# Aquatic Habitat Classification on the St. Croix National Scenic Riverway

by

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# PREFACE

This study relates to Project Number PMIS#84374 of the National Park Service. It was supported under a grant from the National Park Service, St. Croix National Scenic Riverway, in cooperation with the University of Minnesota, Department of Fisheries, Wildlife and Conservation Biology. Professor Jim Perry, University of Minnesota, Department of Fisheries, Wildlife and Conservation Biology, is the principal investigator. Randy Ferrin, Chief of Natural Resources, St. Croix Scenic Riverway, Natural Resources Division, was the co-principal investigator before he retired in October 2005; and Brenda Moraska Lafrancois, aquatic ecologist of the National Park Service, Midwest region, took over his role for this project thereafter. The project is carried out by Haibo Wan, Ph.D student of the University of Minnesota, Water Resources Center and Department of Fisheries, Wildlife and Conservation Biology.

# ABSTRACT

The purpose of this project is to classify the aquatic habitats within the St. Croix National Scenic Riverway (the St. Croix River upstream of the City of Stillwater, Minnesota, and its largest tributary, the Namekagon River), in order to provide a framework for future monitoring and management activities.

The work is done at two levels: *segment* and *reach*. S*egments* have the dimension of 15+ km (10+ miles). *Reaches* are nested within *segments* and have the dimension of 1.5+ km (1+ mile). Our *segments* are the continuation of the *major segments* of Macbeth *et al.* (1999), created by incorporating additional information and rebuilding the rationale. S*egments* are delineated primarily by tributary outlets and channel slopes, while also incorporating information such as ecological regionalization of the basin, land use and land cover, riparian vegetation, and channel substrate. *Segments* integrate environmental impacts on the aquatic communities through hydrologic processes and sediment dynamics at three spatial scales: basin, riparian zone, and channel.

*Reaches* are produced based on the composition of the channel substrate (i.e., frequency of different sized particles, including boulders, cobbles, gravels, sands, silt, and clay). We took substrate videos at the thalweg every 400 m along the Riverway during summer 2004. Proximal sites with similar substrate composition are grouped into *reaches.* We selected substrate as the principal classification variable for two reasons: (1) the diversity and abundance of benthos are related to size and heterogeneity of substrate materials; and (2) fine materials (sands, silt, and clay) are a part of the sediment dynamics within the entire basin and could be used to indicate land use change. Noticeably, sediment and nutrient loading is currently the primary management concern in the St. Croix Basin.

We used biological data to validate the physical classification framework. The mussel data from Doolittle (1988) are the only consecutive and relatively fine-scale data we can find to serve this purpose. Two-Way-INdicator-SPecies-ANalyis (TWINSPAN) was performed to cluster Doolittle’s data. Five clusters were identified and they are spatially consistent with our *segments,* suggesting that *segment* is an effective unit for mussel resource management; no pattern was found at a scale finer than *segment.* Mussels are substrate selective; some species can only live on coarse substrate (boulders, cobbles, pebbles, and gravels). That pattern is consistent with our data analysis. Almost all sites with fine substrate (i.e., sands, silt, clay, muck, and mud) were associated with the lowest species richness ($\leq$3 species) and abundance ($\leq$5 individuals) in Doolittle’s data. Therefore, siltation (i.e., deposition of fine materials) should be regarded as a serious concern for mussel resource management on the Riverway.

Finally, we conclude that no further classification efforts are necessary for the Riverway. The present classification can serve as the basis for a regular, long-term monitoring network. Discharge, sediment and nutrient loading at the major tributary outlets should be monitored monthly. The monitoring of tributary inputs is consistent

with the *segments* proposed here. Within-segment sites can be selected based on *reaches* if a more localized sampling design is desired. Mussel or macroinvertebrate community studies can be performed accompanying the physical monitoring or on a case-specific basis. Parallel to in-stream monitoring, we suggest that monitoring land use changes in the watershed, using GIS and remote sensing data, should occur on a five-year cycle, to respond the rapid urbanization and population growth in the St. Croix basin.

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# CHAPTER 1 OVERVIEW

## 1. Stream Classification

Human activities in a river channel, its riparian zone, or in the basin can affect channel form and function, stream water quality, and aquatic ecosystem health. Natural resource mangers need to evaluate stream ecosystem integrity and take corresponding actions to maintain or restore stream health. Stream classification is usually the first step towards regular monitoring and management activities.

Stream classification is the delineation of the channel into units of different spatial scales. There are no uniform criteria or procedures for stream classification; instead, any classification should have a specific and clear purpose (Mosley 1994). Gordon *et al.* (2004) provided a good review of stream classification and summarized a range of classification methods, including ecological (Vannote *et al.* 1980), geomorphological (Rosgen 1994, 1996), hydrologic, water quality-based, and combined physical-chemical-ecological classifications. It is beyond the scope of this report to provide a detailed discussion of these general classification methods. In our study, we developed an *ad hoc* classification framework for the Riverway for the purpose of aquatic habitat assessment.

Our classification is intended to be a synthetic description of the physical environment regarding the aquatic communities. It provides a reference framework for future biological resource management and research on the Riverway, and it can be used as base line scenario. In order to provide the most detailed information and be compatible with future studies, our principle is to classify the Riverway at the finest practical scale.

## 2. The St. Croix National Scenic Riverway

The St Croix National Scenic Riverway (referred to as "Riverway" later in the report) includes the St. Croix River upstream of Stillwater, Minnesota, and its largest tributary, the Namekagon River. The St. Croix River is a $6^{th}$-order river. It empties into the Mississippi River at Prescott, Wisconsin. The majority of its 248 km (154 miles) length forms the boundary of Minnesota and Wisconsin. The 158 km (98 miles) Namekagon is a $5^{th}$-order river that joins the St. Croix River above Danbury, Wisconsin. The St. Croix and the Namekagon Rivers were designated as the St. Croix National Scenic Riverway by Congress in 1968 and 1972 (Wild and Scenic Rivers Act of 1968; Wild and Scenic Rivers Act of 1972) for their "outstandingly remarkable" scenic, water quality, and fish and wildlife values. The Riverway is administrated by the National Park Service (NPS) upstream from Stillwater, Minnesota, and the 40 km (25 miles) reach below Stillwater is administrated cooperatively by the two states. The river is narrow and wild above St. Croix Falls, braided and wide between St. Croix Falls and Stillwater, and broad and lake-like below Stillwater. The portion below Stillwater is also called "Lake St. Croix". The Xcel Energy St. Croix Hydro Dam (referred to as "Hydro Dam" later in the report), built at the site of an abrupt geologic and elevational discontinuity near St. Croix Falls/Taylor Falls, is the major hydrologic disturbance on the Riverway. To better protect aquatic biota, the dam has been run-of-the-river-operated since 2006. The Hayward and Trego Dams are two hydro dams on the Namekagon. The Hayward Dam impounds Lake Hayward and is now run-of-the river operated. Gordon Dam controls water level at the Gordon Flowage, the headwaters of the St. Croix. Namekagon Dam controls water level at the outlet of Lake Namekagon, the headwaters of the Namekagon. There are also four non-functioning, log crib dams on the Riverway: two at Pacwawong Flowage and Phipps Flowage on the Namekagon, and two at Coppermine and Nevers on the St. Croix. Also, the lock and dam system on the Mississippi River at Redwing, Minnesota has profound influence on the water level in the lower St. Croix (Holmberg *et al.* 1997).

The Riverway has been the subject of years of aquatic ecological study by many agencies, including the Minnesota and Wisconsin Departments of Natural Resources (MDNR, WDNR), the Minnesota Pollution Control Agency (MPCA), the U.S. Geological Survey (USGS), the National Park Service (NPS), and many university researchers (Macbeth *et al.* 1999). Macbeth *et al.* pointed out that the studies before were "sporadic and inconsistent, due to funding and interest specificity." Holmberg *et al.* (1997) provide a good synthesis of that work in their water resources management plan for the Riverway. The plan provided comprehensive information about the Riverway and its basin, as well as the research history and a series of significant data sources. Management priorities were proposed and integrated management was recommended in that plan.

# 3. Classification Efforts on the Riverway

This study is the second classification project on the Riverway. Macbeth *et al.* (1999) built a hierarchical classification framework for a 145 km (90 miles) portion of the St. Croix River, from the confluence with the Namekagon River (River Km 214 (Mile 132.9)) to about 16 km (10 miles) downstream of the Hydro Dam (River Km 69.5 (Mile 43.2)). They used landscape slope (the ratio of topographic elevation in feet to river miles with map-wheel and USGS 7.5-minute topographic quadrangle maps) and basin properties such as bedrock geology, land use/land cover, climate, and ecoregion to classify this portion into four *major segments,* each from 16 to 55 km (10 to 34 miles) long. "Major segments reflect basin-level, long-term influences on the river environment" (Maxwell *et al.* 1995). The first *major segment* is from the confluence to the first major landscape transition (River Km 161.5 (Mile 100.4)), close to Nelson's Landing. The second *major segment* ends at Highway 70 (River Km 140 (Mile 87.0)), close to the Marshland Visitor Center. This boundary is consistent with the transition of several geologic, climatic, and ecoregional properties. The third segment is from Highway 70 to the Hydro Dam (River Km 85.6 (Mile 53.2)). The last segment extends 16 km (10 miles) from the Hydro Dam to River Km 69.5 (Mile 43.2).

