjacent waters because muskrats appear to be selective for small mussels (juveniles and small species). However, selectivity may be beneficial in establishing the possible presence of rare species, because they may be small in size. It was our observation that the selectivity for small mussels is probably due to the physical limitations of a muskrat in opening large shells and to the palatability of some mussel species.

High mussel abundance areas were easily located in the St. Croix and Namekagon Rivers due to exceptionally low water volumes and subsequent water clarity during the period of study. Low water volumes were reported at three locations on the St. Croix and Namekagon Rivers in July of 1987. The three monitoring locations were at St. Croix Falls, Danbury, and Trego, Wisconsin. The 1987 mean average discharge calculated at all three locations for the month of July shows a 46% decrease in volume in comparison to the total calculated mean average discharge for July historically. (U.S. Geologic Survey, 1987) (Table I). Pollywogging and midden searches have eluded to high mussel abundance areas (Fuller, 1978). Also intensive shoreline searches near Native American communities on the Upper St. Croix located aboriginal midden piles, which reflected areas of high mussel abundance in adjacent waters.

The belt line transect method was chosen as an acceptable effective survey technique to study a complete river system. In previous qualitative and quantitative mussel surveys, belt line transects have proven effective (Buchanan, 1978; Stern, 1983). It was reported that the most reasonable method for quantifying mussel communities would be to collect clams in measured areas (Gale, 1975). In comparative studies on quantitative sampling methods for freshwater mussels on the Lower Chippewa River, it was reported that the 60m2 belt line transect was the most efficient means of mussel collection in comparison to 30m2 belt line transects, 1m2, 10m2, and 100m2 circular quadrats. Overall efficiency was determined by average # of mussels/transect, # of mussels/m2, quadrat or transect #, and efficiency in man hours to effectively complete a quantitative study in a 100'x400' area (Table II).

On all transects with a depth greater than .5m, S.C.U.B.A. was used as a collecting method. Skin diving was used as a collection method on transects with a depth less than .5m. Thiel (1981) reported a brail catch efficiency of .7% of the available mussel population. S.C.U.B.A., as a collecting method, was assumed to be 100% efficient. It was reported that S.C.U.B.A., as a collecting method, provides quantitative data, or depth, distribution, and density of mussels, as well as in situ observations (Stern, 1983; Cvancara, 1972; Pace et al., 1975; Ghent et al., 1978).

The 60m2 belt line transect was conducted tying off a free end of 11mm perlon climbing rope to an anchor point on shore, usually a tree or rock. A diver was left on shore with an assistant. The diver's equipment needed to conduct the transect are 2 nylon mesh collecting bags (a 5 lb. lead weight in each), a garden trowel, a 3-pronged cultivator, and a Martin automatic fly reel backed with 20m of parachute chord. The free end of the parachute chord is tied off to a Chouinard D Carabiner. A #4 Sampo Snap Swivel was attached to the fly reel, which is clipped onto the collecting bag. This deters the risk to the diver of being dangerously affixed, or restricted by attached ropes. The Carabiner allows the clam bag and diver to simultaneously traverse the 30 meter line. The 5 lb. weight in the collecting bag holds the bag down in the initial stages of the transect in a strong current.

