Benthic Macroinvertebrate Responses to Sediment Deposition as Criteria for Evaluating and Monitoring the Extent of Habitat Degradation on the Middle Truckee River, California

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Project Executive Summary

This study addresses the question of whether deposited sediment in the Middle Truckee River degrades the biological integrity and function of this segment of the river system. Using a large number of patch-scale or small-area samples along the river, changes in the benthic macroinvertebrate community present were assessed in relation to the cover of fine and sand particles in these patches. This permitted impaired biological conditions to be tied to particular levels of sediment deposition, and this used to define the amount of degraded habitat in the river.

Increased patch-scale cover of fine and sand sediment in quadrats produced clear and significant shifts in reduced density and body size distribution, lower diversity, losses of sensitive organisms but higher proportions of tolerant taxa, and altered food web structure. Significant changes in overall community structure were first apparent between 0-20% FS cover and 20-40% FS, while adjoining groups in the intermediate range were not statistically different (20-80%), and the highest FS of >80% differed from all other groups. This suggests that community types and responses can be divided into low, intermediate and high sediment groupings.

Erosional habitat locations where grid-frames were placed showed only low levels of deposition, so the problem areas under base flow conditions (as in these September surveys) for sediment accumulation are not surprisingly in depositional habitats (low flow, margins, depressions). Of the 1000 quadrat samples taken along 10 sites on the Middle Truckee, 62.5% were under 20% FS cover level where biological integrity is intact, but in 17.4% of quadrats the FS level exceeded 80% cover where aquatic life use was impaired (the other 20% of quadrats were intermediate but still showed significant biological alteration). These limits on biological health imposed by deposited sediments can be used to guide management decisions about where control of sediment sources are most needed, and evaluate the status and trends of sediment and the river ecosystem. The techniques applied and data gathered here provide tools to track the success of measures taken to eliminate sediment problems in the Middle Truckee River.

Introduction and Statement of Problem

This project addresses the question **to what extent is there excess sediment in the Middle Truckee River that impairs aquatic life use?** Aquatic life use is defined under EPA Clean Water Act regulations as a designated use of streams and lakes (often as "cold water habitat" use). Water quality criteria can also be based on biological indicators such as species diversity of aquatic life including benthic macroinvertebrates (BMIs). Sediment in streams is a major source of nonpoint pollution and defining biological effects can provide an important approach to developing guidelines for the amount of deposited sediment that causes reduced diversity, altered food web function, and changes in abundance and types of aquatic life that may inhabit streams. Causation by deposited sediment of changes that are often inhibitory to the vitality of benthic organisms can be demonstrated through studies of what invertebrates are found within habitat patches having differing amounts of fine and sand particle cover (less than 0.06 mm for fines, and 0.06 to 2 mm for sand). This approach to benthic macroinvertebrate bioassessment examines local-scale effects over a gradient of fine/sand cover to determine whether there is habitat degradation from deposited sediments. The amounts of fine/sand at which the stream community is affected in different ways can be used to guide regulatory decisions about how much and where streams or rivers are sediment-impaired, to monitor trends, and evaluate whether control measures show success in improving ecological health.

Sediment pollution of the Middle Truckee (MT) River (Lake Tahoe outflow to California-Nevada state line) from a variety of land use disturbances has resulted in listing as an impaired water body (on the State 303(d) list), and the need to develop TMDL indicators and criteria for guidance of how much sediment impairs beneficial use values of the river. The existing standard is based on suspended sediment or turbidity and states an acceptable standard as less than or equal to 25 mg/L for more than 90% of observations taken in sample observations. To be protective of aquatic life use this standard is of limited value because it fails to address biological impairment by deposited sediment. Deposition patterns vary along the river in response to erosion source areas, channel geomorphology, and flow regime, resulting in an irregular and changing distribution of habitat quality.

<u>Project Goal: Biological Guidance for Sediment TMDL</u>
Define deposited sediment guidelines for monitoring, protecting, and improving the biological health of the Middle Truckee River

<u>Objectives:</u>

1. Describe patch-scale distribution of fine + sand (FS) deposits along the river at representative reaches below tributary stream confluences (patch defined as microhabitats of 30x30 cm area)
2. Collect data to measure biotic responses of BMIs and limiting effects of sediment at the patch-scale for both cover and volume of deposited FS
3. Evaluate reach-scale Index of Biological Integrity change 2004 to 2011 at 8 monitoring stations along Middle Truckee

Previous Results

In the initial phase of this project in 2010, the approach taken was to compare geomorphic reach types along the MT to reference reaches on other large rivers of the region that have less in the way of the intensive land use, roads, and urbanization along the MT corridor. These samples taken in the MT compared geomorphic reach types that were characterized by Balance Hydrologics (see reports by D.Shaw) as immobile vs. mobile. At a larger reach scale then, these are places where large rock deposits confer physical stability to the channel, immobilizing the bed. Mobile reaches in contrast are sections where the bed is more exposed, depositional, but could be mobilized by flows that can re-suspend sediments. In each reach type there were also two methods of macroinvertebrate collection used, one that was restricted to riffle habitats (target riffle) and one that came from mixed habitats that could include riffle, glide, or pool areas in proportion to their occurrence within a reach. The results from this work (Herbst 2011) showed (1) the reference reaches on average supported more BMI diversity than found at any sites on the MT and all had IBI scores (Index of Biological Integrity for eastern Sierra, used for measuring impaired condition) exceeding the impairment threshold while only half 4 of 8 samples from 4 sites on the MT supported the reference level biological integrity, (2) mixed habitats consistently supported more BMI diversity than riffle-areas alone, suggesting habitat variety supported more species than riffles alone, and (3) mobile reaches of smaller and less stable substrates supported less BMI diversity in 3 of 4 cases. Taken together, the MT seems to be less healthy than other large rivers of the region, but this was ambiguous in coarse spatial-scale samples where habitats that could have held more sediment were either more diverse (mixed > riffle), or less diverse (mobile < immobile). What these contrasts fail to specify is the actual relationship of sediment deposition to biological integrity at the small, localized scales where sediments gather and where BMIs reside. Comparing samples collected over large reach areas that are classified in terms of long-term stability (mobile and immobile), or in habitats that broadly overlap (riffles vs. mixed habitats that are composed mostly of riffles), are inappropriate approaches for defining how beneficial life uses are affected by actual sediment deposits.

Methods

In order to redress the problems of mis-match in scale of observations, sediment TMDL criteria and targets would better be served through more extensive and intensive sampling at smaller scales. In outline form, these approaches include the following tasks:

(1) patch-scale sampling of BMIs and Fine-Sand (FS) cover
(2) extent of FS deposition along river at 10 reach locations using ambient sampling to determine exceedances identified in 1, and spatial distribution of sediment problems
(3) pump-core sampling supplement to evaluate bulk-FS sediment effects on indicators (rather than surface cover measures of FS).
(4) repeat samples along river at 2004 stations to evaluate changes and IBI performance

The 10 study sites established along the MT were below tributary junctions, from Bear Creek to sites just above and below the town of Truckee, to downstream at Gray and Bronco Creeks (Figure 1).

Field Work

Grid-Quadrats

Patch-scale sampling was conducting using a quadrat grid-frame of 30x30 cm (square foot) to define an area usually within 10 to 25 cm of the water surface, along margins of the channel. Within this defined area, at 10 locations within each of 10 stream reaches along the MT, the presence of fine or sand sediment was counted at 25 intersecting grid-points (Figure 2), the frame removed, and the area then sampled into a D-frame net by rubbing the surfaces and substrates to 2-5 cm depth by hand while the water current or hand sweeps carried the dislodged invertebrates into the downstream net. The netted sample was placed in a bucket, any leaves or rocks cleaned and removed, and the sample poured through a fine-mesh aquarium net (100 micron mesh), and placed in storage containers preserved in 90% ethanol with a few drops of rose bengal stain (a stain to aid in laboratory sorting of small invertebrates). The 10 locations selected for sampling at each site ranged from no or low cover of FS to complete cover. Along with these total 100 invertebrate collections over the full FS cover range, ambient FS cover at each reach was assessed by placing the frame at regular intervals along channel transects (10 even-spaced across channel width where depth was less than 50 cm) and along channel margins (every 5 m) until a total of 100 frames were counted per site. This resulted in 1000 frames over the 10 reaches sampled and 25,000 point-counts. Each of the patches sampled were also characterized as erosional, with turbulent current present, or depositional, where currents were slow.

Pump-Cores

In samples taken of bulk sediment in studies done in 2004, invertebrates within the surface bed matrix to depth of about 5 cm were taken at 25 locations at 4 sites to supplement 35 collections taken in 2004. The pump-core samples were collected using a custom-built stovepipe sampler (Figure 3; refer to Herbst and Kane 2006 for details). A 16 cm inner diameter (200 cm^2 area), 30 cm length piece of ABS pipe was fit with a polyurethane foam collar that extended 2 cm beyond an inner-beveled edge at one end. The collar formed a seal around the sampler as it was pushed into the substrate to be sampled. Once seated, the substrate inside the sampler was disturbed by hand to entrain sediment and organisms and to remove any large pebble- and cobble-size substrate particles present. Three liters of water and sediment inside the sampler were then pumped into a bucket using a 4.5 cm diameter hand bilge pump. Following pumping, the substrata within the pipe was disturbed once more by hand to entrain sediment and organisms, and five sweeps made with a 10 cm wide, 100 µm aquarium net, followed by one sweep of the water column. Most samples were taken within a water depth range of 10 to 25 cm.

After collection, each sample was processed on the stream bank to quantify the settled volume of fine (i.e. <1 mm) granular and non-granular material, and to separate invertebrates for preservation and identification. Each sample was first passed through a 1 mm mesh, stainless steel sieve into a bucket and washed using a plastic wash bottle filled with stream water. The coarse fraction of leaf and wood debris and sediment remaining in the sieve was rinsed and hand-picked to collect all invertebrates present. The fine fraction was allowed to settle for three minutes, and then the supernatant was slowly poured through a 100 µm aquarium net so that less than one liter of settled particles and water remained in the bucket. Invertebrates and sediment in the net were saved as part of the invertebrate sample. The remaining sediment and water were poured into a one-liter Imhoff cone (filled to capacity), and allowed to settle for ten minutes. Imhoff cones were held in a metal frame mounted to a wood base with a bubble-type level (Figure 3). After settling, the total volume sediment in the cone was recorded. The material in the cone was then processed to remove remaining invertebrates. Following processing, invertebrates from all the sample fractions were combined and preserved in 90% ethanol and rose bengal.