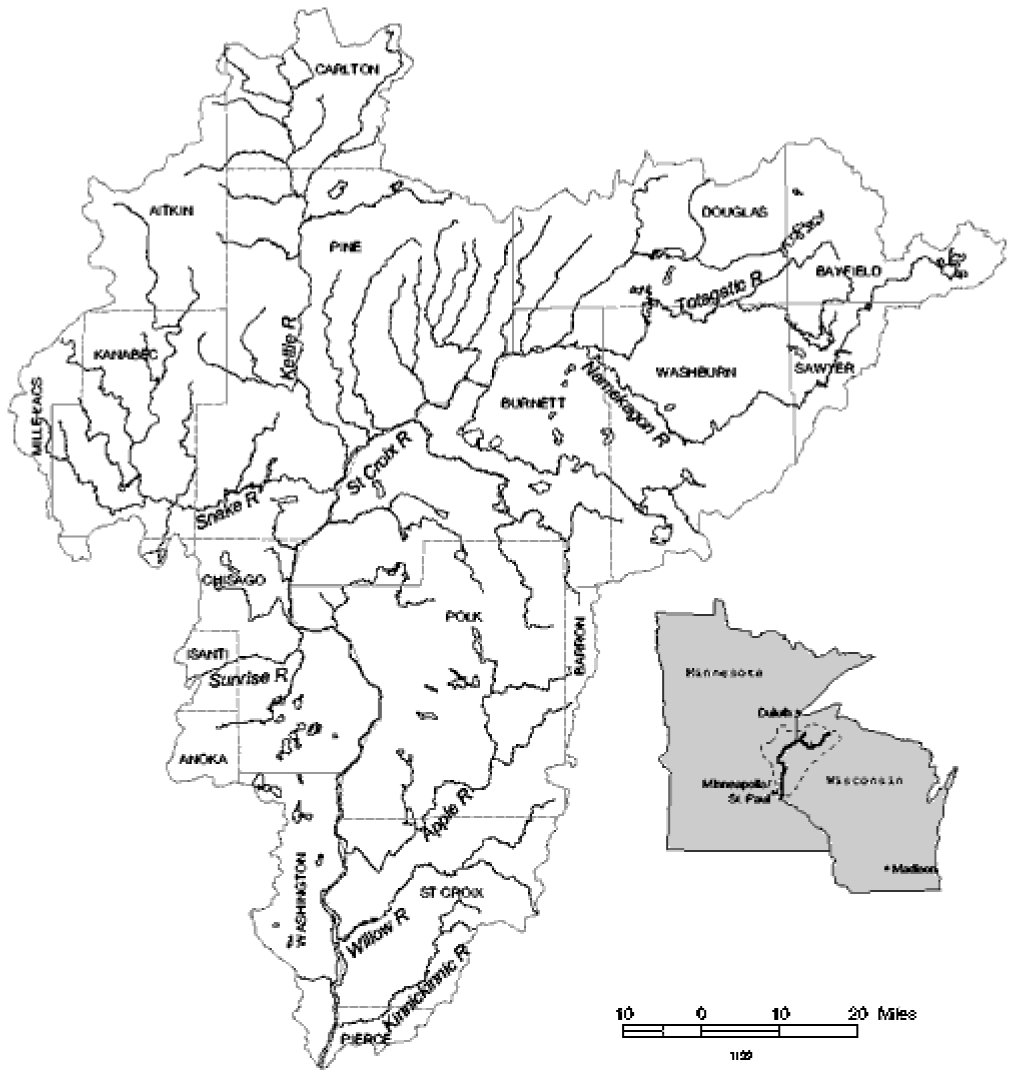


**Figure 1 St. Croix Drainage (from Minnesota PCA)**

The four *major segments* were further divided into 12 *minor segments* primarily by channel gradient (a finer scale perspective on landscape slope), supplemented by meander ratio (the proportion of meandering channel-length to meandering valley-length). *Minor Segments* have dimensions from 3-32 km (2 to 20 miles). "Minor segments reflect the regional, medium-term, fluvial effects on aquatic habitat structure and function" (Meador *et al.* 1993). Macbeth *et al.* (1999) further used a series of channel physical features measured in the field to delineate the Riverway into two finer scales: *reaches* and *patches*. Those finer scale data were used to validate *major and minor segments.* "*Reaches* reflect the localized, short-term influences of geomorphology and riparian land-use on the complexity of river aquatic habitats and their associated biotic communities" (Meador *et al.* 1993); measures at this scale include stream width, bank vegetation, bank slope, and island characteristics. "*Patches* reflect the micro-scale control of biophysical attributes on unique, relatively homogeneous patches in the river" (Frissel *et al.* 1986);

measures at that scale include water depth, flow velocity, conductivity, substrate composition, woody debris characterization, and benthic organisms.

However, because Macbeth *et al.* (1999) had data for only one *minor segment* within each of the three *major segments*, their validation could be made only at the *major segment* level. Their three *major segments* were well separated in their principal component analysis (PCA); differences among segments could be explained by substrate composition, discharge, conductivity, and standardized width/depth. They also conducted cluster analyses on data from field surveys (i.e., physical habitat features, macroinvertebrate community, analyzed separately) within the three *minor segments*, intending to group sites into *reaches*. They concluded, however, that *reaches* did represent the physical features or communities of the aquatic habitats effectively in the low-gradient sections of the river. Finally, they recommended that the finest units or *patches,* which were distinct both longitudinally and laterally, be used in combination with the *reaches.*

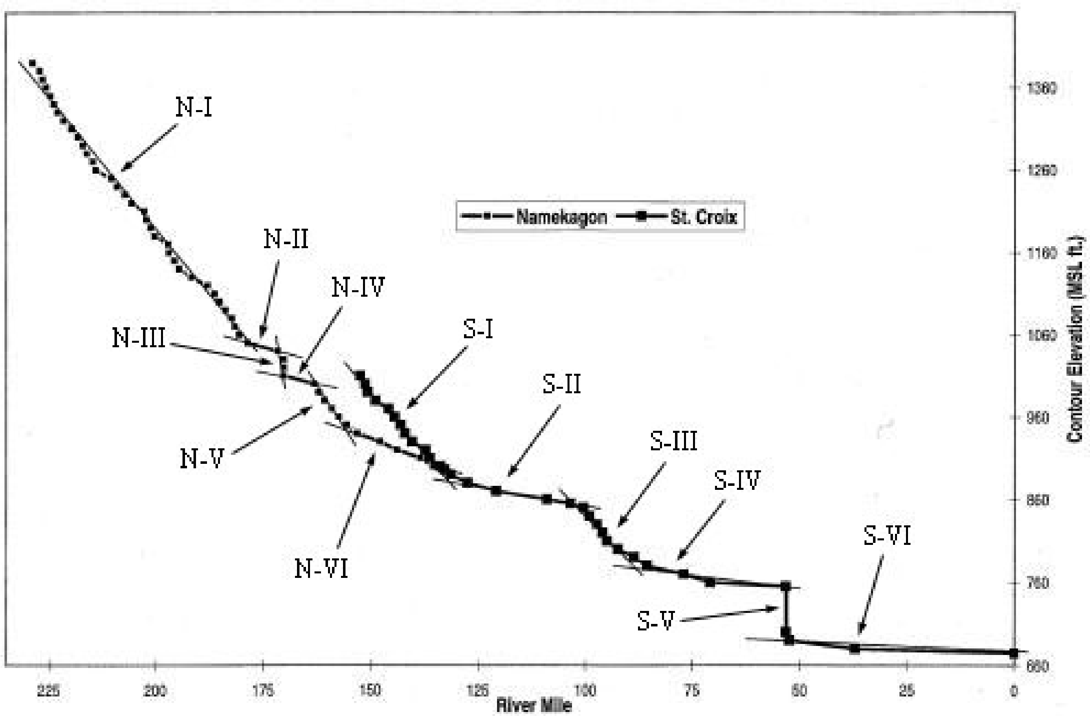


**Figure 2 Major segments of Macbeth *et al.* (1999)** The X-axis is river mile upstream from the confluence of the St. Croix River and the Mississippi River. The Y-axis is the elevation. *Major Segments* on the St. Croix River and the Namekagon River are denoted by “S” and “N” separately.

In brief, Macbeth *et al.* (1999) made a clear distinction at the *major segment* level for the majority of the St. Croix River but further delineation needed to be explored and validated. The goal of this study is to complete the classification at finer scale(s) on the entire Riverway, including physical classification and biological validation.

# CHAPTER 2 DATA AND METHODS

In this chapter, we describe methods for data collection and for building the physical classification framework (which is then described in depth in Chapter 3). Second, we describe methods for our test of the framework using mussel data; validation results of that latter analysis are detailed in Chapter 4.

## 1. Coarse Scale Classification

Our coarse scale classification is a continuation of Macbeth *et al.*'s (1999) *major segments*. We used several basin characteristics and channel slope (i.e., landscape slope and channel gradient as used in Macbeth *et al.*) as well as land use/land cover and tributary information.

### Basin Characteristics

Basin characteristics were summarized by Macbeth *et al.* (1999). They pointed out that the boundary between the Northern Lakes and Forests and the North Central Hardwoods, the two major USGS ecoregions, should play a prominent role in natural resources management within the St. Croix Basin, because that boundary implies significant systematic changes in the environment. The ecoregions were delineated on the basis of geology, land use/land cover, climate, and other data (Appendix 1). The boundary between the two ecoregions is consistent with changes in climate (USDA Zone 3 and 4), bedrock geology (Cambrian sandstone and Precambrian lava flows), and hydrogeology (Precambrian igneous and metamorphic rocks and Mt. Simon-Hinckley-Fond du Lac). Such a boundary is certainly not clear-cut and must be interpreted as having a narrow intermediate zone. For example, there is a noticeable feature in bedrock distribution where a transition to a smaller area of Precambrian lava flows is consistent with the elevation change around Taylor's/St. Croix Falls, which also corresponds to the boundary between two different hydrogeologic (groundwater) zones.

### Land Use/Land Cover

The St. Croix Basin contains a series of sub-basins (i.e., tributary drainage basins). Anthropogenic land use data (total area and percentage) for these sub-basins are given in Appendix 1. Anthropogenic land use percentage data are from Lenz *et al.* (1999). Tributary drainage area data are either from Lenz *et al.* (1999, denoted as [(1)]) or from Boyle *et al.* (1992, denoted as [(2)]). Anthropogenic land use represents agricultural as well as urban lands, while urban land only represents a tiny percentage of land use in these sub-basins. Cells in the "Basin Land Use" column in Appendix 1 are color coded, corresponding to a series of anthropogenic land use percentages (following Lenz *et al.* 1999): < 5%, < 20%, < 40%, < 60%, and > 60% (mostly > 80% in this category). There is an apparent trend of increasing agriculture from the headwaters downstream.