In shallow water ($<$1m) an aid walks the perlon rope out a measured 30 meters. In deep water ($>$1m), the research boat (a 16' Jon Boat with a 15 hp Evinrude motor) was motored out, and moored with a 100 lb. anchor at a distance to accommodate the 30 meter transect. The rope was tied off to a hitch on the bow of the boat, and the rope was taut and affixed so as to be above the water's surface. The perlon rope was marked with blaze orange tape at 5 meter intervals to measure the 30 meter transect efficiently. All divers followed National Atmospheric and Oceanic Administration (N.A.O.A.) diving regulations. The boat operator or the diver assistant was responsible for the placement of the diving flag, before any diver entered the water. The diver collecting entered the water facing upstream, and began traversing the 30m line, probing a 2 meter width through all habitats encountered on the transect. All bottom substrate was probed and sifted to a .25m depth. The 2m sample width was the distance measured from the extended tips of the diver's fingers to their knees (each diver was over 6' tall). All live and dead shells were collected and tabulated on the Wisconsin Mussel Survey form in the boat or on shore (Appendix I). Voucher specimens were collected from each 5 mile section of river, and placed in 5 gallon buckets of ethanol. Data on species diversity, # live, # dead, depth, substrate, and location were taken at each site. All shells collected were reposited at the James Ford Bell Museum in St. Paul, Minnesota. Rare or questionable shell identification was performed by Marian E. Havilik of Malacological Consultants of La Crosse, Wisconsin, William A. Smith, Wisconsin Bureau of Endangered Resources, and Dr. Robert Bright from the University of Minnesota.

Results and Discussion

Thirty-nine species of freshwater unionid mussels live and/or dead were identified during the period of study. Of the 39 species identified, the only specie not found in the St. Croix River was Anodontoides ferusassacianus. This specie was unique to the Namekagon River. Thirty-eight species, and 16 species were identified in the St. Croix and Namekagon Rivers respectively. Only Fusconia ebena, and Potamilus ohienses were not found live. Elliptio crassidens was found live, but not on a designated transect (Table III). The federally endangered, exceptionally rare, or federal category 2 listed species found live were: Lampsilis higginsi, Cumberlandia monodonta, Epioblasma triquetra, Quadrula fragrosa, Simpsonaias ambigua, and Elliptio crassidens. The species identified on the rare mussel list for Wisconsin were: Ellipsaria lineolata, Cyclonaias tuberculata, Quadrula metanevra, Tritigonia verrucosa, and all the species listed above, with the exception of Potamilus ohiensis, which is a relatively common species in other locations in Wisconsin.

Recent important range extensions were documented for Lampsilis higginsi, Quadrula fragrosa, Epioblasma triquetra, Quadrula metanevra, Ellipsaria lineolata, Truncilla donaciformis, Truncilla truncata, and Tritigonia verrucosa previous to the complete river survey (Havilik in prep. oration).

In the federal section 6 survey conducted in conjunction with the complete river survey, range extensions were documented for Elliptio crassidens, Cumberlandia monodonta, and Simpsonaias ambigua up to river kilometer 83.5.

Our survey found all of the above species with the exception of Elliptio crassidens, Cumberlandis monodonta, and Simpsonaias ambigua, but with the addition of Quadrula quadrula, between river kilometer 85.5 - 85.8. Also Cumberlandia monodonta and Simsonaias ambigua were found live in Burnett County Wisconsin at river kilometer 141.3 and 185.2 respectively, representing the most distant range increase for any species.

Mussel Abundance and Distribution

Mussel collections by S.C.U.B.A in 60m2 transects were done in 84 locations. All of the mussels used in the distribution and abundance data were collected by this method. In general the mussels were not randomly distributed, but were clustered in specific areas in both the Namekagon and St. Croix Rivers. This was also noted by Thiel (1981) on the Mississippi River. In all, 4,550 live shells and 2,176 dead shells were collected. In 36 midden pile checks 12,809.5 shells were tabulated.

In most cases the mean live shell data for each species exceeded the dead shell means in both regular transects (RTs) and relative abundance transects (RATs). Considering the greater proportion of live individuals for most species alludes that the mussel populations in the St. Croix and Namekagon Rivers are generally healthy. The only species that showed an excessive death mean in comparison to its live mean was the Asiatic clam Corbicula fluminea. It was our observation that the primary population density for the Asiatic clam was in the warm water proximity of the effluent pipe of the Stillwater power plant. We suspect the Asiatic clams were subsequently spreading during the warm water months, but the cold water in the winter caused a substantial die off littering the bottom with dead shells, or simply that the shells were washing downstream once dead from the area near the power plant.

