STREAM INSECTS AS BIOINDICATORS OF FINE SEDIMENT

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ABSTRACT

Fine inorganic sediment (≤ 2mm) is a major non-point source pollutant in streams. While some fine sediment in streams is natural, loads in human-impacted streams often exceed their capacity to flush these sediments during high flows. Regardless of the source, the negative effects of increased levels of fine sediment in streams are realized in all biotic components of stream ecosystems from microbes to fish and in functional components such as primary and secondary production and nutrient cycling. Bioindicators sensitive to these negative impacts would be a valuable tool for resource managers. We focus on aquatic insects and their usefulness as bioindicators of increased fine sediment in stream ecosystems. Aquatic biomonitoring typically is used in most stream monitoring protocols. One disadvantage of current applications of aquatic biomonitoring is that it does not allow one to discriminate among pollutants. To address this disadvantage we targeted a specific pollutant, fine inorganic sediment, and examined the relationship between fine inorganic sediment and aquatic insects.

A biotic index to be used to detect and monitor changes in stream ecosystem health directly due to increases in fine inorganic sediments is necessary for resource managers as they work to maintain aquatic ecosystem biodiversity and productivity, as well as sustain economic growth. In this study, fine sediment and invertebrate data were analyzed from 562 stream segments from Idaho, Oregon, Washington, and Wyoming. From 661 invertebrate taxa a subset (n=83) of widely-occurring insects was used to develop the fine sediment bioassessment index (FSBI). We found that there are species-specific responses to the amount of fine sediment in the streambed. We also found that traditional metrics such as the ratio of Ephemeroptera (E), Plecoptera (P), Trichoptera (T) to Diptera (D) could not discriminate among streams with varying levels of fine sediment. To test the fine sediment index as a predictor of sediment levels, a subset of streams were scored with the FSBI using an independent data set collected by the Idaho Department of Environmental Quality from the eastern Snake River Basin/ High Desert ecoregion. Using the FSBI score for each stream the percent fine sediment in a the stream was predicted and then compared to the measured value (r^2=0.64). By using the FSBI, one can calculate an index score for a particular stream in the Northwest that will be predictive of fine sediment quantity.

KEYWORDS

Bioassessment, aquatic insects, fine sediment, streams, macroinvertebrates, biological monitoring, water quality

INTRODUCTION

Excessive siltation from anthropogenic sources is the most important cause of lotic ecosystem degradation in the United States in terms of stream distance impacted (USEPA 1990). Suspended sediments reduce light penetration and can increase the erosive capacity of flowing water. Deposited sediments fill pools and substrate interstitial spaces and long-term deposition of sediments can alter channel morphology. These problems are of special concern to environmental managers because increased inorganic sediment loads alter the natural biotic community (algae, macrophytes, invertebrates, and fishes) in streams (Tebo 1955, Cordone and Kelley 1961, Waters 1995, and Wood and Armitage 1997).

Increased inorganic sediment loads, over quantities or frequencies that occur naturally, can have an impact on the stream biota in a number of ways. Increased turbidity by sediments can reduce stream primary production by reducing photosynthesis, physically abrading algae and other plants, and preventing attachment of autotrophs to substrate surfaces (Van Nieuwenhuyse and LaPerriere 1986, Brookes 1986). Decreasing primary production can affect many other organisms in the stream food web. Aquatic macroinvertebrates are affected by habitat reduction and/or habitat change resulting in increased drift, lowered respiration capacity (by physically blocking gill surfaces or lowering dissolved oxygen concentrations), and changing the efficiency of certain feeding activities especially filter feeding and visual predation (Lemly 1982, Waters 1995). Minshall (1984) cited the importance of substratum size to aquatic insects and found that substratum is a primary factor influencing the abundance and distribution of aquatic insects. Aquatic detritivores also can be affected when their food supply either is buried under sediments or diluted by increased inorganic sediment load and by increasing search time for food Deposited sediments affect fish directly by smothering eggs in redds, altering spawning habitat, and reducing overwintering habitat for fry (Cordone and Kelley 1961), and indirectly by altering invertebrate species composition which decreases abundance of preferred prey.

Several studies addressing sediment inputs into lotic ecosystems have been conducted in the northwestern United States (see Waters 1995). Most of these have concentrated on the effects of various silvicultural practices on sedimentation rates. Logging practices such as yarding and site preparation increase sediment inputs into streams. However, logging roads and disturbances associated with their construction have been identified as the primary sources of sediment input into many northwestern streams (Cederhohlm et al. 1981; Furniss et al. 1991). One study emphasized that roads used in forest management operations contributed the most sediments to streams in the Idaho Batholith (Megahan et al. 1991). Currently, silvicultural companies are working on developing and improving methods that lessen fine sediment input to streams.

Sediment delivery into streams is not only anthropogenically derived, it is also a natural process and some sediment can be incorporated into a healthy stream ecosystem These sediment quantities can be measured as they enter a stream, but other than the amount of inorganic sediment present, these measurements tell little about the actual impacts of inorganic sediment on stream organisms. There are other abiotic factors (e.g. temperature, stream gradient, ion concentrations) that vary from stream to stream and may play a role in determining how much inorganic sediment can be tolerated by the stream organisms. It is this variability among streams, even within the same watershed, that confounds the use of sediment measurements alone in detecting ecological impacts. For instance, organisms in one stream may tolerate a different level of inorganic sediment input than organisms found in a nearby stream due to differences in stream gradient. Research supports the hypothesis that stream species have individualistic tolerances for many abiotic factors (Patrick 1973, Mihuc et al. 1996). Aquatic organisms directly respond to aspects of the environment and integrate the composite effects of multiple factors. It is for this reason that measurements of a single abiotic factor typically do not result in an ecologically significant answer.

Use of biomonitoring techniques have numerous advantages over the use of only physicochemical techniques (see Rosenberg and Resh 1993). One of the most important advantages is that freshwater organisms serve as continuous monitors of water quality and can detect sporadic disturbances and pollutants that enter as pulses. In most cases, the disturbance will occur during at least one stage (egg, larva, pupa, adult) of the invertebrate's life cycle. If this stage is susceptible to that disturbance, then changes will be detectable in community structure when sampled at a later time. When using abiotic measures alone, a pulse after a storm, for instance, may not be detected. This is because a storm pulse is a relatively quick phenomenon and an observer may not be present to witness the disturbance occurring. However, this same disturbance would be directly reflected in the biotic community and therefore detectable at a later date through use of an appropriate biomonitoring program.