### Channel Slope

Macbeth *et al.* (1999) created their ***major segments*** based on channel slope (landscape slope in their term), which is demonstrated in Figure 2. Channel slope changes from steep to flat twice upstream of the Hydro Dam on the St. Croix River; each occurs at a convex curve that may represent a hydraulic change from sediment degradation to aggradation. The two curves surround the Marshland Visitor Center, at a location coincident with the boundary between the two ecoregions.

### Tributaries

In our classification, we assign significance to tributaries because they greatly alter hydrologic and nutrient/sediment loading regimes of the main channel (Lenz *et al.* 2003). We use channel slope as the principal criterion for derivation of ***segments;*** major tributaries near slope transitions were used as delineators of our first-level classification unit, *segments*. The details of our *segments* are given in Chapter 3.

## 2. Fine Scale Classification

Although there exist rich physical and biological data sets on the Riverway, those data are neither sufficiently extensive nor at sufficiently fine spatial scale (e.g., 1.5 km) to allow a classification of the entire Riverway. Thus, it was necessary for us to acquire field data of selected variables at a fine spatial scale. Based on literature review, budget and time limitations, the following three variables were selected: substrate composition, water depth, and flow velocity.

### Substrate

Substrate composition is the frequency of different size particles. It can be visually assessed in shallow or clear-water sites, but visual assessment is not possible at deep or turbid sites. Substrate can be collected by a grab sample, in which a tiny area is sampled. We decided to use videos of the substrate as our data source. Benefits of this method include: (1) we can cover a much larger area, (2) the videos can be used for quantitative analysis, and (3) the videos can archived and used by other researchers later.

During a 10-week field season starting at mid-June 2004, we took one-minute video clips of the substrate every 400 m along the thalweg of the St. Croix River from the headwaters to Stillwater and the entire Namekagon River. A SONY ZR80 camcorder was attached to an underwater lens through a waterproof cable. At each site, we recorded substrate in a 1-m radius circle. We also photographed the riparian zone of both banks at each site. Further, we used a FishFinder 80 GPS to record latitude/longitude and water depth, and a Marsh-McBirney digital flow meter to record water velocity. We recorded those data at 1,100 sites, providing a fine scale, longitudinal profile of the riverine environment for use in our classification.

We only sampled at the thalweg but we realized that there is lateral patchiness at reach site. The littoral zone would have more shallow water and more nutrients input from the riparian zone compared to the thalweg. However, the lateral variance along a cross-section reflects the contrast between riparian and thalweg conditions rather than the regional variance of the watershed that is reflected along the river longitudinally. The latter is our classification priority. We decided to sample a single site at each cross-section in order to build a longitudinal profile. We chose to sample at the thalweg because we could experience most variability in flow velocity and substrate composition at that location. The 400-meter interval was chosen to allow us to complete the entire Riverway within the time available and was based on pilot work conducted during the first two weeks of sampling.

Our particle size classes follow the Wentworth Scale (after Cummins 1962).

**Table 1 Wentworth Scale for sediment sizes**

| Substrate type | Particle diameter (mm) |
|---|---|
| Boulder | > 256 |
| Cobble | 64-256 |
| Pebble | 16-64 |
| Gravel | 2-16 |
| Sand | 0.06-2 |
| Silt and Clay | < 0.06 |

Particle sizes were calculated by measuring video screen with known magnification. We imported all video files, and then calibrated screen area by projecting an image and measuring known-diameter objects. There may have been an unknown-quantity bias in distinguishing large gravel vs. small pebbles and large pebbles vs. small cobbles. We tried to reduce these biases by describing these situations as “mix of gravel and pebble” or “mix of pebble and cobble”.

We developed codes to denote substrate composition (Table 2). An ordinal number (code) was assigned to each clip. Together we have 22 classes of substrate composition.

Descriptions of substrate composition for each site are in appendices 2 and 3. Proximate video sites with similar substrate composition were grouped as *reaches* (dimension of 1.5+ km (1+ mile)), constrained by *segments.*

Finally, we selected substrate as the principal classification variable to delineate our fine scale classification units or *reaches.* We chose this metric for two principal reasons: (1) diversity and abundance of benthos are related to the size and heterogeneity of substrate materials and (2) fine materials (i.e., sands, silt, and clay) are part of the sediment dynamics within the entire basin and should indicate land use change in the basin, which is the topic of the field of fluvial geomorphology. Siltation is the most important cause of stream and river pollution in the US, about 50% greater than the second most important cause with regard to stream distance degraded (EPA 1990). Also, sediment and nutrient loading is the primary management concern in the St. Croix Basin at current time.

**Table 2 Substrate composition codes.** ** = abundant, * = present but not abundant

| Class/Substrate | Fine | Gravels | Pebbles | Cobbles | Boulders |
|---|---|---|---|---|---|
| **1** | ** | | | | |
| **2** | ** | ** | | | |
| **3** | ** | ** | * | * | * |
| **4** | ** | * | * | * | * |
| **5** | ** | ** | ** | | |
| **6** | ** | ** | ** | * | * |
| **7** | ** | ** | ** | ** | |
| **8** | ** | ** | ** | ** | * |
| **9** | | ** | | | |
| **10** | | ** | * | * | |
| **11** | | ** | ** | | |
| **12** | | | ** | | |
| **13** | | | ** | ** | |
| **14** | | ** | ** | * | * |
| **15** | | ** | ** | ** | |
| **16** | | | ** | ** | * |
| **17** | | | ** | ** | ** |
| **18** | | | | ** | |
| **19** | | | | ** | ** |
| **20** | | | | | ** |
| **21** | Bedrock | | | | |
| **22** | Covered by thick vegetation, substrate is invisible. | | | | |

## Flow Velocity and Water Depth

There was considerable temporal variation for these two measures during the 10-week field season. We were unable to identify a reliable method for normalizing them; different parts of the Riverway could have different seasonal variability due discharges from different tributaries and we did not have localized seasonal variability data (e.g., discharge, flow velocity, water depth) for the normalization. We did, however decide to collect flow and depth for the insight they might offer when combined with professional judgment in our interpretation of the analyses. Water depth was measured with a FishFinder 80 GPS and water velocity was measured with a Marsh-McBirney digital flow meter. Two flow velocity rates were recorded at each site: 80% and 20% off water surface.

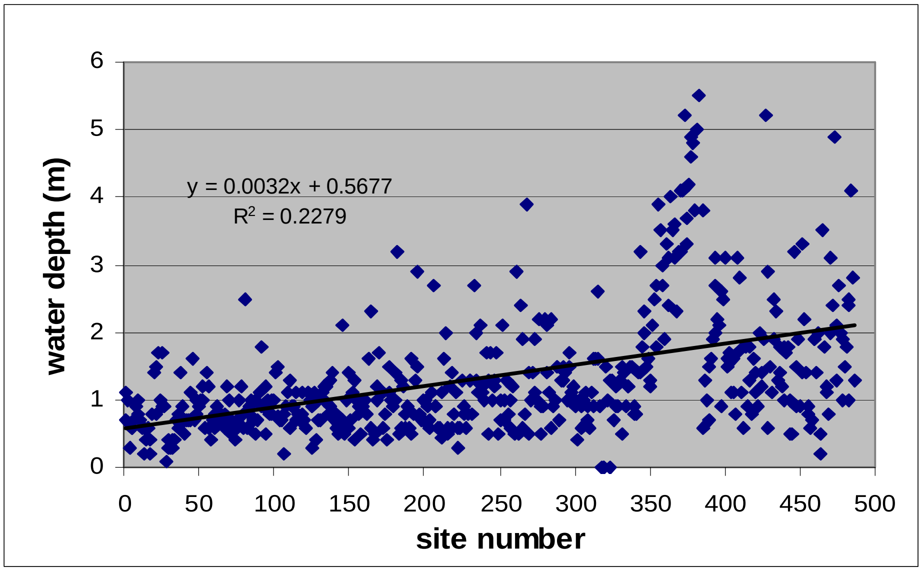


**Figure 3 Water depth profile of the St. Croix River at thalweg**

In general, the St. Croix River becomes gradually deeper downstream (Figure 3). Two outliers (depth >10m) near the St. Croix Visitor Center were removed for visualization. Most of the Namekagon River has a depth of less than 1.5 m (Figure 4) and does not show the tendency to become deeper downstream.

Flow velocity profiles showed no apparent pattern (i.e., 80%, 20% or average) either on the St. Croix River or the Namekagon River. Flow velocity at 80% (Figure 5 and 6) is shown for example.