Target Riffle Composites

At each of the 8 river reaches surveyed in 2004 using a targeted riffle sample method, sampling was repeated in 2012. This method consisted of collections taken from eight spots within riffles zones at each reach at 25 to 125 m downstream of the confluence where tributaries were located. Each locale was sampled using a 500 µm mesh D-frame net by disturbing by hand or foot, a 30-by-30 cm (1 ft^2) area upstream of the net for about 30-60 seconds. The current or hand-sweeps carried the dislodged BMIs into the net. This was repeated at the eight riffle locales and all samples combined in one bucket. Larger leaf, wood and rock debris in the sample were cleaned in the bucket and discarded, and contents were then swirled and strained through a 100 µm aquarium net to collect all but the sand fraction at the bottom of the bucket. This sand fraction was carefully inspected to collect any cased-caddis or shelled-mollusks remaining, and the entire sample preserved in ethanol and rose bengal.

Laboratory Work

Preserved macroinvertebrate field samples were subsampled using a rotating drum splitter, if necessary, and organisms were removed and sorted from subsamples under a 10X stereomicroscope and identified to the lowest practical taxonomic level (usually genus; species when possible based on the availability of taxonomic keys; except for Oligochaeta and Ostracoda which were not identified further). For the targeted riffle samples, a minimum count of 550 organisms was identified, with each subsample sorted and identified entirely to exceed this count. For most grid-quadrat and pump-core samples, all organisms were sorted and identified from each sample. All stages of sample processing and identification were checked using quality control procedures to assure uniformity, standardization, and validation (Herbst 2001).

Data Analysis

For all quadrat-grid samples a suite of density and relative abundance metrics representing taxonomic composition and community structure and tolerance were calculated. Metric responses in relation to FS cover included grouping of taxa according to trophic roles in the food web (functional feeding groups), pollution tolerance of the community (biotic index), diversity of taxa with low tolerance values and percent of total organisms with higher tolerance values, the total and EPT diversity and density (EPT are the mayfly, stonefly, caddisfly taxa), and midge diversity and density (small, more sediment-tolerant taxa). Differences among these metrics were tested between FS cover groups, in six bins of sediment cover, as no FS cover (0 counts), 1-5 counts (4-20% cover), 6-10 (>20-40%), 11-15 (>40-60%), 16-20 (>60-80%), and 21-25 (>80-100%). Multiple comparison Tukey-Kramer tests were used to examine significance of differences (at p=0.05) between all group pairs. Presentation graphs use a box-and-whisker format showing the 25^{th}-75^{th} percentiles as the box, the 95% confidence interval as the whiskers, the mean as the horizontal line and outliers as a colored asterisk. In addition, the 10-metric Eastern Sierra Index of Biological Integrity (IBI) score was calculated for each targeted riffle sample (Herbst & Silldorff 2009). Targeted riffle samples were statistically subsampled using rarefaction

(EcoSim 2012, *Acquired Intelligence, Inc. Kesey-Bear, Pinyon Publishing*) to a fixed count of 500 organisms for calculation of community metrics and the IBI. These metrics and scores were compared over the FS range, among sites, and between-years (2004 and 2011), and IBIs expressed in terms of whether they show samples are supporting or not-supporting of eastern Sierra region reference stream levels of biological integrity.

For the grid-quadrat data, we applied an ordination technique that compares all of the organisms in a sample with those in all others and plots the samples on axes such that the most similar sites in terms of species composition are closest together. This technique, called nonmetric multidimensional scaling (NMS), can also be used to examine whether the locations of plotted samples are correlated with environmental variables, in this case, sediment cover. The correlation of each axis with individual taxa was also used to determine which taxa are driving the differences between samples, and this used as a basis for identifying indicator taxa for low and high levels of FS cover.

All ordination calculations were completed using PC-ORD software (McCune & Mefford 1999). Each NMS ordination was derived from the calculation of a dissimilarity matrix using the Bray-Curtis distance measure, an index of how close ("distant") or similar communities are in the make-up of their constituent species (McCune & Grace 2002). In order to determine whether certain taxa or certain samples might influence the ordination unacceptably, Bray-Curtis distance matrices were calculated for raw abundance (which also accounts for differences in density whereas relative abundance does not. Ordinations were calculated using only those taxa which occurred in more than 5% of the samples (n = 98 taxa of 160; so that the effect of rare taxa could be removed). All ordinations were evaluated based on separation of samples in groups, in six bins of sediment cover, as no FS cover (0 counts), 1-5 counts (4-20% cover), 6-10 (>20-40%), 11-15 (>40-60%), 16-20 (>60-80%), and 21-25 (>80-100%). For the selected ordination, the correlation coefficients between each taxon and the ordination axes were examined to determine which taxa were influential in the ordination. Within-group agreement and between-group distinctness were tested using Multi-Response Permutation Procedure (MRPP) with Bray-Curtis distances (McCune & Grace 2002). This procedure yielded a T or test criterion statistic, an *A*-statistic ($-1 \leq A \leq 1$), describing the effect-size of the grouping, and a *p*-value indicating the likelihood that the calculated differences were due to chance. The optimal ordination had a 3-dimensional solution but is presented as 2-dimension graphic for simplicity.

Results

Food Web Structure, Density and Size Distribution

The grid-quadrat samples showed that with gradual increase in FS cover, the structure of the food web shifted from dominance by grazers of algae-periphyton to collector-gatherers of fine particulate organic matter deposits (pie charts of Figure 4). Grazers decreased from 41% to 14% while collector-gatherers increased from 29% to 62%. Comparing the fauna from quadrats with less than 20% FS cover to any higher FS levels, there was also a decrease in collector-filterers comprised mainly of net-spinning caddisflies from 17% to 9%, and an increase in shredders of leaf litter from 4% to 8%. The proportion of predators remained about the same. Comparing the low FS level (<20%) to higher cover also revealed that the overall density decreased from an average of about 4,000 to 3,000 individuals m^{-2}

(Figure 5), and this was comprised of a diminishing percent of large EPT while small midge flies increased in proportion (Figure 6 A and B). EPT density showed a significant decrease from means of 3,000 m^{-2} or more at <20% FS to 1,000-1,500 m^{-2} or less at FS cover of 20-100% (Figure 7).

Diversity and Sensitivity/Tolerance

Over the 10 sites and 100 quadrat samples, a total of 160 taxa were collected. The total diversity of taxa did not change significantly over the range of FS cover (Figure 8) but the EPT diversity did decline, significantly at the highest FS cover. The absence of change in total diversity while EPT decline is accounted for by an increase in midge diversity of the FS range. While total diversity did not show much composite change, the ordination analysis shows that the identity of taxa comprising the community did change significantly with FS cover (see next section). Similar to EPT diversity, the number of sensitive taxa (with tolerance values of 0, 1 or 2 for a range of 10) declined with FS cover, significantly at the highest FS group (Figure 9). The percent of individuals that have high tolerance values (7-8-9-10 for a range of 10) increased with FS cover (Figure 10), significantly at FS >60%. The decrease in sensitive taxa and increase in tolerant result in a clear increase in overall pollution tolerance (biotic index; the sum product of taxa relative abundance and TV values) of the community over the FS range (Figure 11).

NMS Ordination

The ordination plots (Figure 12 and 13) display similarity in the taxonomic composition of samples where points are close together, and become less similar as points are further apart. The ordination showed separation among the FS cover groups (Figure 12abcd), and as a function of downstream position along the river corridor (Figure 13) but these separated along opposing direction vectors (so the effect of sediment can be separated from the effect of downstream location). Samples from FS levels of 0 and 1-5 counts (<20% cover) did not differ but there was significant separation of FS groupings at counts >20%, and between the >80% FS group and all others (Figure 12abcd and Table 1 (MRPP). Adjoining ranges of intermediate cover 20-40%, 40-60% and 60-80% did not have significant differences. Downstream distance produced significant separation in communities (Figure 13, Table 2) with only adjacent Regional Park and Trout Creek not significantly different (the closest of sites).

Indicator Taxa Analysis

The taxa most correlated with low, intermediate and high levels of FS can be used as indicators of preferences for habitats with particular levels of sediment deposition. Those associated with low end FS cover were mostly large EPT taxa (8 of 11), while 4of 5 were small midges at the high end of FS cover (TABLE 3). Species with intermediate FS preference were in part taxa whose feeding may be subsidized by moderate levels of fine organic particles. Many of the same low sediment EPT indicators found in the quadrats also had significant correlations in pump-cores of 2004 (Herbst and Kane 2006), and included the net-spinning caddis *Ceratopsyche* and *Hydropsyche*, the large perlid stonefly *Calineuria*, the mayfly *Rhithrogena*, and the algae-grazing caddisfly *Glossosoma*. These were common taxa in the river, comprising the most abundant algae grazers, filter-feeders, and the largest invertebrate predator.

Pump-Core Sediment Volume Effects

In contrast to the cover measures of FS in quadrat grid-frames, the pump cores showed how BMI communities changed with the volume of sediment on the stream bottom. As an example, total taxa diversity declined rapidly with increased sediment volume such that above 300 ml of fine sediment (=15 L/m^2 bulk volume <1 mm), diversity was not further depleted with additional volume (Figure 14). This corresponds, according to field notes, to where the surface became 100% covered, suggesting that surface cover rather than volume is what drives the inhibitory effects of sediment deposition on BMIs. With increased volume to 300 ml, EPT diversity declines gradually with added sediment (Figure 15).

Ambient Fine-Sand Cover Along MT in Depositional and Erosional Zones

Along the downstream series of sites on the MT, the level of excessive FS cover (>80%) in depositional areas was lower above the town of Truckee, then increased at sites within and just below town, then declined again at Gray and Bronco Creeks furthest downstream (Figure 16). All these locations in the vicinity of Truckee had more than 50% of quadrats in deposition zones exceeding this highest level of FS cover where biological integrity measures were consistently poor. Using similar language to the turbidity standard, another way of depicting the sediment deposition data is to say that across all habitat types (depositional and erosional), compliance is represented by >90% of observations have a deposition level less than the impaired condition of >80% FS cover (Figure 17). This chart shows that only the upstream sites Bear and Squaw meet this desired condition, while the others mostly attain just 70-80% of observations meeting the criterion. This >80% level is a conservative assessment of impaired conditions as this is the most severe state of biological degradation.

Eastern Sierra IBI Status Along MT

An IBI (index of biological integrity) based on the biological communities of reference streams (stream reaches with minimum levels of human influence) in the eastern Sierra region can be used to evaluate the status and trends of the Middle Truckee. Nearby large rivers with minimal disturbance, the West Walker, East and West Carson, and Markleeville Creek, most comparable in size to the Middle Truckee River, were sampled in 2010 and all were within the range of scoring for unimpaired regional reference streams. On the MT, 5 of 8 in both 2004 and 2011 met the supporting standard, but 3 were not-supporting of the reference condition (impaired). Bear, Squaw and Juniper remain poor, but conditions improved at the site below Martis Creek (Figure 18).