Biomonitoring has become a useful tool to determine the impacts of natural and anthropogenic disturbances on aquatic ecosystems. Because of this, most states currently use biomonitoring in their water quality monitoring programs. Typically, biomonitoring is done with aquatic macroinvertebrates and/or fish, however algae, especially diatoms have great potential to be used as bioindicators as well. Widespread use of bioassessment by industries however, has not been forthcoming due to the lack of sensitivity of traditional biomonitoring protocols to specific pollutants (such as inorganic sediments), high cost, and lengthy sample processing time. Most current bioassessment methods do not look at specific impacts but treat all possible anthropogenic disturbances the same by identifying and enumerating all members of the same taxonomic orders such as Ephemeroptera, Plecoptera, Trichoptera, and Diptera (EPT&D), or by identifying and enumerating all taxa within the community sampled. It is important to note however, that individual species within the same community exhibit broadly differing ranges of tolerance to environmental disturbance. The one apparent axiom is that macroinvertebrates do not respond similarly to increases in fine sediment. For instance, some groups of macroinvertebrates respond favorably with increases in density or biomass, while decreases are seen in others.

Density is a measure of the number of organisms per unit area (abundance/area). Certain stream invertebrate groups (*Baetis* and *Paraleptophlebia* (Ephemeroptera), and Chironomidae (Diptera)) significantly increase in abundance, and therefore density, immediately after an anthropogenic disturbance that may have the potential to increase inputs of fine sediment (Wallace and Gurtz 1986, Mahoney 1984, Weber 1981, Hess 1969, Culp and Davies 1983). Declines in density as a response to anthropogenic disturbance and potential intrusions of fine sediment appear to be more closely associated with the order Plecoptera, (stoneflies) than with the other aquatic orders. The stoneflies, *Alloperla* and *Kathroperla perdita* (Chloroperlidae) declined in density following a clearcut (Culp and Davies 1983) and *Alloperla* declined after a fine sediment addition (Murphy and Hall 1981). Three other Plecoptera taxa also exhibited low densities in response to clearcutting: *Leuctra* (Leuctridae) (Gulp and Davies 1983), *Nemoura* (Nemouridae) (Weber 1981), or sediment addition: *Zapada* (Nemouridae) (Culp and Davies 1983). Culp and Davies (1983) also reported declines in the mayfly, *Cinygmula* (Heptageniidae) and reported no change in density of the Chironomidae. These studies indicate that the use of total aquatic invertebrate densities is not useful in differentiating between fine sediment impacted and unimpacted streams. However, densities of certain taxa such as the Chloroperlidae (stoneflies) may be important when developing a biomonitoring index.

Diversity measures the variety of organisms found in a community by incorporating measures of richness, the number of taxa in a sample, and evenness, the equitability of the differing abundances of each taxa. Diversity often is a strong predictor of community change due to anthropogenic disturbance (Erman and Mahoney 1983, Lemly 1982, Newbold et al. 1980, Robertson 1981). However, others have found increases or no difference in diversity between disturbed and nondisturbed sites (Wood 1977, Murphy and Hall 1981). Overall, diversity was important in determining differences between control and logged streams in studies that used macroinvertebrate and substrate data.

Functional feeding groups are based on stream invertebrate morpho-behavioral mechanisms that have developed over evolutionary time. An example of this is specialized mouthparts (flat blades) to acquire certain resources (algae by scraping). The organism's "function" is determined with respect to its partitioning and processing of available resources in stream ecosystems. Lemly (1982) found that filter-feeding

Trichoptera and Diptera were most affected by the indirect influence of fine sediment. He inferred that this was due to accumulation of inorganic particles in nets and other structures. Scrapers, who feed on periphyton attached to substrate, also have been postulated as a functional feeding group sensitive to fine sediment (see Wasserman et al. 1984). Despite the potential for functional feeding group inclusion in a biomonitoring index, studies have found no differences between feeding groups among reference and disturbed streams. Culp and Davies (1983) reported that trophic guild composition was unexpectedly similar throughout the year between logged and unlogged sites. They attribute this to primary control by abiotic variables such as scour and discharge whereas seasonal difference in food resources was of secondary importance. Duncan and Brusven (1985) working in southeastern Alaskan streams where collector-gatherers were most abundant, found no difference in community composition between logged and unlogged streams. These streams had different energy bases (allochthonous-unlogged, autochthonous-logged) yet similar proportions of feeding groups. They attributed this to differential utilization of resources by the same invertebrate species. *Baetis* can exhibit this differential utilization of resources by switching from amorphous detritus (collector-gatherer) before logging to diatoms (scraper) after logging (Wallace and Gurtz 1986). There also was no clear relationship between functional groups and logging intensity in 25 Washington streams (Wasserman, Cederholm and Salo et al. 1984). The introduction of fine sediments seemed to limit scraper production while having no effect on shredders or collectors.

Despite this variation among the aquatic invertebrates to increases in fine sediment there are apparent trends when examining invertebrate sediment tolerances. The objectives of this study are to determine which taxa, functional feeding groups, or commonly used bioassessment metrics respond to the specific impact of increased fine inorganic sediment, to determine applicability of the FSBI to a broad geographic region, and to use a smaller group of organisms to lower sample cost and speed sample processing. By addressing these issues, several of the more important negative aspects sometimes associated with biomonitoring can be reduced.

In response to the problem of increased inorganic sediments in streams caused by resource extraction practices, progress has been made on developing and improving methods that lessen fine sediment input to streams. An efficient cost-effective biomonitoring tool is needed to document the effectiveness of improved methods, evaluate which new best management practices are most effective at reducing fine sediments, and assess the magnitude and duration of the effect of these fine inorganic sediments on stream ecosystems. The result of this study will be the development of a sensitive, cost-effective bioassessment index (FSBI) using a select group of aquatic macroinvertebrates.

METHODOLOGY

This study used existing stream data from four western states to identify large-scale patterns in macroinvertebrate relationships to fine inorganic sediment. Macroinvertebrate, substrate, and physicochemical data were obtained for 562 streams. These data sets represented 97 stream segments from the Washington Coast Range and Yakima River Basin (R-EMAP sites) (Merritt et al. 1999), 52 sites representing major ecoregions of Washington, 74 sites from Oregon (R-EMAP sites), 69 sites from northern Idaho, 38 sites representing the major ecoregions in Idaho, and 232 sites representing all ecoregions of Wyoming. These sites are mainly Strahler first through fourth order streams. The R-EMAP streams are streams with low chemical pollution, levels of nutrients, alkalinity, and conductivity (Merritt et al. 1999). The majority of streams were in the low sediment category (77%) with less than 30% fines. For this analysis, all contributed databases were organized into a standard Microsoft 97 Excel and Access format. Six hundred and sixty-one invertebrate taxon were reported from the 562 stream segments, these included all aquatic insect orders, as well as other aquatic invertebrates such as Annelida, Nematoda, Crustacea, Mollusca, Turbellaria, and Hydracarina.