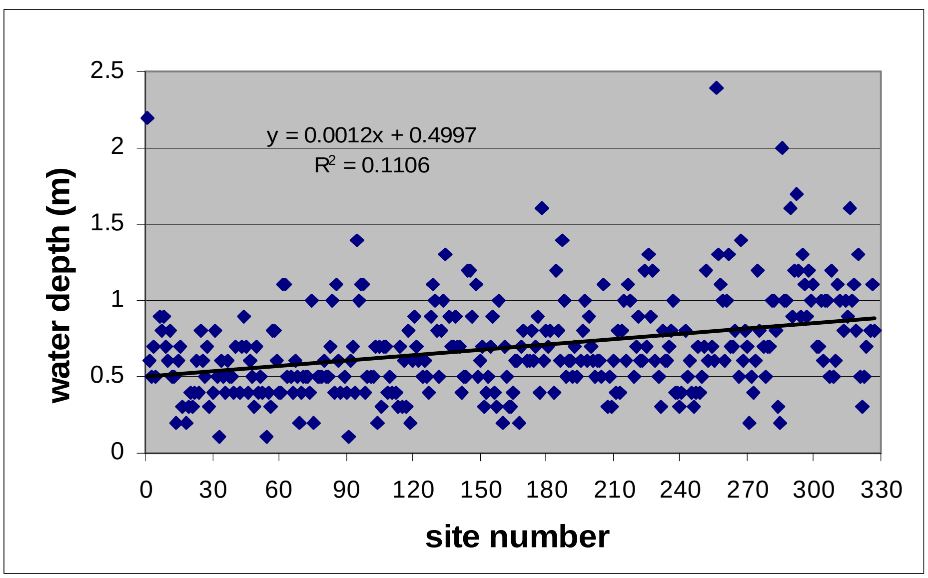


**Figure 4 Water depth profile of the Namekagon River at thalweg**

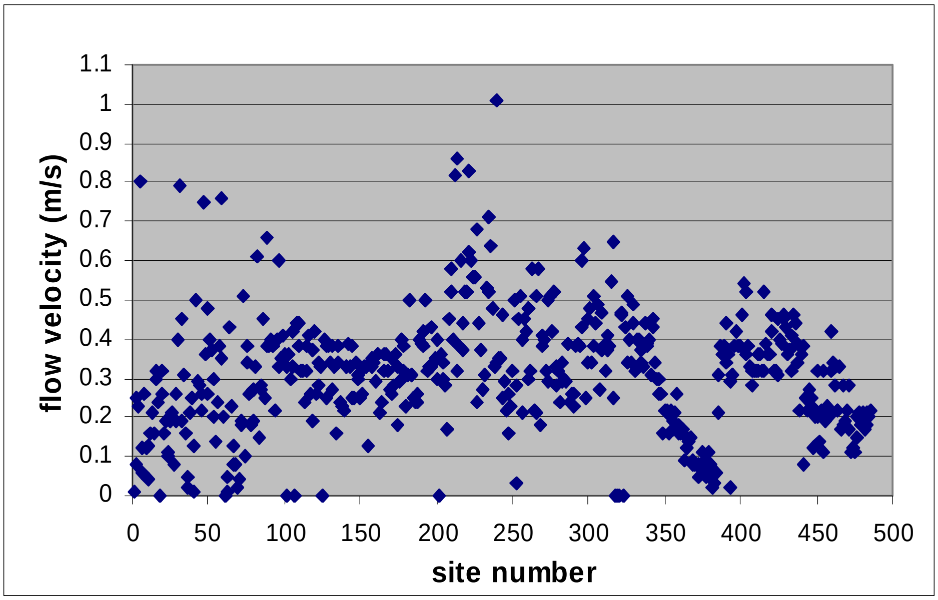


**Figure 5 Flow velocity (@80%) profile of the St. Croix River at thalweg**

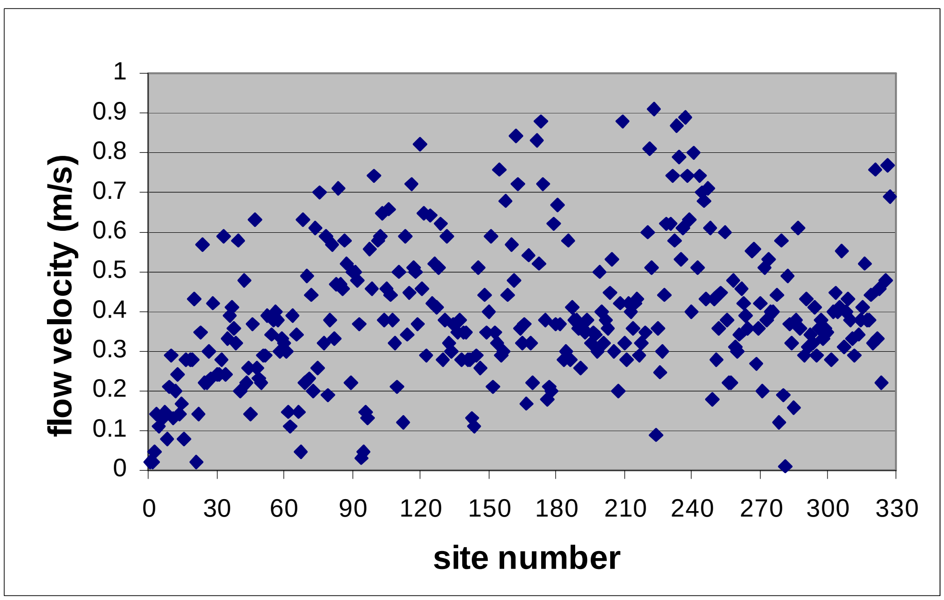


**Figure 6 Flow velocity (@ 80%) profile of the Namekagon River at thalweg**

## Riparian Zone

Riparian vegetation strongly influences watershed sediment dynamics by stabilizing the bank and trapping sediments in surface runoff from adjacent lands. Our riparian photos show that the entire riverbank is well vegetated and has slow slope, offering high sediment retention. It suggests that the riverbank and surface runoff are not likely to be significant sediment sources to the river, although localized conditions will vary.

There are several relevant observations about bank geometry and vegetation along the river: (1) with the exception of high stony gorges near Taylor's/St. Croix Falls, bank geometry is very similar among sites. Nearly the entire river has low bank height (estimated <1 m) and little or no undercutting. (2) Bank slopes are low and vegetated with grasses. (3) There is usually a nearly continuous tree canopy beginning at the top of the bank or within a few 10s of meters; in isolated cases, there is a shrub layer between the trees and grasses or there are shrubs below the tree canopy. This relatively uniform, well vegetated condition suggests that the river banks are stable and generally not significant sources of sediment. However, we have anecdotal evidence of localized unstable, exposed, and eroding banks despite nearby riparian and upland vegetation.

# 3. Validation with Mussel Data

## Data on the Biological Communities

We used biological data to test the physical classification framework. Several kinds of communities on the Riverway are of interest to biologists and managers, including fish, macroinvertebrates, and mussels. Holmberg ***et al.*** (1997) presented a cluster analysis for each of the three communities. The Namekagon River was demonstrated to be distinct from the St. Croix River for fish and mussels (their macroinvertebrate data were only from the St. Croix). The Hydro Dam was found to be coincident with major distributional change of all the three communities. Below the Hydro Dam, mussel communities were further clustered into two categories: lacustrine and riverine sectors. No finer distribution pattern was found for fish in the St. Croix, possibly due to their high mobility. For the same reason, fish data were not useful to us in developing a fine-scale classification. The macroinvertebrate community is a good indicator of habitat and water quality, and is widely used in bio-monitoring. However, no spatially consecutive macroinvertebrate dataset has been published for the Riverway.

The Riverway has a rich, diverse mussel resource, which is an important management concern. Our physical classification framework was tested using mussel data from Doolittle (1988). Their data represent two kinds of sites sampled along the entire Riverway: regular sites, located every 8.2 river km (5.1 mi), and irregular or relative abundance sites located on a selected mussel bed within each 10 river km (6.2 mi). A two meter-wide transect perpendicular to the river course was followed for 30 meters through all sites. We used a subset of 78 sites for the St. Croix River above Stillwater and for the entire Namekagon River, including 46 regular and 32 irregular sites. There were 49 sites on the St. Croix River including 26 regular and 23 irregular ones, and 29 sites on the Namekagon River including 19 regular and 10 irregular ones. Among these sites, there were 3 regular sites on the St. Croix River and 7 regular sites on the Namekagon River that contained no mussels. There were 37 total species in this data set: all but one being Unionids; the exception was *Cumberlandia monodonta*, a Margaritiferid.

### Reciprocal Averaging (RA)

We analyzed mussel communities using TWINSPAN (Hill and Smilauer 2005).That program classifies sites and builds an ordered two-way table based on a site-by-species matrix (Jongman *et al.* 1987). The core algorithm of TWINSPAN is Reciprocal Averaging (RA), a numerical method proposed by Hill (1973). Essentially, RA ordinates species and sites based on the mathematical analysis of abundance and species richness of the communities.

Data were assembled in matrix format. In our mussel data, the column heading is mussel species and the row heading is site; each element value is abundance of a species at a site. Ordination scores are calculated for each row (for species ordination) and each column (for site ordination) based on abundance and richness values in the matrix. The process is iterative; random values are assigned as initial species scores in a column. Then the cross products of the species score column and each site column is calculated to form a row of site scores. Cross products of the site score and the species row are calculated to form an updated species score column. Score calculations continue until final, constant species and site scores are achieved. No matter what the initial species scores assigned, final ordinations of the species and sites will be the same.

# CHAPTER 3 CLASSIFICATION RESULTS

We used all information available to develop a hierarchical classification framework including two spatial scales: *segment* and *reach*. *Segments* have a dimension of 15+ km (10+ miles). *Reaches* are nested within *segments* and have a dimension of 1.5+ km (1+ mile). Our *segments* are the continuation of the *major segments* of Macbeth *et al*. (1999), formed by incorporating additional information and refining the rationale. *Segments* are delineated primarily by tributary outlet and channel slope, but also incorporate other information such as ecoregion (geology, hydrogeology, and climate) and land use/land cover properties of the basin, riparian vegetation, and channel substrate (Appendix 1). *Segments* control riverine communities through hydrologic processes and sediment dynamics at three spatial scales: basin, riparian zone, and channel. *Reaches* are produced by grouping proximal sampling sites (which were at 400 m intervals) that have similar substrate composition. In this chapter, we describe the characteristics of our *segments* and *reaches* within the Riverway. The original data and information we used for classification are in the three appendices.

## 1. Classification on the St. Croix River

### I. Headwaters to Namekagon River (31 km/19 miles)

This *segment* is delineated by the outlet of the Namekagon River. It’s also the first *major segment* of Macbeth *et al.* (1999) and the channel slope is much steeper than that of the downstream *segment* (Figure 2). The *segment* was further divided into six *reaches.*

The first *reach* is from Gordon Dam to Scott's Bridge, a unit about 3.5 km long; it is dominated by boulders and cobbles, sometimes covered with thick vegetation. The second *reach* is about 3.5 km downstream of Scott's Bridge, and is characterized by diverse substrate. The third *reach* is about 3.5 km upstream of the Coppermine Dam and is dominated by sands and gravels. The fourth *reach* is from the Coppermine Dam to the County "T" Landing; it is 4 km miles long and dominated by boulders. The fifth *reach* is from the County "T" Landing to the CCC Bridge Landing. It is about 10 km miles long and mostly dominated by sands and gravels, although several are sites dominated by pebbles/cobbles or boulders. The sixth *reach* is from the CCC Bridge Landing to the outlet of the Namekagon River, which is about 5 km long and dominated by bedrock or boulders/cobbles.