Discussion and Interpretation of Findings

Increased patch-scale cover of fine and sand sediment in quadrats produced clear and significant shifts in reduced density and body size distribution, lower diversity, losses of sensitive organisms but higher proportions of tolerant taxa, and altered food web structure. Significant changes in overall community structure were first apparent between 0-20% FS cover and 20-40% FS, while adjoining groups in the intermediate range were not statistically different (20-80%), and the highest FS of >80% differed from all other groups. This suggests that community types and responses can be divided into low, intermediate and high sediment groupings.

The observed food web shift indicates that as substrata become covered with fine and sand sediments, the algae growing on rock surfaces is buried or growth inhibited and so is lost as a food resource to grazers. This coverage of rock surfaces also eliminates the hard stable substrate that filter feeders often require for attachment, so this guild is reduced as well. The organic particles associated with fines become more available to gatherers of this deposited detritus and so this group comes to dominate. As substrata become buried by deposits, there will therefore be a change in ecosystem function and a reduced ratio of primary productivity (algae photosynthesis) to microbial respiration metabolism (in the bacteria and fungi associated with decomposing particulate organic matter).

With the coverage of substrata and filling of interstitial spaces among rocks by sediment, there are also losses in the availability and complexity of the spatial dimensions of microhabitat for benthic invertebrates. This is likely what leads to the observed reductions in diversity and density and body size of BMIs with increased level of FS cover. The implications of this for higher trophic levels of fish and riparian birds that feed on the submerged or emerging insect life is that both food quantity (density) and quality (size, variety, and nutritional value) become reduced as sediment cover increases.

The fact that sediment volume fails to show any influence above a level that is equivalent to complete surface cover shows that the most effective, and easiest and most relevant measure of sediment deposition is the cover of FS, measured by quadrat grid-frames. The %FS coverage level that produces changes in the biological community and loss of diversity, numbers, and food web values can be used to evaluate how much habitat on the MT River has been compromised and where and to what extent. The areas with <20% level of sediment cover comprises a community type that is most diverse and abundant, of mixed food web function with grazers and filterers abundant. At the intermediate levels of 20-80% FS cover there is another more varied but overall similar community that has shifted to more fine detritus feeders (collector-gatherers) and fewer grazers and filterers. At the highest FS cover >80% there is a highly significant shift to dominance by the detritus gatherers composed mostly of small midge larvae and overall reduced abundance and diversity of all other taxa. This might be thought of in practical terms by using a green-yellow-red (OK-warning-danger) system for defining ecological integrity according to these FS-cover groups that were identified by NMS groups, metric significance levels, food web structure and abundance similarities.

The IBI results run somewhat counter from the trends expected based on ambient sediments (Figures 16, 17, 18). The upper sites at Bear and Squaw have low sediment cover but fail the IBI support level while sites downstream around Truckee often pass the IBI level even though sediment levels are higher (Figure 18). This is true at least of erosional habitat where targeted riffle method samples are taken for the IBI. These samples thus only reflect erosional riffle environments and so fail to represent the habitats where there may be sediment deposition that degrades habitat. Samples taken in 2010 from 4 reaches on the MT (Herbst 2011 report) using both the reach-wide benthos (samples all habitat areas) and target riffle sample methods showed 3 of 4 samples from mobile reaches defined as areas with sediment that could be resuspended, were not attaining the reference level. So it depends on where and how samples are taken from the river in what level of biological integrity is observed. Downstream sites at Bronco, Gray and Canyon 24 where the steeper gradient creates higher energy erosional environments had consistent IBI scores in the reference range. The variation seen in sites along the river also suggests that factors other than sediment influence the community. Certainly one is location, but within locations over time, what is the influence of flow regime, of flood disturbance and flow regulation, of temperature, of habitat complexity, of riparian, of channel dimensions and sediment transport capacity? These are all effects that could be examined in a multi-variate study along sites that are more frequently spaced along the river and in varied habitat types and flow regimes.

Erosional habitat locations where grid-frames were placed showed only low levels of deposition, so the problem areas under base flow conditions (as in these September surveys) for sediment accumulation are not surprisingly in depositional habitats (low flow, margins, depressions). This is evident in the plot of percent of depositional patches for each site that have FS cover levels exceeding the biologically-severe impact level of >80% (Figure 16). Although FS levels below this also alter community attributes and function, this way of expressing the ambient sediment shows worst-case situations where management might be directed. The data also show status of habitat conditions useful for reference in further monitoring. The greatest gains in species diversity especially of sensitive and EPT taxa could be attained by reducing the occurrence of habitat patches in the highest FS cover category of 80-100%. Reducing the frequency of these worst conditions would be most beneficial to improved habitat quality and biological health along the river. Riverwide on the 1000 quadrats over 10 sites combining both erosional and depositional patches, 62.5% of habitat has <20%FS, the best conditions, while in contrast 17.4% of habitat has >80%FS, poorest condition, and the other 20% is intermediate. The deposition patterns show where, for those locations surveyed, potential problem areas exist. These are mostly within the vicinity and just downstream of the town of Truckee, suggesting urbanization sources are most significant in generating persistent sediment (that found at low flow).

Further Monitoring and Management Recommendations

- Implement management to achieve reduction in worst conditions of FS deposition in most vulnerable habitat zones (depositional patches) in areas around Truckee.
- Promote increases in the best habitat conditions where FS deposition is low across all zones of geomorphology (protect those areas with low FS levels and use flushing-flow releases from reservoirs to cleanse habitat during lower flow periods?).
- Bottom-line: Minimize >80% FS, maximize <20% FS habitats.
- How to achieve? What forms of management? BMPs for erosion? In any case, results of this project provide monitoring tools to measure success.
- Monitor FS patch distribution to evaluate habitat quality relative to bioassessment results
- Continue to measure status and trend of IBI on the river and increase the number of locations where biomonitoring occurs to improve the spatial resolution of problem areas.
- Future work might also include studies in tributaries to the MT using patch-scale grid-counts in reach-wide benthos samples to identify sediment-related impairment and detect source areas.

Figures

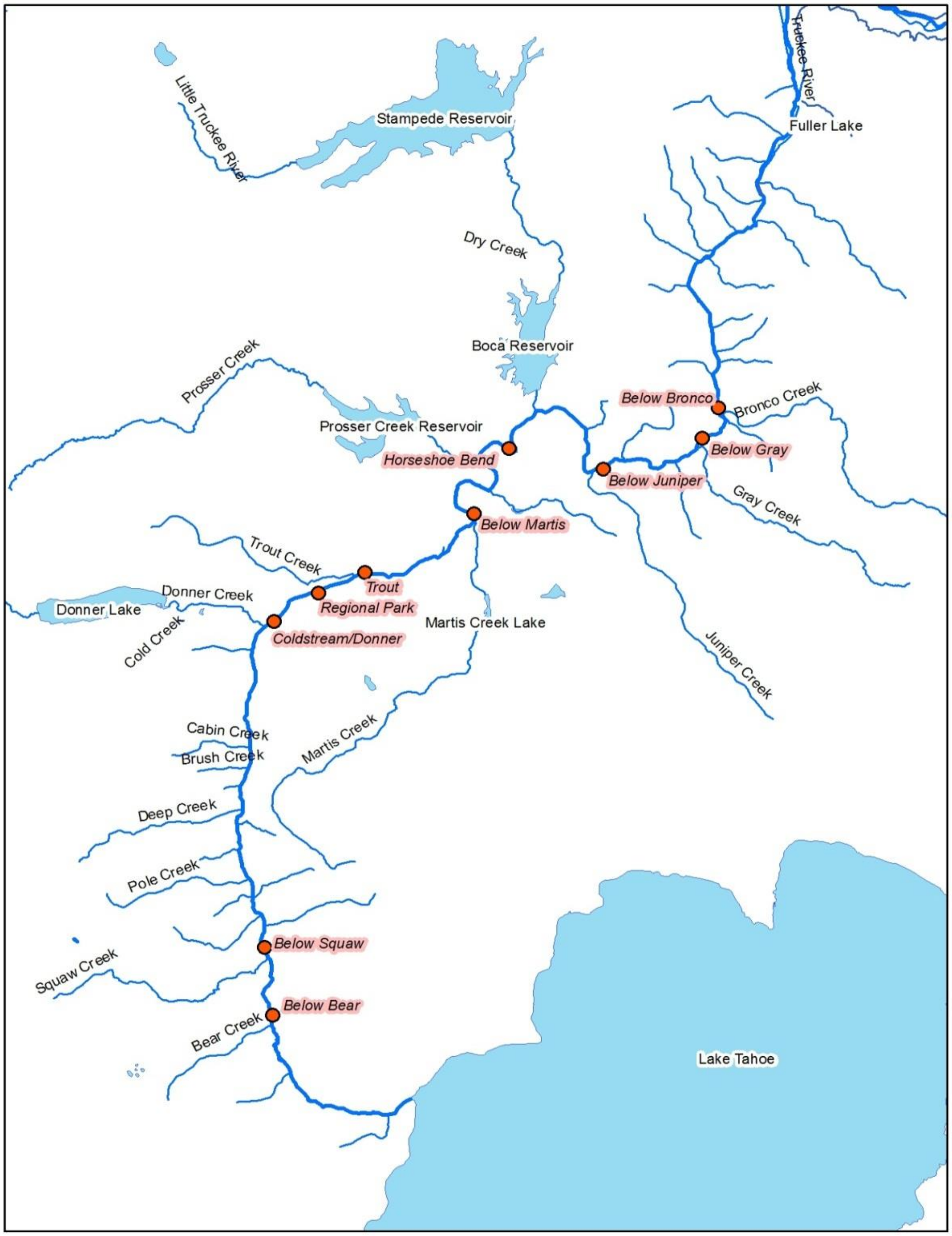

Figure 1. Ten study sites of sediment deposition and benthic macroinvertebrate community structure along the Middle Truckee River in 2011.

