IDENTIFYING THE IMPACTS OF EXCESS FINE SEDIMENT ON BENTHIC MACROINVERTEBRATE COMMUNITIES

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Larissa S Herrera

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Dedication

Throughout my life I've looked up to my grandmother, Sue Ann Parsons. She never really retired from working, she just refocused her energy on helping people in her community. She was an active member of numerous volunteer organizations that provided assistance in the form of housing, clothing, and meals. She completed a Master's degree in nursing in 1955 and a Master's degree in education in 1978 while working full time and raising seven children. Even though she went to Michigan State and dreamed of me following in her footsteps, she was proud of me for graduating from her rival school, the University of Michigan. She has been my inspiration and I hope I touch half as many lives as she did. I would like to dedicate this thesis in her memory.

Abstract

Many streams throughout the United States are negatively impacted by excess fine sediments (sand, silt, and clay). Benthic macroinvertebrates are a commonly-used tool to assess stream condition; however, current methodologies typically are not able to distinguish among stressors. Previous studies have correlated macroinvertebrate communities and traits with excess fine sediments, demonstrating that aquatic macroinvertebrates are sensitive to deposited fine sediment and the assemblages will shift in response. Western Lake Superior streams have a wide range of fine sediment amounts due to clay and sand soils, but have low amounts of other stressors, and thus are a good region to investigate relationships between macroinvertebrate traits and fine sediments. Data were collected from 22 stream sites located along the north shore of Lake Superior in 2010. The data collected in 2010 did not have the desired gradient of fine sediment due to wet conditions that year; therefore, the data were supplemented with data collected by NRRI personnel in earlier years (1997 – 2008). The five sediment stressors used in analyses included percent embeddedness, depth of fine sediments, total percent fine sediments, percent sand, and a combined sediment index created using normalized and transformed embeddedness, depth of fine sediments and total percent fine sediments. Fifty-seven specific taxonomic groups and macroinvertebrate physical and behavioral characteristics (traits) were tested as potential response metrics in linear regressions. In addition, TITAN analyses were used to look for thresholds or sediment stressor values at which a taxon increases greatly, decreases greatly, or disappears from a community. Both the linear regressions and TITAN analyses showed a change in the community structure under conditions of excess sediment in the form of embeddedness, total fines, depth of fines, and/or the combined sediment index. The TITAN analyses also showed a change in the community structure due to increasing proportion sand in the streambed. Furthermore, the analyses identified potential characteristics that may specifically make a particular macroinvertebrate more or less vulnerable to excess fine sediments.

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Introduction

Excess sediment is one reason US rivers and streams can be listed as impaired by the USEPA (USEPA 2004). Impaired streams are defined as bodies of water that do not meet water quality standards due to pollution and degradation (USEPA 2015). Fine sediments are defined as loose particles of sand, silt, and clay (USEPA 2004). While sediment is part of the natural regime of streams, humans have increased stream sediment loading through dams, agriculture, urban development, logging, mining, and channel construction (USEPA 2004). The EPA estimates these human activities account for 70 percent of the total fine sediment delivered to rivers and streams.

The human impact on rivers and streams through increased sediment is reflected in the reactions of various biota. Increased sediment embeddedness can affect the entire ecosystem, from the periphyton to the fish. Embeddedness is defined as the degree to which stream rocks are surrounded and covered by fine sediments in gravel bed streams (USEPA 2004). It negatively affects algal communities because the excess sediment buries rocks, the habitat of periphyton (Yamada and Nakamura 2002). In addition, fish communities are altered when sediments bury their eggs or decrease their spawning habitat of cobbles and gravel (USEPA 2004).

Aquatic invertebrates are intermediates in the stream food web, making them a useful metric of stream condition (Hilsenhoff 1987). Some invertebrates consume algae or periphyton and are subsequently affected by algal population changes (Rosi-Marshall and Wallace 2002, Wallace and Webster 1996). In contrast, many fish are consumers of macroinvertebrates and are affected by the quantity and composition of macroinvertebrate communities (Diehl 1992, Mallory et al. 1994). The second benefit of using macroinvertebrates is their decreased mobility in comparison with fish. Macroinvertebrates, as a whole, are smaller and less able to migrate long distances as larvae. For some of the invertebrates such as caddisflies, it can be very costly and risky to move to better habitat because they have to leave their protective cases (Mondy et al. 2011, Otto 2000). Because macroinvertebrates are less able to migrate and escape stressors, they are a good indicator of stream condition over their life cycle, generally 1-2 years (Rosenberg and Resh 1993). A third consideration for using macroinvertebrates is their taxonomic richness and abundance (Barbour et al. 1999, Rosenberg and Resh 1993). There are very few aquatic habitats in which some species of macroinvertebrate does not live (Davis and Simon 1995). Additionally, the many different taxa and their presence or absence provide insight into the habitat type and its condition (Loeb and Spacie 1994, Rempel et al. 2000, Williams et al. 1997).

The use of the macroinvertebrates as indicators can be beneficial when looking at a particular aspect of stream condition such as excess fine sediment. The varied traits of different taxa may make them more or less sensitive to effects of excess sediment. Therefore, other things being equal, stream sites with differing fine sediment amounts are likely to have different macroinvertebrate assemblages.

Many streams throughout the United States are negatively impacted by excess fine sediments (USEPA 2004). Unfortunately, these streams are often impaired by multiple stressors, making it difficult to separate the impacts of fine sediment from the effects of these other stressors. Streams along the north shore of Lake Superior have an advantage for research on stream sediment because excess sediment and turbidity are often their primary problems. While there are a limited number of north shore streams with other impairments, the majority of these watersheds have low population density and little agriculture. The lack of other major stressors increases the likelihood that the macroinvertebrate communities will be responding primarily to excess fine sediments.

Lake Superior’s north shore begins in Duluth, Minnesota, and continues northeastward into Canada. Streams along the U.S. coast northeast of Duluth flow southeast into Lake Superior, perpendicular to the lake (Fitzpatrick et al. 2006). The headwaters of the streams are characterized by gentle slopes while the middle and lower reaches have steeper slopes (Fitzpatrick et al. 2006) as the streams come down the escarpment leading to the lake. Out of the 188 stream segments examined by Fitzpatrick and colleagues (2006), 19 had slopes greater than 8 percent. In general, the steeper slopes flow over gabbro bedrock and have confined valleys (Fitzpatrick et al. 2006). Steep slopes in confined valleys create a high potential for erosion and landslides (Fitzpatrick et al. 2006). The middle main stems with 2-4 % slopes act as zones of sediment transfer and can be sediment sources depending on the underlying substrate. The gabbro bedrock is erosion resistant while sedimentary rock and glacial deposits are the most vulnerable (Fitzpatrick et al. 2006).

The landscape of the surrounding area also has considerable influence on erosion. While streams may naturally experience a particular level of turbidity or embeddedness, land use can amplify these levels in a stream (Kaufmann et al. 2009). Although the urban area of Duluth has the greatest percentage of impervious surfaces within stream watersheds, reduced infiltration created by cleared land, development, and the road and ditch network pose a problem for north shore streams when combined with the erodible soils (Fitzpatrick et al. 2006). The combination of increased stream flow and erodible soils has led to excess fine sediments and high turbidity, as evidenced by the number of streams listed as impaired for turbidity along the north shore (MPCA 2008).

Stream ecologists have long used macroinvertebrates as a measure of stream condition (Hilsenhoff 1982). While the early work concentrated on nutrient impacts, typically causing dissolved oxygen problems (Hilsenhoff 1982), there has been recent attention given to fine sediment effects on stream invertebrates. Researchers have found decreased taxa richness with increasing deposited sand, silt, and clay sediments (Zweig and Rabeni 2001, Larsen et al. 2009). Larson et al. (2009) measured the percent of fine sediment in 32 stream reaches, ranking each reach along a fine sediment gradient. Sediment amount was strongly correlated with the proportion of bank erosion 500 m upstream, and more weakly correlated to the proportion of bank erosion 1 km upstream, indicating local bank erosion was a strong predictor of the fine sediment present at the sampling point. Larson and colleagues (2009) also measured invertebrates in fast flowing riffles and glides (greater than 55 cm/s), and found a weak increase in Oligochaeta (aquatic worms) with increasing embeddedness and a decrease in EPT (Ephemeroptera, Plecoptera, and Trichoptera) richness and abundance. Additionally, total invertebrate richness declined by approximately five taxa at the most sediment impacted locations (Larson et al. 2009).

Zweig and Rabeni (2001) estimated deposited sediment in two ways. First, they measured surface cover of deposited sediment in a small circular quadrat. Then, they measured embeddedness by measuring the height of each individual particle larger than 1 cm relative to the height of the silt line on the particle. Unlike Larson *et al.* (2009), who sampled riffle areas, Zweig and Rabeni (2001) sampled glide habitats. They used glides (slow moving areas in the stream) because these habitats have intermediate depth and velocity conditions relative to pools and riffles. Glides are also considered to have relatively homogeneous substrate particle size distributions. Zweig and Rabeni (2001) investigated the way various metrics correlated with deposited sediment and found that density, EPT richness, EPT density, and taxa richness were significantly correlated. On average, all streams lost 46 percent of their EPT taxa due to deposited sediment. There was not an obvious sediment threshold in the data; rather the decrease in EPT was linear, with steep decreases at low sediment levels. These two studies, along with many others (e.g., Bourassa and Morin 1995, Gayraud *et al.* 2002, Fossati *et al.* 2001), demonstrate that aquatic invertebrates are sensitive to deposited sediment and the communities will shift in response.

While many studies have looked at how specific macroinvertebrate taxonomic orders or families respond to sediment, trait-based analysis of macroinvertebrate communities provides a complementary way to analyze the community response to excess fine sediment. Trait-based analysis is considered more consistent across spatial scales than identity (taxonomic)-based analysis. (Menezes et al. 2010, Pollard and Yuan 2010, Poff *et al.* 2006). Functional attributes such as feeding group, mobility, and life span are the result of local ecosystem function (Poff *et al.* 2006). Therefore, habitat disturbances such as sedimentation should theoretically alter the proportions or abundances of the various functional groups.

While there are several ways to measure community response using various field and statistical analysis methodologies, ecological thresholds provide a distinctive understanding of community response. Ecological thresholds are defined as critical values at which the population of organisms changes and may cause a system to become altered in a way that may incur high costs, both in terms of alterations to the ecosystem and overall societal costs (Perrings and Pearce 1994). Ecological thresholds may also be defined as rapidly changing zones between alternate ecosystem states or ecological conditions (Baker and King 2010). Ecological thresholds are relevant to macroinvertebrate responses to sediment because looking for them helps to detect community responses in a narrow range of environmental conditions. The Threshold Indicator Taxa Analysis (TITAN) identifies abrupt changes in frequency and abundance of taxa along gradients (Baker and King 2010). Taxa collected from Lake Superior north shore streams experience a range of fine sediment conditions and TITAN analysis allows identification of changes in frequency and abundance of sensitive and tolerant taxa.

Although previous literature suggests a response to sediment by macroinvertebrates (Zweig and Rabeni 2001, Larsen et al. 2009), studies on the north shore of Lake Superior, where turbidity and, by extension, excess sediments are thought to be the primary stressors, should help refine our understanding of macroinvertebrate responses to increased sediment. In this project, I explored this relationship by collecting substrate, sediment, and macroinvertebrate data from Lake Superior streams with the goal of identifying relationships between macroinvertebrate communities and traits, and high levels of fine sediment.

Methods

Site Selection

Site selection began in the winter of 2010 using GIS maps created at the Natural Resources Research Institute (NRRI). The basic parameters used to select potential sites were stream order, distance from Duluth, road access, watershed size, and landuse. Streams classified as second to fourth order were identified as having the maximum suitability for this study due to continuous flowing water and safe wading access. A minimum watershed size of 1000 hectares was used to further assure consistent flowing water. All potential sites were within 100 miles of Duluth to control costs and reduce travel time. Proximity to a road or a bridge assured ease of access and further promoted time efficiency. Lastly, all sites needed to be non-agricultural and non-urban to meet the study's objectives and limit confounding variables. Once the listed parameters were applied to streams flowing into the northwestern coast of Lake Superior, approximately 100 sites were listed as possibilities. Reconnaissance was done before the final set of sites was selected. Sites with potentially unsafe wading conditions and sites that appeared susceptible to drying out by the end of summer were eliminated. Final selection prioritized sites across a range of probable fine sediment accumulation. Ideally, the collection of sites would have a spectrum of embeddedness ranging from 0 to 75 %. Historic data from previous sampling was used along with field observations to forecast potential embeddedness. Using the above criteria, 100 potential sites were narrowed to 22 selected sites (Figure 1-1).

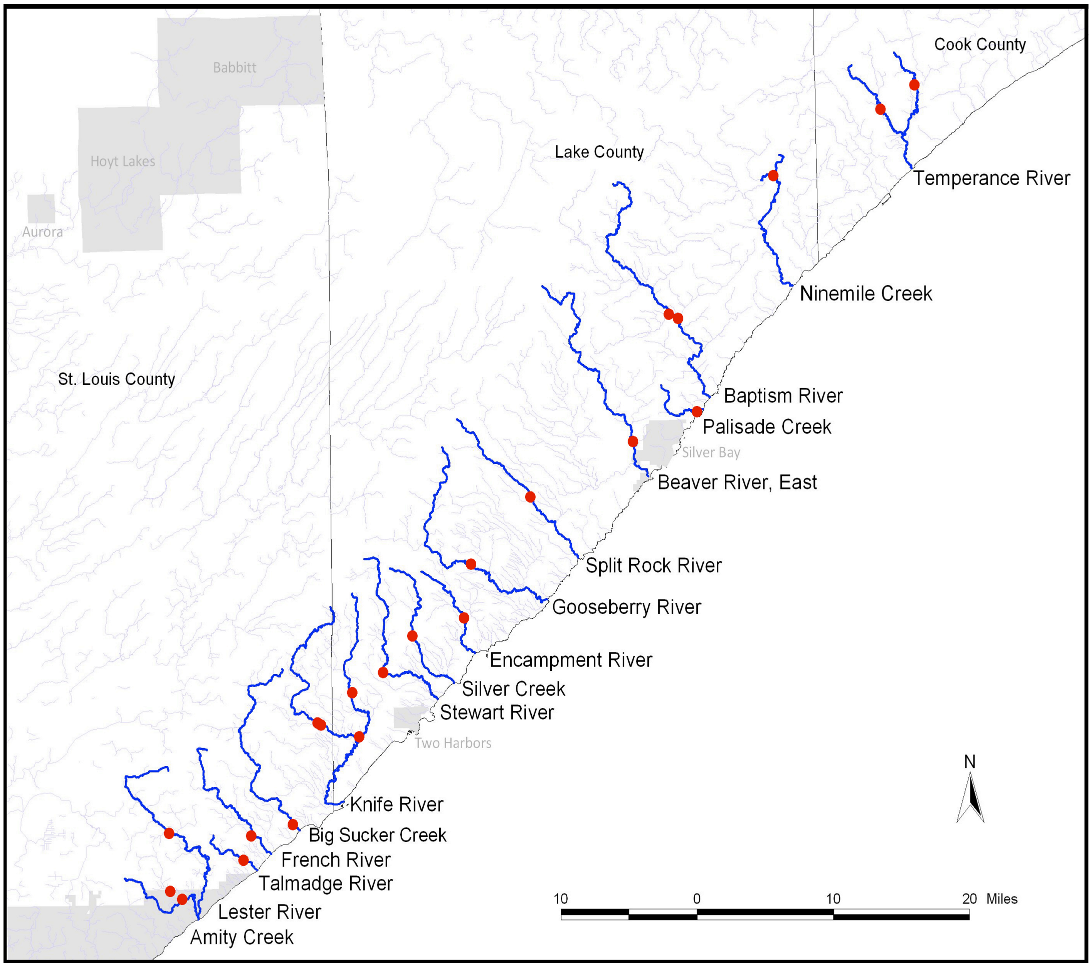

Figure 1-1: Twenty-two north shore sites selected for sampling in the summer of 2010. Some sites are located within the same watershed but are on different branches. Only the Knife River has more than one site on the same branch.

Site set-up

One riffle was chosen at each selected stream site. To avoid macroinvertebrate disturbance while sampling other parameters, the riffle had to be long enough to have separate macroinvertebrate and sediment transects. In addition, the riffles were all located upstream of bridges to avoid road runoff disturbance. The only exception was the West Baptism River, where the transect was located 90 m downstream of the road crossing to minimize effects. The same transect was used for each sediment sampling trip throughout the summer. Bright orange flagging attached to streamside trees and shrubs was used to mark each cross-sectional transect. The downstream portion of the riffle was marked and used for sediment sampling while the upstream portion was reserved for the macroinvertebrate sampling at the end of summer. Care was taken not to disturb the macroinvertebrate portion of the riffle during sediment sampling.

Water Quality and Habitat Data Collection

Water quality was sampled at each site before the sediment or macroinvertebrate sampling. To avoid degrading subsequent samples, a specific order of data collection was used at each site. First, a water grab sample was collected. Then, a transparency tube was used to measure water clarity. If a stream had a higher clarity value than the transparency tube maximum, the maximum value of 120 cm was recorded. Lastly, a Hydrolab MS5 was placed in the water for five minutes and dissolved oxygen, pH, temperature, and conductivity were recorded.

Sediment and Substrate Data Collection

Sediment and flow data were collected using 0.25 m^2quadrats. To collect quadrat data, the stream wetted width was equally divided into four parts. A quadrat was placed in the middle of each of the four sections to take the measurements. If the thalweg, the portion of the stream with the greatest flow rate, was not sampled, an extra quadrat sample was taken at the thalweg. At each quadrat, the velocity was measured using a Marsh-McBirney flow meter. The flow meter was placed at 60 percent of water depth to get the average flow in meters per second. If the sample location was obstructed by large boulders, the flow measurement was taken just upstream of the obstructing boulder. In low flow conditions, the velocity measurements were either recorded as zero if the water was stagnant or if there was shallow flow, the flow meter was placed so it was submerged, if possible.

Streambed substrate particle-size percentages were estimated using the quadrat, placed along the four areas as described above. Substrate size classes consisted of bedrock, boulder, cobble, gravel, sand, silt, and clay (Wentworth 1922). Embeddedness, the amount that boulders, cobble, and gravel are buried by sand, silt, and clay, was also estimated within each quadrat. Embeddedness was estimated by probing around the larger substrates to estimate the percent they were buried, in 5 percent increments. When possible, the height of the rock and the height of sediment burial were measured to find a more precise percentage. A second measure of the amount of fine sediment in the riffle was the depth of fines measurement, made by inserting a sharp plastic rod into the sediment as deep as possible and recording this depth. This was done in each of quadrat samples.

Macroinvertebrates

Macroinvertebrates were collected only once per site, on the last sampling trip, and as the very last thing done at each site to avoid causing turbidity and disturbance for the water quality and sediment measurements. Three macroinvertebrate samples were collected at each site, from the middle and each edge of the riffle. The sampling device used to collect invertebrates varied by site, depending on water depth and substrate type; however, each sampler was quantitative. The Hess sampler (from Wildco) was the most commonly-used sampling device and samples a 0.86 m^2 area of the stream bottom. It has a sharp edge that is pushed into soft substrates and rocks up to large gravel. Due to the need to push the edge into substrate, it was not suitable for large cobbles, boulders or bedrock substrate. In these cases a portable invertebrate box, or PIB, sampler was used. The PIB is similar to a Hess sampler, but it has a foam bottom to create a seal with large rock or bedrock substrates. The PIB samples approximately 0.1 m^2 of stream bottom. When the stream was too shallow to use either the Hess or PIB sampler, it was sampled with a Surber sampler (0.09 m^2). Surber samplers are not completely enclosed, as are the other two, and cannot be easily sealed to the stream bottom. Thus, it is somewhat more difficult to collect a truly quantitative sample using a Surber sampler, and it was only used where neither of the other two devices would work.

For each sampler type, macroinvertebrates were dislodged from the stream bed by tumbling and scrubbing the substrate manually, and were swept into the sampler’s retaining net by the stream current. Samples were preserved using Kahle's solution, a mixture of formalin and ethanol (Wegner 2004).

In the laboratory, macroinvertebrate samples were picked and identified to lowest practical taxonomic unit. Samples were size-fractionated into > 4 mm and 4 mm - 250 μm fractions. The > 4 mm fraction was completely picked and identified, while the smaller size fraction was subsampled and only one half or one quarter of the sample was sorted, depending on the amount of material present. Samples were split into smaller fractions using a plankton splitter. Final invertebrate counts were obtained through multiplication by the splitting proportion. The > 4 mm size fraction was picked under a 2.5 x magnifying light, while the smaller size fraction was picked using a 10x dissecting microscope. Aquatic insects were identified using a dissecting microscope and keys in Merritt *et al*. (2008) and Hilsenhoff (1995). The Chironomidae (Diptera) were identified to genus only for the thalweg sample from each site due to cost constraints. Other macroinvertebrates were identified to lowest practical taxonomic unit using keys in Thorp and Covich (2009), Smith (2001), and Pennak (2001). For consistency, all of the blackfly genera (Simulidae) were analyzed at the family level to match the taxonomic resolution of previous stream macroinvertebrate data housed at NRRI. Due to small sizes and specimen fragility, stoneflies (Plecoptera) were frequently not identified to genus.

