Trout Creek Restoration Monitoring:
Changing Benthic Invertebrate Indicators in a Reconstructed Channel

June 2009

David B. Herbst
Sierra Nevada Aquatic Research Laboratory - University of California
HCR 79, Box 198
Mammoth Lakes, CA 93546
herbst@lifesci.ucsb.edu
760.935.4380

Introduction and Project Background

The encroachment of urban and agricultural development on riparian stream corridors often alters the connectivity, amount and timing of flows, resulting in losses of hydrologic function and ecological integrity (Allan 2004, Poff et al. 2006). Restorations of streams through a variety of structural engineering approaches (e.g. Hunter 1990, Rosgen 1996) have attempted to remedy land use disturbances, and while return to form often drives the design and implementation of projects, ecological measures of recovery and fluvial processes need to be considered. An integral component of stream restoration management is the monitoring of performance indicators that measure the progress of ecological recovery (National Research Council 1992). These indicators may cover a range of habitat features and represent different components of physical and biological structure and function of instream or bank, riparian, and floodplain condition. Monitoring establishes baseline measurements (pre-restoration conditions), the range of natural variability (inter-annual changes), control conditions to set context (similar stream locations not affected by the problem needing restoration action), and also accounts for the historical setting of past channel changes and geomorphic constraints on recovery (Kondolf and Larson 1995). Achievement of ecological response and recovery may require a period of adjustment, but whether restoration activities are effective in accomplishing goals has typically been evaluated only immediately before and after the project construction phase. Channel reconstruction for a project on Trout Creek, El Dorado County, California, enhanced the streambed with larger and more varied substrate habitat conditions, resulting in increased diversity of stream invertebrates in two years immediately following restoration activities. The objective of the present study was to update information on the extent to which recovery was sustained beyond a 5-year period and how recovery is mediated by substrate type.

Trout Creek is a tributary to the Upper Truckee River, reaching confluence just above inflow into Lake Tahoe in the City of South Lake Tahoe, California. Geomorphic problems with Trout Creek stem from channelization of the lower portions of this stream during construction of a 19th century railroad route. The straightened channel produced an incised and eroded bed, sand and sediment deposition, and degraded aquatic and riparian habitat conditions. As a part of efforts to control sediment delivery into Lake

Tahoe and stabilize stream channels in the watershed, a restoration project on Trout Creek was initiated to reconstruct natural channel sinuosity, pool-riffle sequences, substrate composition, bank stability and hydrologic function.

Bioassessment monitoring of the stream invertebrate community of Trout Creek was undertaken as part of the data collected to evaluate the success of channel reconstruction in two sections of this creek: (1) a completely reconstructed channel section above the confluence with Cold Creek, and (2) a partially reconstructed channel (including segments of existing channel where the stream had not been channelized) below the Cold Creek confluence. This monitoring of aquatic life represents a biological baseline for evaluating the effectiveness of new channel construction in improving habitat and enhancing biological integrity. The bottom-dwelling invertebrates of the stream were used as indicators of the quality of habitat and the capacity of the stream to support life. The bioassessment approach to stream monitoring has been used widely to evaluate the status of stream water and habitat quality, measure the effect of pollutants on natural communities, prioritize aquatic resource management problems, develop targets for recovery, and follow the progress of restoration projects using channel reconstruction as conducted here (Davis and Simon 1995, Barbour et al. 1999, Herbst and Kane 2009).

Site Description

The project site was located on lower Trout Creek meadows, above and below confluence with Cold Creek (refer to Figure 1). Restoration of the upper channelized section of stream (above Cold Creek) to control erosion and stabilize the channel involved complete replacement of this upstream reach with an adjacent reconstructed sinuous channel. The channel and bank of the downstream reach (below Cold Creek) was only partly reconfigured, interspersed with existing channel forms where natural sinuosity occurred. The reconstruction project was completed during 2000-2001, with flow of the creek re-directed into the new channels in summer of 2001. Pre-project monitoring of the stream invertebrate community was conducted in late September of 1999 and 2000, and post-project monitoring also in late September of 2002 and 2003. Repeat monitoring to evaluate sustained recovery beyond 5 years was conducted in late September of 2007 and 2008.

Silt and sand deposits, forming a shifting unstable stream bottom environment, dominated both reaches prior to restoration. The post-project streambed was engineered not only to produce alternating riffle-pool habitat in a sinuous channel, but gravel and small cobble substrates were also imported into riffle segments to provide larger and more varied substrate particle sizes. In addition to these restored reaches, an upstream control reach above the project area (above the Pioneer Trail road crossing) was also sampled in the post-project years of 2002-2003 and 2007-2008 to quantify the natural invertebrate community expected for Trout Creek in similar low-gradient meadow habitat, but in an area not subject to channelization and representing the natural geomorphic and hydrologic setting of the lower reaches of this stream.