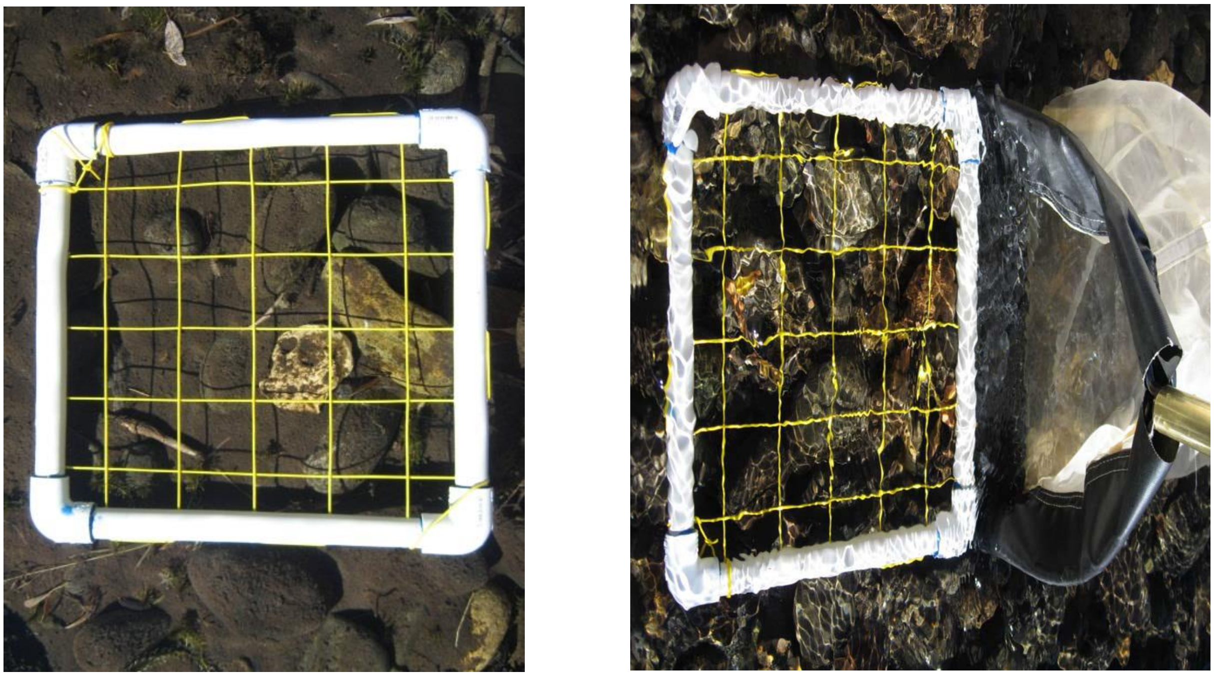

Figure 2. Quadrat grid-frames (30x30 cm) used to do point-counts of fine and sand particles(left), followed by removal of frame and sampling of the invertebrates within that sample space (right).

Figure 3. Pump-core sampling device, using hand-operated bilge pump to remove contents of isolated core area (left) to measure fine sediment volume (right), and associated benthic macroinvertebrates.

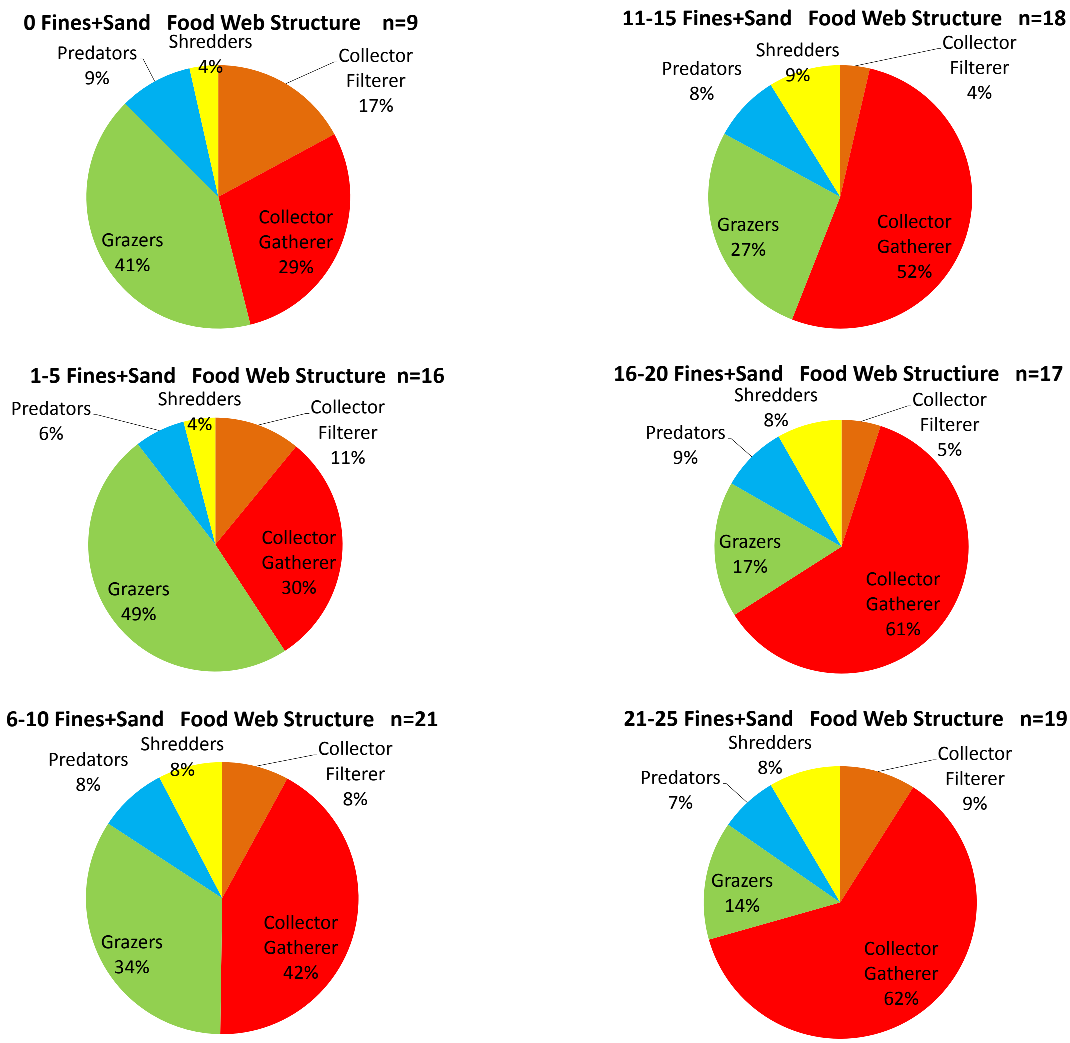

Figure 4. Changes in the food web over the FS cover gradient. Grazers of algae-periphyton decrease, collector-gatherers of fine particle organic matter deposits increase, collector-filterers of suspended organic particles decrease, and shredders of coarse organic matter (e.g. decomposing leaves) increase. Changes suggest less algae cover, more fine and coarse organic matter, and less clean stable substrata for attachment of net-spinning filter-feeding caddis flies.

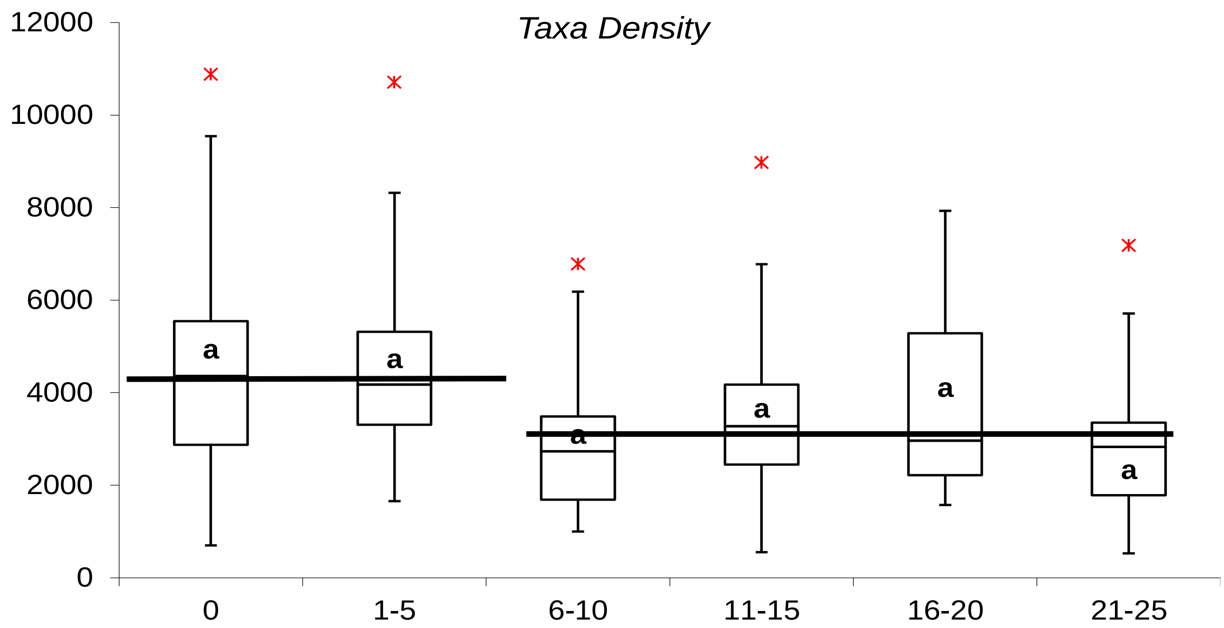

Figure 5. Density of all taxa (number per square meter) declines on average from FS counts less than 20% (0-5 counts) compared to all higher levels of FS cover. Letters show these groups are not statistically different but are consistent trends. All box-whisker plots show minimum to maximum as whiskers, 25th-75th as lower and upper box lines, the median at the cross-bar, and outliers as values greater than 1.5X the interquartile range. Dark cross bar shows over median across connected groups.