Macroinvertebrate data were merged with a traits database parameterized by various scientists and graduate students at NRRI using numerous published sources (listed in references and Appendix C). Traits include functional feeding group, trophic group, mobility, substrate preference, etc. To this database, traits considered potentially reflective of stream sediment conditions were added. These included traits such as presence of a protective case, case type, presence of external gills, gill type, and filtering-feeding mechanism. Traits information was obtained from Merritt *et al.* (2008). For information not readily available for Chironomidae, Dr. Lenonard Ferrington from the University of Minnesota, St. Paul campus, was consulted. Traits tested for correlation with sediment characteristics are listed in Table 1-1.

Statistical Methods

The macroinvertebrate and sediment data for this project were collected throughout the summer of 2010. The sites selected did not have the desired gradient of fine sediment and embeddedness in 2010, potentially due to more rainfall that summer (see discussion). Thus, the data were supplemented with historic data collected by NRRI personnel. The NRRI historic data did not have several sediment measurements per site throughout the summer like the 2010 data, but the data did have the desired range of sediment conditions. The quadrat substrate sampling methodology and macroinvertebrate collection methodology were the same for the two data sets. The NRRI historic dataset contains data from the north and south shore of Lake Superior collected between 1996 and 2010. In contrast, the 2010 dataset (L. Herrera, this study) is from the north shore only. The current study's substrate data were rarified to match that of the NRRI historic dataset. The two datasets were used together in analyses to provide the needed breadth of fine sediment and embeddednss across sites.

The five sediment stressors included percent embeddedness, depth of fines, total fines, percent sand, and a combined sediment index created using normalized and transformed embeddedness, depth of fines and total fines. The combined sediment index has a hypothetical range of 0.01 to 3.0. Fifty-seven specific taxonomic groups and macroinvertebrate physical and behavioral characteristics (traits) were tested as potential response metrics (see results).

Both linear regressions and Threshold Indicator Taxa ANaylsis (TITAN) were used to measure the response of macroinvertebrates to varying sediment conditions. Linear regressions were used to model each potential independent variable against selected sediment variables. JMP (SAS) was used for the regression analysis.

TITAN is a new analytical approach to identify abrupt changes in individual taxa along an environmental gradient (Baker and King 2010). TITAN analyzes individual taxa responses to a stressor. Both positive (z+) and negative (z-) taxa responses are identified. Using the compilation of significant taxa responses to a stressor, TITAN can identify community thresholds. Dr. Katya Kovalenko ran the TITAN analyses for this study using R code.

Results

My project collected data across 22 stream systems on Lake Superior's north shore in 2010. This dataset was combined with the NRRI historic dataset collected on both north and south shore Lake Superior streams between 1996 and 2010. The data collected for this research (summer 2010) and the NRRI historic dataset (Appendix B) were used in combination to provide a greater range of fine sediment variability, particularly for percent embeddedness. The NRRI historic database had embeddedness data available for several of the sites chosen in 2010. However, the embeddedness for the 2010 sites was lower than expected based on the historic data, probably due to higher flows in 2010. The north shore sites in the 2010 dataset had an embeddedness range from 3.75 percent to 30 percent with a skewed distribution towards low percent embeddedness (Figure 1-2). The historic NRRI dataset had a greater range of percent embeddedness, with several sites with greater than 80 percent (Figure 1-3). Thus, adding the historic dataset provided a greater range of embeddedness and other potential sediment stressors. Henceforth, the two datasets will be referred to as the "combined dataset". Table 1-1 shows the mean, maxinum, and minimum of the sediment measurements of the combined dataset. The mean, maximum, and minimum are averages of all of the quadrat data collected at each site.

TABLE 1-1: MEAN, MAXIMUM, AND MINIMUM OF THE SEDIMENT MEASUREMENTS FOR THE COMBINED DATASET. SEE APPENDIX B.

	Percent Embeddedness	Depth of Fines (meters)	Total Fines (percent)	Combined Sediment	Percent Sand
MEAN	25.11	0.06	11.59	1.04	9.09
MINIMUM	0.00	0.00	0.00	0.14	0.00
MAXIMUM	99.90	0.40	93.86	2.58	73.91

TABLE 1-2: MEAN, MAXIMUM, AND MINIMUM OF THE WATER QUALITY MEASUREMENTS FOR THE 2010 DATA.

	Dissolved Oxygen (mg/L)	pH	Temperature (Celsius)	Conductivity (µs/cm)	Transparency (cm)
MEAN	9.44	7.47	18.55	153.38	116.54
MINIMUM	7.00	5.27	8.89	61.80	68
MAXIMUM	11.89	8.76	25.33	330.1	120

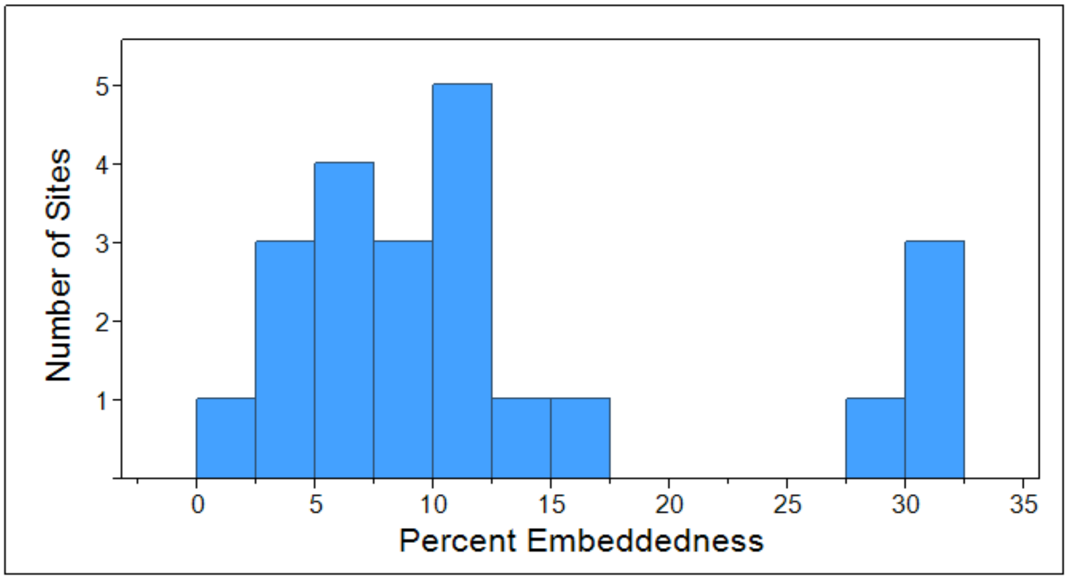

Figure 1-2: Non-transformed percent embeddedness for Lake Superior north shore stream sites sampled in 2010. The embeddedness values are an average of the quadrat data collected across the stream channel.

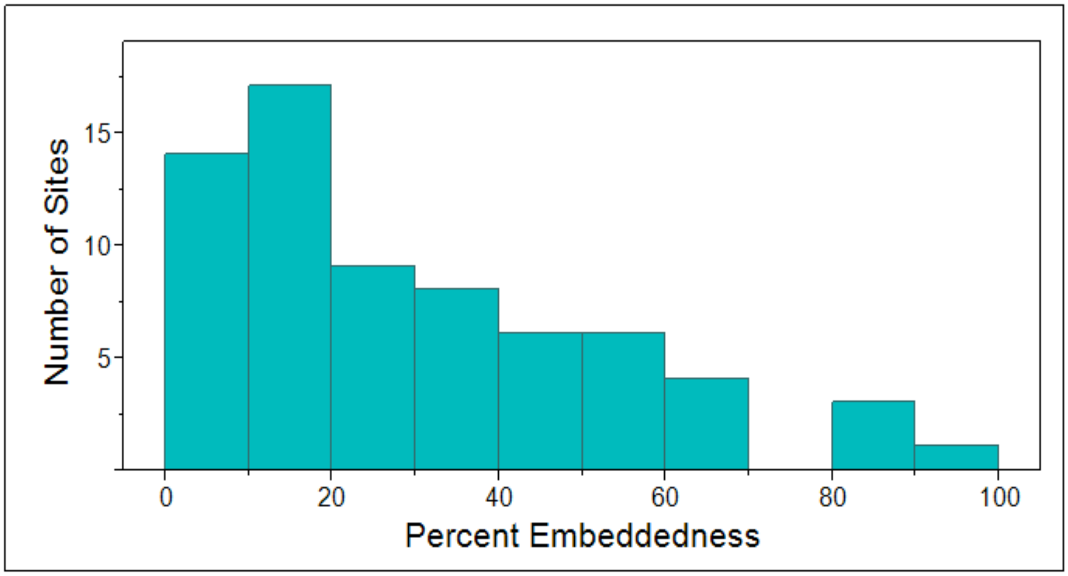

Figure 1-3: Non-transformed percent embeddedness for Lake Superior stream sites sampled prior to 2010 and included in the NRRI historic dataset. The embeddedness values are an average of the quadrat data collected across the stream channel.

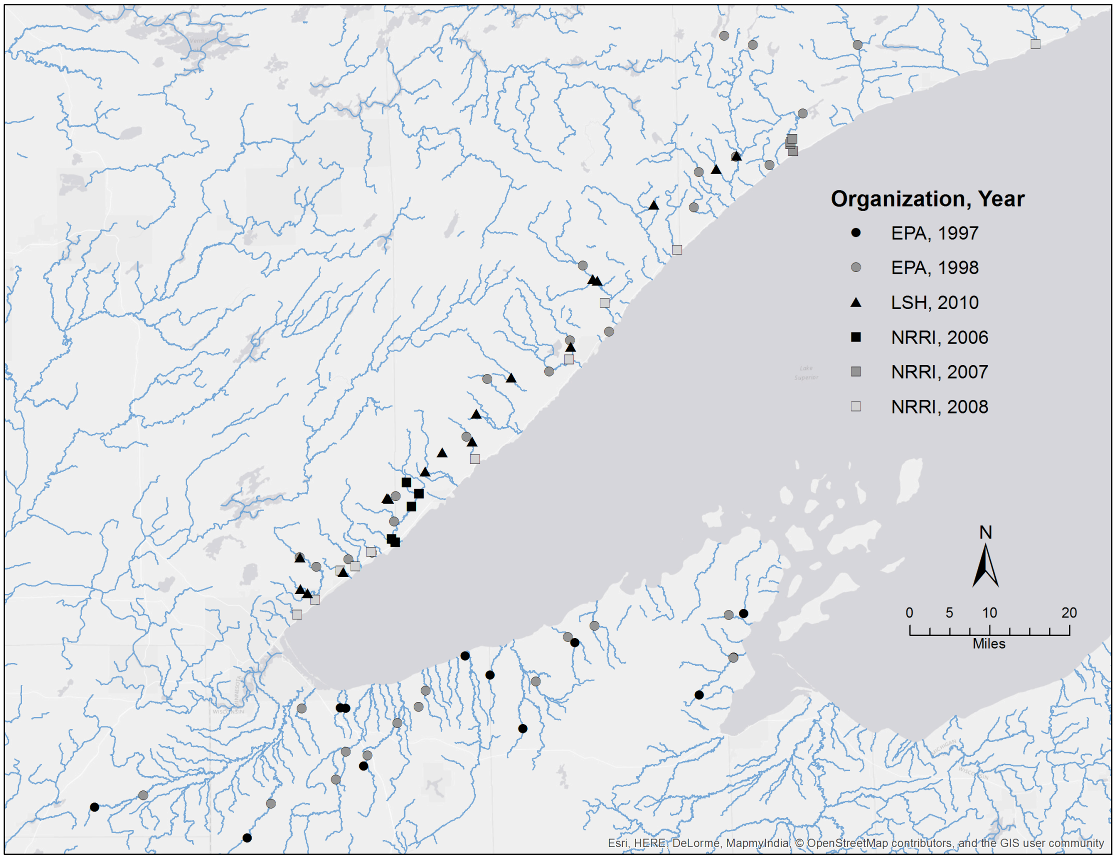

Figure 1-4: Site map of data used for data analyses. The 22 sites sampled for this research are labeled as LSH, 2010. See Appendix A for a complete list of sites.

The combined dataset includes streams located on the north and south shores of the western arm of Lake Superior (Figure 1-4). While all of the streams in the dataset are wadeable, they had differing flow and water depths. The average flow varied from 0.0 m/s (e.g., not flowing) to 1.44 m/s. The average water depth ranged from 0.05 m to 0.61 m. Using the combined dataset allowed for more variability in the sediment measurements, but using streams from the north shore and the south shore of Lake Superior increased the stream type variability. North shore streams tend to have relatively steep gradients while south shore streams generally are lower gradient systems. Additionally, the substrates vary among sites due to the prevalence of sand-dominated substrate on the south shore and bedrock, boulder, and cobble on the north shore. More north shore streams also had erodible clay soils near or upstream of their study reaches. However, while the addition of south shore streams increased the variability in stream types, the historic dataset also increased the range of the sediment stressor variables such as embeddedness.

Linear regressions and TITAN analyses were used to model the relationships between the five sediment stressor variables (embeddedness, depth of fines, total fines, percent sand, and combined sediment) and the macroinvertebrate characteristics. While some of the macroinvertebrate characteristics examined included taxonomic metrics, many were based on the physical and behavioral traits of each taxon. The physical and behavioral characteristics were identified from an NRRI database that was compiled from various sources in the literature (Merritt et al. 2008, Thorp and Covich 1991, Wiggins 2004, Pennak 1978, Armitage et al. 2012). While many characteristics were already in this traits database, new ones were added: protective case, case type, presence of external gills, gill type, and filtering-feeding mechanism. These characteristics could make an invertebrate more or less vulnerable to stress from sediment conditions (Appendix C).

Overall, 57 macroinvertebrate characteristics were analyzed against each sediment stressor using linear regression. The relationships between the sediment stressor values and macroinvertebrate characteristics are presented in Table 1-3. Several linear regressions were selected for representation of strong and weak correlations that had statistical significance. The bolded p-values indicate a relationship depicted in a linear regression graph (Figure 1-5). The entire linear regression equation for each characteristic and each sediment stressor is provided in Appendix D. Overall, 23 macroinvertebrate characteristics had a significant relationship with one or more sediment stressors. Several characteristics had significant correlations with two or three sediment stressors, but none were significantly correlated with all four stressors.

Table 1-3. Linear regressions were used to model the relationship of the selected macroinvertebrate characteristics and four of the sediment stressor variables (combined sediment index, embeddedness, total fines and depth of fines). The correlation significance ($p<0.05$) is denoted by *, and the direction of the relationship is indicated by a (+) or (-). Richness refers to the taxonomic richness, which is the number of different taxa with a particular characteristic. Bolded relationships are illustrated in Figure 1-5. Complete tables with the entire linear regression equations and R^2 values are located in Appendix D.

Macroinvertebrate Characteristic	Combined Sediment P-value	Embeddedness P-value	Total Fines P-value	Depth of Fines P-value
Taxonomic Characteristics				
Proportion Chironomidae	0.8323	0.5285	0.1244	0.9869
Coleoptera Richness	0.1042	0.0314	0.3292	0.3513
Proportion Coleoptera	0.0452* (+)	0.3492	0.0091* (+)	0.0907* (+)
Diptera Richness	0.1412	0.1289	0.0629	0.6520
Proportion Diptera	0.7958	0.3638	0.6941	0.9764
Ephemeroptera Richness	0.1430	0.5346	0.5216	0.0243* (-)
Proportion Ephemeroptera	0.1365	0.4438	0.1867	0.1004
EPT Richness	0.0030* (-)	0.0266* (-)	0.1096	**0.0009* (-)**
Proportion EPT	0.2495	0.1713	0.5809	0.4011
Gastropod Richness	0.4532	0.3041	0.1643	0.7668
Proportion Gastropods	0.5233	0.9177	0.3272	0.4040
Proportion Hydropsyche	0.0634	0.0124* (-)	0.0870	0.6445
Insect Richness	0.0555	0.1949	0.4653	0.0114* (-)
Proportion Insect	0.8733	0.8720	0.7640	0.9829
Proportion Megaloptera	0.3131	0.1977	0.0559 (-)	0.3700
Proportion Mite/Acari	0.2546	0.7845	0.2947	0.1214
Proportion Nematode	0.9402	0.9896	0.6589	0.6085
Odonata Richness	0.7574	0.5414	0.4950	0.7344
Proportion Odonata	0.4268	0.7237	0.5888	0.2909
Proportion Oligochaeta	0.4107	0.5147	0.5572	0.1001
Plecoptera Richness	**0.0146* (-)**	0.0676	0.0658	0.0157* (-)
Proportion Plecoptera	0.2836	0.0751	0.5740	0.8164

Macroinvertebrate Characteristic	**Combined Sediment P-value**	**Embeddedness P-value**	**Total Fines P-value**	**Depth of Fines P-value**
Proportion Trichoptera	0.5029	0.8860	0.2795	0.3833
Trichoptera Richness	0.0021* (-)	0.0195* (-)	0.0605	0.0012* (-)
Taxa Richness	0.1039	0.3701	0.4999	0.0206* (-)
Total number per Meter Squared	0.9755	0.4197	0.9861	0.4509
Trait Characteristics				
Burrower Richness	0.5464	0.4770	0.5602	0.8199
Proportion burrowers	0.9454	0.5557	0.3862	0.8368
Case Richness	0.0202* (-)	0.3137	0.1294	0.0015* (-)
Proportion with Cases	0.3722	0.2341	0.5795	0.2094
Clinger Richness	0.0367* (-)	0.0894	0.3959	0.0154* (-)
Proportion Clingers	0.5481	0.9270	0.0517	0.9745
Depositional Richness	0.6037	0.3926	0.4068	0.7500
Proportion Depositional	0.4939	0.1420	0.4425	0.6314
Erosional Richness	0.0039* (-)	0.0042* (-)	0.1987	0.0065* (-)
Proportion Erosional	0.3370	0.9346	0.0219* (+)	0.5551
Filterer Richness	0.2438	0.3200	0.8350	0.1323
Proportion Filterer	0.0112* (+)	0.0947	0.0154* (+)	0.0228* (+)
Hardbody Richness	0.1194	0.3643	0.3636	0.0452* (-)
Proportion Hardbody	0.0940	0.5372	0.0193* (+)	0.1422
Proportion Long-life	0.8236	0.5711	0.1884	0.3400
Predator Richness	0.1256	0.3627	0.5145	0.0349* (-)
Proportion Predator	0.0223* (-)	0.0027* (-)	0.1105	0.3099
Proportion Scraper	0.0294* (-)	0.009* (-)	0.2889	0.1210
Scraper Richness	0.3527	0.7676	0.6292	0.1422
Proportion Sprawler	0.9429	0.5769	0.6401	0.7060
Sprawler Richness	0.3476	**0.0241* (+)**	0.3191	0.4018
Gill Characteristics				
External Gill Richness	0.0198* (-)	0.1131	0.2839	0.0034* (-)
Proportion External Gills	0.2627	0.6094	0.0259* (+)	0.6882

Macroinvertebrate Characteristic	**Combined Sediment P-value**	**Embeddedness P-value**	**Total Fines P-value**	**Depth of Fines P-value**
Gill Characteristics				
Filamentous Gill Richness	0.0005* (-)	0.007* (-)	0.0626	0.0001* (-)
Proportion Filamentous Gills	0.4529	0.8054	0.1539	0.3645
Lamellate Gill Richness	0.1974	0.0388* (+)	0.0862	0.6962
Proportion Lamellate Gills	0.2513	0.1719	0.9510	0.2305
Operculate Gill Richness	0.8418	0.6816	0.8499	0.8573
Proportion Operculate Gill	0.1310	0.0504* (+)	0.3961	0.3964
Proportion Protected Gill	0.4835	0.5048	0.0953	0.7618
Protected Gill Richness	0.9432	0.1988	0.6969	0.1565

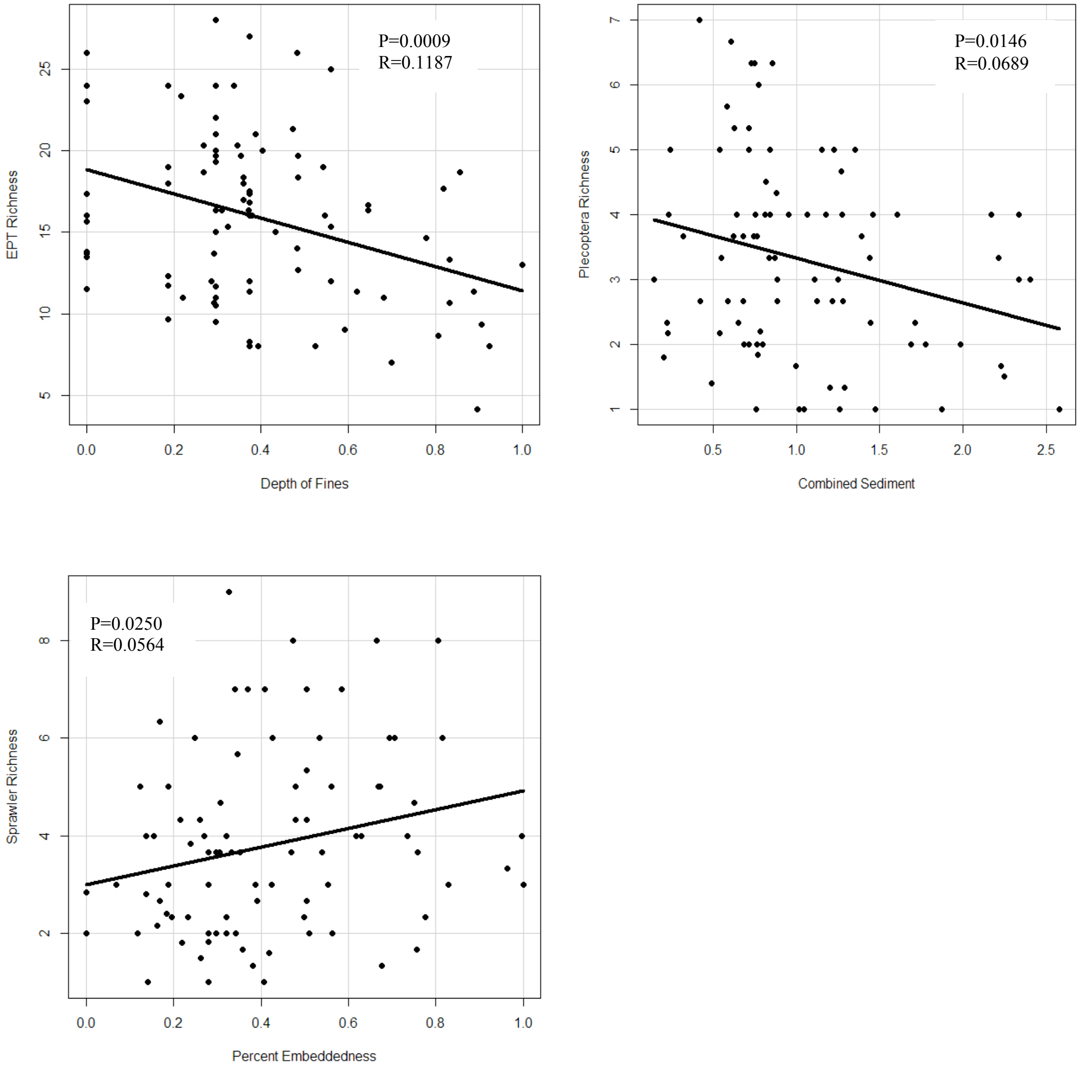

Figure 1-5: Representative relationships between sediment stressor variables (depth of fines, combined sediment, embeddedness, and total percent fines) and selected macroinvertebrate characteristics ($p<0.05$). Two positively-correlated relationships, with a strong relationship and a weaker but still significant example, and one negatively-correlated relationship are shown. The negative relationship had outliers removed but remained significant.