Methods

Substrate composition as silt and sand (<2 mm), gravel (2-16 mm), medium gravel or pebble (16-65 mm) and small cobble (about 65 to 100 mm) was recorded for each set of invertebrate collections. These were recorded as categorical substrate classes in 1999-2000 and 2002-2003, but were quantitative in 2007-2008. The quantitative sampling of substrate composition consisted of measures taken within the riffle sections sampled for invertebrates. Along five transects encompassing the sample area, set at intervals of one meter, substrate sizes were measured at 5 equal-spaced points across the wetted channel width for a total of 25 points for each riffle area sampled. Substrates less than 0.25 mm were called fines, 0.25-2 mm sand, and larger than this the size was measured as the intermediate axis of particle width (to within 1 mm). Natural large sized substrates were rare or absent over the pre-project reaches (some cement blocks formed large substrate in a few locations), and the channel bed at that time was almost entirely silt and sand with some gravel deposits.

In each of the three study reaches (upper project above Cold Creek, lower project below Cold Creek, and above project upstream of Pioneer Trail; Figures 1 and 2 aerial photos) five benthic invertebrate samples were collected, each in separate riffle segments separated from one another by 2-3 riffle-pool sequences. Each sample consisted of a composite collection from three square-foot locations across the channel in the shallow erosional riffle habitats. Samples were collected using a standard D-frame net of 250-

micron mesh size and 12 inch (30 cm) opening width. The net rim was placed against the stream bottom just below of each sample area and the substrate disrupted by hard to release inhabitant invertebrates which then were swept with the current into the horizontal collection net. The three composites per riffle section were then collected in a bucket and the contents mixed/swirled and the floating organisms and organic debris poured off through a fine-mesh aquarium net, leaving sand and gravel behind (known as elutriation). Elutriation was repeated until no further organic matter could be separated from sand/gravel. The remnant sand and gravel was then visually inspected in shallow white pans to remove any remaining sand-case caddisflies or other invertebrates that did not come off with elutriation. These field-processed samples were then preserved with alcohol and Rose Bengal stain and returned to the laboratory for sorting under a 10X stereomicroscope. Prior to sorting, subsampling of field samples was conducted using a rotating drum sample splitter, so that the number of organisms sorted was usually in the range of 250-1000 total. Organisms were identified to genus level (or species/ species group), including midges and mites, with the exception of oligochaetes and ostracodes (seed-shrimp and segmented worms, collectively 1-2% of all organisms). The body lengths of sorted and counted organisms were also measured to quantify the frequency and density of organisms larger than 5 mm. These large invertebrates usually have longer life cycles, requirements for stable substrates and food resources, and are the preferred prey of fish, amphibians, and riparian birds (when adult insects emerge). Data analysis also included measures of overall taxonomic richness (diversity), the sensitive EPT group richness (mayflies, stoneflies and caddisflies or Ephemeroptera, Plecoptera and Trichoptera), small-bodied midges (chironomidae) that are often tolerant of sedimentation, and dominance of the most common taxon as an indicator of reduced heterogeneity in community composition.

In addition to the composite riffle samples, invertebrates were also collected from single quadrat samples in 2007-2008. Grid-frames (30x30 cm area with 5 intersecting cross-wires of 25 points) were placed at five separate locations within each study site, selected to represent a range of cover by fine and sand (FS) substrates. The net was set below the frame as each quadrat was selected, and after recording the number of intersect points with FS present, the frame was removed and the sample area swept into the D-net.

This sampling enabled direct patch-scale determination of the relation of FS particle cover to invertebrates present. In 2008, the entire upstream control area became a series of ponds created by beaver dams. Previously surveyed riffle segments that were submerged were sampled using this quadrat method at the same locations rather than the combined riffle transect samples. The limited riffle habitat that was present was found in short segments below dams before entering the next downstream pool, and five of these were also sampled with quadrat grid-frames in 2008.

Sampling was conducted under late summer baseflow conditions in all years (late September), though peak flows in May and June varied between years (Figure 3). In 2006, between the initial post-project surveys and the 2007-2008 repeats, flows were very high, providing conditions for suspended and bedload transport that would test the persistence of the gravel and cobble substrates added during habitat reconstruction. During pre-project sampling, collection locations were not restricted to the dominant streambed substrate at the time (sand), but were selected to represent the range of patch-scale variation that could be found, including localized gravel deposits. The pre-project habitat in the channelized stream consisted mostly of shifting sand and silt substrates, while the new stream channels created during restoration consisted mainly of mixed gravel and cobble-sized rocks within the riffle habitat sections.

Results

Previous data (Herbst 2004) indicated that biological integrity had improved in Trout Creek in both the partial and complete reconstruction reaches in comparisons of several measures before and after the project was completed. The indicators of recovery further suggested that much of this was attributable to increased availability of gravel and cobble substrates that were introduced (River Run Consulting 2006) and supported higher diversity of taxa with a larger body size distribution.