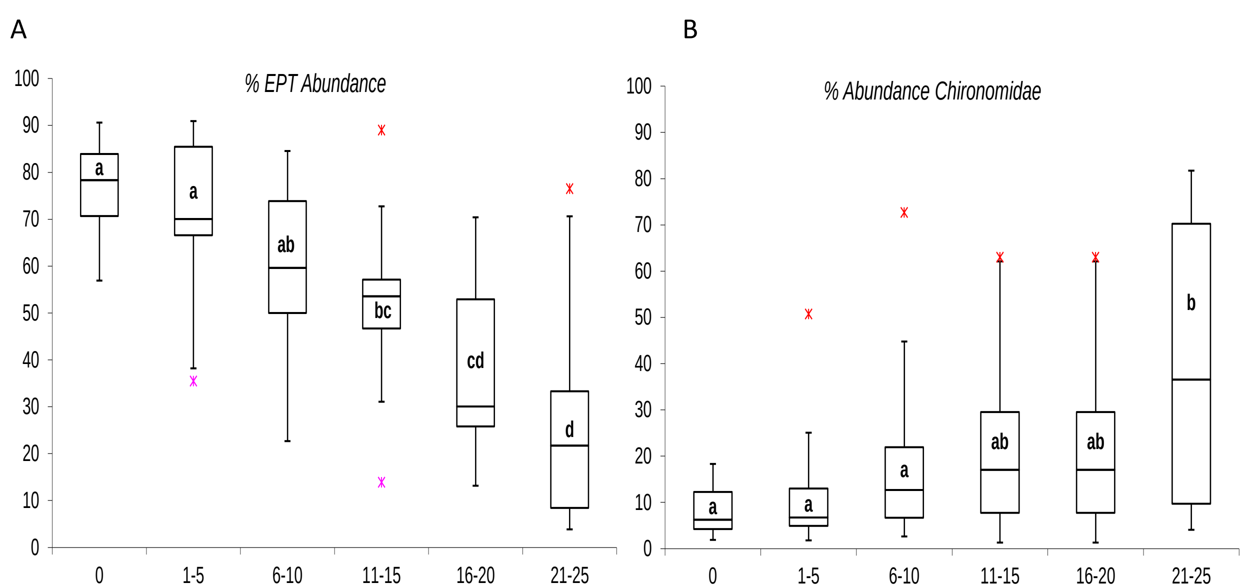

Figure 6 AB. EPT decline while chironomid midges increase in proportion with increased FS cover counts (groups that do not share letter codes are significantly different by Tukey-Kramer test p<0.05).

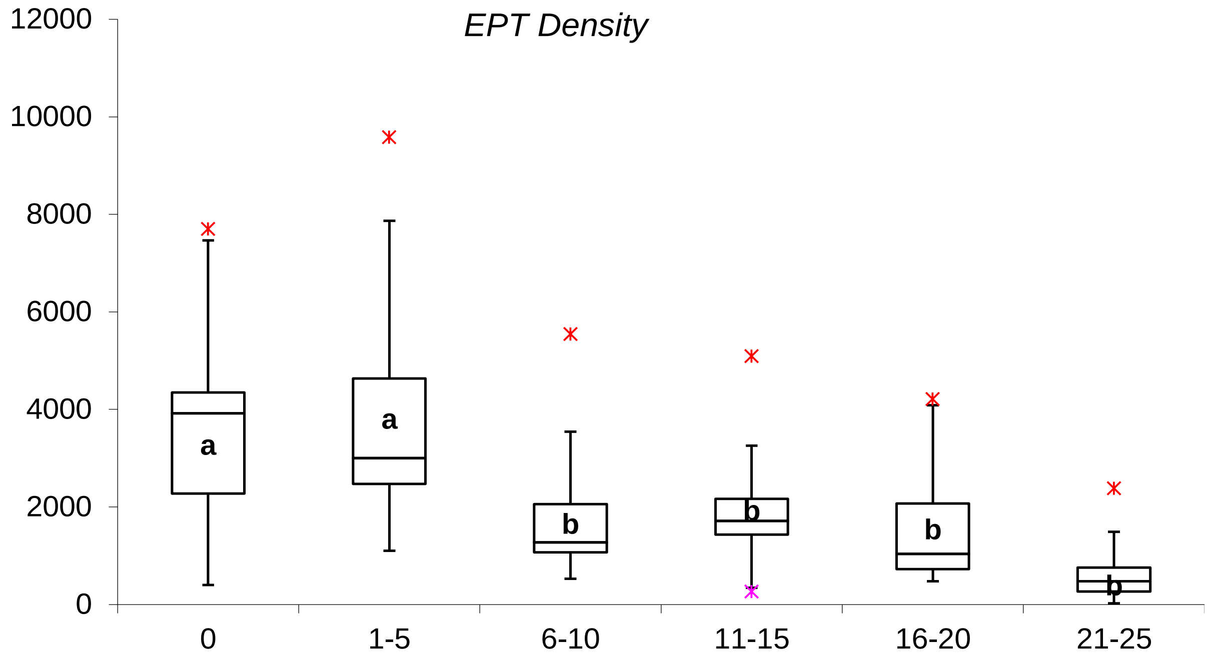

Figure 7. Density of EPT taxa = mayflies, stoneflies, caddisflies (number /m^2 on y-axis) in relation to sediment fine-sand (FS) counts in quadrats. Letters show significant ($p<0.05$) differences between the low FS group (<20% cover) and all higher FS coverage.

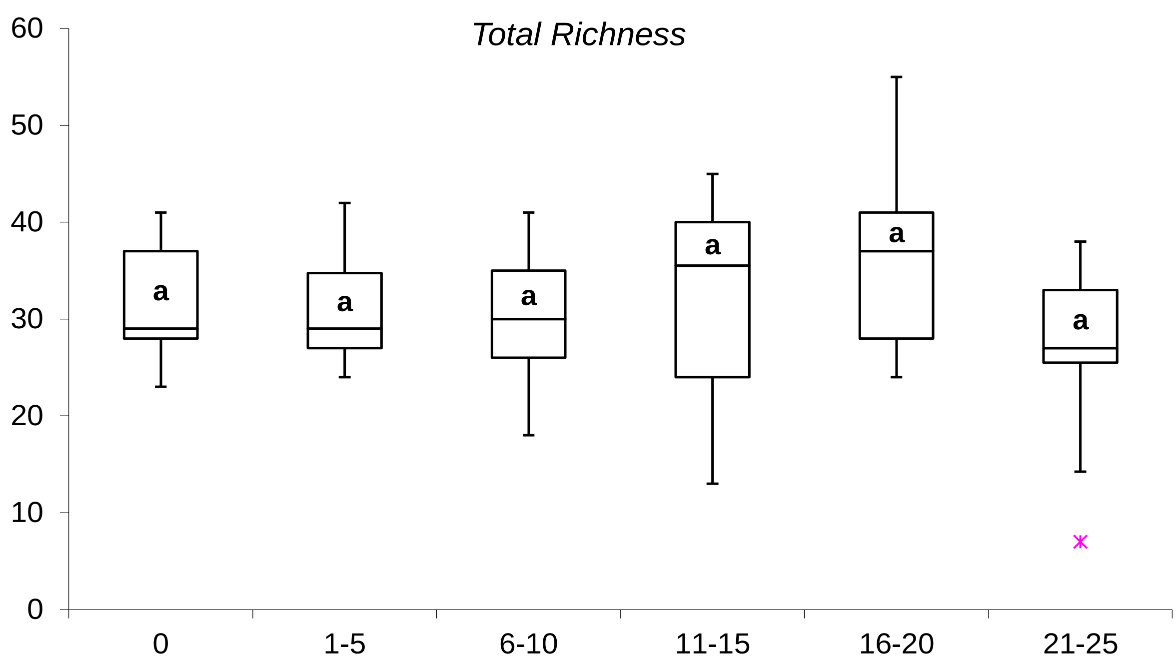

Figure 8. Total taxa richness diversity in relation to sediment fine-sand (FS) counts in quadrats. There were no significant differences across the FS cover range.

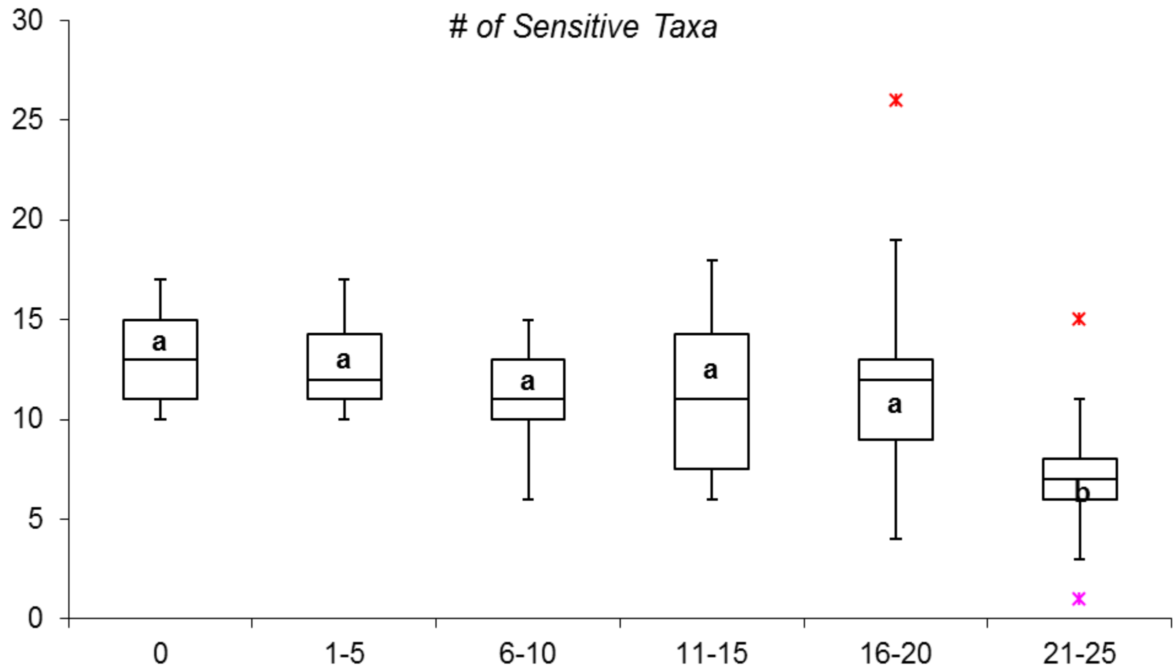

Figure 9. Richness diversity of sensitive taxa having low tolerance values (TVs) 0-2. Tukey-Kramer test differs at the highest FS cover.