Traditional community group metrics such as EPT, EPT/D ratios, richness, Simpson's diversity, and abundance were first analyzed using scatter plots and multiple regressions to determine if they had high enough resolution as biomonitoring tools when considering only substrate data. Specific taxa and members of certain functional feeding groups such as filter-feeders and scrapers also were examined to determine their usefulness as indicators of changes in fine sediments. Then, because the macroinvertebrate and substrate data were collected by several different methods, emphasis was placed on the presence or absence of macroinvertebrate taxa and the percent fine inorganic sediment in the stream. Percentage of fine sediment (particles <2 mm in diameter, sand, silt, and clay) was determined for each stream at a 10% level of resolution. Correlations between individual taxa and substrate size were analyzed to determine if significant relationships exist.

Macroinvertebrates were then placed into one of four tolerance categories based on their presence/absence in each fine sediment percentage category. Macroinvertebrates considered for inclusion in the fine sediment bioassessment index were given a score based on which fine sediment tolerance category they had maximal occurrence (Appendix A). It was clear in several instances that there were aberrant sediment classifications for a few streams that appeared to have an overestimation of percent fine sediment. These few streams affected many taxa, greatly extending their tolerance ranges. Because of this, taxa occurrence outside 0.1% to 3% of the total occurrences was considered an outlier and not included in the analysis. The scores assigned to taxa ranged from extremely intolerant to fine sediment (score of 10) to extremely tolerant to fine sediment (score of 1). The scores mirrored the ten sediment categories so that an insect with maximal occurrence in <10% fines received a score of 10, 11% to 20% fines a score of 9, 21% to 30% fines a score of 8, 31% to 40% fines a score of 7, 41% to 50% fines a score of 6 and so on ending at a score of 1 for insects found in 91% to 100% fines (Figure 1). If all species in a particular genus had the same score all species were collapsed into that genus and assigned one score. Otherwise, the genus level score reflects an average of all species scores within that genus (Appendix A). All individual FSBI scores are summed to provide a total FSBI score for the particular stream reach.

Preliminary, verification of the Fine Sediment Bioassessment Index was done using the 1997 Idaho Department of Environmental Quality (ID DEQ) Beneficial Use Reconnaissance Project (BURP) data set. Results for the eastern Snake River Basin/High Desert ecoregion are included and verification will continue on the remaining ID ecoregions. Macroinvertebrates from 39 Snake River Basin streams were scored using the FSBI scores derived from the initial study. Linear regressions were used to compare the FSBI score to reported % fine sediment in the streams. For streams where no sediment data was available predictions of % fine sediment based on the macroinvertebrate assemblages were made using the FSBI model.

RESULTS

Traditional Metrics

Tests of traditional metrics such as EPT, richness, and Simpson's diversity, were conducted only for WY and ID streams using macroinvertebrate and Wolman pebble counts (n=270). In the comparisons between traditional bioassessment metrics and percent fine sediment in the stream, only richness and %EPT showed significance in some cases but not all (Table 1). Richness and %EPT could differentiate between a stream with very low fine sediment and a stream with very high fine sediment, but both metrics were incapable of any finer differentiation. There was no significant difference when comparing EPT/Chironomidae and Simpson's diversity among the five percentage fine sediment categories (Table 1). Preliminary results suggest that the traditional bioassessment metrics investigated lack sufficient resolution to discriminate between the different percentage fine sediment categories. For example, %EPT could differentiate only the lowest fine sediment category (streams with < 20% fine sediment) from all the other percentage categories (streams with 21% to 100% fine sediment). Simpson's diversity could not differentiate between any of the fine sediment percentage categories.

Fine Sediment Bioassessment Index (FSBI)

Several criteria were important to the overall goals of this study. These were widespread geographic utility, ease of use, and cost-effectiveness. Keeping these criteria in mind, several exclusions were made with groups that were at very coarse levels of taxonomic resolution, mostly tolerant to fine sediment, rare, and/or difficult to identify. The first exclusion accounted for all taxa identified only to coarse levels of taxonomic resolution, extremely rare taxa, and rare taxa. This included taxa left at the taxonomic level of family, order, phylum, or unknown (n=118). These coarse taxonomic groupings did not provide meaningful information as members of these large groups exhibited varying tolerances from sediment intolerant to extremely tolerant. Macroinvertebrate pupae also were excluded due to their rarity. The extremely rare taxa (n=261) were those occurring in less than 2% (n=12 streams) of the total 562 stream segments. Many of the extremely rare taxa had not been previously reported from the northwestern United States or were identified with non-recognized species designations. The rare taxa (n=90) were defined for this study as those occurring in only 13 to 50 (3%-9%) of the 562 streams. Some of the rare taxa (n=32) are included in the index at the generic level but the individual species tolerances have not been determined. Their exclusion from the index was based on low probability of wide geographic distribution and diminished reliability of sediment tolerance values due to small sample sizes. The rare taxa, while initially excluded in developing the fine sediment bioassessment index, may be included in further revisions of the index if their tolerance to fine sediment can be determined either experimentally or by the addition of more stream segments.

The second exclusion targeted noninsects. This included 22 non-insect taxa groupings that occurred in greater than 9% of the stream segments. The majority of these taxa groupings were fine sediment tolerant (n=15) or moderately fine sediment tolerant (n=6). Only one taxon Lumbricina, an Oligochaeta, was moderately intolerant. The exclusion of the noninsects will increase ease of use and cost-effectiveness related to taxonomic identifications of these groups. In most cases, the Annelida, Nematoda, and Turbellaria, as well as some Gastropoda and Bivalvia, must be sent to taxonomists specializing in these groups for proper identification.