While the linear regression analyses used macroinvertebrate characteristics grouped by various categories such as order or gill type, the TITAN analyses used individual taxa and their proportional abundance to identify thresholds or stressor values at which a taxon increases greatly, decreases greatly, or disappears from a community (Figures 1-6 to 1-9). The TITAN analyses were performed on percent fines, percent embeddedness, total fines, percent sand, and the combined sediment index. Generally, taxa responded to more than one sediment stressor; however, many responded more strongly to one of the stressors than to the others. While there were many taxa with a negative (z-) response to increasing sediment, several taxa responded positively (z+) to increasing sediment. Good indicator taxa are those with a strong standardized response and narrow quantile intervals. On the graphs, the good indicator taxa are those with larger circles and shorter lines (less variability in their response). A good overall TITAN response is one in which multiple indictor taxa have large circles with short lines with the response being found at similar sediment metric levels. Such a response would indicate that multiple taxa were being affected by a similar amount of sediment, and that the response was more abrupt than gradual, indicating more of a threshold than a linear response.

These data analyses showed that macroinvertebrates were responding to percent embeddedness. Percent embeddedness ranged from 0.00 to 99.69 percent across all stream sites. The taxa frequency in the dataset ranged from 90 (Chironomidae) to 3 (Corixidae, *Culicuoides*) out of 90 total sites. Although some of the taxa were only present at a few sites and may be locally uncommon, their presence may be an indicator of a sensitive community. Fifty-nine taxa were identified as reliable indicator taxa ($p<0.05$). There were 22 negative indicator taxa (taxa that declined with increasing sediment) and 37 positive indicator taxa (Figure 1-6). Most of the negative indicator taxa (z-) appeared to decrease at roughly 15 % embeddedness (Figure 1-6), while the positive indicator taxa increased at about the same embeddedness. This provides evidence of a community threshold in the range of 10 to 20 % embeddedness.

The total fine sediments percentages ranged from 0.00 to 93.86 % in the combined dataset. The taxa frequency of occurrence at sites ranged from 68 (*Ferrissia*) to 4 (*Attenella, Baetisca, Hyalella, Hydroperla*) out of 90 sites. Three of the uncommon taxa, only present at four sites, were negative indicators. Thirty taxa were identified as reliable indicator taxa for total percent fine sediments ($p<0.05$). There were 14 negative indicator taxa and 16 positive indicator taxa (Figure 1-7). Two taxa (*Atennella*, change point (cp) =0.94 and *Ceraclea*, cp=0.93) had extremely low threshold responses and narrow quantile intervals, indicating a consistently sensitive response to very low levels of total fines. The negative indicator taxa had a sum (z-) change point of 0.18 % (Figure 1-7) while the positive indicator taxa (z+) had a sum (z+) change point of 27.14 % (Figure 1-7). Overall, the taxa had weaker responses to total fines than to the other sediment stressors, as evidenced by the size of change points (circles on the graph).

Percent sand in stream substrate ranged from 0.00 to 73.91 %. The taxa frequency ranged from 90 (Chironomidae) to 3 (C*eratopogon,* Lepidoptera) of 90 sites. Twenty-nine taxa were identified as reliable indicator taxa ($p<0.05$). There were 39 negative indicator taxa and 22 positive indicator taxa (Figure 1-8). The negative indicator taxa (z-) had a sum (z-) change point of 0.17 % (Figure 1-8). The positive indicator taxa (z+) had a sum (z+) change point of 0.11 % (Figure 1-8). Although the majority of the negative indicator taxa had wide quantile intervals indicating a weaker community threshold, the sensitive indicator taxa had narrow quantile intervals indicating a strong threshold response. Additionally, the number of sensitive taxa was greater for percent sand than for any of the other sediment variables tested, further indicating a strong community response.

The combined sediment index (CSI) had values ranging from 0.14 to 2.58. The taxa frequency ranged from 70 (*Hydropsyche*) to 4 (*Baetisca, Hydroperla*) of 90 sites. Fifty-one taxa were identified as reliable indicator taxa ($p<0.05$). There were 34 negative indicator taxa and 17 positive indicator taxa (Figure 1-9). The negative indicator taxa (z-) had a sum (z-) change point of 0.84 (Figure 1-9), while the positive indicator taxa (z+) had a sum (z+) change point of 1.05 (Figure 1-9). The combined sediment variable had the greatest number of indicator taxa. The negative indicator taxa had narrower quantile intervals, on average, and a smaller change point range than the positive indicator taxa, indicating a stronger threshold for the negative (sensitive) indicator taxa. Both the sensitive and tolerant taxa had a similar change point, which provides evidence of a community threshold in the range of 0.80 to 1.0 for the combined sediment variable.

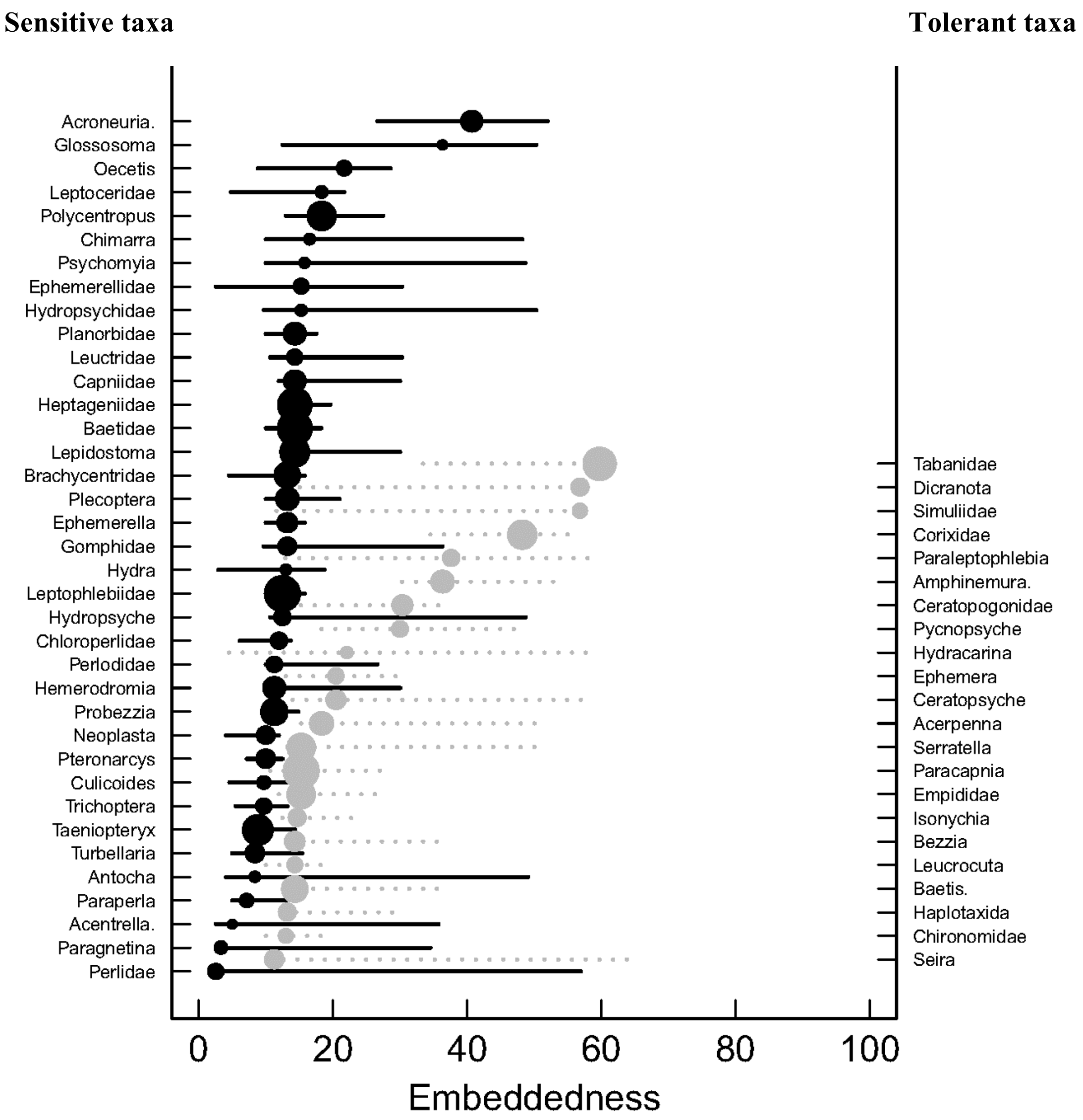

Figure 1-6: TITAN analysis of change points (0.05-0.95 bootstrap quantile intervals [QI]) for significant ($p \leq 0.05$) sensitive (left and black) and tolerant (right and grey) macroinvertebrates along the embeddedness gradient. Narrow QIs and consistent change points are indicative of a community threshold response. The size of the circle is indicative of the strength of the response. Therefore, larger circles with shorter lines are the strongest indicator taxa. Sensitive taxa appear to decrease at approximately 15 % embeddedness with tolerant taxa appearing to increase at approximately the same percent embeddedness. This indicates a moderate to strong community threshold in the range of 10-20 percent embeddedness. (Credit for graph: Dr. K. Kovalenko)

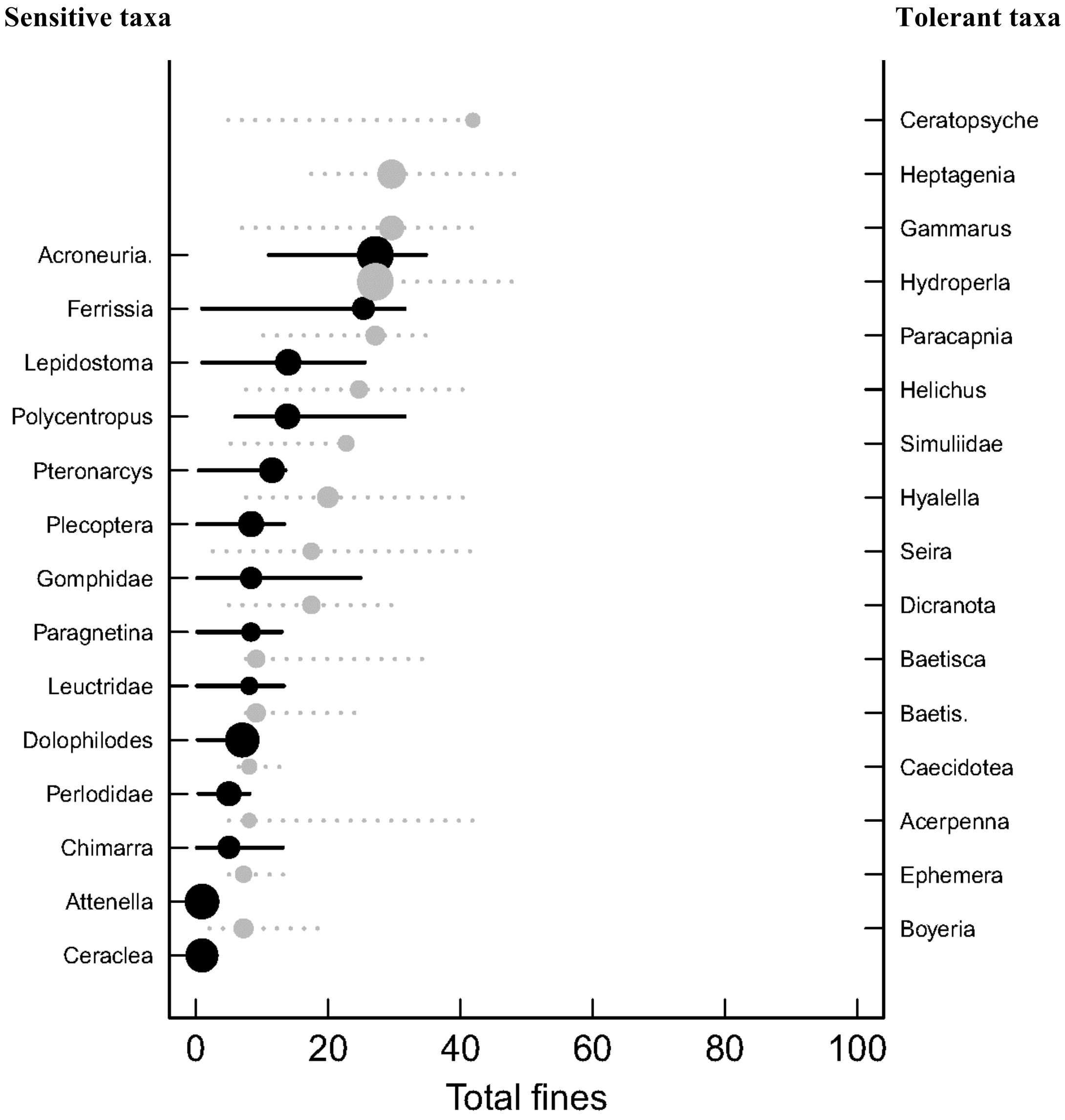

Figure 1-7: TITAN analysis of change points (0.05-0.95 bootstrap quantile intervals [QI]) for significant ($p \leq 0.05$) sensitive (left and black) and tolerant (right and grey) macroinvertebrates along the total fines gradient. Narrow QIs and consistent change points are indicative of a community threshold response. The overlap of several sensitive and tolerant taxa is indicative of a wide and poorly-resolved community threshold response (see text). Two taxa (*Attenella* and *Ceraclea*) appear to respond strongly to low levels of total percent fine sediments. (Credit for graph: Dr. K. Kovalenko)

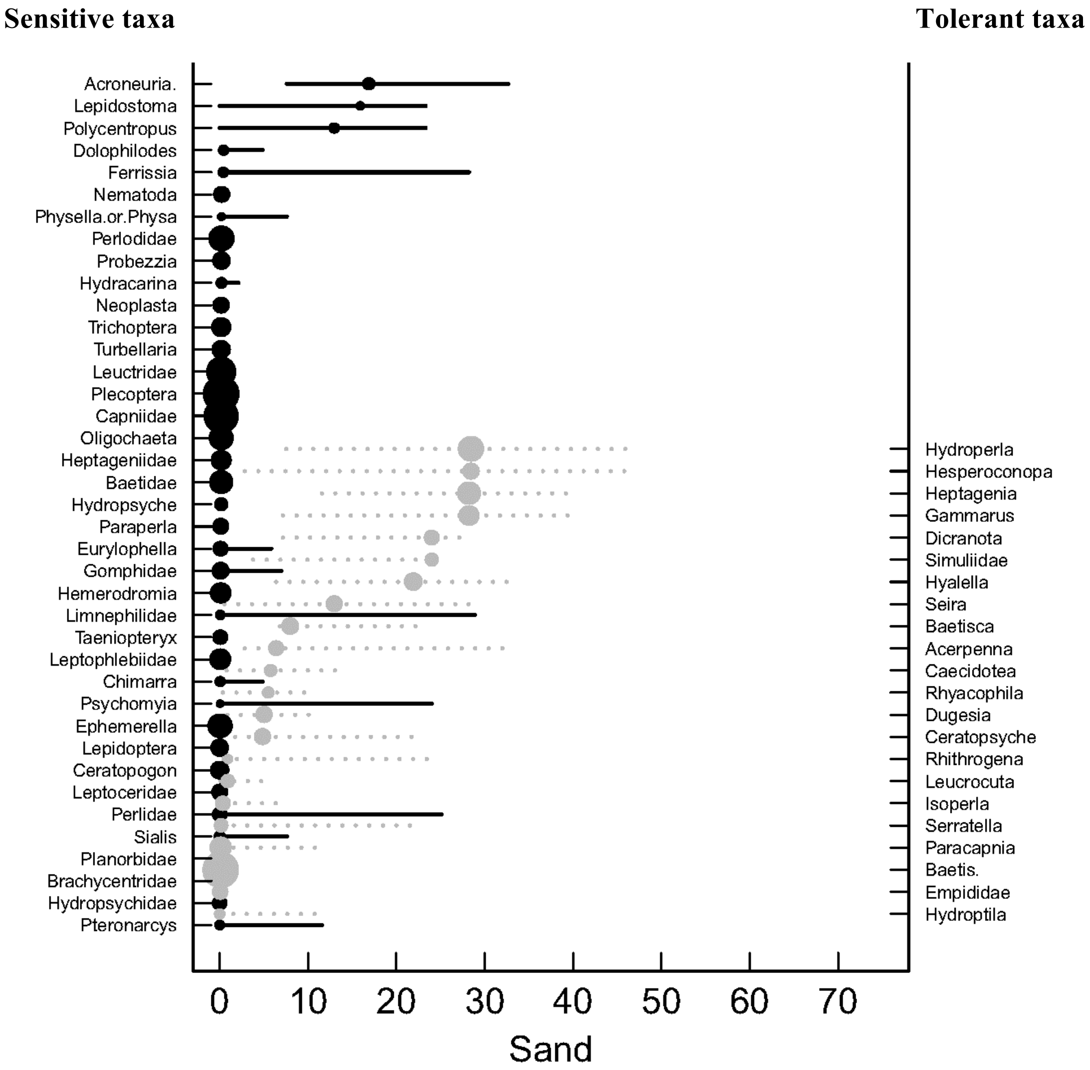

Figure 1-8: TITAN analysis of change points (0.05-0.95 bootstrap quantile intervals [QI]) for significant ($p \leq 0.05$) sensitive (left and black) and tolerant (right and grey) macroinvertebrates along the percent sand gradient. The sensitive taxa have narrow QIs and consistent change points, indicating a strong response by the sensitive taxa to very low levels of sand. (Credit for graph: Dr. K. Kovalenko)

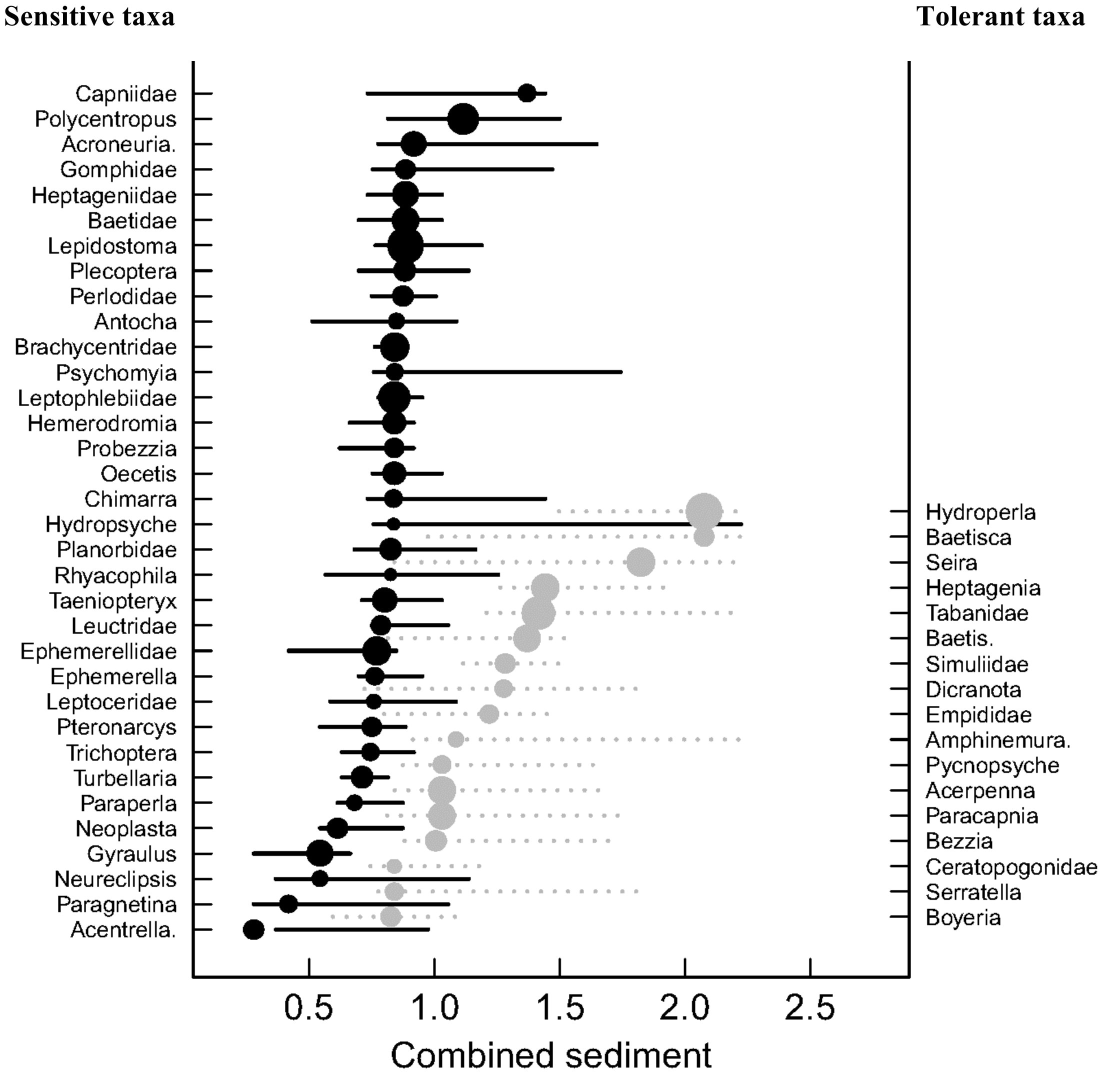

Figure 1-9: TITAN analysis of change points (0.05-0.95 bootstrap quantile intervals [QI]) for significant ($p \leq 0.05$) sensitive (left and black) and tolerant (right and grey) macroinvertebrates along the combined sediment index gradient. Narrow QIs and consistent change points are indicative of a community threshold response. Many taxa showed sensitivity to sediment using this metric. The sensitive taxa have a narrow range of responses and appear to have a threshold between 0.5 and 1.0 on the CSI scale. (Credit for graph: Dr. K. Kovalenko)

Both the linear regression analyses and the TITAN analyses identified macroinvertebrate responses to sediment. The linear regressions identified macroinvertebrate metrics that respond to varying sediment levels, while the TITAN analyses identified community shifts in response to sediment levels. Together, the analyses provide insight into macroinvertebrate responses to increasing levels of stress from sediment.