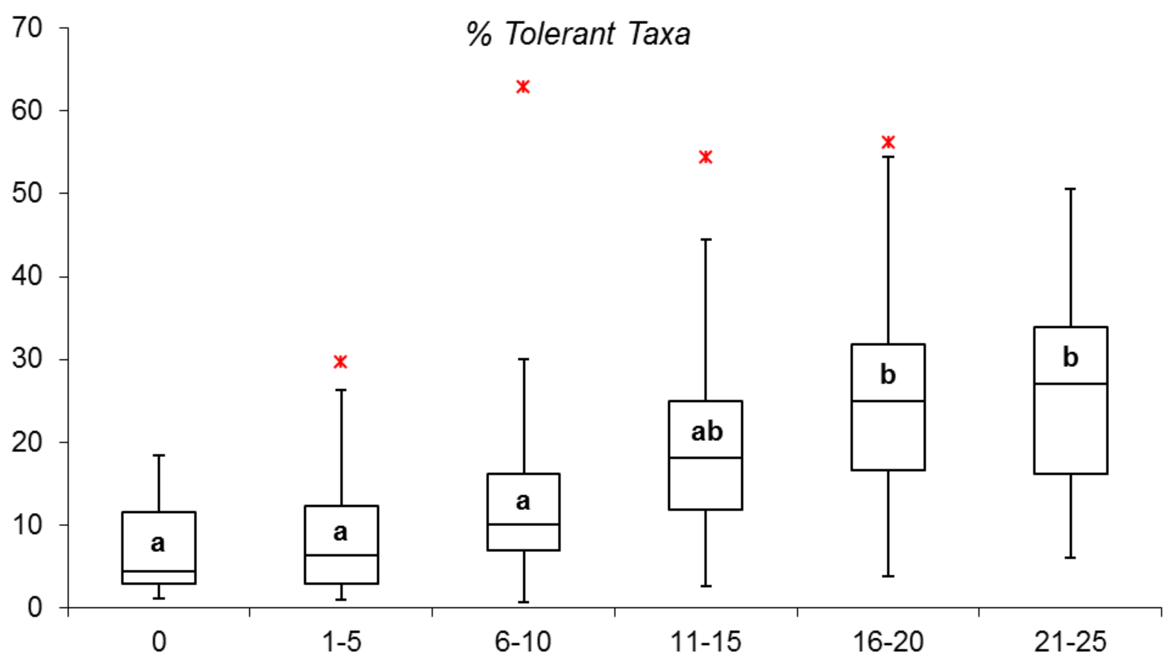

Figure 10. Percent abundance of tolerant invertebrates (TVs=7-10) in samples at increased FS cover counts. Tukey-Kramer tests differ for FS cover >60% compared to low FS levels.

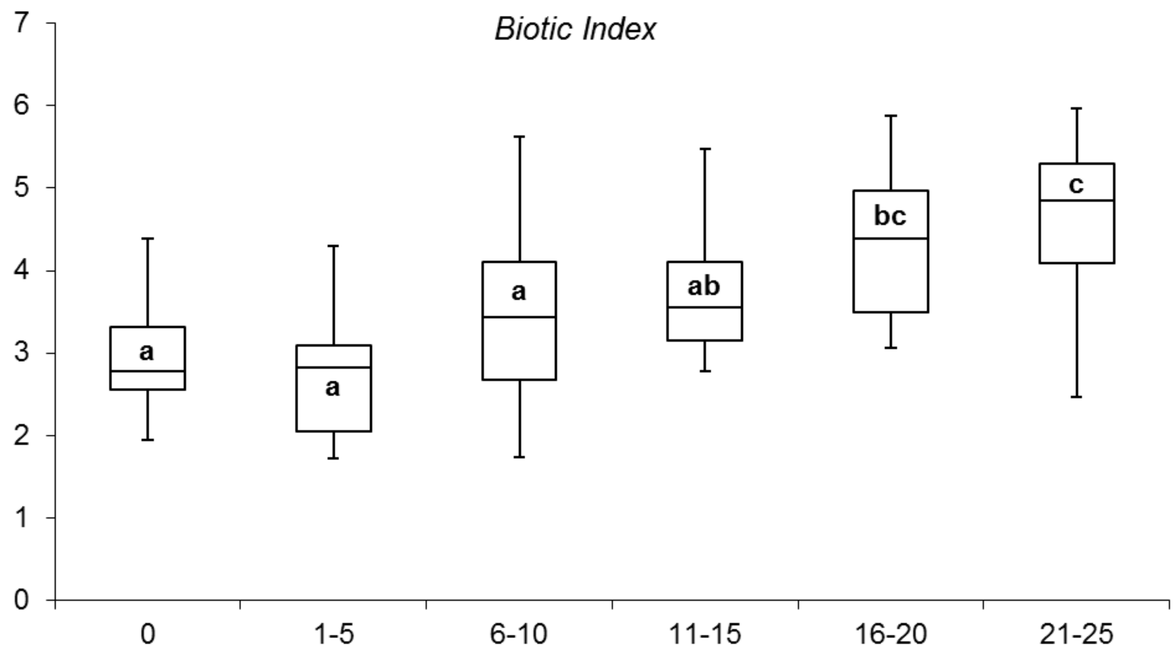

Figure 11. Composite community tolerance or biotic index, an indicator of how much the community is comprised of BMIs that are sensitive (low scores) or tolerant (higher scores) to pollution or habitat degradation including uncontaminated sediment pollution.

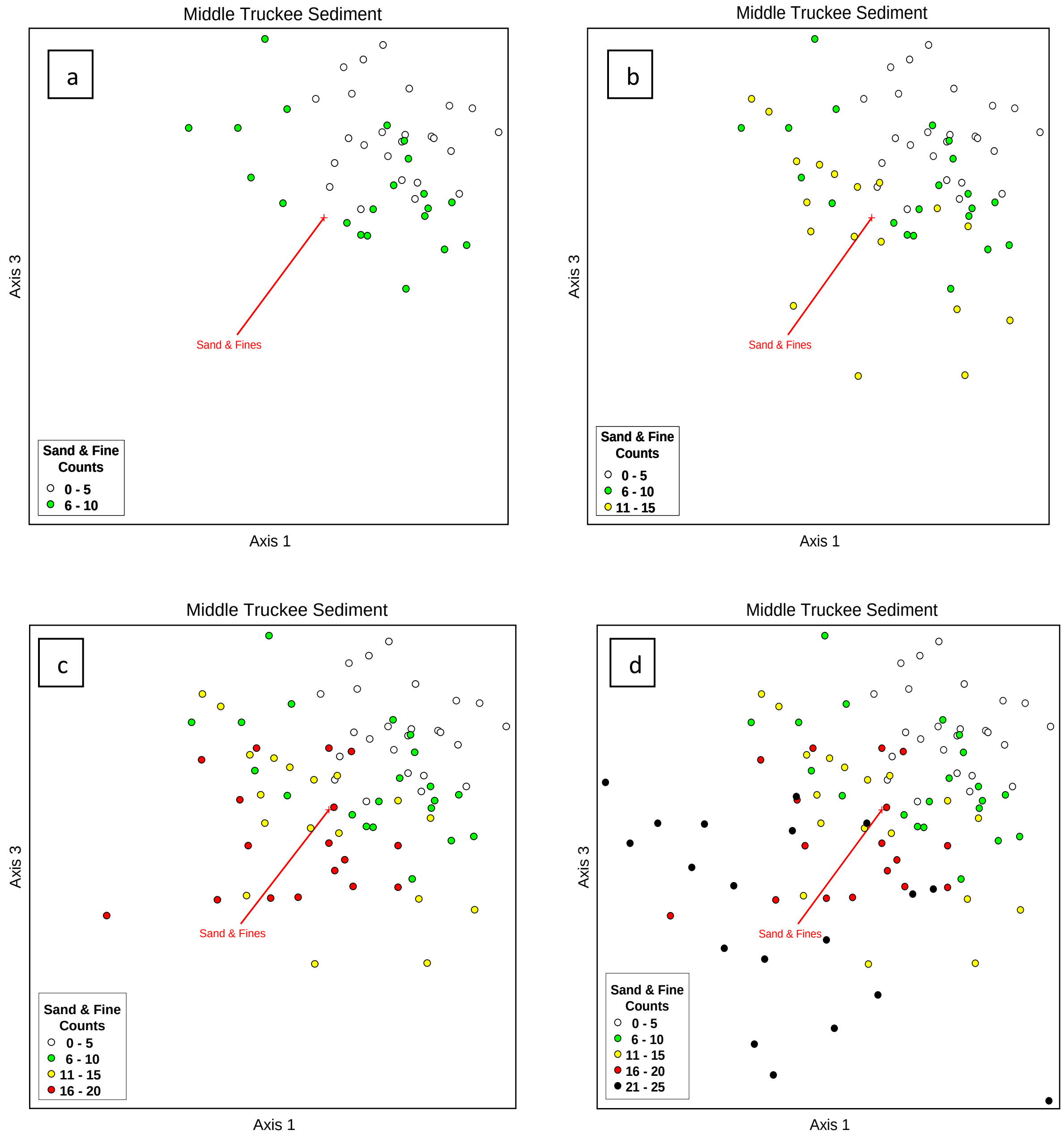

Figure 12abcd. Nonmetric multidimensional scaling (NMS) ordination of FS cover groups from quadrat grid-frame samples on the MT. The plots show sequential changes as FS groups are added and vector of environmental correlation in red. The groups at 0 and 1-5 did not show significant difference and are combined as the open symbols. The first significant community divergence is at 6-10 (in Fig a; 20-40%), adding 11-15 (40-60%) does not differ from 6-10 (in b), but adding 16-20 does differ from 6-10 but not 11-15 (in c). The high sediment group with FS counts of 21-25 (>80%) is significantly different from all others (in d; also see Table 1). This can be expressed as FS groups that do not differ share underlines:

0% 4-20% 20-40% 40-60%
40-60% 60-80%
>80-100%

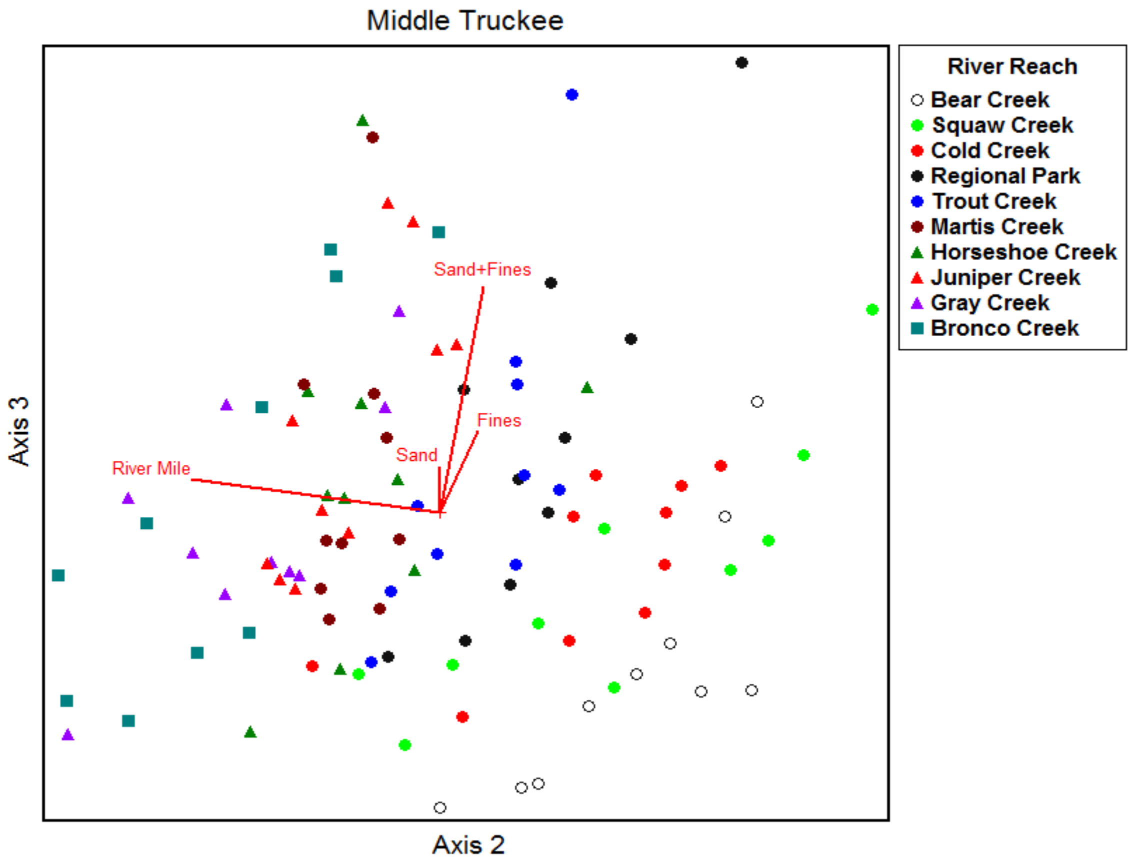

Figure 13. Ordination of quadrat samples color-coded according to site location along Middle Truckee and showing environmental correlation of both spatial vectors of downstream distance and patch FS cover. Community similarity (proximity of points) decreases with distance and with FS cover but these are separate along orthogonal vectors (effects of each are independent). Within each site, despite biological community differences between locations, the amount of FS deposition is what alters the type of invertebrate life that is found.

Figure 14. The diversity of taxa in pump core samples declines rapidly and saturates at about 300 ml.

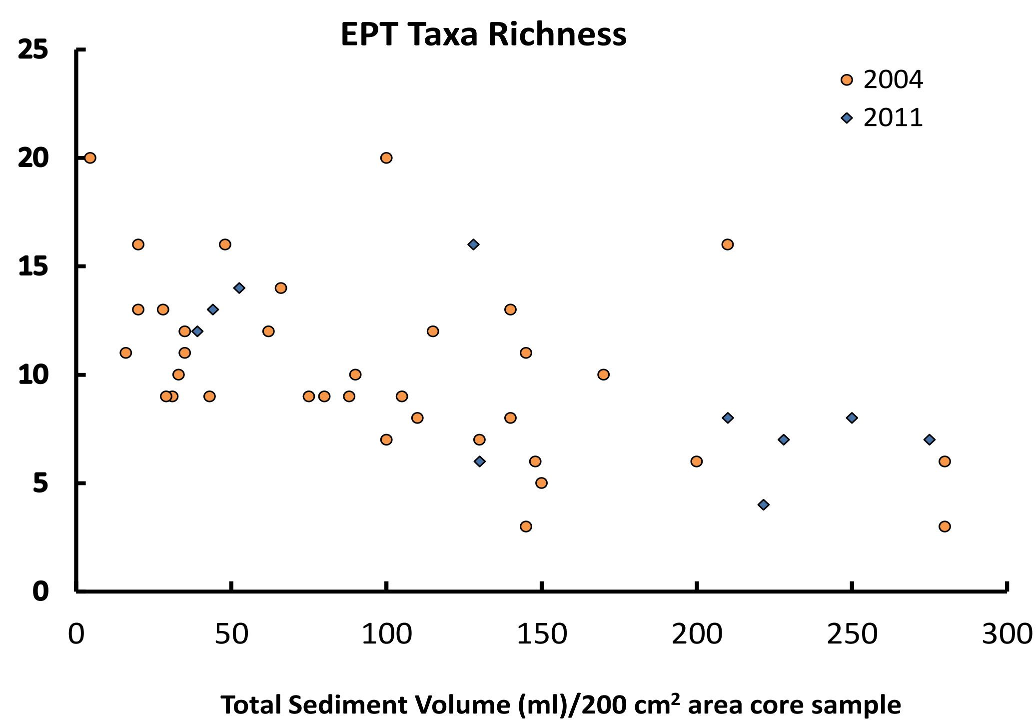

Figure 15. Richness diversity of EPT declines over the sediment volume range where FS surface cover is not yet complete.

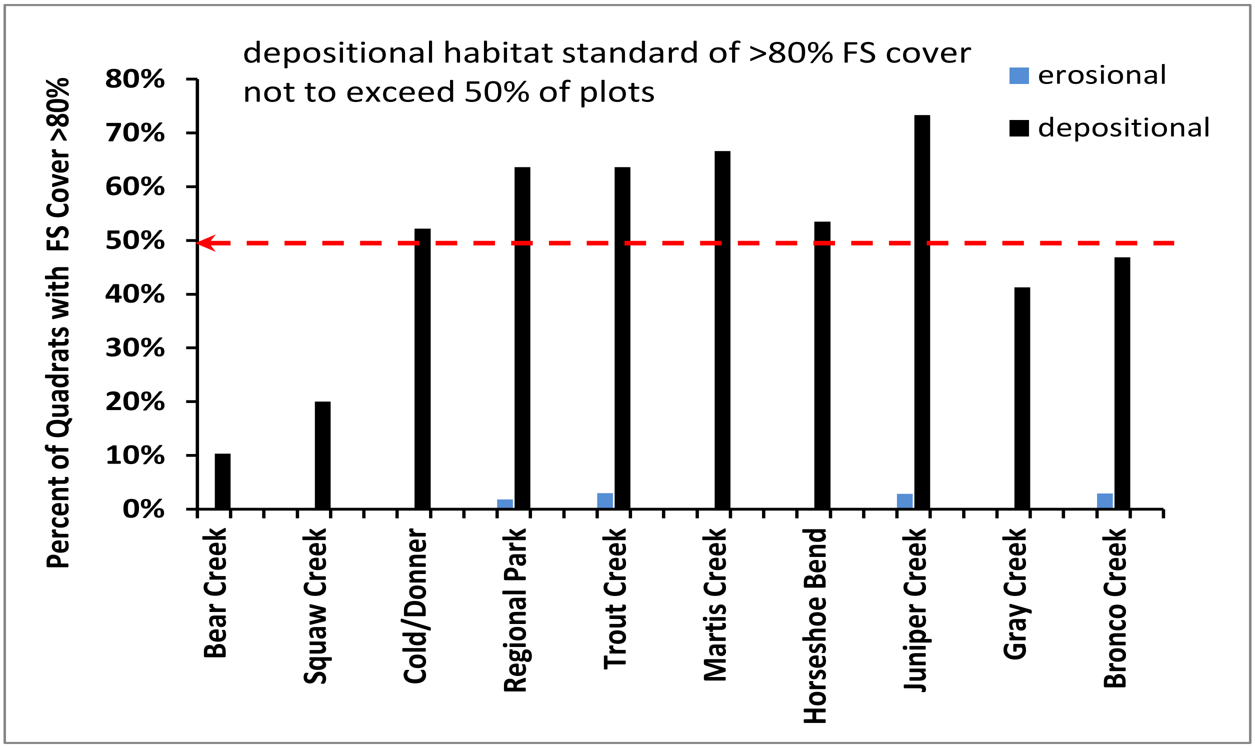

Figure 16. Percent of ambient FS quadrats in depositional and erosional habitat patches along the downstream series of MT study sites. This shows a potential management target of no more than half (50%) of quadrats taken in vulnerable depositional zones should exceed the 80% FS cover where biological impacts are severe.

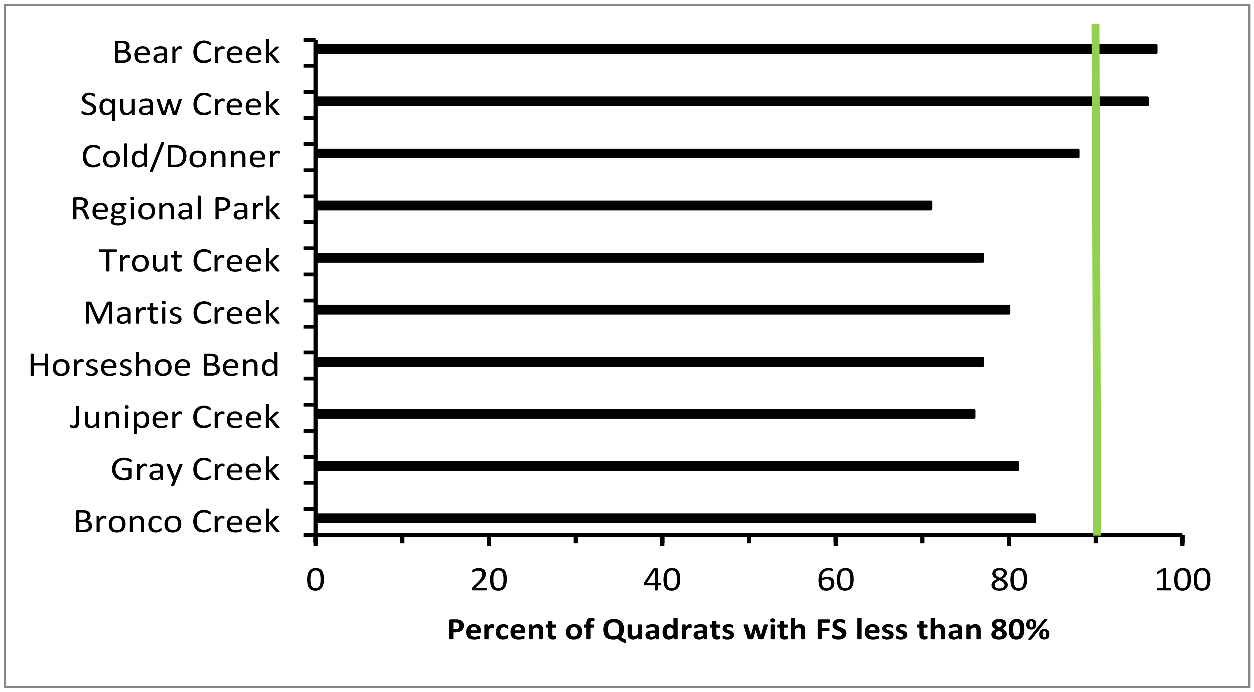

Figure 17. Using the phrasing of current turbidity standards, the occurrence of what is thought to be a conservative estimate for healthy deposited sediment levels for aquatic life (<80% cover) should exceed 90% of observations. This shows only the upper two sites meeting this desired status.