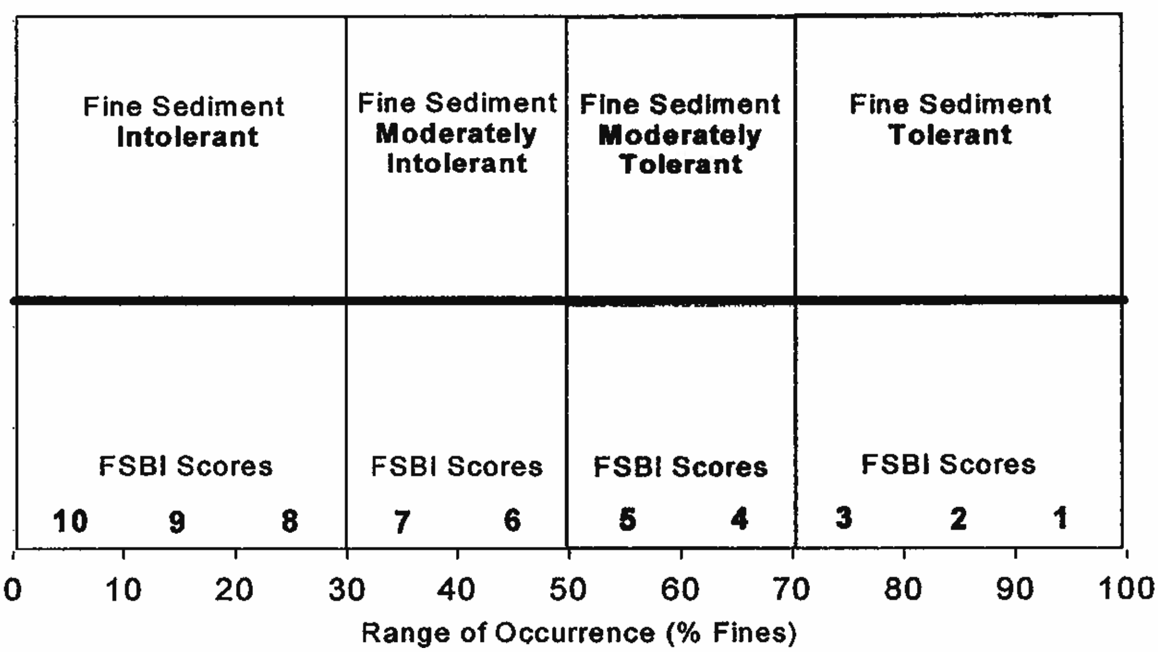
The third exclusion targeted the Dipteran family Chironomidae. Twenty-nine Chironomidae genera were identified from the contributed data sets. Of the 29 genera, 27 (93%) were moderately tolerant (n=4) or extremely tolerant (n=23) of fine sediment. Due to the overwhelming sediment tolerance of the Chironomidae and added cost in their identification, they were excluded from the fine sediment bioassessment index.

Table 1. Richness, Percent E (Ephemeroptera), P (Plecoptera), T (Trichoptera), EPT/Chironomidae, and Simpson's diversity index mean values (± S.E.) for Wyoming and Idaho streams (n=270) relative to percent fine sediment. Different lower-case letters indicate significantly different means ($p<0.05$), as determined by Tukey's test.

% Fines	Richness	Tukey's	% EPT	Tukey's	EPT/Chironomidae	Tukey's	Simpson's	Tukey's
0-20	35.92±0.71	a	0.51±0.01	a	15.89±1.95	a	0.16±0.01	a
21-40	30.24±1.56	b	0.39±0.02	b	8.32±4.33	a	0.21±0.02	a
41-60	32.2±2.73	ab	0.23±0.04	c	1.83±7.41	a	0.19±0.03	a
61-80	27.43±3.99	ab	0.3±0.06	bc	3.44±11.32	a	0.15±0.05	a
81-100	23.5±3.73	b	0.16±0.06	c	5.8±11.32	a	0.18±0.05	a

Of the 661 taxa initially considered in this study, 83 insect taxon groupings occurred in 51 or more of the 562 streams and were used to develop an index using macroinvertebrate presence/absence in relation to percent fine sediment occurrence. The majority of these taxa occurred in all four western states and across several ecoregions. These 83 taxa were placed into one of ten categories based on their maximal percent fine sediment occurrence. These ten categories consisted of 10% increments from 0% fine sediment to 100% fine sediment. Insects from these ten categories also were placed into one of four sediment-tolerance categories, insects found in streams with 0% to 30% fines are classified FINE SEDIMENT INTOLERANT, from 31% to 50% fines they are MODERATELY FINE SEDIMENT INTOLERANT, from 51% to <70% fines they are MODERATELY FINE SEDIMENT TOLERANT, and from 71% to 100% fines they are FINE SEDIMENT TOLERANT (Figure 1). There are 6 taxa that appear intolerant to fine sediment, 23 taxa that appear moderately intolerant to fine sediment, 30 that appear moderately tolerant to fine sediment, and 24 that appear tolerant to fine sediment (Appendix A). The subset of insects (n=83) considered for inclusion in the fine sediment bioassessment index were given a FSBI score based on which fine sediment tolerance category they had maximal occurrence (Appendix A).

Figure 1. Aquatic insect divisions and the four fine sediment tolerance categories. Fine sediment bioassessment scores were assigned to insects in relation to their maximal percent fines occurrence. For example, if an insect was found in streams with percent fine sediment up to 51% but not over 60%, it would receive a score of 5.



The 1997 BURP Snake River Basin/High Desert Ecoregion data set (n=39) from the Idaho Department of Environmental Quality was scored using the FSBI (Figure 2). There was a significant (p= 0.0001) decrease in FSBI score as percent fines increased. One stream, Darby Creek, had a low FSBI score and a low percentage of fine sediment. One possibility is that there were one or more anthropogenic disturbances other than fine sediment intrusion affecting the stream. Further investigation is needed however, as Darby Creek is listed as an EPA water quality limited stream (303(d) listing) for flow alteration and sediment addition. Perhaps the alteration of flow is impacting the community to a greater extent than the fine sediment. The FSBI was developed for insect/substrate relationships only. Another potential for the FSBI is to predict the % fine sediment in a stream based solely on the macroinvertebrate assemblages. This was done for 37 of the 39 Snake River Basin streams. Darby Creek was excluded because of multiple and confounding anthropogenic disturbances. Predicted % fine sediment closely followed measured % fine sediment (r^2=0.637) (Figure 3). The range of FSBI scores for the Snake Ecoregion ranged from 3 to 143. These can be compared to a range of FSBI scores determined for the Idaho Middle Rockies Ecoregion of 5 to 129 (author, unpublished data).