Discussion

Excess fine sediments have been identified as a stressor influencing the macroinvertebrate community (Jones et al. 2012, Larsen et al. 2011, Relyea et al. 2010, Wagenhoff et al. 2012, Wagenhoff et al. 2011, Zweig and Rabeni 2001). Although most streams have more than one stressor, using Lake Superior streams away from human disturbance provided an opportunity to look at streams with excess fine sediments were the primary stressor. The data collected in 2010 were supplemented with historic data to provide a greater range of the stressor variables. The historic data (collected in the mid-1990's and early 2000's) were gathered throughout several years of varying weather (i.e. rainfall) patterns and provided a greater range of the stressor variables. A large proportion of the sites sampled in 2010 had embeddedness levels lower than 33 percent, a threshold proposed in the literature as the hypothetical stress point (Bjorn 1977). Five of the historic sites overlapped with the 2010 sites. Two of the overlapping sites had lower sediment measurements (Knife-Airport and Palisade), one site (Knife-Stanley) had similar measurements, and two sites (French and Sucker) had higher measurements in 2010 (Table 1-4). This could be due to differences in collection dates as well as rainfall patterns in the watersheds. The sediment measurements in both datasets were taken during one time period and may not be representative of the conditions throughout the summer.

TABLE 1-4: DIFFERENCES IN THE SEDIMENT MEASUREMENTS FOR SITES SAMPLED IN 2010 AND AS PART OF THE HISTORIC DATASET

SITE NAME	SITE NUMBER	PERCENT EMBEDDEDNESS	DEPTH OF FINES (M)	TOTAL FINES (PERCENT)	COMBINED SEDIMENT
FRENCH (2010)	5	27.50	0.05	25.00	1.35
FRENCH	127	14.64	0.01	5.77	0.71
SUCKER (2010)	7	10.00	0.03	5.00	0.81
SUCKER	160	4.61	0.00	0.45	0.24
KNIFE-AIRPORT (2010)	68	6.00	0.02	6.00	0.71
KNIFE-AIRPORT	132	30.71	0.40	6.98	1.71
KNIFE-STANLEY (2010)	79	30.00	0.05	13.00	1.27
KNIFE-STANLEY	136	36.50	0.09	13.94	1.47
PALISADE (2010)	85	4.60	0.02	1.00	0.55
PALISADE	147	12.96	0.01	5.00	0.68

One of the potential reasons the 2010 dataset had few sites with high amounts of fine sediment was due to the rainfall for the 2010 summer. Three weather stations, centered throughout the sampling area, were used to compare rainfall across years (Duluth Airport, Grand Marais, and Wolf Ridge, NSW 2015). The precipitation data included data from 1995 to 2015. The summer sampling season of 2010 appears to have higher than average rainfall for June, August, and September (Figure 1-10). The Duluth airport station shows 2010 being a year with the total yearly rainfall (May 1st through October 31st) as the second highest yearly total over the 20 year period (Figure 1-11). The Wolf Ridge station also depicts 2010 as a high rainfall year. Only the Grand Marais station does not depict the 2010 year with one of the highest total rainfalls. Due to the variability in rainfall between the different stations, the sites sampled in 2010 may have experienced different periods of high flow, with only the streams furthest from Duluth experiencing an “average” year of rainfall and streamflow. While stream gauge information was not available for each stream nor was the gauge close to the sample site, looking at the flow gauges for one of the available sites shows frequent dates in 2010 with a high discharge. Compared to the prior year, the discharge of the Knife River in 2010 is frequently high during the summer (Figure 1-12). In addition to looking at several years of discharge data for the Knife River, two other streams were graphed to visually examine the discharge peaks during the 2010 sampling season (Figure 1-14). All three streams had frequent high discharge peaks and many were sampled after high discharge events, including the final sampling date.

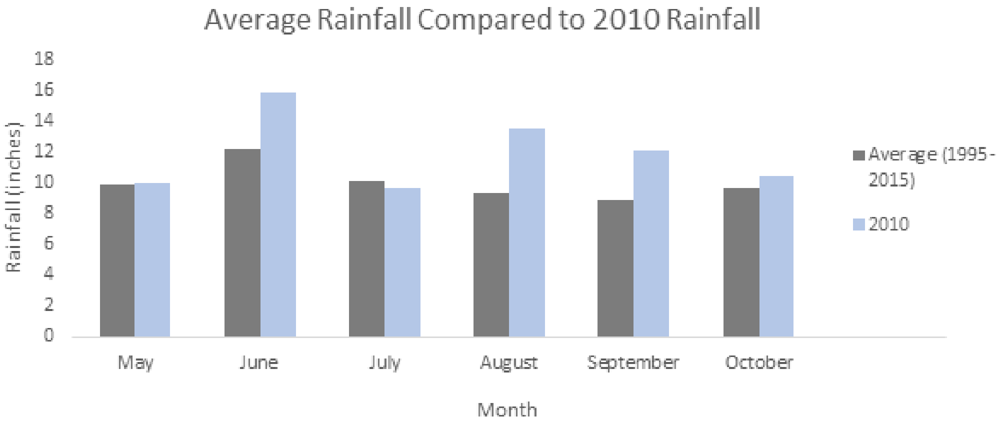

Figure 1-10: Average rainfall data from three stations compiled and compared to the 2010 rainfall. Several months in 2010 had rainfall greater than the average, including June, August, and September.

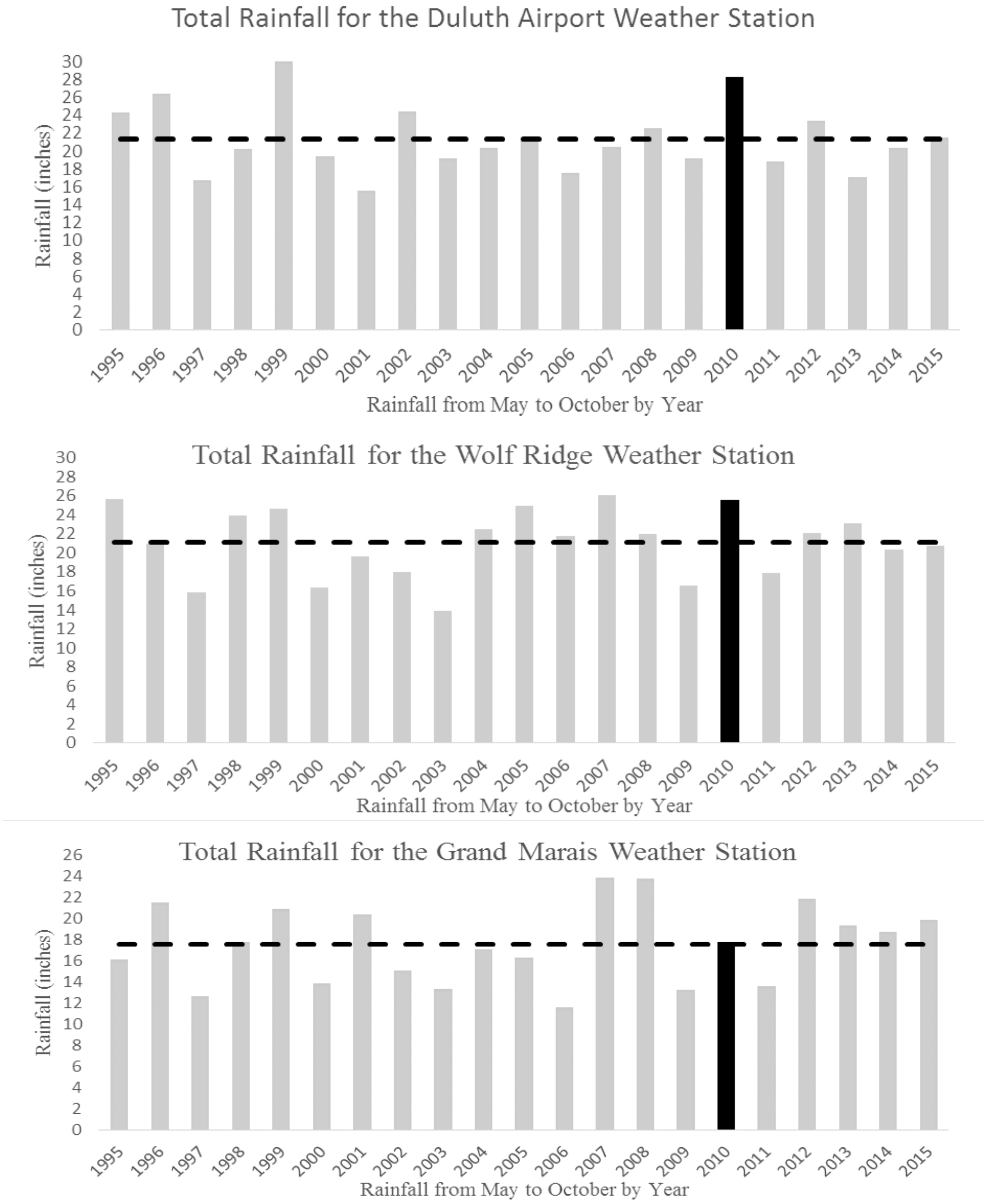

Figure 1-11: Total rainfall from May 1st to October 31st, by year for the three weather stations. For the Duluth Airport weather station, 2010 had the second highest average rainfall for the selected time period (1995 to 2015), and the rainfall was also higher than average at Wolf Ridge. Only the Grand Marais weather station shows 2010 as an average rainfall year. The average rainfall is depicted as a dashed line.

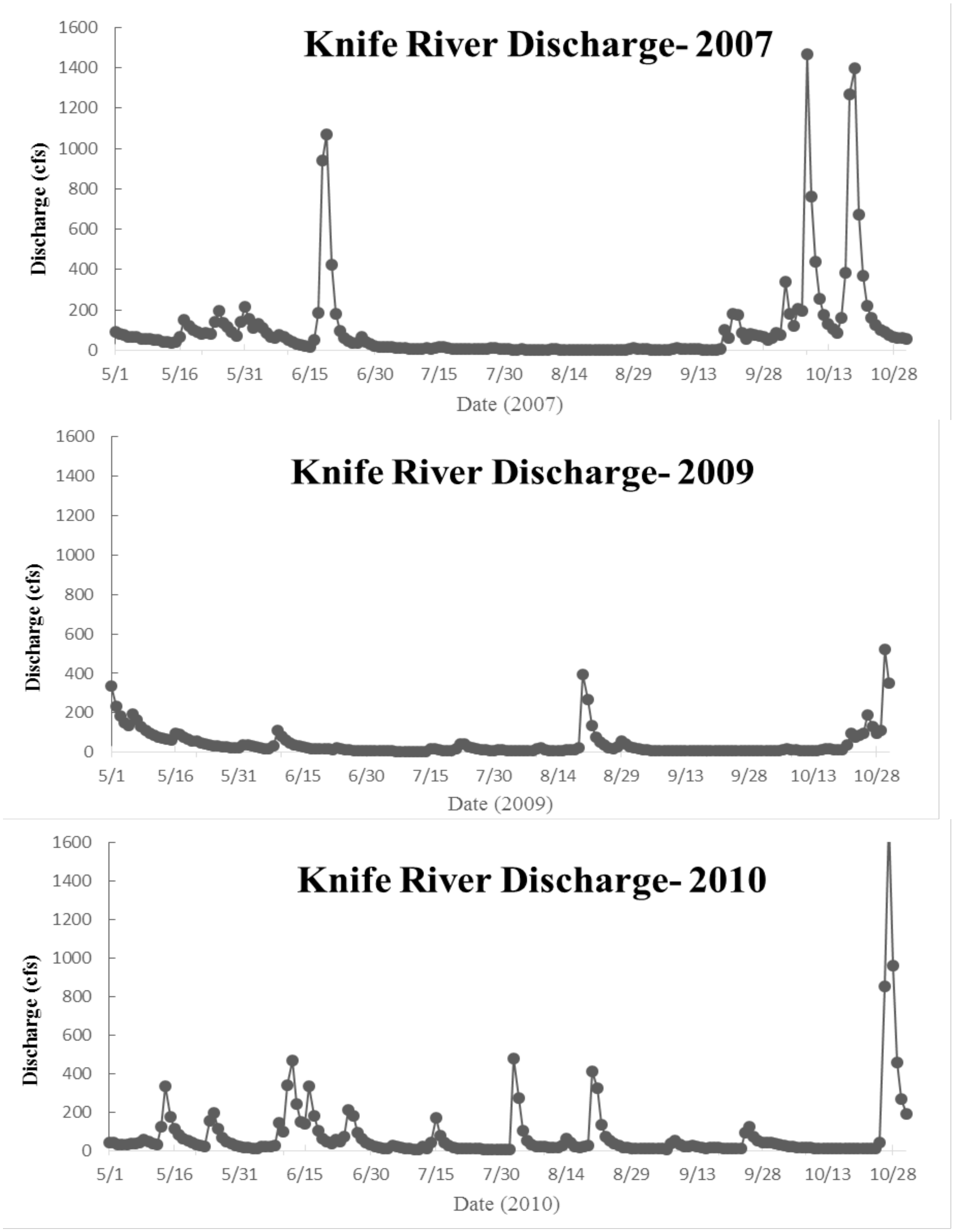

Figure 1-12: Comparisons of the discharge for the Knife River in 2007, 2009, and 2010. 2009 was a year with lower than average rainfall, 2010 was the year the data were sampled, 2007 was a close-to-average year. Data were taken from the Minnesota Department of Natural Resources Cooperative Stream Gaging website (www.dnr.state.mn.us/waters/csg).

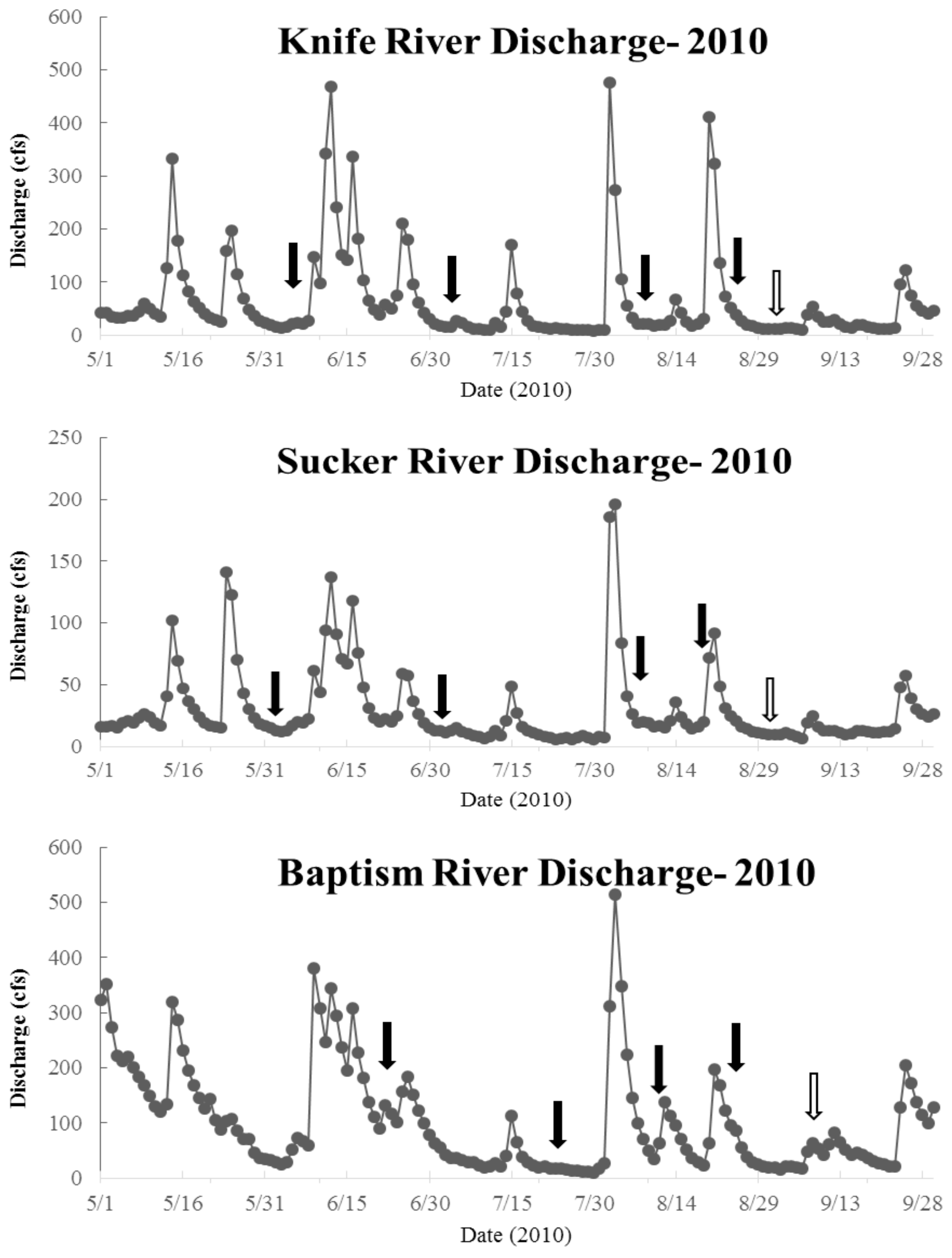

Figure 1-13: Comparisons of the discharge for several sites that were sampled in 2010. The gauges are not located at the sample site so the discharge data is a proxy for the probable discharge peaks upstream. The arrows are the sediment (black) and sediment/invertebrate (white) sample dates in 2010. Data were taken from the Minnesota Department of Natural Resources Cooperative Stream Gaging website (www.dnr.state.mn.us/waters/csg).

High stream flows, such as flow patterns due to storm events, have increased power and therefore the ability to move fine sediments, particularly for smaller streams (Hendee et al. 2012). In general (given adequate sediment supply), velocity is correlated with a stream's power to move sediment and substrate, and thus should be correlated to stream sedimentation. As flow and sediment values were only collected once, prior movement of sediment due to high flows was not measured. Studies of sediment transport and flow regimes have shown that the critical shear stress, the value at which a bedload can move, is grain-size dependent, meaning the ability of a flow event to move sediments is dependent on the size of the sediments in the stream bed (Allan and Castillo 2007, Knighton 2014, Rubin and Topping 2001, Smith et al. 2009). Differences in stream bed sediment composition lead to differing impacts of flow events on suspended sediment and sediment mobilization (Salant et al. 2008). For example, sand-dominated streambeds have much more frequent sediment mobilization events than gravel-dominated streambeds (Salant et al. 2008). The more frequent or greater rainfall events near Duluth in 2010 likely led to removal of more of the fine sediments in these streams, either by saltation (e.g., sand particles) or by suspension. Both types of fine sediment movement are likely to negatively affect various macroinvertebrates, potentially in differing ways.