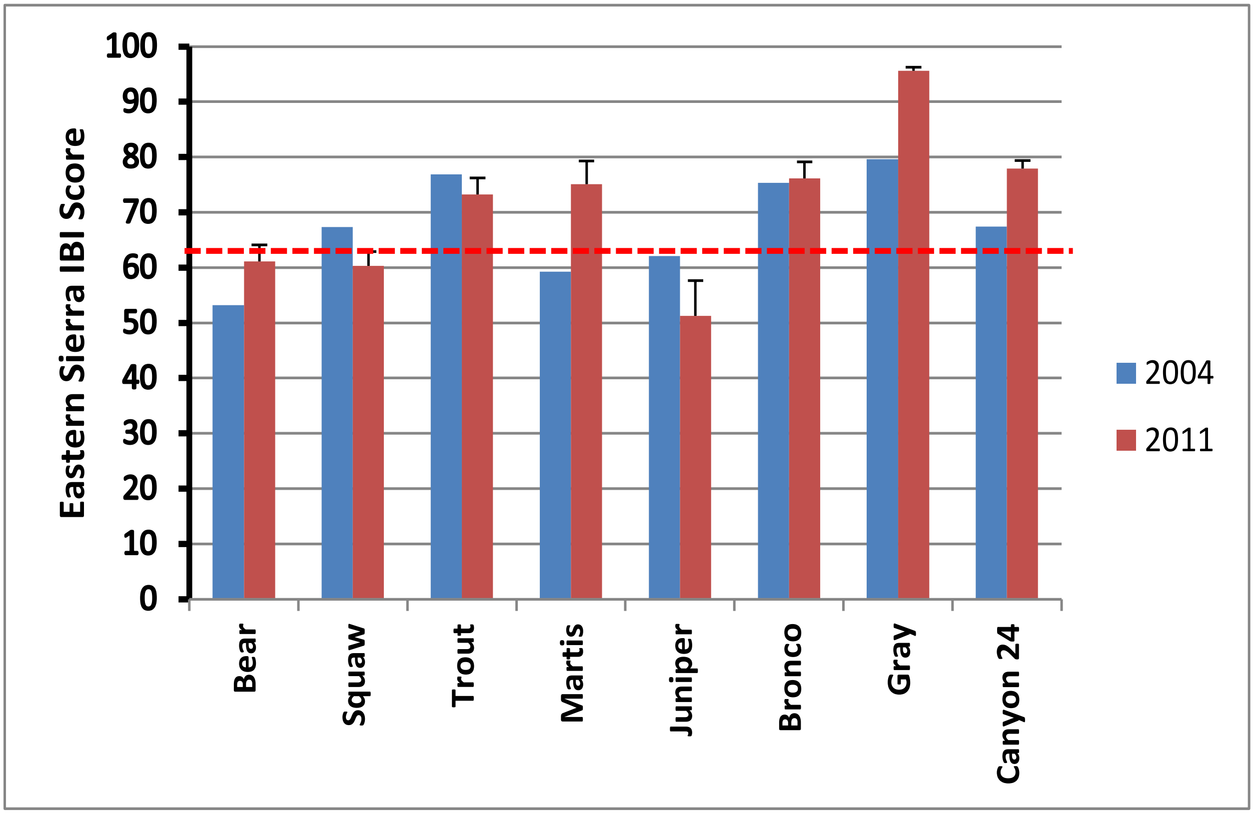

Figure 18. Eastern Sierra IBI scores contrasting 2004 and 2011 sampling on the Middle Truckee River. The dashed red line shows the threshold of lower 5% of the regional reference sites and indicates the assessment does not support reference (minimal-disturbance) biological integrity. The 2011 surveys show the standard deviation of 5 statistical re-samples of the total sample counts to fixed counts of 500 (this done just once for the 2004 data set).

Tables

TABLE 1.

PAIRWISE COMPARISONS of Quadrat FS Sediment Cover Groups in MRPP tests

Note: p values not corrected for multiple comparisons.

Group (N): 0%(9),4-20%(16),20-40%(21),40-60%(18),60-80%(17),80-100%(19)

Compared			T	A	p
0	vs.	4-20%	0.99142688	-0.00704466	0.85359645 ns
0	vs.	20-40%	-2.41111082	0.01648024	0.02560265
0	vs.	40-60%	-4.22780915	0.03390121	0.00181187
0	vs.	60-80%	-6.50513014	0.04858059	0.00005480
0	vs.	80-100%	-11.15718242	0.08455502	0.00000018
4-20%	vs.	20-40%	-3.42564333	0.01802955	0.00677003
4-20%	vs.	40-60%	-6.39926942	0.03818878	0.00006816
4-20%	vs.	60-80%	-9.25383519	0.05550618	0.00000185
4-20%	vs.	80-100%	-16.26077603	0.10271288	0.00000000
20-40%	vs.	40-60%	-0.46801932	0.00246256	0.27147541 ns
20-40%	vs.	60-80%	-3.47360751	0.01686377	0.00575586
20-40%	vs.	80-100%	-9.49161856	0.04421087	0.00000038
40-60%	vs.	60-80%	0.99206950	-0.00575750	0.86200338 ns
40-60%	vs.	80-100%	-3.56757834	0.01854369	0.00432024
60-80%	vs.	80-100%	-3.68991668	0.01826522	0.00356073

Table 2. Pairwise comparisons among sites in MRPP tests (n=10 each site).

Compared			T	A	p	
Bear	vs.	Bronco	-9.29355699	0.12623933	0.00000450	
Bear	vs.	Cold	-6.06309908	0.07292129	0.00022145	
Bear	vs.	Gray	-10.93808103	0.17607877	0.00000427	
Bear	vs.	Horseshoe	-7.39903742	0.08623091	0.00002111	
Bear	vs.	Juniper	-8.96443967	0.12875410	0.00000694	
Bear	vs.	Martis	-9.82780553	0.14317936	0.00000747	
Bear	vs.	Reg.Park	-6.98965940	0.07954694	0.00003934	
Bear	vs.	Squaw	-2.89161790	0.03730206	0.01634018	
Bear	vs.	Trout	-7.22975837	0.09340017	0.00005907	
Bronco	vs.	Cold	-9.41100511	0.13146663	0.00001697	
Bronco	vs.	Gray	-7.49079445	0.09058617	0.00003339	
Bronco	vs.	Horseshoe	-5.97559166	0.06404544	0.00019526	
Bronco	vs.	Juniper	-6.35336342	0.08586036	0.00022482	
Bronco	vs.	Martis	-7.79066872	0.10539257	0.00004810	
Bronco	vs.	Reg.Park	-8.43763443	0.10782701	0.00001534	
Bronco	vs.	Squaw	-8.98630881	0.12585684	0.00000874	
Bronco	vs.	Trout	-8.14310847	0.11309917	0.00002734	
Cold	vs.	Gray	-10.86255040	0.16382189	0.00000554	
Cold	vs.	Horseshoe	-7.10044707	0.08226909	0.00010079	
Cold	vs.	Juniper	-8.44498109	0.11572555	0.00002321	
Cold	vs.	Martis	-8.99568632	0.12681869	0.00004644	
Cold	vs.	Reg.Park	-4.23590282	0.04307244	0.00222380	
Cold	vs.	Squaw	-4.06576629	0.04912088	0.00436701	
Cold	vs.	Trout	-4.69216382	0.05295871	0.00153704	
Gray	vs.	Horseshoe	-10.08324777	0.14341484	0.00000579	
Gray	vs.	Juniper	-10.14491823	0.15644950	0.00000442	
Gray	vs.	Martis	-10.71251592	0.18326684	0.00000964	
Gray	vs.	Reg.Park	-10.37813709	0.16368067	0.00000792	
Gray	vs.	Squaw	-10.68733208	0.17622258	0.00000590	
Gray	vs.	Trout	-10.40867426	0.16989836	0.00000826	
Horseshoe	vs.	Juniper	-3.00723954	0.03396211	0.01264486	
Horseshoe	vs.	Martis	-5.09630852	0.05061779	0.00054014	
Horseshoe	vs.	Reg.Park	-5.14787663	0.05587449	0.00035471	
Horseshoe	vs.	Squaw	-5.95444819	0.07097753	0.00023834	
Horseshoe	vs.	Trout	-4.43832259	0.04679366	0.00113648	
Juniper	vs.	Martis	-3.61212135	0.04225254	0.00686645	
Juniper	vs.	Reg.Park	-7.10398419	0.08885236	0.00004596	
Juniper	vs.	Squaw	-7.76324816	0.11178298	0.00003772	
Juniper	vs.	Trout	-5.94930707	0.07969802	0.00033667	
Martis	vs.	Reg.Park	-6.56479437	0.07993402	0.00024301	
Martis	vs.	Squaw	-9.28235420	0.13296851	0.00001941	
Martis	vs.	Trout	-5.01602843	0.06516556	0.00144055	
Reg.Park	vs.	Squaw	-4.33857195	0.04638652	0.00138703	
Reg.Park	vs.	Trout	0.51411081	-0.00561362	0.64758307	ns
Squaw	vs.	Trout	-3.99007173	0.04551096	0.00351416	

Table 3. Indicator analysis showing the list of taxa that had significant correlations with low, intermediate and high levels of FS coverage, shown as the different colors.

Taxa	Maxgrp	Ind. value	Mean	S.Dev	p*
P_aviceps	0	30.4	13.3	3.53	0.001
Hydropsyche	0	30.1	15.5	3.25	0.0014
C_californica	0	29.8	13	3.65	0.0018
Sperchon	0	27.3	16.4	3.16	0.0068
R_hyalinata	0	26	11.4	3.91	0.0082
Baetis	0	25.1	17.6	2.71	0.015
T_discoloripes	0	17.3	9.7	3.84	0.049
Ceratopsyche	1	31.2	16.9	3.11	0.0014
Rhithrogena	1	27.2	17	2.84	0.0046
Glossosoma	1	25.3	19	2.06	0.007
Wormaldia	1	15.2	6.8	3.74	0.0346
Ameletus	3	18.4	10.4	3.67	0.04
A_delantala	4	25	14.9	3.61	0.0176
Capniidae	4	16.6	8.2	3.7	0.0336
Lebertia	4	22.9	17.5	2.75	0.0444
Odontomesa	5	35.8	8.3	3.91	0.0006
Phaenopsectra	5	29.2	12.6	3.84	0.004
Tanytarsus	5	25.1	12.5	3.81	0.0098
Centroptilum	5	21.7	9.1	3.85	0.0114
Parametriocnemus	5	18.6	10.1	3.77	0.0332

Mostly EPT, 8 of 11 taxa

Mostly midges, 4 of 5 taxa

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