DISCUSSION

The results from data analyzed are in agreement with the reported results for a large-scale data set of 900 streams in the western United States that examined the relationships of certain Ephemeroptera (mayflies) to streambed substrate (data from Aquatic Ecosystem Analysis Laboratory, U.S.D.A., Forest Service, Intermountain Region, Ogden, Utah, and Brigham Young University, Provo, Utah). Magnum and Winget (1991) found *Drunella doddsi* to be highly correlated to streams with coarse substrates. Streams with moderate to high percentages of fine sediments did not support *D. doddsi.* This also was true for all occurrences (n=219) of *D. doddsi* in this study. *D. doddsi* did not occur in streams with more than 37% fine sediment and were classified for this index as moderately intolerant to fine sediment (Fig. 4). Winget and Mangum (1991) also found *Tricorythodes minutus,* a mayfly, preferred fines over coarser substrates and was found in high numbers when a large amount of fine sediments were present. We found similar results, *T. minutus* was classified as moderately tolerant to fine sediment, found in streams of 70% fines or less, and found in relatively high abundances in all percentage categories from 0% to 60% fine sediment (Fig. 5). other Ephemeroptera that were reported fine sediment intolerant or moderately intolerant both in the literature and in this research include *Acentrella, Caudatella, Epeorus,* and *Rithrogena* (Lemly 1982, McHenry 1991, Mahoney 1984, McClelland and Brusven 1980, and McClelland 1972). Ephemeroptera that were reported fine sediment tolerant to moderately tolerant both in the literature and in this research include *Ameletus, Baetis, Drunella spinifera, Ephemerella, Heptagenia criddlei, Paraleptophlebia,* and *Tricorythodes minutus.* Ephemeroptera appear to be a promising order that contains sediment-tolerant and intolerant taxa from which several indicator species can be drawn.

Figure 2. Comparison of fine sediment index score versus percent fine sediment in the Idaho Snake River Basin ecoregion.

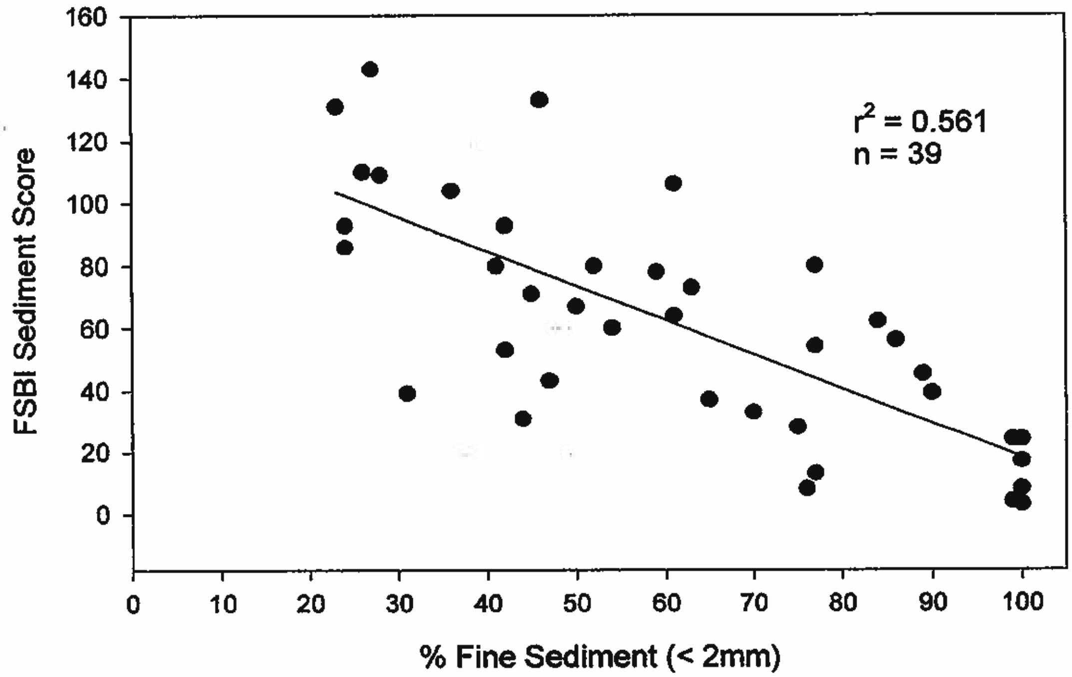
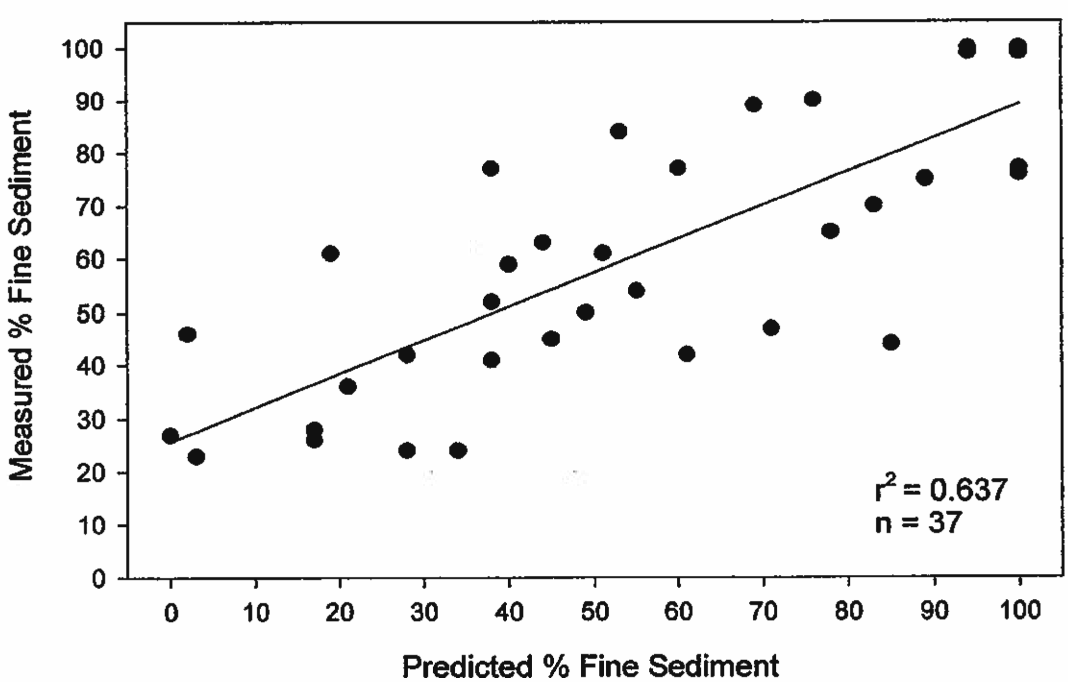