With the addition of the historic dataset, the number of sites was increased from 22 to 90. The majority of the 2010 data (22 sites) was collected from sites with embeddedness in the low range. The additional data increased the number of sites with high levels of embeddedness. However, the dataset was still heavily skewed toward low embeddedness and an arcsin square root transformation was used to even out the distribution (Figure 1-14).

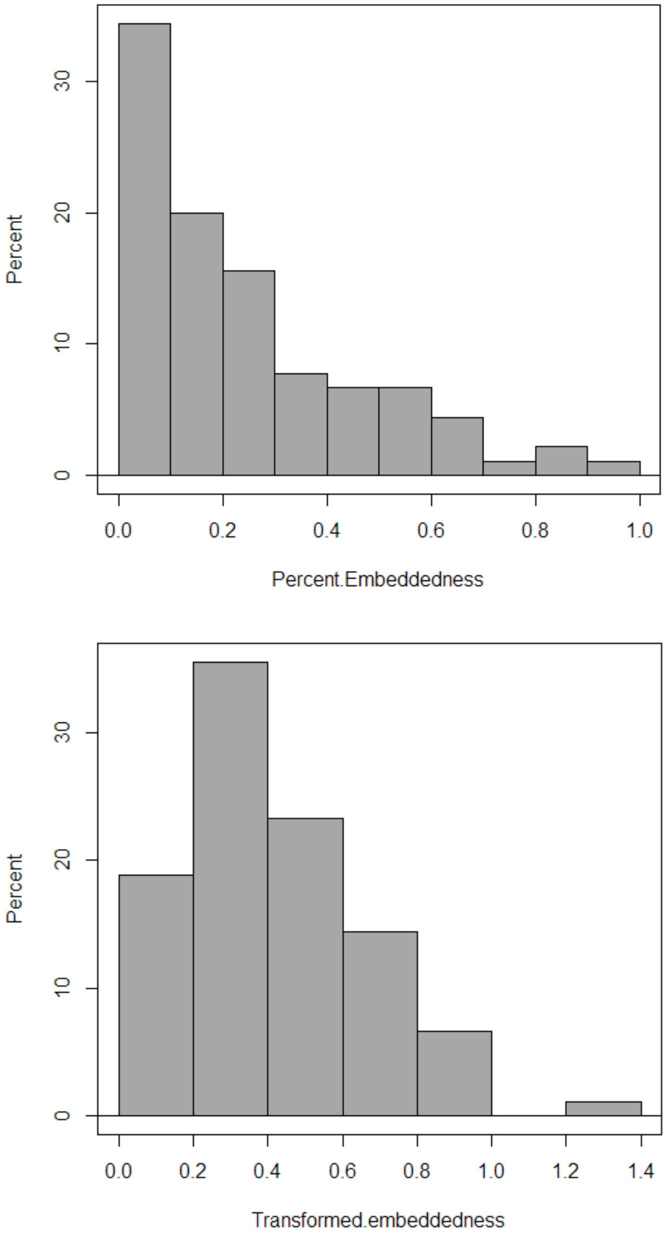

Figure 1-14: Comparisons of the distribution of embeddedness across sites. Prior to transformation, the percent embeddedness was heavily skewed towards low levels of the stressor. After transformation, the percent embeddedness is more evenly distributed.

Both the linear regressions and TITAN analyses showed a change in the community structure under conditions of excess sediment in the form of embeddedness, total fines, depth of fines, and/or the combined sediment index. The TITAN analyses also show a change in the community structure due to increasing proportion sand in the streambed. The linear regressions showed impacts on specific taxonomic groups such as macroinvertebrate genera or orders, or on physical or behavioral traits. Alternatively, the TITAN analyses showed individual taxa responses grouped to show a stressor threshold at which the community composition shifts (based on multiple individual taxa shifting). The TITAN analyses showed several taxa responding to several stressors, but it also showed several taxa that responded to one stressor alone. The linear regressions showed similar results. In many instances, a taxonomic group or trait had a significant response to one stressor but not the others. This could indicate a lack of differentiation among sediment size classes when collecting the data. While the proportion sand had a strong threshold for the TITAN analysis, the clay and silt categories would not even work in TITAN.

Many of the sediment measurements were based on estimation in the field using hand texturing while estimating percent coverages viewed through the water column, all of which diminishes accuracy. Rarely is a substrate pure sand, silt, or clay, and often a mixture is present. However, macroinvertebrates may respond differently to substrates with larger proportions of sand versus clay. For example, some macroinvertebrates use sand to build protective cases while other macroinvertebrates burrow into substrates and need clay and silt so their burrows do not collapse. Additionally, the effect of embeddedness may depend on whether it is from sand, silt, or clay. Due to the use of the historic dataset, the sediment size fractionation data collected in 2010 could not be used. Particle size fractionation data for the historic data may have helped to distinguish the size classes more thoroughly and test the potential responses of the macroinvertebrates to the different fine sediment size classes..

Although the linear regression analyses used broad taxonomic, physical, and behavioral characteristics, several of the results corresponded to the TITAN analyses of macroinvertebrate genera proportional abundances. In particular macroinvertebrate taxa, a wide range of gill types are present. Macroinvertebrates have several different gills types that may have various levels of fragility and therefore susceptibility to damage. Of the known types of external gills, several categories exist, including filamentous gills, operculate gills, and lamellate gills. Operculate gills are generally triangular to rectangular shaped and are larger than other gill types. Operculate gills cover other, more fragile, gills and are thought to be protective of the gills they cover, as well as being a hardier gill type. Filamentous gills are generally numerous gills attached at one point. They are generally long and thin, and therefore were hypothesized to be more susceptible to damage from sediment although the literature currently does not appear to specifically examine gill types in relation to potential stressors. The taxonomic richness of invertebrates with filamentous gills metric had one of the strongest relationships with the sediment stressor variables and several taxa in the TITAN analysis were part of the community that decreased with increasing sediment (Appendix D). Macroinvertebrate gills are subject to physical damage by sediment abrasion and clogging, and invertebrates may have to spend energy cleaning or repairing damaged structures (Jones et al. 2011, Waters 1995). The taxa with filamentous gills that were sensitive taxa in the TITAN analysis included *Acroneuria, Acentrella, Baetidae, Ceraclea, Hydropsyche,* Hydropsychidae*, Lepidostoma,* Leptophlebiidae*,* Leptoceridae*, Oecetis, Paragnetina, Pteronarcys, Sialis,* and *Taeniopteryx*.

Lamellate gills are generally square or rectangular shaped with a translucent appearance; however, variation occurs within this designation. Taxonomic richness for the lamellate gill trait increased with increasing embeddedness but was not significantly correlated with any other stressor. Furthermore, proportional abundance of macroinvertebrates with lamellate gills was not significantly correlated with any of the sediment stressors. This could be due to the variation within the lamellate gill category as well variation of taxa with lamellate gills. Although the generally pollution-sensitive mayflies have lamellate gills, so do the relatively pollution-tolerant damselflies. The lamellate gills of damselflies are attached at the end of their abdomen and are much larger than those of the mayflies, which may make them less sensitive than those of mayflies. Of the taxa with external gills that TITAN identified as sensitive to one of the sediment stressors (total of 20 taxa), four taxa have lamellate gills while fifteen have filamentous gills. Only one sensitive taxa had operculate gills, but that could be due to the general rarity of operculate gills. The site with the greatest number of taxa with operculate gills still only had four taxa. Operculate gill taxa richness was not correlated with any of the sediment stressors, likely due to the low number of taxa with this characteristic, and proportional abundance of macroinvertebrates with operculate gills was only positively correlated with increasing embeddedness. Experimental studies examining high levels of suspended sediment and the effect on the mortality of two mayfly taxa with lateral abdominal gills did not find a correlation with suspended sediment (Suren et al. 2005). However, the authors suggest long term effects of sediment deposition may cause reduction in macroinvertebrates due to several other factors, such as filling of interstitial spaces or contamination of food sources, not related to direct mortality (Suren et al. 2005).

EPT taxa richness has been correlated with deposited sediment in previous studies and was hypothesized to be significant for the north shore (Angradi 1999, Kaller and Hartman 2004, Wagenhoff et al. 2012, Zweig and Rabeni 2001). In this study, EPT richness was significantly negatively correlated with increasing depth of fines, embeddedness, and combined sediment index. Many of the sensitive taxa identified by TITAN were in the EPT orders as well. However, proportional abundance of EPT was not significantly correlated with any of the sediment stressor variables. This could indicate a certain number of EPT taxa existing under all sediment conditions, but as the sediment stressors increase, the sensitive taxa disappear while at the same time the tolerant taxa are increasing in abundance and thus keeping the overall EPT proportion the same. Using a broad classifier such as EPT (combined orders) loses two levels of taxonomic resolution when running regressions, but TITAN analyses can potentially demonstrate which specific EPT taxa are responding strongly to sediment stress. Of the sensitive taxa, 35 (66%) were EPT taxa. Of the tolerant taxa, 18 (50%) were EPT taxa.

Macroinvertebrate assemblages have been shown to respond to increasing levels of deposited fine sediment (Kaller and Hartman 2004, Larsen et al. 2011, Mcclelland and Brusven 1980, Pollard and Yuan 2010, Relyea et al. 2010, Wagenhoff et al. 2012). Various characteristics have been tested and shown to respond to increasing sediment levels, such as EPT richness and clinger richness (Angradi 1999, Kaller and Hartman 2003, Wagenhoff et al. 2012, Zweig and Rabeni 2001). In this study, a greater understanding of characteristics (such as gill type) that make a particular macroinvertebrate genus vulnerable was sought. Gill type was significantly correlated to several of the sediment stressors. Further research could better refine the results of this study. Genera within a family may have differing gill types. Using macroinvertebrates from the same family but with different gill types could more authoritatively indicate whether specific gill types lead to greater vulnerability to fine sediments. Other studies could also further refine these characteristics and separate out the EPT taxa metrics from some of the other significant characteristics. For example, predatory behavior could lead to increased vulnerability to excessive sediments, but is also a characteristic that could be driving the response of EPT taxa to sediment variables just because many of these taxa are predatory. If specific characteristics that are the root cause of a taxon being vulnerable to increased fine sediments could be identified conclusively, the absence of those specific characteristics in a stream could indicate the specific stressor in the stream as fine sediments. These metrics would then create a truly diagnostic indicator of changes to macroinvertebrate communities due to excess fine sediment. Large amounts of macroinvertebrate data have already collected because macroinvertebrates are a common stream condition indicator. Thus, creation of a diagnostic indicator that would provide additional information without additional sampling cost could be a benefit to managers.

Conclusion

The linear regression analyses and the TITAN analyses supported the hypothesis of community composition alteration under increasing sediment stress. In addition, the use of these two types of analyses allowed a greater understanding of why the macroinvertebrate community might shift in response to various sediment stressors. Examining the taxa identified in TITAN analyses as sensitive to various sediment variables in conjunction with the broader physical, behavioral, and taxonomic characteristics of linear regression allowed the exploration of potential characteristics making macroinvertebrates more or less vulnerable to fine sedimets in stream substrates. This also inspired creation of additional hypotheses and research questions. In some cases, the TITAN analyses identified a stressor amount at which the community appeared to begin to shift and the linear regression analyses provided possible reasons why particular taxa in the sensitive community shifted. Further analysis of the sensitive taxa identified by TITAN might provide additional information about what makes particular taxa disappear in the presence of the various sediment stressors. Additionally, testing new datasets as they become available and comparing the TITAN results could provide further evidence for particular taxa being sensitive and the use of those taxa as sediment stress indicators. A larger dataset or a dataset with multiple years of data could strengthen the statistical relationships and provide further evidence for specific taxon sensitivity.

Using a larger, combined dataset from several years of north shore data removed some of the influence of the greater summer precipitation from the 2010 data. While the rainfall from 2010 summer was not outside the 95 percent confidence interval for normality, it was at the higher end of the summer precipitation range. The use of the NRRI historic dataset to supplement this project's 2010 dataset allowed for a greater range in the stressor variables and, therefore, the emergence of stronger relationships. While the historic dataset added 49 sites, there were still relatively few sites experiencing extremely high levels of embeddedness, depth of fines, or total fines. This could be due to a lack of Lake Superior streams with extremely high levels of embeddedness, a limited dataset, or an inability to capture the levels of sediment the macroinvertebrates are experiencing. Additionally, while this project looked at measures of sediment stress by characterizing the bottom substrate, rainstorm- or snowmelt-related turbidity might also be a stressor. Due to the flashiness of north shore streams and safety concerns, none of the streams were sampled during the times of highest flow and, therefore, potentially greatest stress. The effects of fine sediments could be most impactful to the macroinvertebrate biotic communities when they are mobilized in the water column. Many macroinvertebrates are small and therefore could be susceptible to pelting by high flow suspended sediments, depending on the availability of refugia and scouring power of individual storm events. Although the 2010 dataset had additional sediment data, it was unable to capture the full range of conditions faced by the macroinvertebrates (Appendix E).

One of the benefits of using macroinvertebrates for stream research is their ability to reflect conditions over their 1-3 year life cycles; however, this could be a drawback if actual variability of habitat conditions is not being captured. While the TITAN analyses demonstrate differences in the macroinvertebrate community composition across sites as a function of various sediment stressors, the impact of excess fine sediments has not been resolved. More controlled experiments (e.g., in experimental stream channels) could look at the influence of specific gill types and their susceptibility to clogging or abrasion damage. A field study could pair sites above and below a disturbance that is increasing the sediment load in a stream. A potential disturbance could be a bridge replacement or road construction project. Culvert and road construction has been demonstrated to increase fine sediment loads (Hendrick et al. 2010, Lachance et al. 2008, Wellman et al. 2000). Using a paired study could eliminate confounding factors such as watershed and stream size and provide a level of sediment disturbance for a set time period. This project adds to the evidence that there is an impact on stream macroinvertebrates from excess fine sediments (c.f. Hedrick et al. 2010, Kaller and Hartman 2004, Larsen et al. 2010, Mcclelland and Brusven 2008, Pollard and Yuan 2010, Relyea et al. 2010, Wagenhoff et al. 2012). Because streams are incredibly complex ecological systems, a combination of field and laboratory studies may be need to identify the specific causes of susceptibility to sediment stressors.

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Appendix A: Site information for research locations

AGENCY	PROJECT	LOCATION	SITE	YEAR	SITE # (2010)	SITE #	Latitude	Longitude
EPA	Brady-EPA	Baptism River	Baptism	1998		103	47.443000	-91.283000
EPA	Brady-EPA	Beaver River	Beaver	1998		106	47.252000	-91.379000
EPA	Brady-EPA	Beaver River	E. beaver	1998		106	47.308000	-91.322000
EPA	Brady-EPA	Blind Temperance	Blind Temp	1998		110	47.634000	-90.866000
EPA	Brady-EPA	Caribou Creek	Caribou	1998		113	47.709000	-90.683000
EPA	Brady-EPA	Cascade River	Cascade	1998		115	47.830000	-90.530000
EPA	Brady-EPA	Encampment River	Encampment	1998		122	47.137000	-91.603000
EPA	Brady-EPA	French River	French	1998	5	127	46.918000	-91.921000
EPA	Brady-EPA	Lester River	Lester2	1998		137	46.922600	-92.050100
EPA	Brady-EPA	Lester River	Lester3	1998		138	46.905000	-92.006000
EPA	Brady-EPA	Onion River	Onion	1998		146	47.617000	-90.777000
EPA	Brady-EPA	Palisade River	Palisade	1998	85	147	47.322000	-91.217000
EPA	Brady-EPA	Skunk Creek	Skunk	1998		158	47.241000	-91.545000
EPA	Brady-EPA	Stanley River	Stanley	1998		159	46.985000	-91.798000
EPA	Brady-EPA	Sucker River	Sucker	1998	7	160	46.929000	-91.858000
EPA	Brady-EPA	Talmadge River	Talmadge	1998		162	46.895000	-91.942000
EPA	Brady-EPA	Temperance River	Temperance	1998		164	47.836000	-90.812000
EPA	Brady-EPA	Two Island River	Two Island	1998		166	47.544000	-90.983000

AGENCY	PROJECT	LOCATION	SITE	YEAR	SITE # (2010)	SITE #	Latitude	Longitude
EPA	Brady-EPA	Knife River	W. Knife	1998		167	47.031000	-91.793000
EPA	Brady-EPA	Cross River	Cross	1998			47.608000	-90.967000
EPA	Brady-EPA	Sawbill Creek	Sawbill	1998			47.854000	-90.889000
NRRI-UMD	Hershey-Wold	Little Knife River	Little Knife	1996			46.949800	-91.819000
NRRI-UMD	Hershey-Wold	Chester Creek	Chester Creek	1996			46.814300	-92.098900
NRRI-UMD	Hershey-Wold	East Split Rock River	East Split Rock	1996			47.241100	-91.453200
NRRI-UMD	Hershey-Wold	Knife River	Knife	1996			47.085300	-91.768300
NRRI-UMD	Hershey-Wold	McCarthy Creek	McCarthy Cree	1996			47.076100	-91.780000
NRRI-UMD	Hershey-Wold	Miller Creek	Miller Creek	1996			46.778500	-92.141300
NRRI-UMD	Hershey-Wold	Skunk Creek	Skunk Creek	1996			47.243000	-91.547600
NRRI-UMD	Hershey-Wold	Tischer Creek	Tischer Creek	1996			46.818000	-92.055200
NRRI-UMD	Hershey-Wold	West Branch Knife River	West Branch K	1996			47.022500	-91.807300
NRRI-UMD	Knife TMDL	Knife River	Knife-Airport	2006	68	132	47.055600	-91.763600
NRRI-UMD	Knife TMDL	Knife River	Knife-Culvert	2006		133	47.034600	-91.730700
NRRI-UMD	Knife TMDL	Knife River	Knife-Fish trap	2006		134	46.947100	-91.795700
NRRI-UMD	Knife TMDL	Knife River	Knife-Shilhon	2006		135	46.953200	-91.806200
NRRI-UMD	Knife TMDL	Knife River	Knife-Stanley	2006	79	136	47.012100	-91.751700
NRRI-UMD	Miller TMDL	Miller Creek	M108	2008			46.771100	-92.140300
NRRI-UMD	Miller TMDL	Miller Creek	M208	2008			46.780800	-92.142400

AGENCY	PROJECT	LOCATION	SITE	YEAR	SITE # (2010)	SITE #	Latitude	Longitude
NRRI-UMD	Miller TMDL	Miller Creek	M308	2008			46.792100	-92.157500
NRRI-UMD	Miller TMDL	Miller Creek	M408	2008			46.802700	-92.162200
NRRI-UMD	Miller TMDL	Miller Creek	M508	2008			46.810600	-92.166600
NRRI-UMD	Poplar TMDL	Poplar River	PRA	2007		150	47.640900	-90.712100
NRRI-UMD	Poplar TMDL	Poplar River	PRB	2007		151	47.653400	-90.719200
NRRI-UMD	Poplar TMDL	Poplar River	PRC	2007		152	47.657400	-90.718300
NRRI-UMD	Poplar TMDL	Poplar River	PRD	2007		153	47.663300	-90.713300
NRRI-UMD	Streamscale	Keene Creek	KE08	2008		130	46.735500	-92.175300
NRRI-UMD	Streamscale	Kingsbury Creek	KB08	2008		131	46.725000	-92.193000
NRRI-UMD	Streamscale	Chester Creek	CC08	2008			46.814700	-92.098300
NRRI-UMD	Streamscale	Mission Creek	MS08	2008			46.667700	-92.274800
NRRI-UMD	SWANS	Baptism River	BT08	2008		104	47.374400	-91.226900
NRRI-UMD	SWANS	Beaver River	BE08	2008		107	47.273000	-91.324800
NRRI-UMD	SWANS	Brule River	BR08	2008		112	47.820500	-90.051400
NRRI-UMD	SWANS	Caribou River	CB08	2008		114	47.467900	-91.029800
NRRI-UMD	SWANS	Encampment River	EN08	2008		123	47.096100	-91.580100
NRRI-UMD	SWANS	French River	FR08	2008		128	46.904900	-91.903000
NRRI-UMD	SWANS	Sucker River	SR08	2008		161	46.931000	-91.860100
NRRI-UMD	SWANS	Talmadge River	TR08	2008		163	46.897300	-91.942600

AGENCY	PROJECT	LOCATION	SITE	YEAR	SITE # (2010)	SITE #	Latitude	Longitude
NRRI-UMD	SWANS	Tischer Creek	TC08	2008		165	46.818700	-92.058000
NRRI-UMD	SWANS	Amity Creek	Amity 2	2008			46.845100	-92.010900
NRRI-UMD	SWANS	Amity Creek	Amity 1	2007			46.844300	-92.010300
NRRI-UMD	SWANS	Amity Creek	Amity East 3	2005			46.859200	-92.033000
NRRI-UMD	SWANS	Amity Creek	Amity East 2	2008			46.857500	-92.029900
NRRI-UMD	SWANS	Amity Creek	Amity East 1	2008			46.856700	-92.029300
NRRI-UMD	SWANS	Flute Reed River	FL08	2008			47.847000	-89.966400
NRRI-UMD	LSH Masters	Amity Creek		2010	2		46.864200	-92.048700
NRRI-UMD	LSH Masters	West Branch Knife River		2010	3		47.027700	-91.815900
NRRI-UMD	LSH Masters	Lester River		2010	4		46.921700	-92.048600
NRRI-UMD	LSH Masters	Talmadge River		2010	6		46.894500	-91.934100
NRRI-UMD	LSH Masters	Stewart River		2010	8		47.074700	-91.713900
NRRI-UMD	LSH Masters	East Branch Amity Creek		2010	9		46.857200	-92.030200
NRRI-UMD	LSH Masters	West Branch Knife River	Little Knife	2010	10		47.025800	-91.811700
NRRI-UMD	LSH Masters	Blind Temperance		2010	55		47.635400	-90.864400
NRRI-UMD	LSH Masters	Hockamin Creek		2010	56		47.418200	-91.257300
NRRI-UMD	LSH Masters	East Branch Beaver		2010	63		47.295700	-91.319900
NRRI-UMD	LSH Masters	Moose Creek		2010	69		47.550000	-91.088700
NRRI-UMD	LSH Masters	Gooseberry River		2010	75		47.177900	-91.575500

AGENCY	PROJECT	LOCATION	SITE	YEAR	SITE # (2010)	SITE #	Latitude	Longitude
NRRI-UMD	LSH Masters	Silver Creek		2010	77		47.109200	-91.667300
NRRI-UMD	LSH Masters	Encampment River		2010	82		47.127300	-91.587600
NRRI-UMD	LSH Masters	Heartbreak Creek		2010	84		47.612000	-90.919200
NRRI-UMD	LSH Masters	Baptism River		2010	90		47.414400	-91.245100
NRRI-UMD	LSH Masters	Split Rock		2010	95		47.242400	-91.480400

* Sites with a 2010 site number were sampled in the summer of 2010 for the Master's thesis work. Several sites were sampled in 2010 and earlier years and have two site numbers.