For the less common species (species found in $<$ 5 locations) there are not enough data to substantiate any quantitative values on density. These species were: Lampsilis higginsi, Quadrula fragrosa, Epioblasma triquetra, Elliptio crassidens, Cumberlandia monodonta, Simpsonaias ambigua, Ellipsaria lineolata, Quadrula quadrula, Anondontoides ferrussacianus, Fusconia ebena, Lasmigona complanata, Potamilus ohiensis, Toxolasma parvus, and Truncilla donaciformis. The data shows that these species were the least abundant and had the lowest frequency of occurrence in the complete riverway. Due to the low frequency of occurrence, and population densities for these individual species, this survey may not have sampled enough to adequately represent their populations.

The relative abundance for live clams found in relative abundance transects (RATs) and regular transects (RTs) each suggest the greatest abundance for Actinonaias ligamentina carinata. This species accounted for 23% of the total population riverwide (Table IV). For one occurrence Cumberlandia monodonta had a relatively high abundance of 0.5%. which is not a true indication of its actual abundance since it is a colonial species (Smith pers. comm.). The density data for mussels in transects containing each species live in regular transects indicate a mean of 20.0 individuals for Cumberlandia monodonta. These 20 individuals were found in 1 location (Table V). This not only illustrates island distribution for the species, but its colonial habits. This distributional pattern was true for Simpsonaias ambigua also.

In both RATs and RTs live shell density data showed that Actinonaias ligamentina carinata was found in the highest density. Fusconia flava, Elliptio dilatata, Amblema plicata, and Lampsilis radiata all show high densities and their individual density values are variable dependent on transect type (Table V). These species occur in the highest density, frequency and overall abundance in the riverway. The mussel density for transects containing each species for live clams on a RAT surveys indicate Truncilla truncata as ranking 3rd in density though being found in only 7 transects on the river. The corresponding high standard deviation suggests that this species is in concentrated island populations in several portions of the river below St. Croix Falls in high densities (Table V).

Cluster analysis by species indicates that less common species were more likely to be found with other uncommon species. Common species were found with other common species. For instance, Actinonaias ligamentina carinata, is associated with Elliptio dialatata, Fusconia flava, Lampsilis radiata, and Lampsilis ventricosa, while a less common species such as Truncilla truncata is associated with Quadrula metanevra and Tritigonia verrucosa, which are uncommon also (Table VI).

Distributional apsects of clustering by species diversity shows patterns of island distribution. Interestingly, the clusters with the largest species diversity are the areas that contain the least common species in the riverway (Table VII). These areas were not necessarily areas of high mussel densities.

An interesting aspect of distribution is that 56 percent of all mussels collected live on transects occurred at 21 locations between T40N - T43N and that 41.3 percent of the mussels occurred at 33 locations between R18W - R20W.

The aspect of Town (north) as a latitudinal coordinate in relation to distribution shows that 56.6 percent of the mussels occurred in the upper sections of the St. Croix River, and lower portions of the Namekagon River. In analysis of the distribution tables, the area from river kilometer 88.1 - 78.6 in the Namekagon River shows a lack of mussel concentrations. This section is a cold water trout stream, and it was our observation that this area was poor for mussel species diversity and abundance. Trout waters are probably poor mussel waters.

Bottom Substrate and Depth

Twenty-three percent of all the mussels collected live were found in a sand and gravel substrate. Sand, gravel and rock, and any combination thereof consisted of 64.2 percent of the substrate where mussels were collected on the survey. Detritus, mud and shifting sand constituted 3 percent of the substrate where mussels were found (Table VIII). In mud, detritus and shifting sand bottom substrates *Toxolasma parvus*, *Ligumia recta*, *Anodonta grandis*, and *Anodonta imbecillis* were found.

Fago et al. (1986) reported that the St. Croix River's stream bottom consisted primarily of sand, gravel, rubble, muck, and silt with limited areas of boulder and detritus.