Figure 3. Predicted % fine sediment in Snake River Basin streams derived from FSBI scores compared to measured % fine sediment



Other groups reported in the literature also may be important, for example, *Arctopsyche grandis* (caddisfly) and *Pteronarcys californica* (stonefly) both prefer a large pebble type substrate over coarse and fine sands (Brusven and Prather 1974). We found *Arctopsyche grandis* to be extremely intolerant to fine sediment whereas *Pteronarcys californica was* moderately intolerant to fine sediment (Fig. 6 & 7). In addition to these two taxa, several other Trichoptera (T) and Plecoptera (P) were reported both in the literature and in this research as fine sediment intolerant or moderately intolerant such *as Brachycentrus* (T), *Glossosoma* (T), *Neothremma* (T), *Hesperoperla pacifica* (P), and *Cultus* (P). It is important to note that the caddisfly *Neothremma* was the most fine-sediment intolerant taxa; it was absent from streams with a substrate composition over 20% fine sediment. Fine-sediment tolerant and moderately tolerant Trichoptera and Plecoptera included *Hydropsyche* (T), *Sweltsa* (P), Leuctridae (P), *Zapada* (P), *Yoraperla brevis* (P), and *Calineuria californica* (P). The majority of the Diptera were found to be fine sediment tolerant or moderately tolerant.

To date the fine sediment bioassessment index includes a straightforward scoring system of common aquatic insect larvae/nymphs, the majority of which are identified to the taxonomic level of genus. Insects found in stream samples will be given a score from the fine sediment index only if they appear on the FSBI table, the sum of these individual scores is the FSBI score for that stream reach (Appendix A). At this point enumeration of insects is not needed, also non-insects or rare insects are not included in the index. Scores for streams fall on a continuum from high scores, representing streams with a low percentage fine sediment, to low scores representing streams with a high percentage of fine sediment. It is expected that, while the scoring system will be the same for the northwestern United States, the scores will vary among regions. Currently, we are establishing this range of scores for particular regions in the refining and verification steps of the FSBI development. FSBI scores were similar also for streams among different years (data not shown).

There are several potential ratio metrics that we currently are testing that would use a subset of the 83 taxa identified as common to the Northwest. Because traditional EPT metrics lack resolution due to members of EPT taxa being found in all sediment categories, we are examining a modified intolerant EPT to tolerant EPT ratio as well as a modified EPT/D ratio. Other ratios identify orders or families that have members in each of the fine sediment categories such as the stoneflies and the caddisfly family Hydropsychidae. We are examining morphological characteristics that seem to influence insect distribution. For instance, preliminary results indicate that insects with ventral gill placement are intolerant to high percentages of fine sediment in streams. Another potential ratio includes those organisms which cling to substrate and appear to be more intolerant to fine sediment than those which burrow or swim in the water column. Also, we found a decrease in scrapers with little to no change in the other functional feeding groups. Currently, the fine sediment bioassessment index is a scoring system similar to the Hilsenhoff index, however these ratios may provide information faster than scoring the taxa of a particular stream with the current FSBI. Some of the ratios mentioned, upon

Figure 4. Range of occurrence in percent fine sediment for *Drunella doddsi*, a mayfly, in the northwestern United States. The first two letters in the index correspond to a northwestern state.

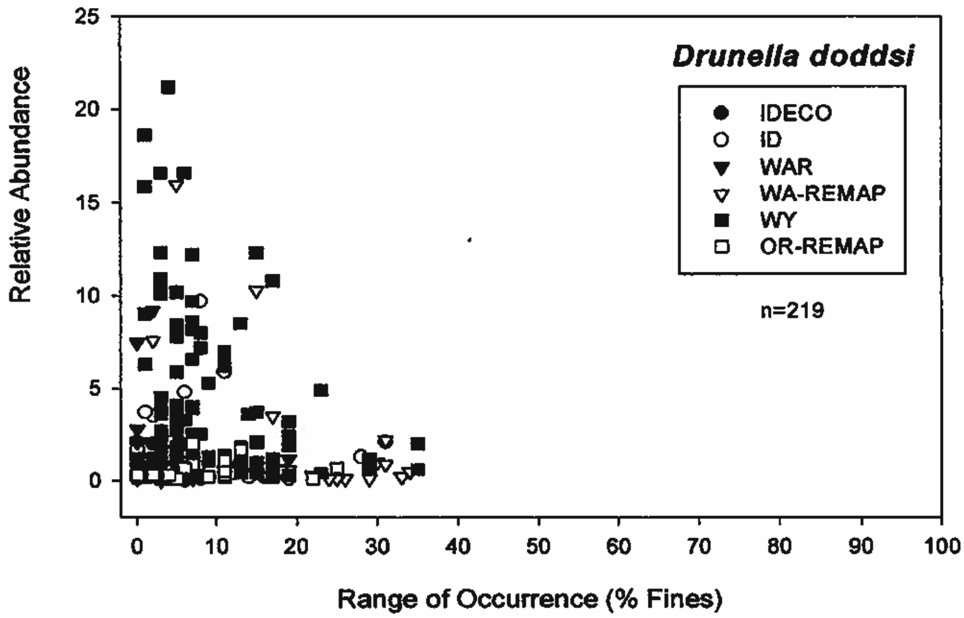


Figure 5. Range of occurrence in percent fine sediment for *Tricorythodes minutus*, a mayfly, in the northwestern United States. The first two letters in the index correspond to a northwestern state.