## II. Namekagon River to Yellow River (19 km/12 miles)

This *segment* ends at the outlet of the Yellow River, an important tributary of the St. Croix River. There is less than 5% anthropogenic land use in the drainage area (Appendix I). It's the first half of the second *major segment* of Macbeth *et al.* (1999) and the slope is lower than that of the upstream *segment* (Figure 2).

There are two *reaches* in this *segment.* The first is from the outlet of the Namekagon River to the Riverside Landing, which is about 7 km long and characterized with diverse substrate, although boulders are rare. The second *reach* is from the Riverside Landing to the outlet of the Yellow River, which is about 13 km; it is dominated by sands and gravels, as is the downstream *segment.* The prevalence of sands in the second reach and the following *segment* could be a result of siltation. This deposition is possibly due to contributions from the Namekagon River with resulting deposition in this relatively flat portion.

## III. Yellow River to Kettle River (41 km/25.5 miles)

This *segment* ends at another important tributary of the St. Croix River, the Kettle River. Most of the drainage area has an anthropogenic land use percentage between 20~35%. This *segment* is delineated into three *reaches:* the first is from the outlet of the Kettle River to Norway Point, which is about 32 km. It is dominated by sands and gravels, the same as the last *reach* of the second *segment.* This *reach* is the second half of the second *major segment* of Macbeth *et al.* (1999). The second *reach* is from Norway Point to the upper edge of Nelson's Landing, about 5 km; it also is dominated with sand and gravels like the first *reach*, but it has a much steeper slope (Appendix 1). The third *reach* is from the upper edge of Nelson's Landing to the Kettle River, about 5 km. It is characterized by diverse particles, except that sands are rare. The second and third *reaches* belong to the third *major segment* of Macbeth *et al.* (1999) and have a much steeper slope than the first *reach* (Appendix 1).

## IV. Kettle River to Snake River (8 km/5 miles)

This *segment* ends at an important tributary of the St. Croix River, the Snake. It is part of the fourth *major segment* of Macbeth *et al.* (1999). Anthropogenic land use percentage is about 30% in the drainage area of this *segment* (Appendix 1). The first *reach* extends about 3 km downstream of the Kettle River, and is characterized with diverse particles except sands. The second *reach* is about 1.5 km long and is dominated by sands and gravels. The third *reach* is about 2 km long and is characterized by diverse particles except boulders.

## V. Snake River to Sunrise River (34 km/21 miles)

This *segment* ends at the outlet of the Sunrise River, another important tributary of the St. Croix. The anthropogenic land use in the *segment* ranges between 40% and 60%. It approximately coincides with the first half of the fourth *major segment* of Macbeth *et al*. (1999), except the first few km belong to their third *major segment*. There are five *reaches* in this *segment*. The first *reach* is from the outlet of the Snake River to Raspberry Landing, which is about 5 km. It is characterized with diverse particles except boulders. The ecoregion boundary occurs near Raspberry Landing. The second *reach* is from Raspberry Landing to the Rush City Ferry, about 11 km. It is characterized by diverse particles except boulders; sands are common in this *reach*. The third *reach* is about 5 km downstream from the Rush City Ferry and is dominated by sands and gravels. The fourth *reach* is about 3 km long and characterized by diverse particles except boulders. The fifth *reach* ends at the outlet of the Sunrise River, is about 4 km long and dominated by sands and gravels.

## VI. Sunrise River to St. Croix Visitor Center (28 km/17.5 miles)

This *segment* ends at the St. Croix Visitor Center. It's the second half of the fourth *major segment* of Macbeth *et al*. (1999). The entire *segment* is dominated by sand and gravel but we tentatively divided it into two *reaches* using water depth. The first *reach* is from the Sunrise River to Deer Creek Camp, about 16 km; it is characterized by a depth less than two meters. The second *reach* is from Deer Creek Camp to the St. Croix Visitor Center, about 11 km; water is generally deeper than three meters. In fact, the last 6 km were deeper than four meters, and the last 1.5 reached a depth of 5-10 meters. Although those specific depths will vary with hydrology, it is apparent that the second *reach* indicates a graduation from river run to reservoir condition.

We did not sample between the St. Croix Visitor Center and Minnesota Interstate Park due to high water velocities. This area can be treated as a discrete *segment* for future applications. This portion contains an abrupt elevation decrease near the Hydro Dam, an area assigned as the fifth *major segment* by Macbeth *et al*. (1999).

## VII. Minnesota Interstate Park to Stillwater (40 km/25 miles)

This *segment* is from Minnesota Interstate Park to the Boomsite Park (City of Stillwater), which is about 40 km; it is characterized by very smooth slopes (Appendix 1) and dominated by sands and gravels. The *segment* is not further divided into *reaches*. There is a high anthropogenic land use percentage in the drainage area (i.e., 60-90%). The *segment* is a part of the sixth *major segment* of Macbeth *et al*. (1999). Their sixth *major segment* is from the Hydro Dam to the confluence with the Mississippi River. We did not sample downstream of the Boomsite Park, where the river becomes lake-like.

# 2. Classification of the Namekagon River

The Namekagon River drains an area of about 1482 $km^2$ (Boyle *et al.* 1992), about 97% of which is of forest and lakes (Lenz *et al.* 2003). The entire Namekagon watershed belongs to the Northern Lakes and Forests ecoregion. The watershed contains two types of bedrock geology: Cambrian sandstone and Precambrian lava flow. The border between the two is near Whispering Pines Landing. The watershed also contains two types of bedrock hydrogeology: Mt. Simon-Hinckley-Fond du Lac and Precambrian Igneous and Metamorphic Rocks, the border being near Trego Dam.

MacBeth *et al*. (1999) created six *major segments* on the Namekagon River based on channel slope. We adopted those as our *segments* with slight modifications, then created *reaches* within *segments* using substrate composition. Detailed descriptions of our five *segments* and *reaches* follow:

## I. Namekagon Dam to Earl Park (97 km/60 miles)

This is the first *major segment* of Macbeth *et al.* (1999). It has steeper slopes than that of the following *segment* (Figure 2). There are nine *reaches* within this segment, based on substrate composition. The first *reach* ends at County "M" Landing, is about 10 km long and either covered with thick vegetation or dominated by cobbles. The second *reach* ends at Pacwawong Flowage. We did not sample the Flowage or include it in our classification framework but it can be treated as an additional *reach* for future applications, considering its unique flowage condition. It is about 15 km long and is characterized by diverse particles, although about 3/4 of the sites are dominated by sands/ gravels. The third *reach* starts at Pacwawong Dam and ends at Phipps Flowage (the Flowage was partially sampled and can be treated as an additional *reach* for future applications because of its flowage condition). It is about 13 km long and is characterized by diverse particles, although boulders are rare. The fourth *reach* is about 6.5 km long from Phipps Dam to Hayward Dam. We lost the substrate data for a portion of this reach and have chosen to retain it as a distinct *reach* for safety's sake. The fifth *reach* is about 8 km miles long downstream of Hayward Dam and is characterized by gravels, pebbles, and cobbles. The sixth *reach* is about 5 km miles long, characterized by sands and gravels. The seventh *reach* is about 6.5 km long and dominated by gravels, pebbles, and cobbles. The eighth *reach* is about 9 km long, characterized by diverse particles where sands are common. The ninth *reach* is about 8 km long to Earl Park and is dominated by sands.

## II. Earl Park to Trego Dam (9 km/5.5 miles)

This *segment* has lower slopes than does the preceding *segment* (Figure 2). There are two *reaches* within this *segment* (not including the flowage). The first is about 3 km long and characterized by diverse particles except boulders. The second *reach* is about 4 km miles long and dominated by sands.

The Trego Flowage is downstream of the second *reach;* we did not sample it but it can be treated as an additional *reach* for future applications. Near Trego Dam, there is a short portion (less than 1.5 km) of sudden elevation decrease; this is the third *major segment* of Macbeth *et al.* (1999). Trego Dam is consistent with the boundary of two types of hydrogeology. The portion from Earl Park to the abrupt elevation decrease is their second *major segment.*

### III. Three miles downstream of the Trego Dam

This is the fourth *major segment* of Macbeth *et al.* (1999). Slopes in this *segment* are similar to that of the precedent *segment*, but the two are separated by the abrupt elevation decrease near Trego Dam (Figure 2). This *segment* has lower slopes than does the downstream *segment.* It is not further divided into *reaches* and is characterized with diverse particles except boulder.

### IV. Six miles downstream to Whispering Pines Landing

This is the fifth *major segment* of Macbeth *et al.* (1999). The *segment* has steeper slopes than does the preceding and following *segments* (Figure 2). It is not further divided into *reaches* and is characterized by diverse particles except boulder.

### V. Whispering Pines Landing to the confluence with the Namekagon River (35 km/22 miles)

This is the sixth *major segment* of Macbeth *et al.* (1999). The *segment* has lower slopes than does of the preceding *segment* (Figure 2). The *segment* is divided into two *reaches:* first is about 16 km miles long and ends near McDowell Bridge; it is characterized by diverse particles except boulder. Sands are common. The second reach is about 19 km long and ends at the confluence with the *St. Croix River;* it is dominated by sands and gravels.