The streambed in both partial and complete reconstructed channels retained a substantial fraction of gravel to cobble size substrate in 2007-2008, but over the intervening years since project completion, the riffle habitats that had been covered with gravel-pebble-cobble substrates now contain about 20% fines and sand composition (Figure 4). Though overall geomorphic integrity of the channel appears to be retained, there has been bank sloughing observed at some of the meander bends of the new channel, and some of the pools show signs of incision, deepening, and deposition of fines and sand. It is possible that some of these changes occurred during high flows in 2006 that could have carried suspended and bed load sand (Figure 5).

Invertebrate bioassessment responses show that despite the retention of much of the rock substrate introduced during restoration, the indicators have returned to levels near the former stream condition. The initial post-restoration gains in richness diversity for all taxa and among the EPT taxa were reduced in 2007-2008 to levels within the range of the unrestored stream (Figures 6 and 7). The density of invertebrates greater than 5 mm in size was also reduced below the range found in 2002-2003 in the complete restoration reach, but was more varied in the partial restoration reach. Dominance by a single taxon in the restored reaches also increased after having declined from pre-restoration conditions, but this was also seen at the control site. For diversity measures and size, the control reach maintained indicator levels.

There was considerable variation found in the most common taxa comprising the community. In the pre-restoration and the intial post-restorations samples, the mayfly *Baetis* was a common dominant invertebrate, but it became rare in all the 2007-2008 samples. The small stonefly *Sweltsa* has been common throughout all sample periods as has the mayfly *Ephemerella*, but two other mayflies, *Paraleptophlebia* and *Cinygmula* became much more common in both the initial and recent post-restoration period. The riffle beetle *Optioservus*, the filter-feeding midge *Rheotanytarsus*, and *Cricotopus* (*Nostococladius*), a midge found only in association with blue-green alga *Nostoc*, have also become more abundant in the most recent sample period 2007-2008.

The quadrat samples demonstrate that FS cover has an important influence on the diversity and composition of the invertebrate community. As FS cover increased, the total and EPT taxa richness levels declined (Figures 10 and 11), with all samples below 30% FS having more than 30 total taxa and 10 EPT present, while over 60% of samples above 40% FS had less than 30 total taxa, and almost 90% had 10 or fewer EPT. The percent of EPT in quadrats declined substantially as FS cover increased (Figure 12), though even at low levels of FS, quadrats from the complete restoration area had reduced %EPT. In the samples taken from the beaver-pond flooded control reach of 2008, the localized effect of low fine-sand cover below dams was in stark contrast to submerged quadrats. The short segments below dams held higher diversity, and a greater fraction of EPT than the former riffles that had been covered by sediment in the beaver ponds. The biotic index, a measure of the composite tolerance of the community to poor water quality and habitat conditions, showed a graded increase with %FS cover (Figure 13).

Although quadrat samples of FS substrate cover were collected only in 2007 and 2008, substrate classes recorded for pre-project samples permitted contrast of sand-only substrates with those having mixed gravel content. These samples also showed also that the presence of some gravel enhanced EPT diversity (Figure 14).

Discussion

The biological integrity improvements observed in the first two years following channel reconstruction do not appear to have been entirely sustained after an additional four to five years. While gravel and pebble rock substrates remain in riffles, more sand and fines have become deposited on the bed (Figure 4). Rock substrates form the habitat that support the most invertebrate diversity and larger body sizes, whether examined before or after habitat restoration (Figures 6 through 14). As this habitat varies, so does the benthic invertebrate community. Rock substrates support the growth of algal periphyton, and trap organic matter in the form of leaves and wood that accumulates in crevices. Algae and decomposing organic matter form the food base to aquatic invertebrates, so bed substrate composition is an important determinant of both habitat and food resources availability. These substrates are also more stable under higher flows, providing attachment and refuge not afforded by sand.

The changing dominance of various taxa over different locations and times, with some taxa found throughout the study period and others predominating before or after restoration, suggest that establishment, recruitment, and colonization varies considerably among species, often independent of the influence of restoration. While declines in indicators of biological integrity such as richness diversity and reduced numbers of large organisms suggest that there was some regression in the status of restoration, the changes that have occurred are not simply a return to the same community present before restoration, but one with altered taxonomic composition. The stream community may be continuing to adjust and shift patterns of relative abundance just as the geomorphic environment itself continues to adjust to annual and seasonal variations in flow regime and sediment flux (the size fractions and amount of sediment transported in and out). These dynamic processes, changing the spatial and temporal distribution of habitat patches, create a heterogeneous environment, ultimately favoring the long-term maintenance of biological diversity (Townsend 1989). In this context, restoration should not be expected to achieve some static state of community structure, but should reach a condition within the range of natural streams in the region (references) and retain the capacity for recolonization from refuge habitats such as the rocky substrate patches that support the most variety in taxa.