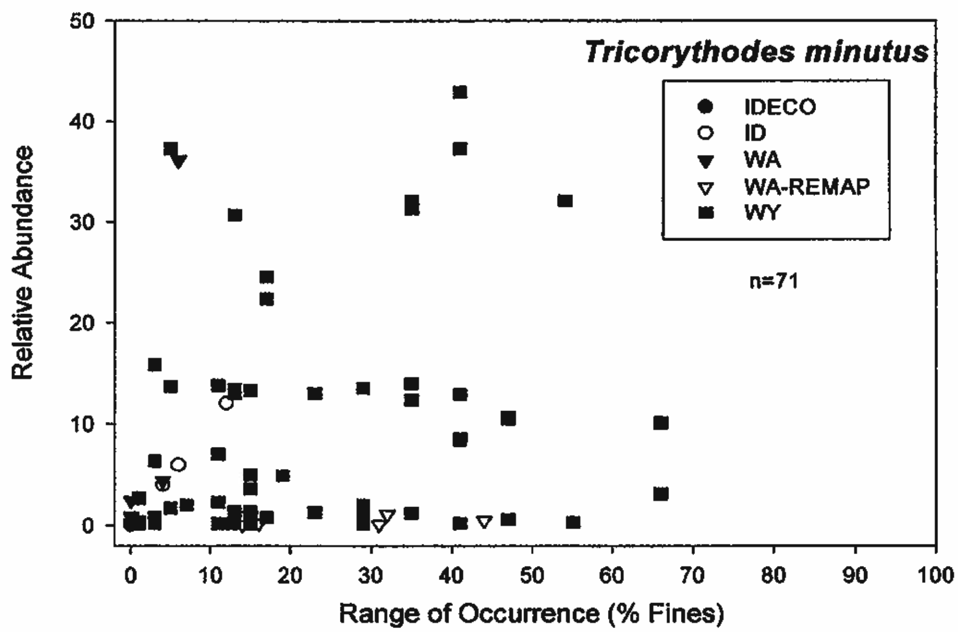


Figure 6. Range of occurrence in percent fine sediment for *Arctopsyche grandis*, a caddisfly, in the northwestern United States. The first two letters in the index correspond to a northwestern state.

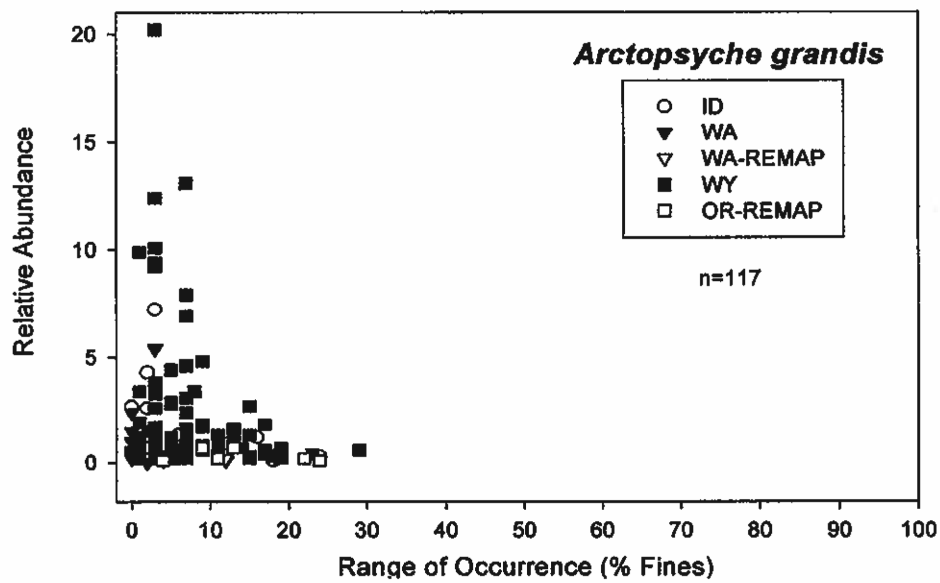
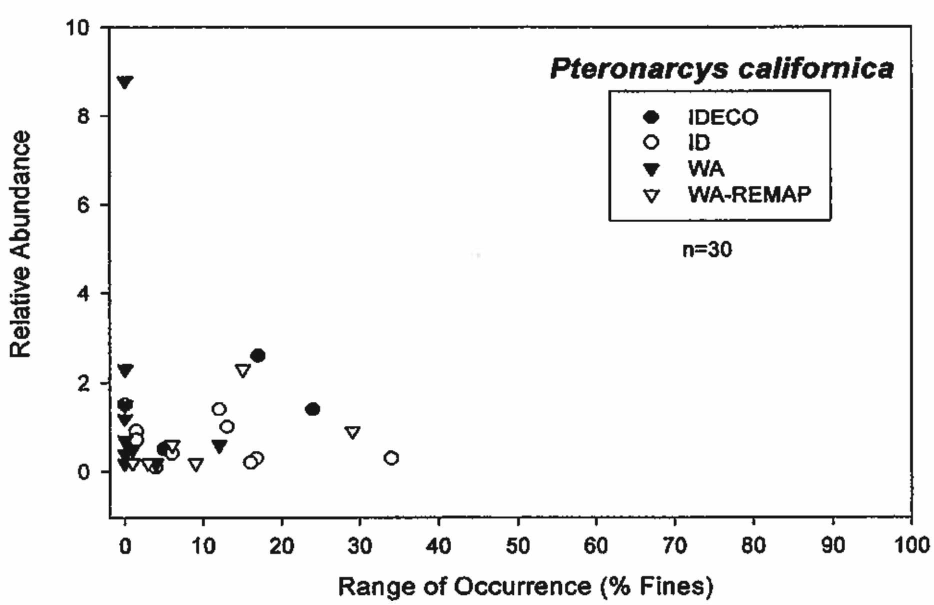


Figure 7. Range of occurrence in percent fine sediment for *Pteronarcys californica*, a stonefly, in the northwestern United States. The first two letters in the index correspond to a northwestern state.



further examination, most likely will not stand alone but be incorporated into one of the multi-metric biotic indices commonly used in stream management programs.

There are several applications of the fine sediment bioassessment index for northwestern streams. The FSBI could be used to determine sediment scores for the macroinvertebrates in a specific stream and then compared to other streams in the study, ecoregion, or northwest United States. The index could be used alone to predict the amount of fine sediment in a stream based on the macroinvertebrate assemblage, as seen with the data for the Snake River Basin streams. The index also could be used in combination with other metrics on full scale studies of streams. If the invertebrates have already been identified, the index is easily applied to taxa lists from these streams. By using only presence/absence of insect taxa, one could go to data from previous years for a particular stream and assess if the insect communities have changed over time and determine if it was due to increased fine sediment input. This may help managers determine effects of the land-use practice by having a "before" and "after" fine sediment index score. Advantages of the FSBI are that taxa lists can be used from previous studies, not all taxa need be identified and no enumeration of insects is necessary, this cuts the cost of sample analysis by approximately two-thirds.