Niney-six percent of all the live mussels collected occurred when river depth was 0.5m - 3.5m. The greatest proportion (36%) were collected when river depth was 1m. A single *Anodonta g. corpulenta* was found at a depth of 10m representing the greatest depth were a mussel was found on the riverway (Table IX). In general the freshwater unionid mussels were found in shallow depths, though this is biased considering the annual variables in river volumes.

Recommendations

1. Conduct at least one more year's research to refine inventory data to quantify rare species populations so management recommendations for permanent *mussel refuges can be ascertained.

2. Research reproductive parameters of rare mussel species in especially important mussel refuge areas.

3. Monitor rare mussel populations on a 3-5 year basis, while a complete river system survey should be conducted every 10 years by the transect method described by this study.

4. Initiate periodic water chemistry studies that target factors that may effect mussel populations. A present concern would be ammonia's effect on mussel populations in the St. Croix River. Graczyk (1986) reported that trend analysis for selected parameter loads at the St. Croix River at St. Croix Falls show that water quality has not significantly changed from 1974-81 except for the apparent 26% per year total increase in ammonia. Accompanied by this fact is ammonia's negative effects of mussel populations, as reported by Havilik and Marking (1987). A concentration of 5 ppm of ammonia was lethal to 40% of *Amblema p. plicata*, and *Anodonta g. grandis*, in 7 days (Horne and McIntosh, 1979).

5. Review impacts of "stink baits" by using mussel meats for fishing purposes in select areas of the St. Croix. Both *Lampsilis higginsi*, and *Quadrula fragrosa*, were found freshly killed for use as stink bait during

the research period. (Havilik in prep. 1987).

6. Actively monitor land use decisions that would potentially impact water quality.
7. Research, monitor, and evaluate the effect of dams on mussel populations and distribution. Special and immediate research should be targeted at the St. Croix Falls hydro-electric facility considering the area below the dam has a good concentration of rare mussel species that may be adversely effected.
8. Develop and enact mussel education programs for a diverse population spectrum. The initial stages of educational directive should be targeted at field personnel, interpreters, and law enforcement.
9. Support research on host species determination and life history work on Cumberlandia mondonta, Quadrula fragrosa, Cyclonaias tuberculata, Elliptio crassidens, Epioblasma triquetra, and Simpsonaias ambigua.
10. Evaluate mussels as a bio-monitor of riverine ecosystems.
11. Coordinate future fish research, or limnological projects with mussel research.
12. Research, monitor, and evaluate the effects of sewage treatment and fish hatchery effluent releases into the St. Croix River. Considering that each are potentially prime point sources for ammonia contamination. Again the area below the hydroelectric facility in St. Croix Falls is off immediate concern.

* - Potential mussel refuge areas and locations of exceptional mussel beds.

Locations are determined by river kilometer.

1. St. Croix River

   River km - 85.8 - 57.4 Refuge areas
   131.8 - 209.9
   28.4, 236, 246

2. Namekagon

   River km - 48.1, 101.5, 156.9

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Literature Cited

Andersen, A. April 17, 1987. N.P.S. Memo to Regional Chief Scientist on Scope of Work - Naiad Mussel Ecology of St. Croix Riverway.

Baker, Frank Collins. 1928. The Freshwater Mollusca of Wisconsin. Democrat Printing Company, Madison, Wi. pp. 1-495.

Bridges, W. R. 1958. Freshwater Mussel Resources of the Tennessee River in the Area of New Johnsonville, Tennessee. U.S. Dept. of the Interior. Fish and Wildlife Service, Bur. Comm. Fish Prog. Rep. (under contract 14-17 - 008-501). 29 pp.

Bright, Robert. University of Minnesota, St. Paul, Mn.

Buchanan, A. 1976a. Status of Knowledge Report [on] Naiads of the Meramec Basin. Part I: Test. Missouri Department of Conservation, Jefferson City. pp. 1-66.

Buchanan, A. 1976b. Status of Knowledge Report [on] Naiads of the Meramec River Basin. Part II: Species Distribution Maps. Missouri Department of Conservation, Jefferson City. pp. 1-49.