Appendix B: Sediment data for the five sediment variables used in the linear regression and TITAN analysis

Location	Site	Shore	Proportion Embeddedness	Proportion Total Fines	Depth of Fines (meters)	Combined Sediment	Proportion Sand
Amity-Martin	2	N	0.1694	0.1708	0.2669	0.6071	0.0000
W. Knife	3	N	0.1961	0.0980	0.2923	0.5864	0.0436
Lester	4	N	0.3207	0.1075	0.3869	0.8150	0.0000
French	5	N	0.4799	0.3965	0.4733	1.3498	0.0000
Talmadge	6	N	0.2974	0.2101	0.3715	0.8790	0.0000
Sucker	7	N	0.2797	0.1708	0.3593	0.8098	0.0036
Stewart	8	N	0.2328	0.1227	0.3238	0.6792	0.0061
Amity Bank	9	N	0.3075	0.0759	0.3783	0.7617	0.0000
Little Knife	10	N	0.1961	0.1318	0.2923	0.6202	0.0000
Blind Temperance	55	N	0.5039	0.1874	0.4843	1.1756	0.0482
Heartbreak	56	N	0.1694	0.1476	0.2669	0.5839	0.0000
E. Beaver	63	N	0.5039	0.2904	0.4843	1.2786	0.0417
Knife-Airport	68	N	0.2151	0.1874	0.3091	0.7117	0.0000
Moose	69	N	0.3458	0.0000	0.4025	0.7482	0.0000
Gooseberry	75	N	0.1234	0.0759	0.2164	0.4156	0.0000
Silver	77	N	0.2611	0.1203	0.3457	0.7271	0.0000
Knife-Stanley	79	N	0.5039	0.2794	0.4843	1.2675	0.0838
Encampment	82	N	0.2797	0.2172	0.3593	0.8562	0.0000

Location	Site	Shore	Proportion Embeddedness	Proportion Total Fines	Depth of Fines (meters)	Combined Sediment	Proportion Sand
Hackamin	84	N	0.2709	0.0000	0.3530	0.6239	0.0000
Palisade	85	N	0.1879	0.0759	0.2848	0.5486	0.0000
W. Baptism	90	N	0.2797	0.0000	0.3593	0.6390	0.0000
Split Rock	95	N	0.2493	0.1874	0.3368	0.7735	0.0000
Amity-EPA1997	100	N	0.1380	0.1819	0.0000	0.3200	5.5300
Amity-SWANS-AB08	101	N	0.1629	0.2586	0.0000	0.4215	11.1200
Amnicon-EPA1998	102	S	0.5611	0.3940	0.2958	1.2509	23.4600
Baptism-EPA1998	103	N	0.1556	0.0759	0.0000	0.2315	0.9500
Baptism-SWANS08	104	N	0.1408	0.1593	0.1867	0.4868	4.3300
Bardon-EPA1998	105	S	0.6942	0.0364	0.2197	0.9502	0.2070
Beaver-EPA1998	106	N	0.4089	0.2831	0.3733	1.0653	12.0200
Beaver-SWANS08	107	N	0.2379	0.2081	0.2958	0.7418	7.3200
Black2-EPA1997	108	S	0.9969	0.3625	0.8558	2.2151	20.6600
Black3-EPA1998	109	S	0.6733	0.0598	0.5419	1.2750	0.2470
Blind Temperance-EPA1997	110	N	0.4071	0.2827	0.4334	1.1232	13.0600
Bluff-EPA1997	111	S	0.6693	0.0437	0.5463	1.2594	0.2098
Brule-SWANS08	112	N	0.1170	0.0835	0.0000	0.2005	1.1900
Caribou-EPA1997	113	N	0.3524	0.0000	0.2958	0.6482	0.0000
Caribou-SWANS08	114	N	0.2797	0.2038	0.2958	0.7794	7.0100
Cascade-EPA1998	115	N	0.3260	0.2128	0.0000	0.5388	6.8800

Location	Site	Shore	Proportion Embeddedness	Proportion Total Fines	Depth of Fines (meters)	Combined Sediment	Proportion Sand
Chester-SWANS08	116	N	0.3062	0.3934	0.2958	0.9954	24.5400
Clevedon-EPA1997	117	S	0.7769	0.0536	0.6986	1.5292	0.4786
Cranberry-EPA1998	118	S	0.6654	0.4594	0.4825	1.6073	28.4300
Cross-EPA1998	119	N	0.4799	0.2877	0.1867	0.9543	12.6900
Dutchman-EPA1997	120	S	0.6767	0.3900	0.8067	1.8734	23.1700
East Beaver-EPA1997	121	N	0.9626	0.5948	0.7783	2.3357	48.1100
Encampment-EPA1997	122	N	0.3581	0.1394	0.3733	0.8708	3.2400
Encampment-SWANS08	123	N	0.1837	0.1683	0.1867	0.5387	4.8300
Fish-EPA1998	124	S	0.8290	0.5699	0.8324	2.2313	44.6100
Flag2-EPA1997	125	S	0.4980	0.4443	0.8324	1.7747	28.4600
Flag3-EPA1998	126	S	0.7060	0.0734	0.6812	1.4606	0.6614
French-EPA1997	127	N	0.3414	0.1837	0.1867	0.7117	5.4700
French-SWANS08	128	N	0.1380	0.4027	0.2958	0.8366	25.6600
Iron-EPA1998	129	S	0.4739	0.1814	0.1867	0.8419	5.1400
Keene-SWANS08	130	N	0.3334	0.4958	0.3733	1.2025	36.8100
Kingsbury-SWANS08	131	N	0.2632	0.2552	0.2958	0.8142	10.8600
Knife-Airport-TMDL2006	132	N	0.5107	0.2025	1.0000	1.7131	0.0000
Knife-Culvert-TMDL2006	133	N	0.4244	0.3390	0.5240	1.2874	4.8700
Knife-Fishtrap-TMDL2006	134	N	0.3824	0.0000	0.3733	0.7557	0.0000
Knife-Shilhon-TMDL2006	135	N	0.3421	0.1150	0.5600	1.0171	2.2900

Location	Site	Shore	Proportion Embeddedness	Proportion Total Fines	Depth of Fines (meters)	Combined Sediment	Proportion Sand
Knife-Stanley-TMDL2006	136	N	0.5640	0.2898	0.6200	1.4738	6.0200
Lester2-EPA1997	137	N	0.4691	0.0735	0.2958	0.8385	0.9400
Lester3-EPA1998	138	N	0.4259	0.1203	0.2958	0.8420	2.1500
Lil Sioux-EPA1997	139	S	0.7556	0.5954	0.8973	2.2483	48.3100
Middle2-EPA1997	140	S	0.5389	0.3292	0.8198	1.6879	16.0500
Middle3-EPA1998	141	S	0.5039	0.2373	0.4825	1.2237	8.6000
Muskeg-EPA1997	142	S	1.3382	0.0759	0.9247	2.3387	0.7610
Nemadji2-EPA1997	143	S	1.0000	0.6744	0.9068	2.5811	50.3500
Nemadji3-EPA1998	144	S	0.5842	0.2274	0.2958	1.1074	7.8600
Npike-EPA1997	145	S	0.5532	0.3323	0.5600	1.4455	17.7100
Onion-EPA1997	146	N	0.3912	0.1210	0.3733	0.8855	2.4400
Palisade-EPA1997	147	N	0.3202	0.1708	0.1867	0.6776	4.9000
Pearson-EPA1998	148	S	0.7343	0.0469	0.3931	1.1743	0.3042
Pikes3-EPA1998	149	S	0.6187	0.0523	0.3733	1.0444	0.4182
Poplar-A-TMDL2007	150	N	0.4177	0.2658	0.0000	0.6835	10.7500
Poplar-B-TMDL2007	151	N	0.2797	0.0621	0.3733	0.7151	0.6700
Poplar-C-TMDL2007	152	N	0.2797	0.1101	0.3733	0.7632	2.1000
Poplar-D-TMDL2007	153	N	0.3207	0.0731	0.3733	0.7671	0.9300
Poplar-EPA1998	154	N	0.3695	0.0875	0.2958	0.7529	1.3300
Silver-EPA1998	155	S	0.8062	0.8029	0.5600	2.1690	73.9100

Location	Site	Shore	Proportion Embeddedness	Proportion Total Fines	Depth of Fines (meters)	Combined Sediment	Proportion Sand
Sioux2-EPA1997	156	S	0.7503	0.4271	0.8067	1.9841	28.0100
Sioux3-EPA1998	157	S	0.8153	1.0000	0.5917	2.4070	53.1400
Skunk-EPA1997	158	N	0.6299	0.1145	0.6457	1.3902	2.2700
Stanley-EPA1997	159	N	0.7593	0.0352	0.6457	1.4402	0.2026
Sucker-EPA1998	160	N	0.1881	0.0508	0.0000	0.2390	0.4200
Sucker-SWANS08	161	N	0.0000	0.2191	0.0000	0.2191	8.0900
Talmadge-EPA1997	162	N	0.2978	0.0291	0.8875	1.2144	0.1407
Talmadge-SWANS08	163	N	0.0000	0.2250	0.0000	0.2250	8.5300
Temperence-EPA1998	164	N	0.0680	0.0759	0.0000	0.1438	0.8100
Tischer-SWANS08	165	N	0.2197	0.2786	0.2958	0.7941	12.8700
Two Island-EPA1998	166	N	0.5332	0.3239	0.2958	1.1529	15.7900
West Knife-EPA1997	167	N	0.3867	0.2025	0.2958	0.8850	6.7700

Shore: N= North Shore of Lake Superior, S=South Shore of Lake Superior

Appendix C: Macroinvertebrate information added to the Natural Resources Research Institute database

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Polycentropodidae	Gills-No	[2]Page 453	--	--	Case-No	--	[2]Page 453	Body type-Soft
Nyctiophylax	Gills-No	[2]Page 453	--	--	Case-No	Filterer-net	[2]Page 440	Body type-Soft
Neureclipsis	Gills-No	[2]Page 443	--	--	Case-No	Filterer-net	[2]Page 440	Body type-Soft
Chimarra	Gills-No	[4]Page 223	--	--	Case-No	Filterer-net	[2]Page 443	Body type-Soft
Dolophilides	Gills-No	[4]Page 223	--	--	Case-No	Filterer-net	[2]Page 443	Body type-Soft
Psychomyiidae	Gills-No	[4]Page 224 [2]Page 521	--	--	Case-No	--	[2]Page 521	Body type-Soft
Psychomyia	Gills-No	[2]Page 521	--	--	Case-No	--	[2]Page 521	Body type-Soft
Brachycentridae	Gills-Varies	--	--	--	Case-Yes	Varies	[2]Page 453	Body type-Soft
Brachycentrus	Gills-Yes	--	Filterer-legs	[2]Page 440	Case-Yes	Wood	[2]Page 484	Body type-Soft
Helicopsychidae	--	--	--	--	Case-Yes	Sand/ Rocks	[2]Page 451	Body type-Soft
Helicopsyche	--	--	--	--	Case-Yes	Sand/ Rocks	[2]Page 451	Body type-Soft
Apatania	--	--	--	--	Case-Yes	Minerals/ Rocks	[2]Page 456	Body type-Soft
Limnephilidae	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Varies	[2]Page 456	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Trichoptera	--	--	--	--	--	--	--	Body type-Soft
Himalopsyche	External Gills-Yes	²Page 523	Gill type-Tuft	²Page 503	Case-No	--	²Page 453	Body type-Soft
Rhyacophila	External Gills-Varies	²Page 523	--	--	Case-No	--	²Page 453	Body type-Soft
Agapetus	Gills-No	²Page 453	--	--	Case-Yes	Rock	²Page 443	Body type-Soft
Leucotrichia	--	--	--	--	Case-Yes	Silk	²Page 493	Body type-Soft
Agraylea	Gills-Yes	²Page 497	Gill type-Filamentous	²Page 497	Case-Yes	Silk/algae	²Page 497	Body type-Soft
Neotrichia	Gills-Yes	²Page 497	Gill type-Filamentous	²Page 497	Case-Yes	Sand/ Rocks	²Page 497	Body type-Soft
Ochrotrichia	Gills-No	²Page 497	--	--	Case-Yes	Silk/sand	²Page 497	Body type-Soft
Stactobiella	Gills-No	²Page 497	--	--	Case-Yes	Silk	²Page 497	Body type-Soft
Ceratopsyche	External Gills-Yes	²Page 451	Gill type-Filamentous	²Page 451	Case-No	Filterer-net	²Page 440	Body type-Soft
Diplectrona	External Gills-Yes	²Page 451	Gill type-Filamentous	²Page 451	Case-No	Filterer-net	²Page 440	Body type-Soft
Macrostemum	External Gills-Yes	²Page 440	Gill type-Filamentous	²Page 446	Case-No	Filterer-net	²Page 493	Body type-Soft
Arctopsychidae	External Gills-Yes	²Page 440	Gill type-Filamentous	²Page 446	Case-No	Filterer-net	²Page 440	Body type-Soft
Arctopsyche	External Gills-Yes	²Page 440	Gill type-Filamentous	²Page 446	Case-No	Filterer-net	²Page 491	Body type-Soft

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Parapsyche	External Gills-Yes	[2]Page 440	Gill type-Filamentous	[2]Page 446	Case-No	Filterer-net	[2]Page 491	Body type-Soft
Cyrrellus	External Gills-Yes	[2]Page 440	--	--	Case-No	Filterer-net	[2]Page 519	Body type-Soft
Cernotina	External Gills-Yes	[2]Page 519	--	--	Case-No	Filterer-net	[2]Page 521	Body type-Soft
Dipseudopsidae	External Gills-Yes	[2]Page 443	--	--	Case-No	Filterer-net	[2]Page 443	Body type-Soft
Phylocentropus	External Gills-Yes	[2]Page 443	--	--	Case-No	Filterer-net	[2]Page 443	Body type-Soft
Philopotamidae	External Gills-Yes	[4]Page 223	--	--	Case-No	Filterer-net	[2]Page 443	Body type-Soft
Phryganeidae	Gills-Yes	[5]Page 12	Gill type-Filamentous	[5]Page 12	Case-Yes	Varies	[2]Page 439/ 453	Body type-Soft
Banksiola	Gills-Yes	[2]Page 519	Gill type-Filamentous	[2]Page 519	Case-Yes	Plant	[2]Page 519	Body type-Soft
Phyganea	Gills-Yes	[2]Page 519	Gill type-Filamentous	[2]Page 519	Case-Yes	Wood	[2]Page 439	Body type-Soft
Ptilostomis	Gills-Yes	[2]Page 519	Gill type-Filamentous	[2]Page 519	Case-Yes	Wood	[2]Page 439	Body type-Soft
Fabria	Gills-Yes	[2]Page 519	Gill type-Filamentous	[2]Page 519	Case-Yes	Plant	[2]Page 439	Body type-Soft
Lepidostomatidae	Gills-Varies	[5]Page 175	--	--	Case-Yes	Varies	[2]Page 456	Body type-Soft
Hesperophylax	Gills-Yes	[5]Page 179	Gill type-Filamentous	[2]Page 507	Case-Yes	Plant	[2]Page 456	Body type-Soft
Hydatophylax	Gills-Yes	[2]Page 507	Gill type-Filamentous	[2]Page 507	Case-Yes	Wood	[2]Page 504	Body type-Soft

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Limnephilus	Gills-Yes	[2]Page 507	Gill type-Filamentous	[2]Page 507	Case-Yes	Varies	[2]Page 508	Body type-Soft
Pycnopsyche	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Varies	[2]Page 504	Body type-Soft
Platycentropus	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Plant	[2]Page 508	Body type-Soft
Asynarcus	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Plant	[2]Page 503	Body type-Soft
Ironoquia	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Varies	[2]Page 510	Body type-Soft
Frenesia	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Rock	[2]Page 508	Body type-Soft
Pseudostenophylax	Gills-Yes	[2]Page 503	Gill type-Filamentous	[2]Page 503	Case-Yes	Rock	[2]Page 507	Body type-Soft
Goeridae	Gills-Varies	[2]Page 488	Gill type-Filamentous	[2]Page 488	Case-Yes	Rock	[2]Page 456	Body type-Soft
Molannidae	Gills-Yes	[5]Page 200	Gill type-Filamentous	[5]Page 200	Case-Yes	Sand	[2]Page 456	Body type-Soft
Molanna	Gills-Yes	[5]Page 200	Gill type-Filamentous	[5]Page 200	Case-Yes	San	[2]Page 456/ 512	Body type-Soft
Leptoceridae	Gills-Varies	--	--	--	Case-Yes	Varies	[2]Page 451	Body type-Soft
Nectopsyche	--	--	--	--	Case-Yes	Plant	[2]Page 500	Body type-Soft
Leptocerus	Gills-Yes	[1]Page 201	Gill type-Filamentous		Case-Yes	Silk	[2]Page 500	Body type-Soft
Setodes	Gills-No	[1]Page 202	--	--	Case-Yes	Rock	[2]Page 500	Body type-Soft

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Triaenodes	Gills-Yes	[1]Page 201	Gill type-Filamentous		Case-Yes	Plant	[2]Page 451/500	Body type-Soft
Apatania	--	--	--	--	Case-Yes	Rock	[2]Page 456	Body type-Soft
Apataniidae	--	--			Case-Yes	Rock	[2]Page 456	Body type-Soft
Odontoceridae	Gills-Yes	[5]Page 203	--	--	Case-Yes	Rock	[2]Page 460	Body type-Soft
Psilotreta	Gills-Yes	[5]Page 203	--	--	Case-Yes	Rock	[2]Page 512	Body type-Soft
Beraeidae	--	--	--	--	Case-Yes	Sand	[2]Page 460	Body type-Soft
Beraea	--	--	--	--	Case-Yes	Sand	[2]Page 460	Body type-Soft
Sericostomatidae	Gills-Yes	[5]Page 213	--	--	Case-Yes	Rock	[2]Page 460	Body type-Soft
Agarodes	Gills-Yes	[5]Page 213	--	--	Case-Yes	Rock	[2]Page 460	Body type-Soft
Rhyacophilidae	External Gills-Varies	[2]Page 523	--	--	Case-No	--	[2]Page 453	Body type-Soft
Glossosomatidae	Gills-No	[2]Page 453	--	--	Case-Yes	Rock	[2]Page 453	Body type-Soft
Glososoma	Gills-No	[2]Page 453	--	--	Case-Yes	Rock	[2]Page 453	Body type-Soft
Protoptila	Gills-No	[2]Page 453	--	--	Case-Yes	Rock	[2]Page 453	Body type-Soft
Hydroptilidae	--	--	--	--	Case-Yes	Varies	[2]Page 451	Body type-Soft