# CHAPTER 4 MUSSEL COMMUNITY ANALYSIS

Holmberg *et al.* (1997) reported results of a cluster analysis on mussel data collected by Doolittle (1988); they used the EPA computer software "BIOSIM1" (Pearson and Pinkham 1992). Four clusters were detected: the Namekagon River, excluding a stretch from Trego Dam to Trego Park flowage; the St. Croix above the mouth of Snake to below the Kettle River Rapids, excluding a stretch from the mouth of the Yellow to the mouth of the Clam; the St. Croix from the mouth of the Snake to the Hydro Dam (no were data available from the Wild River downstream to the Hydro Dam); and the lacustrine part below the mouth of the Apple. They assumed that differences between the first segment and the other three were due to hydrologic differences between the

Namekagon and the St. Croix. The Hydro Dam was an apparent boundary in mussel distribution patterns. The lacustrine condition could explain the fourth segment.

Hornbach (2001) reported results of a cluster analysis on a synthesized St Croix River mussel dataset. Two separate clusters were found, one above and one below the Hydro Dam. He suggested that the Dam functions as a migration barrier to fish, which host mussel larvae. The cluster below the Hydro Dam was further divided into two sub-clusters, separated by Stillwater: the upper one is more riverine and the lower more lacustrine (i.e., Lake St. Croix). The cluster above the Hydro Dam also was divided into two sub-clusters separated approximately by the Sunrise River (below the Kettle River Rapids); Hornbach attributed this disjunction to channel slope ("stream gradient" in his term).

Holmberg *et al.* (1997) and Hornbach (2001) used the same 16 segments on the St. Croix River. Those 16 are separated by tributaries and differences in channel slope. Both papers summed abundance and species richness for sites within each segment but based their analyses on different datasets. Holmberg used the dataset collected by Doolittle (1988). Hornbach (2001) used a dataset that synthesized data from MNDNR, WDNR, and NPS.

There are significant confluences between the two analyses. The Namekagon River marks a distinct segment (Holmberg *et al.* 1997), the lacustrine part below Stillwater is an independent segment, the Hydro Dam characterizes a major shift in the mussel community, and the Kettle represents a major shift of the mussel community above the Hydro Dam. These cluster boundaries also are reflected in our physical classification.

In Hornbach's (2001) cluster analysis, the subfamilay Ambleminae was prevalent below the Dam and the subfamily Lamsilinae was prevalent above the Dam. He commented on differences between the two subfamilies in reproductive habit and fish hosts, but it is not clear how these factors might control mussel community distribution.

We tried to further dissect mussel distribution patterns on the Riverway and to test the utility of our classification framework by using TWINSPAN to analyse Doolittle's mussel dataset, then interpret the results using our classification framework. In contrast to previous studies, we did not pre-process the data using a *prior* classification framework (i.e., we did not group sites within segments). Instead, we sought patterns at the finest scale possible in a bottom-up way.

## 1. Cluster Analysis of Mussel Communities

The 68 non-empty sites in Doolittle's (1988) dataset were clustered using TWINSPAN. At the first dichotomy, the sites are clustered into two groups (i.e., 0 and 1 in Table 3). The 54 "0" sites are widely distributed among the St. Croix and Namekagon rivers. All but one of the 14 "1" sites are in the St. Croix. This demonstrates that the mussel communities of the two rivers are distinct at the uppermost level of the hierarchy.

**Table 3 Results of the TWINSPAN cluster analysis (ranked by river mile)**

| SITE | CODE | 1st | 2nd | 3rd |
|---|---|---|---|---|
| **RM028.1** | **010** | 0 | 1 | 0 |
| **RM032.2** | **010** | 0 | 1 | 0 |
| **RM032.3** | **010** | 0 | 1 | 0 |
| **RM034.9** | **010** | 0 | 1 | 0 |
| **RM036.9** | **010** | 0 | 1 | 0 |
| **RM038.4** | **010** | 0 | 1 | 0 |
| **RM040.8** | **010** | 0 | 1 | 0 |
| **RM044.2** | **110** | 1 | 1 | 0 |
| **RM046.4** | **010** | 0 | 1 | 0 |
| **RM050.3** | **110** | 1 | 1 | 0 |
| **RM050.8** | **110** | 1 | 1 | 0 |
| **RM051.6** | **010** | 0 | 1 | 0 |
| **RM051.8** | **111** | 1 | 1 | 1 |
| **RM062.5** | **010** | 0 | 1 | 0 |
| **RM063.2** | **100** | 1 | 0 | 0 |
| **RM063.8** | **100** | 1 | 0 | 0 |
| **RM064.1** | **010** | 0 | 1 | 0 |
| **RM066.2** | **010** | 0 | 1 | 0 |
| **RM069.1** | **010** | 0 | 1 | 0 |
| **RM070.1** | | | | |
| **RM072.2** | **010** | 0 | 1 | 0 |
| **RM072.9** | **011** | 0 | 1 | 1 |
| **RM077.5** | **010** | 0 | 1 | 0 |
| **RM077.8** | **010** | 0 | 1 | 0 |
| **RM081.4** | **011** | 0 | 1 | 1 |
| **RM083.3** | **100** | 1 | 0 | 0 |
| **RM086.2** | **011** | 0 | 1 | 1 |
| **RM090.1** | **101** | 1 | 0 | 1 |
| **RM092.0** | **011** | 0 | 1 | 1 |
| **RM096.1** | **010** | 0 | 1 | 0 |
| **RM097.8** | **011** | 0 | 1 | 1 |
| **RM099.5** | **010** | 0 | 1 | 0 |
| **RM102.5** | **010** | 0 | 1 | 0 |
| **RM103.0** | **100** | 1 | 0 | 0 |
| **RM104.2** | **010** | 0 | 1 | 0 |
| **RM114.5** | **100** | 1 | 0 | 0 |
| **RM117.0** | **010** | 0 | 1 | 0 |
| **RM118.2** | **100** | 1 | 0 | 0 |
| **RM122.0** | **011** | 0 | 1 | 1 |
| **RM124.0** | **100** | 1 | 0 | 0 |
| **RM126.3** | **011** | 0 | 1 | 1 |
| **RM130.5** | **010** | 0 | 1 | 0 |

| | | | | |
|---|---|---|---|---|
| **RM132.8** | **011** | 0 | 1 | 1 |
| **RM134.3** | | | | |
| **RM139.9** | **011** | 0 | 1 | 1 |
| **RM143.5** | | | | |
| **RM146.1** | **011** | 0 | 1 | 1 |
| **RM148.5** | **001** | 0 | 0 | 1 |
| **RM152.8** | **101** | 1 | 0 | 1 |
| **NM002.0** | **010** | 0 | 1 | 0 |
| **NM005.1** | | | | |
| **NM012.5** | | | | |
| **NM017.5** | | | | |
| **NM022.0** | | | | |
| **NM022.2** | **010** | 0 | 1 | 0 |
| **NM032.1** | **101** | 1 | 0 | 1 |
| **NM032.3** | **010** | 0 | 1 | 0 |
| **NM032.8** | **010** | 0 | 1 | 0 |
| **NM038.3** | **010** | 0 | 1 | 0 |
| **NM042.2** | **010** | 0 | 1 | 0 |
| **NM046.7** | **010** | 0 | 1 | 0 |
| **NM050.8** | **010** | 0 | 1 | 0 |
| **NM056.2** | **010** | 0 | 1 | 0 |
| **NM057.4** | **011** | 0 | 1 | 1 |
| **NM062.6** | **001** | 0 | 0 | 1 |
| **NM066.5** | **001** | 0 | 0 | 1 |
| **NM067.1** | | | | |
| **NM072.2** | | | | |
| **NM076.5** | **010** | 0 | 1 | 0 |
| **NM078.0** | **010** | 0 | 1 | 0 |
| **NM078.6** | **001** | 0 | 0 | 1 |
| **NM081.0** | **010** | 0 | 1 | 0 |
| **NM081.3** | | | | |
| **NM087.3** | **010** | 0 | 1 | 0 |
| **NM087.9** | **010** | 0 | 1 | 0 |
| **NM093.0** | **010** | 0 | 1 | 0 |
| **NM096.1** | **000** | 0 | 0 | 0 |
| **NM098.3** | **000** | 0 | 0 | 0 |

The “1” sites were further divided into “10” and “11” sites. All four “11” sites are below the Hydro Dam and all 10 “10” sites are above the Dam, including one in the Namekagon River. The “0” sites were further divided into “01” and “00” sites. There are three “00” sites in the St. Croix River, both above the Hydro Dam. All six “00” sites on the Namekagon River are above Springbrook Rapids. The 46 “01” sites were widely distributed throughout the St. Croix and Namekagon. The “01” sites were further divided into 9 “011” and 37 “010” sites. All the “011” sites were above the mouth of the Sunrise, including one in the Namekagon. The "010" sites were distributed throughout the Namekagon River as well as below the mouth of the Yellow River the St. Croix.

**Table 4 Mussel communities in the Riverway.** *Segment* N represents the Namekagon River; *Segments* 1-7 represent our divisions of the St. Croix. Numbers in parenthesis represent the number of non-empty sites in a segment (column) or mussel cluster (row). A single color represents the distribution of a specified mussel cluster.

| Segment | N(22) | 1(4) | 2(5) | 3(9) | 4(1) | 5(8) | 6(6) | 7(13) |
|---|---|---|---|---|---|---|---|---|
| **Length (km)** | 158 | 31 | 19 | 41 | 8 | 34 | 28 | 40 |
| **"00" (7)** | 5 | 1 | | 2 | | | | |
| **"010" (36)** | 15 | | | 5 | | 3 | 4 | 9 |
| **"011" (11)** | 1 | 2 | 4 | | | 3 | | |
| **"10" (10)** | 1 | 1 | 1 | 3 | | 2 | 2 | |
| **"11" (4)** | | | | | | | | 4 |

These results show that the mussel communities in the Namekagon River function as an independent *segment* from the St. Croix River ("0" vs. "1"), the Hydro Dam is a significant delineator for the communities in the St. Croix River ("11" vs. "10"), and the Sunrise River ("011" sites) serves as an ecological delineator in the Riverway. These results agree with the previous clustering studies. In contrast, however, our study did not include the lacustrine portion below Stillwater and our results did not suggest that the Snake River serves as significant delineator for mussel distribution (in contrast to the findings of Holmberg *et al.* 1997). We did, however, find that the Yellow River serves as a delineator in the St. Croix River ("010" sites). We used TWINSPAN to analyze the St. Croix and Namekagon data separately and found the same clusters.