Cairns, J., Jr. and Pratt, J. R. 1986. "Developing a Sampling Strategy." Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Systems, ASTM STP 894, B. G. Isom, Ed., American Society for Testing and Materials, Philadelphia, Pa. pp. 166-168.

Cvancara, A. M. 1972. Lake Mussel Distribution as Determined by S.C.U.B.A. Ecol. 53: 154-157.

Dawley, C. 1947. Distribution of Aquatic Mollusks in Minnesota. American Midland Naturalist, 38: 671-697.

Fago, D. 1986. Distribution and Relative Abundance of Fishes in Wisconsin, Vol. VII, St. Croix River Basin. Tech. Bull. No. 159. Department of Natural Resources, Madison, Wi.

Fuller, S. L. H. 1978. Freshwater Mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River: Observations at Selected Sites Within the 9-Foot Channel Navigation Project on Behalf of the United States Army Corps of Engineers. Academy of Natural Sciences, Philadelphia, Pa. pp. 178-181.

Gale, W. F. 1975. Bottom Fauna of a Segment of Pool 19, Mississippi River, near Fort Madison, Iowa, 1967-1968. Iowa State J. Res., 49: 353-372.

Ghent, A. H., R. Singer and L. J. Singer. 1978. Depth Distributions Determined with S.C.U.B.A., and Associated Studies of the Freshwater Unionid Clams, *Elliptio complanata*, and *Anodonta grandis*, in Lake Bernard, Ontario. Can. J. Zool. 56: 1654-1663.

Graczyk, D. J. Water Quality in the St. Croix National Riverway, Wisconsin.

United States Dept. of the Interior, U.S. Geologic Survey. Lakewood Co. pp. 17-19.

Havilik, Marian. Malacological Consultants, 1603 Mississippi Street, La Crosse, Wi, 54601.

Havilik, M. E., and L. E. Marking. 1987. Effects of Contaminants of Naiad Mollusks (Unionidae): A Review. United States Dept. of the Interior, Fish and Wildlife Service. Resource Pub. 164, Washington, D.C.

Horne, F. R., and S. McIntosh. 1979. Factors Influencing Distribution of Mussels in Blanco River of Central Texas. Nautilis 93: 119-133.

Isom, B. G. 1971. Mussel Fauna Found in Fort Loudon Reservoir, Tennessee River, Knox County Tennessee. Malacological Review 4: 127-130.

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

Mathiak, H. A. 1979. A River Study of the Unionid Mussels of Wisconsin 1973-1977. Sandshell Press, P.O. Box 44, Horicon, Wi, 54032. 75 pp.

Pace, G. L., E. J. Szuch and R. W. Dapson. 1975. S.C.U.B.A. Associated Studies of Freshwater Snails. Bull. American Malacological Union. 1975: 68.

Pokrzwinski, A. G. 1987. An Evaluation of Quantitative Sampling Methods for Freshwater Unionid Mussels. Unpub. Paper, Unviersity of Wisconsin, Eau Claire.

Smith, W. A. Natural Heritage Inventory Coordinator, Wisconsin DNR, Box 7921, Madison, Wi, 53707.

Stern, Edward M. 1983. Depth Distribution and Density of Freshwater Mussels (Unionidae) Collected with S.C.U.B.A. from the Lower Wisconsin and St. Croix Rivers. The Nautilus 97 (1): 36-42.

Thiel, P. A. 1981. A Survey of Unionid Mussels in the Upper Mississippi River (pools 3 through 11). Wis. Dept. Natur. Resour., Tech. Bull. 124. 25 pp.

United States Department of the Interior. 1987. National Park Service, St. Croix National Riverway, Cumulative File Information. St. Croix Falls, Wi.

United States Department of the Interior. 1987. United States Geological Survey, Cumulative File Information for St. Croix and Namekagon Rivers, Madison, Wi.