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Case material	Source Page	Trait
Hydroptila	Gills-Yes	[2]Page 497	--	[2]Page 497	Case-Yes	Sand	[2]Page 451	Body type-Soft
Hydropsychidae	External Gills-Yes	[2]Page 451	Gill type-Filamentous	[2]Page 451	Case-No	Filterer-net	[2]Page 440	Body type-Soft
Hydropsyche	External Gills-Yes	[2]Page 451	Gill type-Filamentous	[2]Page 451	Case-No	Filterer-net	[2]Page 440	Body type-Soft
Cheumatopsyche	External Gills-Yes	[2]Page 451	Gill type-Filamentous	[2]Page 451	Case-No	Filterer-net	[2]Page 440	Body type-Soft
Oxyethira	Gills-No	[2]Page 497	--	--	Case-Yes	Sand	[2]Page 497	Body type-Soft
Micrasema	--	--	--	--	Case-Yes	Sand/Plant	[2]Page 485/484	Body type-Soft
Lepidostoma	Gills-Yes	[5]Page 175	Gill type-Filamentous	[5]Page 175	Case-Yes	Varies	[2]Page 440/500	Body type-Soft
Neophylax	Gills-Yes	[2]Page 527	Gill type-Filamentous	[2]Page 527	Case-Yes	Rock	[2]Page 527	Body type-Soft
Ueniodae	Gills-Varies	--	--	--	Case-Yes	Rock	[2]Page 456	Body type-Soft
Goera	Gills-Yes	[2]Page 488	Gill type-Filamentous	[2]Page 488	Case-Yes	Varies	[2]Page 456	Body type-Soft
Leptoceridae	Gills-Yes	[2]Page 501	Gill type-Filamentous	[2]Page 501	Case-Yes	Varies	[2]Page 451	Body type-Soft
Ceraclea	Gills-Yes	[2]Page 500	Gill type-Filamentous	[2]Page 500	Case-Yes	Varies	[2]Page 500	Body type-Soft
Oecetis	Gills-Yes	[2]Page 501	--	--	Case-Yes	Varies	[2]Page 500	Body type-Soft
Mystacides	Gills-Yes	[2]Page 501	--	--	Case-Yes	Plant	[2]Page 500	Body type-Soft

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Elmidae	--	--	--	--	Body type-Hard	--	--	--
Hydrophilidae	External Gill-No	[2]Page 613	--	--	Body type-Hard	[2]Page 574/ 613	--	--
Helichus	External Gill-No	--	--	--	Body type-Hard	[2]Page 632	--	--
Optioservus	External Gill-Yes	[2]Page 578	Operculum	[2]Page 578	Body type-Hard	--	--	--
Dubiraphia	External Gill-Yes	[2]Page 632	Operculum	[2]Page 632	Body type-Hard	--	--	--
Stenelmis	External Gill-Yes	[2]Page 58	Operculum	[2]Page 58	Body type-Hard	--	--	--
Oreodytes	--	--	--	--	Body type-Hard	--	--	--
Gomphidae	External Gill-No	[2]Page 240	Internal Gills	[2]Page 240	Body type-Soft	--	--	--
Boyeria	External Gill-No	[2]Page 240	Internal Gills	[2]Page 240	Body type-Soft	--	--	--
Cordulegaster	External Gill-No	[2]Page 240	Internal Gills	[2]Page 240	Body type-Soft	--	--	--
Neoplasta	External Gill-No	--	--	--	Body type-Soft	--	--	--
Tabanidae	External Gill-No	--	--	--	Body type-Soft	[2]Page 701	--	--
Chrysops	External Gill-No	--	--	--	Body type-Soft	[2]Page 703	--	--
Tabanus	External Gill-No	--	--	--	Body type-Soft	[2]Page 703	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Simuliidae	External Gill-Yes	²Page 45	Gill type-Filamentous	²Page 45	Body type-Soft	--	--	--
Simulium	External Gill-Yes	²Page 45	Gill type-Filamentous	²Page 45	Body type-Soft	--	--	--
Dixidae	External Gill-No	--	--	--	Body type-Soft	²Page 694	--	--
Dixa	External Gill-No	--	--	--	Body type-Soft	²Page 694	--	--
Ephydridae	External Gill-No	--	--	--	Body type-Soft	²Page 708	--	--
Phoridae	External Gill-No	--	--	--	Body type-Soft	²Page 706	--	--
Ceratopogonidae	External Gill-No	²Page 43	--	--	Body type-Soft	²Page 687	--	--
Bezzia	External Gill-No	²Page 43	--	--	Body type-Soft	²Page 687	--	--
Culicoides	External Gill-No	--	--	--	Body type-Soft	²Page 687	--	--
Ceratopogon	External Gill-No	--	--	--	Body type-Soft	²Page 687	--	--
Dasyhelea	External Gill-No	--	--	--	Body type-Soft	²Page 687	--	--
Probezzia	External Gill-No	--	--	--	Body type-Soft	²Page 687	--	--
Empididae	External Gill-No	--	--	--	Body type-Soft	²Page 704	--	--
Chelifera	External Gill-No	--	--	--	Body type-Soft	--	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Hemerodromia	External Gill-No	--	--	--	Body type-Soft	--	--	--
Clinocera	External Gill-No	--	--	--	Body type-Soft	--	--	--
Tipulidae	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Tipula	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Antocha	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Dicranota	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Limonia	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Hexatoma	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Limnophila	External Gill-No	--	Internal Gills	[2]Page 774/773	Body type-Soft	[2]Page 775	--	--
Athericidae	External Gill-No	--	--	--	Body type-Soft	[2]Page 701	--	--
Atherix	External Gill-No	--	--	--	Body type-Soft	[2]Page 701	--	--
Ophiogomphus	External Gill-No	[2]Page 240	Internal Gills	[2]Page 240	Body type-Soft		--	--
Calopteryx	External Gill-Yes	[2]Page 240	Gill type-Lamellae	[2]Page 240	Body type-Soft		--	--
Argia	External Gill-Yes	[2]Page 240	Gill type-Lamellae	[2]Page 240	Body type-Soft		--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Lepidoptera	--	--	--	--	Body type-Soft	²Page 556	--	--
Decapoda	--	--	--	--	Body type-Hard	--	--	--
Orconectes	--	--	--	--	Body type-Hard	--	--	--
Nigronia	External Gill-Yes	²Page 427	Gill type-Filamentous	²Page 427	Body type-Soft	--	--	--
Corydalus	External Gill-Yes	²Page 427	Gill type-Filamentous	²Page 427	Body type-Soft	--	--	--
Chauliodes	External Gill-Yes	²Page 427	Gill type-Filamentous	²Page 427	Body type-Soft	--	--	--
Sialis	External Gill-Yes	²Page 427	Gill type-Filamentous	²Page 427	Body type-Soft	--	--	--
Acroneuria	External Gill-Yes	²Page 318	Gill type-Filamentous	²Page 318	Body type-Soft	²Page 312	Merovoltine	²Page 72
Capniidae	External Gill-No	²Page 321	--	--	Body type-Soft	²Page 312	Univoltine	²Page 72
Chlorperlidae	External Gill-No	²Page 318	--	--	Body type-Soft	²Page 312	Semivoltine	²Page 73
Leuctridae	External Gill-No	²Page 318	--	--	Body type-Soft	²Page 312	Univoltine/ Semivoltine	²Page 73
Paragnetina	External Gill-Yes	²Page 318	Gill type-Filamentous	²Page 318	Body type-Soft	²Page 312	--	--
Chloroperla	External Gill-No	²Page 327	--	--	Body type-Soft	²Page 312	--	--
Paraperla	External Gill-No	²Page 327	--	--	Body type-Soft	²Page 312	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Perlidae	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Plecoptera	--	--	--	--	Body type-Soft	[2]Page 312	--	--
Pteronarcys	External Gill-Yes	[2]Page 313	Gill type-Filamentous	[2]Page 313	Body type-Soft	[2]Page 312	--	--
Taeniopteryx	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 313	Gill, single fingerlike	--
Perlodidae	--	--	--	--	Body type-Soft	[2]Page 318	--	--
Agnetina	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Perlesta	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Perlinella	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Neoperla	External Gill-Yes	[2]Page 318	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Alloperla	External Gill-No	[2]Page 318	--	--	Body type-Soft	[2]Page 312	--	--
Haploperla	External Gill-No	[2]Page 318	--	--	Body type-Soft	[2]Page 312	--	--
Pteronarcyidae	External Gill-Yes	[2]Page 313	Gill type-Filamentous	[2]Page 318	Body type-Soft	[2]Page 312	--	--
Clioperla	External Gill-No	[2]Page 329	--	--	Body type-Soft	[2]Page 334	--	--
Isoperla	External Gill-No	[2]Page 329	--	--	Body type-Soft	[2]Page 329	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Isogenoides	External Gill-No	²Page 329	--	--	Body type-Soft	²Page 329	--	--
Cultusldecisus	External Gill-No	²Page 333	--	--	Body type-Soft	²Page 334	--	--
Megarcys	External Gill-Yes	²Page 329	--	--	Body type-Soft	²Page 329	--	--
Helopicus	External Gill-Yes	²Page 334	--	--	Body type-Soft	²Page 334	--	--
Arcynopteryx	External Gill-No	²Page 332	--	--	Body type-Soft	²Page 332	--	--
Leuctra	External Gill-No	²Page 329	--	--	Body type-Soft	²Page 329	--	--
Zealeuctra	External Gill-No	²Page 329	--	--	Body type-Soft	²Page 329	--	--
Paracapnia	External Gill-No	²Page 321	--	--	Body type-Soft	²Page 321	--	--
Allocapnia	External Gill-No	²Page 321	--	--	Body type-Soft	²Page 312	--	--
Capnia	External Gill-No	²Page 321	--	--	Body type-Soft	²Page 312	--	--
Nemouridae	External Gill-Varies	²Page 313	--	--	Body type-Soft	²Page 312	--	--
Amphinemura	External Gill-Yes	²Page 320	Gill type-Filamentous	²Page 320	Body type-Soft	²Page 312	--	--
Nemoura	External Gill-No	²Page 320	--	--	Body type-Soft	²Page 312	--	--
Ostrocerca	External Gill-No	²Page 320	--	--	Body type-Soft	²Page 312	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Prostoia	External Gill-No	[2]Page 320	--	--	Body type-Soft	[2]Page 312	--	--
Shipsa	External Gill-No	[2]Page 320	--	--	Body type-Soft	[2]Page 312	--	--
Soyedina	External Gill-No	[2]Page 320	--	--	Body type-Soft	[2]Page 312	--	--
Taeniopterygidae	External Gill-Varies	[2]Page 318	--	--	Body type-Soft	[2]Page 312		
Stropteryx	External Gill-No	[2]Page 318	--	--	Body type-Soft	[2]Page 312	--	--
Oemopteryx	External Gill-No	[2]Page 318	--	--	Body type-Soft	[2]Page 312	--	--
Ephemeroptera	External Gill-Yes	[2]Page 43/ 181	--	--	Body type-Soft	--	--	--
Acentrella	External Gill-Yes	[2]Page 190	Gill type-Filamentous	[2]Page 190	Body type-Soft	[2]Page 227	Mobility-Swim/ Clinging	[2]Page 227
Baetidae	External Gill-Yes	[2]Page 190	Gill type-Filamentous	[2]Page 190	Body type-Soft	[2]Page 227	--	--
Caenis	External Gill-Yes	[2]Page 186	Gill type-Operculate	[2]Page 186	Body type-Soft	[2]Page 227	Uni & multi-voltine	[2]Page 70
Heptageniidae	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[8]Page 8	Body type-Soft	[2]Page 227	--	--
Epeorus	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[2]Page 194	Body type-Soft	[2]Page 227	--	--
Stenonema	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[2]Page 194	Body type-Soft	[2]Page 227	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Rhithrogena	External Gill-Yes	[2]Page 194	Gill type-Lamellae	[2]Page 194	Body type-Soft	[2]Page 194	--	--
Ephemera	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	Univoltine	[2]Page 70
Ephemerella	External Gill-Yes	[2]Page 199	Gill type-Lamellae	[2]Page 199	Body type-Soft	[2]Page 199	--	--
Ephemerellidae	External Gill-Yes	[2]Page 186	Gill type-Lamellae	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Eurylophella	External Gill-Yes	[2]Page 186	Gill type-Operculate	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Isonychia	External Gill-Yes	[2]Page 193	Gill type-Filamentous	[2]Page 193	Body type-Soft	[2]Page 193	Bivoltine	[2]Page 70
Leptophlebia	External Gill-Yes	[2]Page 198	Gill type-Filamentous	[2]Page 198	Body type-Soft	[2]Page 198	--	--
Leptophlebiidae	External Gill-Yes	[2]Page 198	Gill type-Filamentous	[2]Page 198	Body type-Soft	[2]Page 198	--	--
Paraleptophlebia	External Gill-Yes	[2]Page 199	Gill type-Filamentous	[2]Page 199	Body type-Soft	[2]Page 198	--	--
Baetisca	External Gill-Yes	[2]Page 186	Gill type-Shielded	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Baetiscidae	External Gill-Yes	[2]Page 186	Gill type-Shielded	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Potamanthidae	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Anthopotamus	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Polymitarcyidae	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Ephoron	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186	Body type-Soft	²Page 186	--	--
Ephemeridae	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186	Body type-Soft	²Page 186	--	--
Hexagenia	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186/ 202	Body type-Soft	²Page 186	--	--
Litobrancha	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186	Body type-Soft	²Page 186	--	--
Pentagenia	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186	Body type-Soft	²Page 186	--	--
Palingenidae	External Gill-Yes	²Page 186	Gill type-Filamentous	²Page 186	Body type-Soft	²Page 186	--	--
Caenidae	External Gill-Yes	²Page 186	Gill type-Operculate	²Page 186	Body type-Soft	²Page 186	--	--
Brachycercus	External Gill-Yes	²Page 186	Gill type-Operculate	²Page 186	Body type-Soft	²Page 186	--	--
Cercobrachys	External Gill-Yes	²Page 202	Gill type-Operculate	²Page 186	Body type-Soft	²Page 202	--	--
Neoephemeridae	External Gill-Yes	²Page 186	Gill type-Operculate	²Page 186	Body type-Soft	²Page 186	--	--
Neoephemera	External Gill-Yes	²Page 186	Gill type-Operculate	²Page 186	Body type-Soft	²Page 186	--	--
Habrophlebia	External Gill-Yes	²Page 198	Gill type-Filamentous	²Page 198	Body type-Soft	²Page 198	--	--
Chorterpes	External Gill-Yes	²Page 198	Gill type-Lamellae	²Page 198	Body type-Soft	²Page 198	--	--
Habrophlebiodes	External Gill-Yes	²Page 198	Gill type-Filamentous	²Page 201	Body type-Soft	²Page 201	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Serratella	External Gill-Yes	[2]Page 198/199	Gill type-Lamellae	[2]Page 198/199	Body type-Soft	[2]Page 198/199	--	--
Drunella	External Gill-Yes	[2]Page 199	Gill type-Lamellae	[2]Page 199	Body type-Soft	[2]Page 199	--	--
Attenella	External Gill-Yes	[2]Page 199	Gill type-Lamellae	[2]Page 199	Body type-Soft	[2]Page 199	--	--
Leptohyphidae	External Gill-Yes	[2]Page 186	Gill type-Operculate	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Tricorythodes	External Gill-Yes	[2]Page 186	Gill type-Operculate	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Behningiidae	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Dolania	External Gill-Yes	[2]Page 186	Gill type-Filamentous	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Ameletidae	External Gill-Yes	[2]Page 186	Gill type-Lamellae	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Ameletus	External Gill-Yes	[2]Page 186	Gill type-Lamellae	[2]Page 186	Body type-Soft	[2]Page 186	--	--
Siphlonuridae	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--
Siphlonurus	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--
Metretopodidae	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--
Siphloplecton	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--
Metretopus	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--

Taxon Name	Trait	Source Page	Trait	Source Page	Trait	Source Page	Trait	Source Page
Baetis	External Gill-Yes	[2]Page 188	Gill type-Lamellae	[2]Page 188	Body type-Soft	[2]Page 188	--	--
Cloeon	External Gill-Yes	[2]Page 190	Gill type-Lamellae	[2]Page 190	Body type-Soft	[2]Page 190	--	--
Heterocloeon	External Gill-Yes	[2]Page 190	Gill type-Lamellae	[2]Page 190	Body type-Soft	[2]Page 190	--	--
Callibaetis	External Gill-Yes	[2]Page 190	Gill type-Lamellae	[2]Page 190	Body type-Soft	[2]Page 190	--	--
Isonychiidae	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[2]Page 193	Body type-Soft	[2]Page 193	--	--
Pseudironidae	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[2]Page 193	Body type-Soft	[2]Page 193	--	--
Stenacron	External Gill-Yes	[2]Page 194	Gill type-Lamellae	[2]Page 197	Body type-Soft	[2]Page 194	--	--
Heptagenia	External Gill-Yes	[2]Page 194	Gill type-Lamellae	[2]Page 194	Body type-Soft	[2]Page 194	--	--
Pseudiron	External Gill-Yes	[2]Page 193	Gill type-Lamellae	[2]Page 193	Body type-Soft	[2]Page 193	--	--

Appendix C: Data Sources

[1] LLoyd, J. T., 1921. The biography of the North American caddis fly larvae.

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* Trichoptera with cases were not counted as having external gills in the database

Appendix D: Full linear regression equations for the four sediment variables

Macroinvertebrate Characteristic	**Combined Sediment P-value**	**Combined Sediment R^2 Value**	**Combined Sediment Slope**	**Combined Sediment Y-Intercept**
		Taxonomic Characteristics		
Proportion Chironomidae	0.8323	0.0005	-0.0069	0.3535
Coleoptera Richness	0.1042	0.0311	0.2129	1.4012
Proportion Coleoptera	0.0452*	0.0448	0.0248	0.0331
Diptera Richness	0.1412	0.0244	0.5563	4.4871
Proportion Diptera	0.7958	0.0008	0.0080	0.3837
Ephemeroptera Richness	0.1430	0.0242	-0.5623	5.8947
Proportion Ephemeroptera	0.1365	0.0250	-0.0335	0.2002
EPT Richness	0.0030*	0.0958	-2.9245	18.9080
Proportion EPT	0.2495	0.0150	-0.0314	0.4500
Gastropod Richness	0.4532	0.0071	0.0991	1.4360
Proportion Gastropods	0.5233	0.0046	0.0023	0.0098
Proportion Hydropsyche	0.0634	0.0386	-0.0567	0.1599
Insect Richness	0.0555	0.0410	-2.7856	26.8030
Proportion Insect	0.8733	0.0003	0.0029	0.8710
Proportion Megaloptera	0.3131	0.0116	-0.0003	0.0011

Macroinvertebrate Characteristic	**Combined Sediment P-value**	**Combined Sediment R^2 Value**	**Combined Sediment Slope**	**Combined Sediment Y-Intercept**
Proportion Mite/Acari	0.2546	0.0147	-0.0127	0.0766
Proportion Nematode	0.9402	0.0001	0.0002	0.0054
Odonata Richness	0.7574	0.0014	0.0435	1.4347
Proportion Odonata	0.4268	0.0072	0.0018	0.0030
Proportion Oligochaeta	0.4107	0.0077	0.0075	0.0204
Plecoptera Richness	0.0146*	0.0689	-0.6897	4.0217
Proportion Plecoptera	0.2836	0.0129	-0.0139	0.0669
Proportion Trichoptera	0.5029	0.0051	0.0125	0.1829
Trichoptera Richness	0.0021*	0.1028	-1.6451	9.1076
Taxa Richness	0.1039	0.0298	-2.7860	31.1295
Total number per Meter Squared	0.9755	0.0000	126.2075	22017.5410
Trait Characteristics				
Burrower Richness	0.5464	0.0042	-0.1958	4.2419
Proportion burrowers	0.9454	0.0001	0.0022	0.3837
Case Richness	0.0202*	0.0598	-0.7577	4.2592
Proportion with Cases	0.3722/ 0.0355*[1]	0.0091	-0.0101	0.0777
Clinger Richness	0.0367*	0.0487	-2.0084	17.2587

Macroinvertebrate Characteristic	Combined Sediment P-value	Combined Sediment R^2 Value	Combined Sediment Slope	Combined Sediment Y-Intercept
Proportion Clingers	0.5481	0.0041	0.0167	0.3888
Depositional Richness	0.6037	0.0036	-0.1158	2.2744
Proportion Depositional	0.4939	0.0053	-0.0111	0.0653
Erosional Richness	0.0039*	0.0908	-2.0352	13.0322
Proportion Erosional	0.3370	0.0105	0.0240	0.2346
Filterer Richness	0.2438	0.0154	-0.3817	4.6776
Proportion Filterer	0.0112*	0.0709	0.0500	0.0885
Hardbody Richness	0.1194	0.0290	-0.2331	2.6861
Proportion Hardbody	0.0940	0.0315	0.0209	0.0431
Proportion Long-life	0.8236	0.0006	0.0003	0.0015
Predator Richness	0.1256	0.0268	-0.8937	7.8671
Proportion Predator	0.0223*	0.0579	-0.0263	0.0978
Proportion Scraper	0.0294*	0.0528	-0.0310	0.1274
Scraper Richness	0.3527	0.0098	-0.3228	4.5792
Proportion Sprawler	0.9429	0.0001	-0.0012	0.0734
Sprawler Richness	0.3476	0.0100	0.3299	3.4646

Macroinvertebrate Characteristic	Combined Sediment P-value	Combined Sediment R^2 Value	Combined Sediment Slope	Combined Sediment Y-Intercept
Gill Characteristics				
External Gill Richness	0.0198*	0.0602	-1.9494	16.1709
Proportion External Gills	0.2627	0.0142	0.0298	0.3390
Filamentous Gill Richness	0.0005*	0.1298	-1.8396	9.7201
Proportion Filamentous Gills	0.4529	0.0064	0.0144	0.1958
Lamellate Gill Richness	0.1974	0.0188	0.3833	1.7928
Proportion Lamellate Gills	0.2513	0.0149	-0.0178	0.1084
Operculate Gill Richness	0.8418	0.0005	0.0310	1.8346
Proportion Operculate Gill	0.1310	0.0257	0.0241	0.0471
Proportion Protected Gill	0.4835	0.0056	0.0167	0.2112
Protected Gill Richness	0.9432	0.0001	0.0561	9.0161