The results of our mussel community cluster analyses are consistent with our physical habitat classification at the *segment* level; *segments* seem to be an appropriate vehicle for inventorying and understanding mussel resources of the Riverway (Table 4).

# 2. Mussel Ecology on the Riverway

## Species distribution on the Riverway

Previous studies have explored mussel community distribution on the Riverway, documenting *segment* level pattern. The following section describes the species level distribution among segments.

*Anodontoides ferussacianus* and *Lasmigona compressea* primarily were found in the Namekagon River. *A. ferussacianus* was only found above the Pacwawong Dam. *L. compressea* was rarely found in the St. Croix River, but commonly found in the Namekagon River.

*Anodonta grandis* was found in the Namekagon River and above the Dam in the St. Croix River. *Actinonaias ligamentina*, *Elliptio dilatata*, *Lampsilis ventricosa*, *Lampsilis* *radiate, Fusconaia flava, Lasmigona costata, Strophitus undulates* and *Alasmidonta marginata* all were common in both the St. Croix River and the Namekagon River.

*Amblema plicata, Ligumia recta, Pleurobema sintoxia* and *Cyclonaias tuberculata* were common in the St. Croix River but not in the Namekagon River. There are total of 15 species in the Namekagon River, one of which was found only in the Namekagon. In contrast, there are 32 species in the St. Croix River, 18 of which occur only in the St. Croix River. However, the observations here were only based on Doolittle's data set. We have literature that suggests about 40 species total for the Riverway.

Longitudinal patterns in mussel communities are apparent in the St. Croix. There is progressively higher species richness downstream from the headwaters; the increase is especially apparent in rare species. *Obovaria olivaria* was found only below the Namekagon. *Leptodea fragilis* and *Potamilus alatus* were found only below the Yellow. *Truncilla truncata* and *Obliquaria reflexa* were found only below the Sunrise. Nine species were only found below the Dam, among them several are rare. Three other species are rare and distributed occasionally on the Riverway.

**Table 5. Mussel species distribution on the Riverway**

| Species | Sites | Distribution | Segments |
|---|---|---|---|
| *Anodontoides ferussacianus* | 3 | Upper Namekagon | N |
| *Lasmigona compressea* | 9 | Common on the Namekagon River, uncommon on the St. Croix River | N |
| *Anodonta grandis* | 7 | Namekagon and St. Croix above the Dam | N |
| *Actinonaias ligamentina* | 48 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Elliptio dilatata* | 40 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Lampsilis ventricosa* | 39 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Lampsilis radiata* | 38 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Fusconaia flava* | 37 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Lasmigona costata* | 31 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Strophitus undulatus* | 25 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Alasmidonta marginata* | 24 | Common on the St. Croix River and the Namekagon River | N, I-VII |
| *Amblema plicata* | 27 | Common on the St. Croix River, uncommon on the Namekagon River | I-VII |
| *Ligumia recta* | 24 | Common on the St. Croix River, uncommon on the Namekagon River | I-VII |
| *Pleurobema* | 21 | Common on the St. Croix River, uncommon | I-VII |

| | | | |
|---|---|---|---|
| *sintoxia* | | on the Namekagon River | |
| *Cyclonaias tuberculata* | 20 | Common on the St. Croix River, uncommon on the Namekagon River | I-VII |
| *Quadrula pustulosa* | 24 | Common on the St. Croix River | I-VII |
| *Obovaria olivaria* | 14 | Below the Namekagon River | II-VII |
| *Leptodea fragilis* | 13 | Below the Yellow River | III-VII |
| *Potamilus alatus* | 13 | Below the Yellow River | III-VII |
| *Truncilla truncata* | 12 | Below the Sunrise River | VI-VII |
| *Obliquaria reflexa* | 7 | Below the Sunrise River | VI-VII |
| *Quadrula metanevra* | 7 | Below the Dam | VII |
| *Tritogonia verrucosa* | 6 | Below the Dam | VII |
| *Truncilla donaciformis* | 5 | Below the Dam | VII |
| *Anodonta grandis corpulenta* | 4 | Below the Dam | VII |
| *Epioblasma triquetra* | 3 | Below the Dam | VII |
| *Ellipsaria lineolata* | 2 | Below the Dam | VII |
| *Lampsilis higginsi* | 1 | Below the Dam | VII |
| *Quadrula quadrula* | 1 | Below the Dam | VII |
| *Fusconaia ebena* | 1 | Below the Dam | VII |
| *Cumberlandia monodonta* | 2 | Uncommon below the Snake River | Insignificant |
| *Anodonta imbecillis* | 2 | Uncommon on the St. Croix River | Insignificant |
| *Lasmigona complanata* | 2 | Uncommon on the St. Croix River | Insignificant |

## Species richness and abundance

We found a log-linear relationship between abundance and species richness in this dataset (Figure 7), similar to that reported by Hornbach (2001) on a synthetic dataset.

We expressed abundance and richness in clusters (Figure 8) and indicated with different colors. This pattern allows us to offer preliminary comments on longitudinal patterns in the combination of individual abundance and species richness on the Riverway.

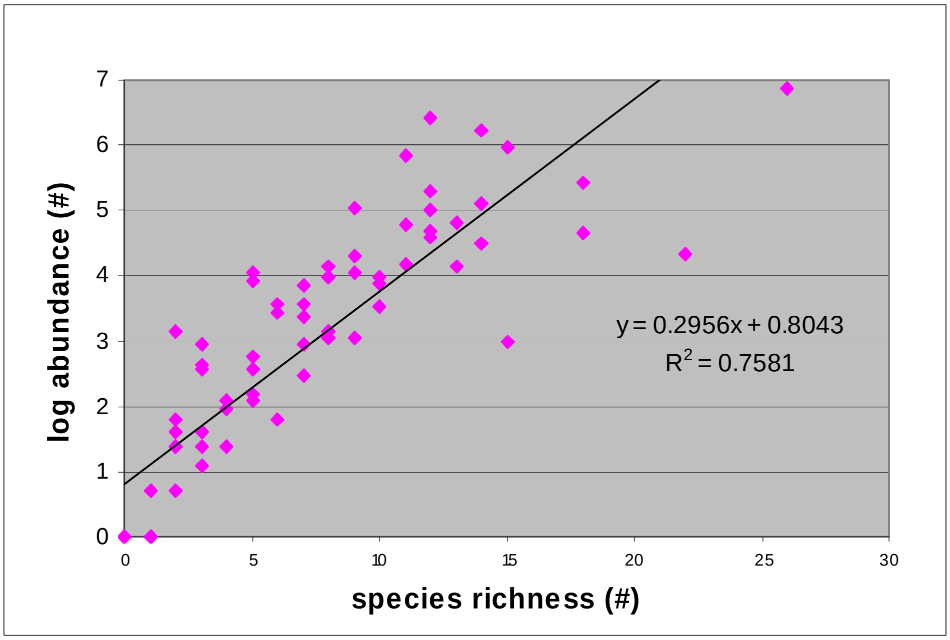


**Figure 7 Relation between mussel abundance and species richness in the Riverway**

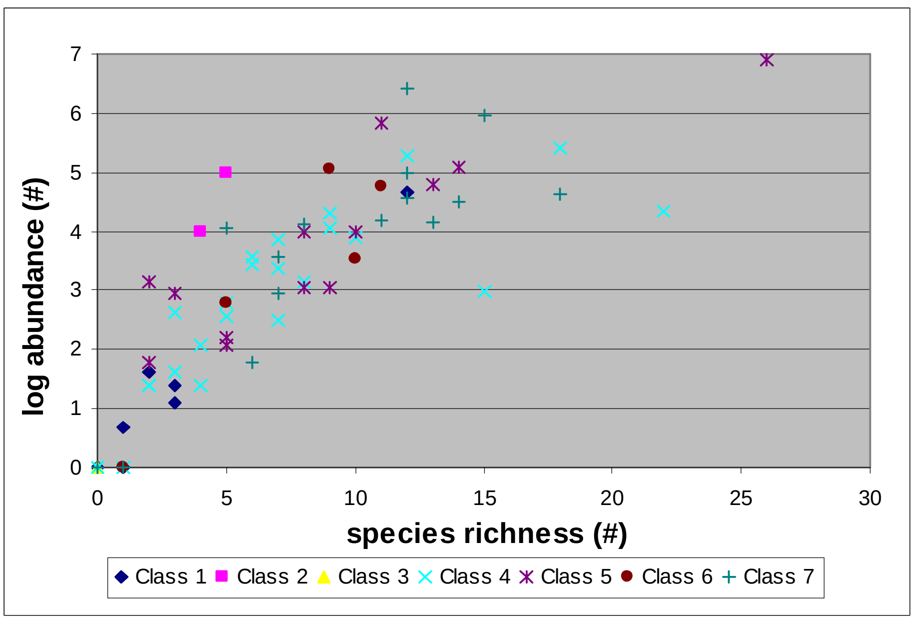


**Figure 8 Log abundance vs. species richness**

There was no clear longitudinal pattern of species richness or individual abundance along the river (Figure 9). However, we found that the three sites below and closest to the Hydro Dam (River Km 81 (Mile 50.3), 81.8 (Mile 50.8) and 83.4 (Mile 51.8)) had extraordinary species richness, and were similar to the site near Nevers Dam Landing (River Km 102.7 (Mile 63.8)).