Wisconsin Department of Natural Resources. 1987. Bureau of Endangered Resources, Cumulative File Information, Madison, Wi.

Table I: Summary of Discharge Volume in Cubic Feet Per Second for the St. Croix and Namekagon Rivers for the Month of July

Site	Status	Date	Discharge (CFS)
Trego, WI	lowest vol.	1934	235
"	highest vol.	1958	1,026
"	mean ave.	1928-86	485
"	present	1987	*352
Danbury, WI	lowest vol.	1934	514
"	highest vol.	1958	3,230
"	mean ave.	1914-86	1,299
"	present	1987	*779
St. Croix Falls, WI	lowest vol.	1934	1,014
"	highest vol.	1952	17,260
"	mean ave.	1902-86	4,106
"	present	1987	*2,052

* - Provisional Data (U.S.G.S., 1987)

Table II: Sampling Efficiency Comparison

Method	Avg. # Mussels Quadrat	Avg. # Mussels m2	Adequate Sample Quadrat or Transect #	Efficiency /Man Hours
1m2 Circular Plot	0.15	0.15	587	21.2
10m2 Circular Plot	0.45	0.05	200	10.7
100m2 Circular Plot	2.68	0.03	36	4
30m2 transect	1.4	0.05	106	26.6
60m2 transect	3.2	0.05	28	7

In a sample area 100' x 400'

(From An Evaluation of Quantitative Sampling Methods for Freshwater Unionid Mussels. Unpub. Paper, U.W.-Eau Claire, Pokrywinski, 1987).

Table III: Scientific and Common Names of Mussels Collected in the St. Croix and Namekagon Rivers in 1987

Scientific Name	Common Name	Live/ Dead	Namekagon River	St. Croix River
Anodontoides ferusassianus	Cylinder	L	X	-
Cumberlandia monodonta	Spectacle Case	L	-	X
Quadrula fragrosa	Winged Mapleleaf	L	-	X
Q. pustulosa	Pimpleback	L	X	X
Q. metanerva	Monkeyface	L	-	X
Q. quadrula	Mapleleaf	L	-	X
Tritigonia verrucosa	Buckhorn	L	-	X
Cyclonaias tuberculata	Purple Wartyback	L	X	X
Fusconia flava	Pigtoe	L	X	X
F. ebena	Ebony Shell	D	-	X
Amblema plicata	Threeridge	L	X	X
Pleurobema sintoxia	Ohio River Pigtoe	L	X	X
Elliptio crassidens	Elephant Ear	L	-	X
E. dilatata	Spike	L	X	X
Obliquaria reflexa	Threehorn	L	-	X
Potamilus alatus	Pink Heelsplitter	L	-	X
P. ohiensis	Pink Papershell	D	-	X
Leptodea fragilis	Fragile Papershell	L	-	X
Ellipsaria lineolata	Butterfly	L	-	X
Truncilla truncata	Deertoe	L	-	X
T. donaciformis	Fawnfoot	L	-	X
Obovaria olivaria	Hickorynut	L	-	X
Actinonaias ligamentina carinata	Mucket	L	X	X
Ligumia recta	Black Sandshell	L	X	X
Toxolasma parvus	Lilliput	L	-	X
Lampsilis higginsi	Higgins Eye	L	-	X
L. radiata	Fat Mucket	L	X	X
L. ventricosa	Pocketbook	L	X	X
Lasmigona complanta	White Heelsplitter	L	-	X
L. compressa	Creek Heelsplitter	L	X	X
L. costata	Fluted Shell	L	X	X
Alasmidonta marginata	Elk Toe	L	X	X
Anodonta g. grandis	Floater	L	X	X
A. g. corpulenta	Stout Floater	L	-	X
A. imbecillis	Paper Floater	L	-	X
Strophitus undulatus	Squaw Foot	L	X	X
Simsonaias ambigua	Salamander Mussel	L	-	X
Corbicula fluminea	Asiatic Clam	L	-	X
Epioblasma triquetra	Snuff Box	L	-	X