* Indicates a p-value less than 0.05

[1] P-value for selected characteristic with an outlier observation removed (Site 55, Knife at Airport, North Shore, Combined sediment of 1.7131, proportion with cases of 0.0631)

Macroinvertebrate Characteristic	**Embeddedness (Embed) P-value**	**Embed P-value¹**	**Embed R^2 Value**	**Embed Slope**	**Embed Y-Intercept**
Taxonomic Characteristics					
Proportion Chironomidae	0.5285		0.0045	0.0464	0.3266
Coleoptera Richness	0.0314		0.0539	0.6738	1.3430
Proportion Coleoptera	0.3492		0.0100	0.0265	0.0477
Diptera Richness	0.1289		0.0260	1.3008	4.5140
Proportion Diptera	0.3638		0.0094	0.0636	0.3650
Ephemeroptera Richness	0.5346		0.0044	-0.5432	5.5394
Proportion Ephemeroptera	0.4438		0.0067	-0.0393	0.1819
EPT Richness	0.0266*	0.0764	0.0547	-5.0086	17.9888
Proportion EPT	0.1713		0.0212	0.0844	0.4531
Gastropod Richness	0.3041		0.0132	0.2879	1.4163
Proportion Gastropods	0.9177		0.0001	-0.0008	0.0126
Proportion Hydropsyche	0.0124*	0.0147*	0.0690	-0.1717	0.1738
Insect Richness	0.1949		0.0190	-4.2987	25.7266
Proportion Insect	0.8720		0.0003	0.0067	0.8712
Proportion Megaloptera	0.1977		0.0188	0.0008	0.0011

Macroinvertebrate Characteristic	Embeddedness (Embed) P-value	Embed P-value[1]	Embed R^2 Value	Embed Slope	Embed Y-Intercept
Proportion Mite/Acari	0.7845		0.0009	-0.0069	0.0664
Proportion Nematode	0.9896		0.0000	0.0000	0.0056
Odonata Richness	0.5414		0.0055	0.2030	1.3970
Proportion Odonata	0.7237		0.0014	0.0018	0.0041
Proportion Oligochaeta	0.5147		0.0048	0.0135	0.0225
Plecoptera Richness	0.0676	0.0571	0.0392	-1.2092	3.8084
Proportion Plecoptera	0.0751		0.0356	-0.0391	0.0727
Proportion Trichoptera	0.8860		0.0002	-0.0060	0.1985
Trichoptera Richness	0.0195*	0.0819	0.0605	-2.8605	8.6088
Taxa Richness	0.3701		0.0091	-3.4999	29.7129
Total number per Meter Squared	0.4197		0.0074	7491.8273	18693.7660
Trait Characteristics					
Burrower Richness	0.4770		0.0058	-0.5230	4.2602
Proportion burrowers	0.5557		0.0040	0.0424	0.3679
Case Richness	0.3137		0.0115	-0.7543	3.7899
Proportion with Cases	0.2341		0.0161	-0.0305	0.0801

Macroinvertebrate Characteristic	**Embeddedness (Embed) P-value**	**Embed P-value[1]**	**Embed R^2 Value**	**Embed Slope**	**Embed Y-Intercept**
Clinger Richness	0.0894		0.0324	-3.7172	16.7453
Proportion Clingers	0.9270		0.0001	-0.0058	0.4087
Depositional Richness	0.3926		0.0096	-0.4302	2.3400
Proportion Depositional	0.1420		0.0243	-0.0538	0.0766
Erosional Richness	0.0042*	0.0261*	0.0895	-4.5822	12.8586
Proportion Erosional	0.9346		0.0001	-0.0047	0.2616
Filterer Richness	0.3200		0.0112	-0.7392	4.5939
Proportion Filterer	0.0947	0.0306*	0.0314	0.0754	0.1085
Hardbody Richness	0.3643		0.0099	-0.3283	2.5835
Proportion Hardbody	0.5372		0.0043	0.0176	0.0574
Proportion Long-life	0.5711		0.0049	0.0012	0.0012
Predator Richness	0.3627		0.0095	-1.2198	7.4511
Proportion Predator	0.0027*	0.0025*	0.0979	-0.0775	0.1033
Proportion Scraper	0.009*	0.0209*	0.0749	-0.0837	0.1306
Scraper Richness	0.7676		0.0010	-0.2332	4.3417
Proportion Sprawler	0.5769		0.0036	0.0216	0.0629

Macroinvertebrate Characteristic	Embeddedness (Embed) P-value	Embed P-value[1]	Embed R^2 Value	Embed Slope	Embed Y-Intercept
Sprawler Richness	0.0241*	0.0250*	0.0565	1.7741	3.0542
External Gill Richness	0.1131		0.0283	-3.0160	15.4300
Proportion External Gills	0.6094		0.0030	0.0309	0.3570
Gill Characteristics					
Filamentous Gill Richness	0.0070*	0.0307*	0.0797	-3.2680	9.1918
Proportion Filamentous Gills	0.8054		0.0007	-0.0107	0.2154
Lamellate Gill Richness	0.0388*	0.0278*	0.0476	1.3825	1.6047
Proportion Lamellate Gills	0.1719		0.0211	-0.0480	0.1102
Operculate Gill Richness	0.6816		0.0020	0.1435	1.8063
Proportion Operculate Gill	0.0504*	0.0120*	0.0428	0.0704	0.0422
Proportion Protected Gill	0.5048		0.0051	0.0360	0.2132
Protected Gill Richness	0.1988		0.0189	2.2854	8.0973

* Indicates a p-value less than 0.05

[1] P-value for selected characteristics with an influential observation removed (Site 142, Muskeg EPA, South Shore, Embeddedness of 99.9 %Transformed embeddedness of 1.3382%)

Macroinvertebrate Characteristic	Total Fines P-value	Total Fines R² Value	Total Fines Slope	Total Fines Y-Intercept
Taxonomic Characteristics				
Proportion Chironomidae	0.1244	0.0266	-0.1523	0.3795
Coleoptera Richness	0.3292	0.0113	0.3867	1.5326
Proportion Coleoptera	0.0091*	0.0747	0.0983	0.0376
Diptera Richness	0.0629	0.0388	2.1522	4.5989
Proportion Diptera	0.6941	0.0018	-0.0374	0.4002
Ephemeroptera Richness	0.5216	0.0047	-0.7596	5.4738
Proportion Ephemeroptera	0.1867	0.0197	-0.0915	0.1851
EPT Richness	0.1096	0.0288	-4.9298	16.9317
Proportion EPT	0.5809	0.0035	-0.0464	0.4273
Gastropod Richness	0.1643	0.0240	0.6244	1.4113
Proportion Gastropods	0.3272	0.0109	0.0107	0.0099
Proportion Hydropsyche	0.0870	0.0329	-0.1608	0.1357
Insect Richness	0.4653	0.0061	-3.2921	24.6150
Proportion Insect	0.7640	0.0010	0.0170	0.8704
Proportion Megaloptera	0.0559/ 0.0318*[1]	0.0409	-0.0016	0.0011

Macroinvertebrate Characteristic	Total Fines P-value	Total Fines R^2 Value	Total Fines Slope	Total Fines Y-Intercept
Proportion Mite/Acari	0.2947	0.0125	-0.0358	0.0712
Proportion Nematode	0.6589	0.0022	-0.0028	0.0062
Odonata Richness	0.4950	0.0069	0.3223	1.4131
Proportion Odonata	0.5888	0.0033	0.0038	0.0041
Proportion Oligochaeta	0.5572	0.0035	-0.0156	0.0316
Plecoptera Richness	0.0658	0.0397	-1.6249	3.6675
Proportion Plecoptera	0.5740	0.0036	-0.0169	0.0597
Proportion Trichoptera	0.2795	0.0133	0.0620	0.1825
Trichoptera Richness	0.0605/ 0.	0.0395	-3.1314	8.0738
Taxa Richness	0.4999	0.0052	-3.5733	29.0021
Total number per Meter Squared	0.9861	0.0000	220.3332	22101.9100
Trait Characteristics				
Burrower Richness	0.5602	0.0039	-0.5809	4.1641
Proportion Burrowers	0.3862	0.0085	-0.0845	0.4043
Case Richness	0.1294	0.0259	-1.5330	3.8027
Proportion with Cases	0.5795	0.0035	0.0193	0.0630

Macroinvertebrate Characteristic	**Total Fines P-value**	**Total Fines R^2 Value**	**Total Fines Slope**	**Total Fines Y-Intercept**
Clinger Richness	0.3959	0.0082	-2.5387	15.7158
Proportion Clingers	0.0517	0.0423	0.1645	0.3704
Depositional Richness	0.4068	0.0091	-0.5619	2.2778
Proportion Depositional	0.4425	0.0067	-0.0383	0.0621
Erosional Richness	0.1987	0.0187	-2.8379	11.5277
Proportion Erosional	0.0219*/ 0.0546*[3]	0.0583	0.1740	0.2218
Filterer Richness	0.8350	0.0005	-0.2103	4.3254
Proportion Filterer	0.0154*	0.0649	0.1468	0.1086
Hardbody Richness	0.3636	0.0100	-0.4126	2.5404
Proportion Hardbody	0.0193*	0.0607	0.0889	0.0455
Proportion Long-life	0.1884/ 0.0490*[2]	0.0195	-0.0047	0.0028
Predator Richness	0.5145	0.0049	-1.1806	7.1958
Proportion Predator	0.1105	0.0287	-0.0568	0.0827
Proportion Scraper	0.2889	0.0128	-0.0468	0.1052
Scraper Richness	0.6292	0.0027	-0.5163	4.3549
Proportion Sprawler	0.6401	0.0025	-0.0246	0.0775

Macroinvertebrate Characteristic	Total Fines P-value	Total Fines R^2 Value	Total Fines Slope	Total Fines Y-Intercept
Sprawler Richness	0.3191	0.0113	1.0746	3.5748
Gill Characteristics				
External Gill Richness	0.2839	0.0130	-2.7746	14.7513
Proportion External Gills	0.0259*	0.0551	0.1802	0.3309
Filamentous Gill Richness	0.0626	0.0388	-3.0917	8.4748
Proportion Filamentous Gills	0.1539	0.0230	0.0837	0.1926
Lamellate Gill Richness	0.0862	0.0331	1.5617	1.8528
Proportion Lamellate Gills	0.9510	0.0000	-0.0029	0.0905
Operculate Gill Richness	0.8499	0.0004	-0.0910	1.8860
Proportion Operculate Gill	0.3961	0.0082	0.0418	0.0631
Proportion Protected Gill	0.0953	0.0312	0.1211	0.2022
Protected Gill Richness	0.6969	0.0018	0.9406	8.8690

* Indicates a p-value less than 0.05

[1]P-value for selected characteristic with an outlier observation removed (Site 55, Knife at Airport, North Shore, Total fines of 0.2025, Proportion Megaloptera 0.0075)

[2]P-value for selected characteristic with an outlier observation removed (Site 49, Flag 3, South Shore, Total fines of 0.2738, Proportion Long-lived 0.0566)

[3]P-value for selected characteristic with an outlier observation removed (Site 68 N. Pike, South Shore, Total Fines 0.3323, P. Erosional 0.6635 & Site 80 Sioux3, South Shore, Total Fines 1.0, P. Erosional 0.3851)

Overall, the total fines linear regressions and correlations had the greatest number of outliers and the lowest number of data points with large total fines values so it was less reliable and more prone to outliers. If the outliers didn't change the significance, the new p-values were not recorded.

Macroinvertebrate Characteristic	**Depth of Fines P-value**	**Depth of Fines R^2 Value**	**Depth of Fines Slope**	**Depth of Fines Y-Intercept**
Taxonomic Characteristics				
Proportion Chironomidae	0.9869	0.0000	0.0012	0.3458
Coleoptera Richness	0.3513	0.0104	0.2810	1.5085
Proportion Coleoptera	0.0907*	0.0322	0.0479	0.0398
Diptera Richness	0.6520	0.0023	0.3910	4.9107
Proportion Diptera	0.9764	0.0000	-0.0021	0.3929
Ephemeroptera Richness	0.0243*	0.0564	-1.9563	6.0908
Proportion Ephemeroptera	0.1004	0.0304	-0.0843	0.1989
EPT Richness	0.0009*	0.1187	-7.4261	18.8286
Proportion EPT	0.4011	0.0080	-0.0523	0.4382
Gastropod Richness	0.7668	0.0011	-0.0839	1.5652
Proportion Gastropods	0.4040	0.0079	0.0067	0.0095
Proportion Hydropsyche	0.6445	0.0024	-0.0324	0.1137
Insect Richness	0.0114*	0.0705	-8.3246	27.2275
Proportion Insect	0.9829	0.0000	-0.0009	0.8745
Proportion Megaloptera	0.6885	0.0018	0.0003	0.0007

Macroinvertebrate Characteristic	**Depth of Fines P-value**	**Depth of Fines R² Value**	**Depth of Fines Slope**	**Depth of Fines Y-Intercept**
Proportion Mite/Acari	0.1214	0.0270	-0.0391	0.0791
Proportion Nematode	0.6085	0.0030	0.0024	0.0046
Odonata Richness	0.7344	0.0017	-0.1063	1.5170
Proportion Odonata	0.2909	0.0127	0.0056	0.0027
Proportion Oligochaeta	0.1001	0.0304	0.0340	0.0146
Plecoptera Richness	0.0157*	0.0676	-1.5678	3.9318
Proportion Plecoptera	0.8164	0.0006	-0.0052	0.0581
Proportion Trichoptera	0.3833	0.0087	0.0371	0.1811
Trichoptera Richness	0.0012*	0.1131	-3.9360	8.9664
Taxa Richness	0.0206*	0.0595	-8.9801	31.8156
Total number per Meter Squared	0.4509	0.0065	-7044.0395	24965.7330
Trait Characteristics				
Burrower Richness	0.8199	0.0006	-0.1686	4.1052
Proportion Burrowers	0.8368	0.0005	0.0149	0.3800
Case Richness	0.0015*	0.1090	-2.3330	4.4021
Proportion with Cases	0.2094	0.0178	-0.0323	0.0800

Macroinvertebrate Characteristic	**Depth of Fines P-value**	**Depth of Fines R^2 Value**	**Depth of Fines Slope**	**Depth of Fines Y-Intercept**
Clinger Richness	0.0154*	0.0649	-5.2889	17.2796
Proportion Clingers	0.9745	0.0000	0.0020	0.4054
Depositional Richness	0.7500	0.0013	0.1728	2.0823
Proportion Depositional	0.6314	0.0026	0.0178	0.0466
Erosional Richness	0.0065*	0.0810	-4.3849	12.6637
Proportion Erosional	0.5551	0.0040	0.0337	0.2462
Filterer Richness	0.1323	0.0256	-1.1213	4.7280
Proportion Filterer	0.0228*	0.0575	0.1027	0.0995
Hardbody Richness	0.0452*	0.0475	-0.6786	2.7139
Proportion Hardbody	0.1422	0.0243	0.0418	0.0416
Proportion Long-life	0.3116	0.0116	0.0027	0.0007
Predator Richness	0.0349*	0.0501	-2.7892	8.0522
Proportion Predator	0.3099	0.0117	-0.0270	0.0811
Proportion Scraper	0.1210	0.0271	-0.0506	0.1153
Scraper Richness	0.1422	0.0243	-1.1584	4.7058
Proportion Sprawler	0.7060	0.0016	-0.0147	0.0780

Macroinvertebrate Characteristic	**Depth of Fines P-value**	**Depth of Fines R^2 Value**	**Depth of Fines Slope**	**Depth of Fines Y-Intercept**
Sprawler Richness	0.4018	0.0080	-0.6719	4.0772
Gill Characteristics				
External Gill Richness	0.0034*	0.0933	-5.5123	16.3519
Proportion External Gills	0.6882	0.0018	0.0244	0.3603
Filamentous Gill Richness	0.0001*	0.1531	-4.5574	9.6245
Proportion Filamentous Gills	0.3645	0.0094	0.0397	0.1949
Lamellate Gill Richness	0.6962	0.0017	-0.2660	2.2989
Proportion Lamellate Gills	0.2305	0.0163	-0.0425	0.1068
Operculate Gill Richness	0.8573	0.0004	0.0639	1.8413
Proportion Operculate Gill	0.3964	0.0082	0.0310	0.0598
Proportion Protected Gill	0.7618	0.0011	-0.0165	0.2351
Protected Gill Richness	0.1565	0.0229	-2.5226	10.0866

* Indicates a p-value less than 0.05

Appendix E: Sediment data collection and laboratory analysis methodology

Sediment and Substrate Data Collection

Sediment data were collected using several common methods including a Wolman pebble count, sediment particle size fractionation and quadrat-based estimates of substrate size percent cover. All methods were used each time the stream was sampled, a total of five times throughout the summer of 2010. Because the data then had to be matched to the NRRI historic dataset, only the sediment data from the final sampling date were actually used in data analyses.

The sediment samples were taken in a specific order to avoid one methodology influencing the results of another. Quadrats were used first, as they are the least disruptive to the substrate. To divide the stream into equal portions for sediment sampling, a cross-sectional transect was marked across the stream using a meter tape. Bankfull and wetted width were determined. The bankful width was divided by four to create four sampling locations for the quadrats. For sites or sampling dates during which a quadrat ended up on dry streambed or an island, the dry quadrats were not used in data analysis. An extra quadrat sample was taken at the thalweg, if it was not included in the original four quadrats. At each quadrat, the velocity was measured using a Marsh-McBirney flow meter. The flow meter was placed at 60 percent of water depth to get the average flow in meters per second. If the sample location was obstructed by large boulders, the flow measurement was taken just upstream of the obstructing boulder. In low flow conditions, the velocity measurements were either recorded as zero if the water was stagnant or if there was shallow flow, the flow meter was placed so it was submerged, if possible.

Streambed substrate particle-size percentages were estimated using a 0.25 m^2 quadrat, placed along the transect as described above. Substrate size classes consisted of bedrock, boulder, cobble, gravel, sand, silt, and clay (Wentworth 1922). To ensure consistency, the same person determined the percentage estimates on each sampling trip. Embeddedness, the amount that boulders, cobble, and gravel are buried by sand, silt, and clay, was also estimated within each quadrat. Embeddedness was estimated by probing around the larger substrates to estimate the percent they were buried, in 5 percent increments. When possible, the height of the rock and the height of sediment burial were measured to find a more precise percentage. A second measure of the amount of fine sediment in the riffle was the depth of fines measurement, made by inserting a sharp plastic rod into the sediment as deep as possible and recording this depth. This was done in each of the four or five quadrat samples.

The Wolman pebble count has become one of the predominant methods for evaluation of stream substrate (Wolman 1954). The Wolman methodology creates a grid across the entire riffle and samples are chosen based on a zigzag pattern (Wolman 1954). The Wolman methodology was modified because sampling the entire riffle would have disturbed the macroinvertebrates. Rather than creating a grid across the whole riffle and zigzag sampling, I used my cross-sectional transect on which the other sediment measurements were made to determine sediment sampling locations. The transect length was divided by one hundred and sediment was selected from one hundred equally spaced points along the meter tape. Each sediment particle was measured at the intermediate axis, which is not the longest or shortest of the three sides, but rather the side with the length that falls in-between. The pebble sizes were categorized according to a standard size class table. For pebbles too small to measure, their category was estimated and they were assigned the corresponding size. The substrate that felt gritty was assigned as sand, the substrate that felt silky was assigned as silt and the sticky substrate was assumed to be clay. Sand was assigned a size of 0.97mm, silt was 0.003mm and clay was 0.001mm. While pebbles were measured across the entire bankfull width, only the pebbles collected in the wetted width were used to find the frequency distribution. Unfortunately, Wolman pebble counts were not collected when the NRRI historic macroinvertebrate data were collected; thus, the pebble counts collected for this project were not used in the final analyses.

The final sediment measurement consisted of collecting a sample of the fine sediment for particle size analysis. Sediment was collected from the stream bed at several locations across the transect, placed in a clean sample container, and returned to the laboratory.

Sediment Laboratory Analyses

The water and sediment samples collected from the sites were refrigerated and frozen, respectively. They were processed in the laboratory after the field season. When the sediment samples were processed, they were thawed, placed in small pre-weighed metal pans, weighed, and dried at 105 Celsius for 24-48 hours. They were then re-weighed (to obtain dry weight), re-wetted, and ashed at 500 C for at least one hour to burn off the organic material. Samples were re-weighed to determine ash-free dry weight and placed through a series of sieve sizes ranging from 4.0 to 0.063 mm. After being shaken through the sieves, the material in each sieve was weighed one final time. The bottom pan captured the finest material and was weighed as well. The sieves allowed the material to be placed in a series of size classes for more exact particle size percentages than what could be estimated in the field. The size classes were coarse sand (4-1mm), sand (1-0.25mm), fine sand (0.25-0.063mm), and silt and clay (<0.063mm). Not all sites in the historic NRRI dataset included particle size information. To standardize the data, particle size analysis data were not used in the final statistical analyses.