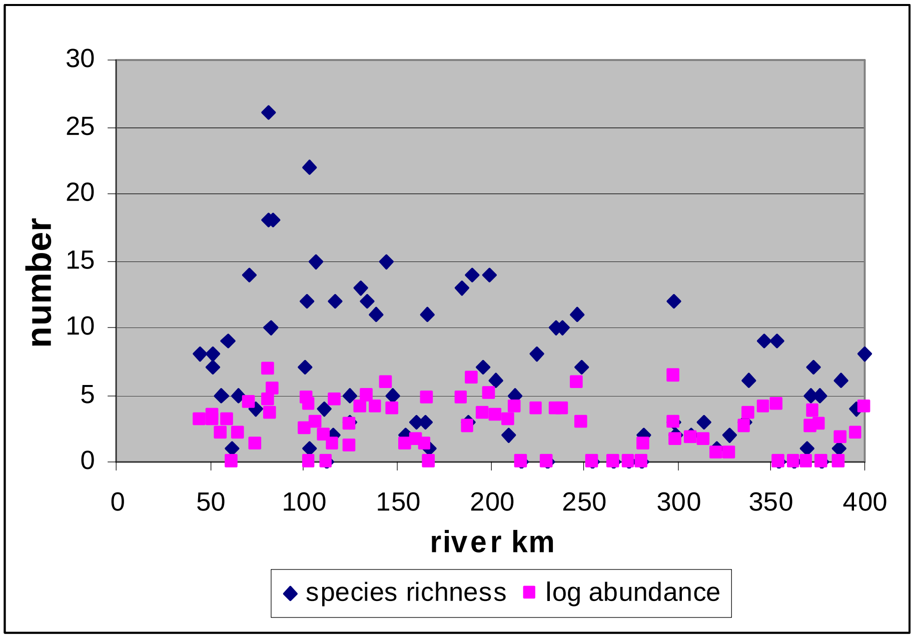


**Figure 9 Species richness and log abundance along the Riverway**

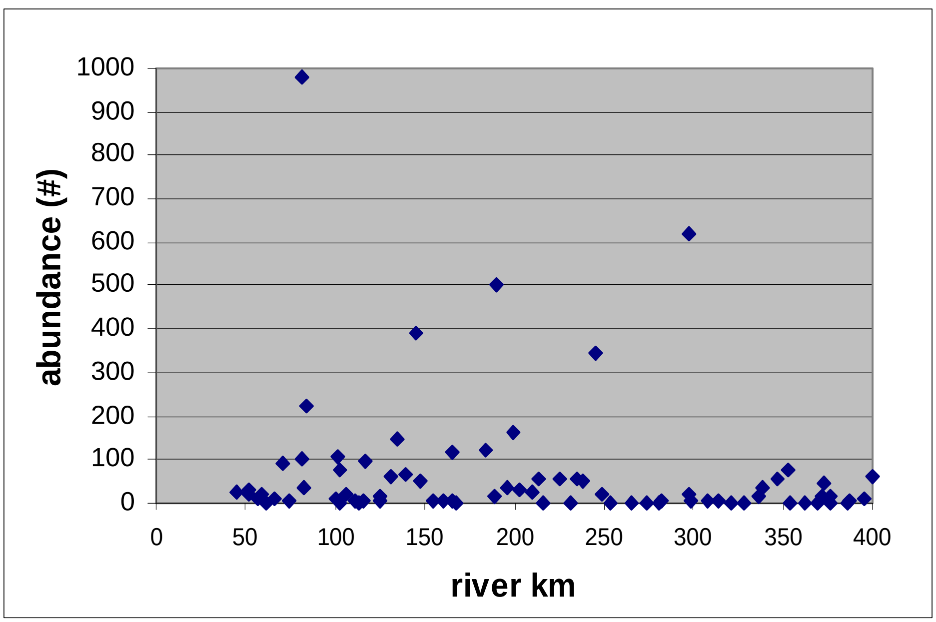


**Figure 10 Individual species' abundance along the Riverway**

Further, we found several anomalous sites with extraordinarily high mussel density (Figure 10): River Km 81.8 (Mile 50.8), 145.1 (Mile 90.1), 190.3 (Mile 118.2), 246 (Mile 152.8) and Namekagon Km 51.7 (Mile 32.1). The site at River Km 81.8 (Mi 50.8) is characterized by a high density of *Fusconaia ebena* and that is the only *F. ebena* population on the Riverway. The sites at River Km 145.1 (Mile 90.1), 190.3 (Mile 118.2) and Namekagon Km 51.7 (Mile 32.1) are characterized by high densities of *Actinonaias ligamentina* population. The high density at headwater site River Km 246 (Mile 152.8) is caused by four species, including *Actinonaias ligamentina*.

## Substrate

Doolittle (1988) characterized substrate using the following size designations: S – sand, M – mud, G – gravel, C- cobble, R – rock, K – muck, D – detritus, and T – silt. In our analysis, we regarded sand, mud, muck and silt collectively as fine material.

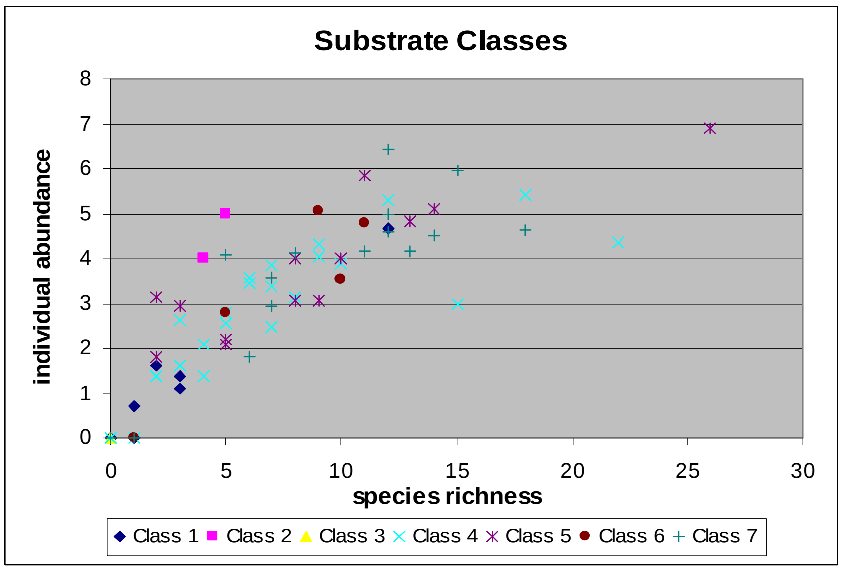


**Figure 11. Mussel species density versus species richness, among substrate classes** Class 1-Fine materials (i.e., sand, silt, muck and mud), Class 2-Gravel, Class 3-Rock, Class 4-Fine material and gravel, Class 5-Fine material and rock, Class 6-Gravel and rock, and Class 7-Fine material, gravel and rock.

Mussels are substrate selective; some species can only live on coarse substrate (gravels, pebbles, cobbles and boulders), a pattern consistent with our mussel community analysis. Almost all sites with fine substrate (i.e., sand, silt, clay, muck and mud) were associated with lowest species richness (≤3 species) and individual abundance (≤5 individuals). Fine-material sites had the lowest mussel density and diversity. Seventy eight sites were incorporated into our analysis. There were 13 fine-material sites (River Km 61.8 (Mile 38.4), 101.8 (Mile 63.2), 112.9 (Mile 70.1), 124.8 (Mile 77.5), 165.0 (Mile 102.5), 167.8 (Mile 104.2), and 216.2 (Mile 134.3), Namekagon Km 8.2 (Mile 5.1), 52.8 (Mile 32.8), 75.2 (Mile 46.7), 108.0 (Mile 67.1), 116.2 (Mile 72.2) and 130.9 (Mile 81.3)). Twelve of them had no more than three mussel species and no more than five individuals. The two sites with a gravel substrate had similar species richness and density; the single rock site did not have any mussels. The four types of sites with composite substrate (classes 4, 5, 6 and 7 in Figure 11) did not have a distinct pattern of species richness or density by species. Based on this analysis, siltation (deposition of fine materials) should be seriously considered as a strong influence in mussel resource research and management.

# CHAPTER 5 RECOMMENDATIONS

Our classification at the scale of ***segments*** incorporates rich information and provides results consistent with the observed distribution of mussel communities. No within-segment variance of the mussel community was found. We suggest that ***segment*** seems an appropriate spatial scale for mussel resource management in the Riverway. ***Reaches*** were produced on the basis of channel substrate. By combining substrate composition with the mussel communities from Doolittle's dataset (1988), we found that fine material substrates always were related to the low mussel species richness ($\leq$3) and abundance ($\leq$5). That is seen as support for use of substrate composition as a principal classification variable for these aquatic habitats and for suggesting that siltation should be a concern for the future mussel resource management in the Riverway.

The ultimate goal of this classification was to provide a theoretical basis for a long-term monitoring network. Furthering that goal, we suggest that discharge and sediment and nutrient loading at the major tributary outlets should be monitored at least monthly, with additional samples reflecting seasonal variability (i.e., spring run-off, June rains). Monitoring tributary inputs is consistent with the ***segments*** proposed here. Within-segment sites can be selected based on ***reaches*** if a more localized sampling design is desired. Mussel or macroinvertebrate community studies could be conducted in parallel to physical monitoring or on a case-specific basis. With the rapid urbanization (MWBAC 1994) and high population growth rate (Metropolitan Council 1996) in the St Croix, land use in the watershed will remain a compelling concern in the coming decades. Therefore, parallel to in-stream monitoring, we suggest that monitoring an active GIS-based analysis of land use change should be maintained, updating files on at least on a five-year interval.

The sources of siltation in the watershed should be further delineated. That goal will be at least partially achieved by ongoing effort work in the watershed. The Science Museum of Minnesota, St. Croix Watershed Research Station (SCWRS) has begun an analysis using land use scenarios to estimate effects on watershed loads of sediment and phosphorus in the Willow River and the Sunrise River, using the SWAT model (the Soil & Water Assessment Tool) model (Almendinger, personal communication). Also, Valley Creek is monitored routinely as part of the Watershed Outlet Monitoring Program (WOMP) performed by Metropolitan Council Environmental Services (MCES). Once these studies progress, it will be possible to design and implement BMPs in areas at risk of higher-than-normal rate of erosion.

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