The FSBI scoring system must be further tested, refined, and field procedures standardized before it is ready for widespread use. We are determining the accuracy, level of sensitivity, and ease of use of the FSBI. Accuracy will be determined by the ability of the index to detect changes directly attributable to increased inorganic sediment inputs, irrespective of other factors. Sensitivity will be calculated as the degree of resolution between percent fine sediment categories. Optimally, the FSBI would be able to differentiate fine sediment at the 10% level. Ease of use criteria will include frequency and intensity of collection, as well as difficulty and taxonomic level of identification of organisms. For instance, if the majority of sensitive taxa identified as indicators can be found in the streams at a certain time of the year then only one sampling date will be needed. One apparent trend is that the usual time to sample for the impacts of fine sediment is in the summer at baseflow when sediment is not being moved and is filling in or covering habitat (see Weber 1981, Culp and Davies 1983, and Murphy 1979).

There is great potential in the ability of the Fine Sediment Bioassessment Index to determine changes in aquatic organism populations and assemblages directly caused by increases in inorganic sediments. We feel confident that stream macroinvertebrates represent physical conditions in the stream with respect to streambed substrate and can be used successfully in monitoring these streams for change. Upon completion, the FSBI can be used in northwestern biomonitoring protocols either alone or in concert with other metrics.

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Appendix A. Fine sediment tolerance categories and index scores for aquatic insects.

INSECT ORDER	TAXON	# OF STREAMS PRESENT (N=562)	FSBI Index Score
INTOLERANT TO FINE SEDIMENT			**(0% to 30% fines)**
Ephemeroptera			
	Caudatella spp.	53	8
	Epeorus grandis	54	8
Plecoptera			
	Megarcys spp.	73	8
Trichoptera			
	Arctopsyche grandis	117	8
	Arctopsyche spp.	122	8
	Ecclisomyia spp.	52	8
	Oligophlebodes spp.	74	8
MODERATELY INTOLERANT TO FINE SEDIMENT			**(31% to 50% fines)**
Diptera			
	Antocha spp.	196	6
	Atherix spp.	72	6
Ephemeroptera			
	Acentrella spp.	105	6
	Attenella spp.	70	7
	Cinygmula spp.	256	6
	Drunella coloradensis/flavilinea	92	7
	Drunella doddsi	219	7
	Drunella grandis	63	7
	Drunella grandis/spinifera	188	7
	Drunella spinifera	52	7
	Drunella spp.	502*	7
	Epeorus albertae	77	6
	Epeorus longimanus	80	6
	Epeorus spp.	291*	6
	Rhithrogena spp.	279*	6
Plecoptera			
	Cultus spp.	56	7

Appendix A. (cont.)

INSECT ORDER	TAXON	# OF STREAMS PRESENT (N=562)	FSBI Index Score
MODERATELY INTOLERANT TO FINE SEDIMENT (cont.)			
Plecoptera (cont.)			
	Doroneuria spp.	67	7
	Hesperoperla pacifica	154	7
	Pteronarcys spp.	55	6
	Zapada oregonensis	**99**	**6**
Trichoptera			
	Apatania spp.	89	7
	Brachycentrus americanus	117	7
	Brachycentrus occidentalis	67	6
	Brachycentrus spp.	204*	6
	Dicosmoecus spp.	66	6
	Glossosoma spp.	239	6
	Neophylax spp.	86	6
	Rhyacophila Betteni grp.	131	6
	Rhyacophila Hyalinata grp.	**58**	**7**
MODERATELY TOLERANT TO FINE SEDIMENT			**(51% to 70% fines)**
Coleoptera			
	Heterlimnius corpulentus	104	5
	Heterlimnius spp.	249	5
	Narpus concolor	52	5
	Narpus spp.	104	5
	Zaitzevia spp.	215	5
Diptera			
	Clinocera spp.	84	5
	Glutops spp.	79	5
	Hemerodromia spp.	57	5
	Pericoma spp.	140	5
Ephemeroptera			
	Ameletus spp.	209	4
	Baetis bicaudatus	110	5
	Baetis bicaudatus/tricaudatus	547	5
	Baetis spp.	572*	4

Appendix A. (cont.)

INSECT ORDER	TAXON	# OF STREAMS PRESENT (N=562)	FSBI Index Score
MODERATELY TOLERANT TO FINE SEDIMENT (cont.)			
Ephemeroptera (cont.)			
	Baetis tricaudatus	399	5
	Diphetor hageni	165	4
	Ephemerella inermis/infrequens	230	4
	Ephemerella spp.	251*	4
	Paraleptophlebia bicornuta	59	5
	Serratella spp.	168	5
	Serratella tibialis	141	5
	Tricorythodes minutus	71	4
	Tricorythodes spp.	99	4
Plecoptera			
	Calineuria californica	116	5
	Skwala spp.	189	5
	Sweltsa spp.	317	4
	Visoka cataractae	53	5
	Yoraperla spp.	64	5
	Zapada spp.	499*	4
Trichoptera			
	Hydropsyche spp.	242	5
	Hydroptila spp.	95	5
	Lepidostoma - sand case larvae	86	5
	Micrasema spp.	217	4
	Parapsyche elsis	88	4
	Parapsyche spp.	110	4
	Rhyacophila Brunnea grp.	228	5
	Rhyacophila Coloradensis grp.	69	4
	Rhyacophila spp.	916*	5
TOLERANT TO FINE SEDIMENT			**(71% to 100%)**
Coleoptera			
	Cleptelmis ornata	58	2
	Cleptelmis spp.	150	2
	Lara avara	78	2
	Optioservus spp.	348*	3

Appendix A. (cont.)

INSECT ORDER	TAXON	# OF STREAMS PRESENT (N=562)	FSBI Index Score
TOLERANT TO FINE SEDIMENT (cont.)			
Diptera			
	Chelifera spp.	205	2
	Dicranota spp.	232	2
	Dixa spp.	98	1
	Hexatoma spp.	253	3
	Limnophila spp.	59	2
	Simulium spp.	268	3
	Tipula spp.	98	3
Ephemeroptera			
	Cinygma spp.	64	2
	Heptagenia/Nixe spp.	78	2
	Paraleptophlebia spp.	426	2
Megaloptera			
	Sialis spp.	109	1
Plecoptera			
	Isoperla spp.	219	2
	Malenka spp.	68	2
	Zapada cinctipes	308	3
	Zapada columbiana	66	3
Trichoptera			
	Cheumatopsyche spp.	100	2
	Lepidostoma - panel case larvae	51	2
	Lepidostoma spp.	312	2
	Psychoglypha spp.	52	3
	Rhyacophila Sibirica grp.	178	3
	Wormaldia spp.	86	2

*denotes multiple species present in particular genus