Although sustainable restoration is likely to hinge on maintaining rocky substrates in riffles, status and progress may be defined biologically both by the variety found in the control stream reach, and that defined by regional reference conditions. Using an upstream control stream reach to define desired condition provides only limited context for what might be expected after restoration. While not the subject of the restoration actions, upstream controls are not necessarily undisturbed. The control reach above Pioneer Trail, for example, is still adjacent to urban influences (Figure 3) and exposed to erosion from land use disturbances, as well as disturbances from the activities of non-native species (i.e., beavers). If the control reach is insufficient to represent stream potential, regional reference standards may also be used for assessment.

Herbst and Silldorff (2009) recently developed an index of biological integrity (IBI) for the eastern Sierra Nevada ecoregion that is based on reference streams throughout the region, including the Lake Tahoe basin. Based on that regional IBI, assessments in 2007 showed scores for the partial restoration area in the “supporting” (i.e., unimpaired) range (with scores >62), but the complete restoration reach scored in the “not supporting” (i.e., impaired) range (<50 based both on riffle and reach-wide methods). Whatever the cause of the degradation, these scores indicate that the restoration efforts to date have not fully restored healthy instream communities.

Restoration designed to engineer channels of a particular type that resist processes of geomorphic change has been criticized as an unnatural restriction of form (Kondolf 1995, Simon et al. 2007). Placement of rock substrates that are not natural in their abundance in the restored channels may not be stable features, so some long-term equilibrium under varied flows and sediment transport may be required before the stream bed is in a quasi-equilibrium state (Simon and Hupp 1986). Substrate composition may provide a responsive indicator of both the physical channel restoration process and benthic habitat quality for aquatic life. With the restored stream channel still in an unstable state it is difficult to predict when and where processes of scouring and filling will occur, but substrate cover data collected across study sites will track the temporal and spatial scales of geomorphic adjustments.

One of the goals of the Trout Creek project was to restore connectivity of the stream and floodplain. Evidence of this was demonstrated using paired flow gauge monitoring data above and below the project area before and after channel reconstruction that showed elevated water table level and increased summer flows (Tague et al. 2008). Although this suggests that hydrologic conditions have improved, these processes may not have a strong connection to the response of instream habitat and benthic biota.

Less fine and sand cover within the matrix of larger substrates (gravel, pebble, cobble) yields more diverse invertebrate communities, supporting the assumption that reduced sedimentation is an important driver of sustained ecological recovery. This association was demonstrated in the quadrat grid-frame samples where improved response measures were usually found at lower levels of fine and sand cover (Figures 10-13). An exception to this was apparent within the quadrats collected in the complete restoration area where even though low FS cover promoted diversity, the percent EPT was lower than found at other sites. With entirely replaced channel and streambed in this area, the absence of local recolonization sources may limit abundance of these taxa. Where fines and sand were abundant in quadrats, as in the former channelized stream, lower diversity and smaller organisms persist. Even the earlier pre-project samples in areas with gravel substrates supported more diverse invertebrate communities but were present only in localized patches (Figure 14).

Beaver dam construction within the control project area provides further insight on the influence of hydrogeomorphic change and how sedimentation alters benthic invertebrate communities. Extensive deposition within these ponded areas showed that diversity was reduced and sediment-tolerant chironomids became dominant (50% in ponds compared to only 20% in the short riffle segments below beaver dams). This loss of upstream colonization source may further slow the recovery process within the downstream restoration project area.

Summary and Conclusions

1. The revisitation of aquatic invertebrate community recovery at the Trout Creek restoration project suggests that composite indicators of diversity and size structure of the instream community have declined from the initial post-restoration gains. This finding suggests that improvements in stream health that were documented shortly after completion of the project are both diminished and in flux, and indicates a need for long-term monitoring of such restoration efforts.

2. The changes detected in aquatic invertebrate assemblages include a shift in the composition of the community and not simply a return to the pre-restoration state. This shift may reflect ongoing adjustments of the channel to flows and sediment flux that has brought sand and fine particles back into riffle habitats. Whether these ongoing erosion and depositional processes reach some steady state, the presence of rocky and other coarse substrates will continue to be integral to sustaining habitat conditions supporting diverse benthic invertebrate life.

3. Relative to regional stream biological criteria (i.e., an IBI developed for the eastern Sierra ecoregion), the partial restoration reach meets a definition supporting the integrity of aquatic life, but the complete restoration reach scores in the “not supporting” (i.e., impaired) range. Thus, the available data indicate that the efforts to date have not yet restored a healthy stream environment.

4. Future monitoring of this changing system should be conducted to assess both the physical environment of instream substrate composition and benthic invertebrate community indicators.

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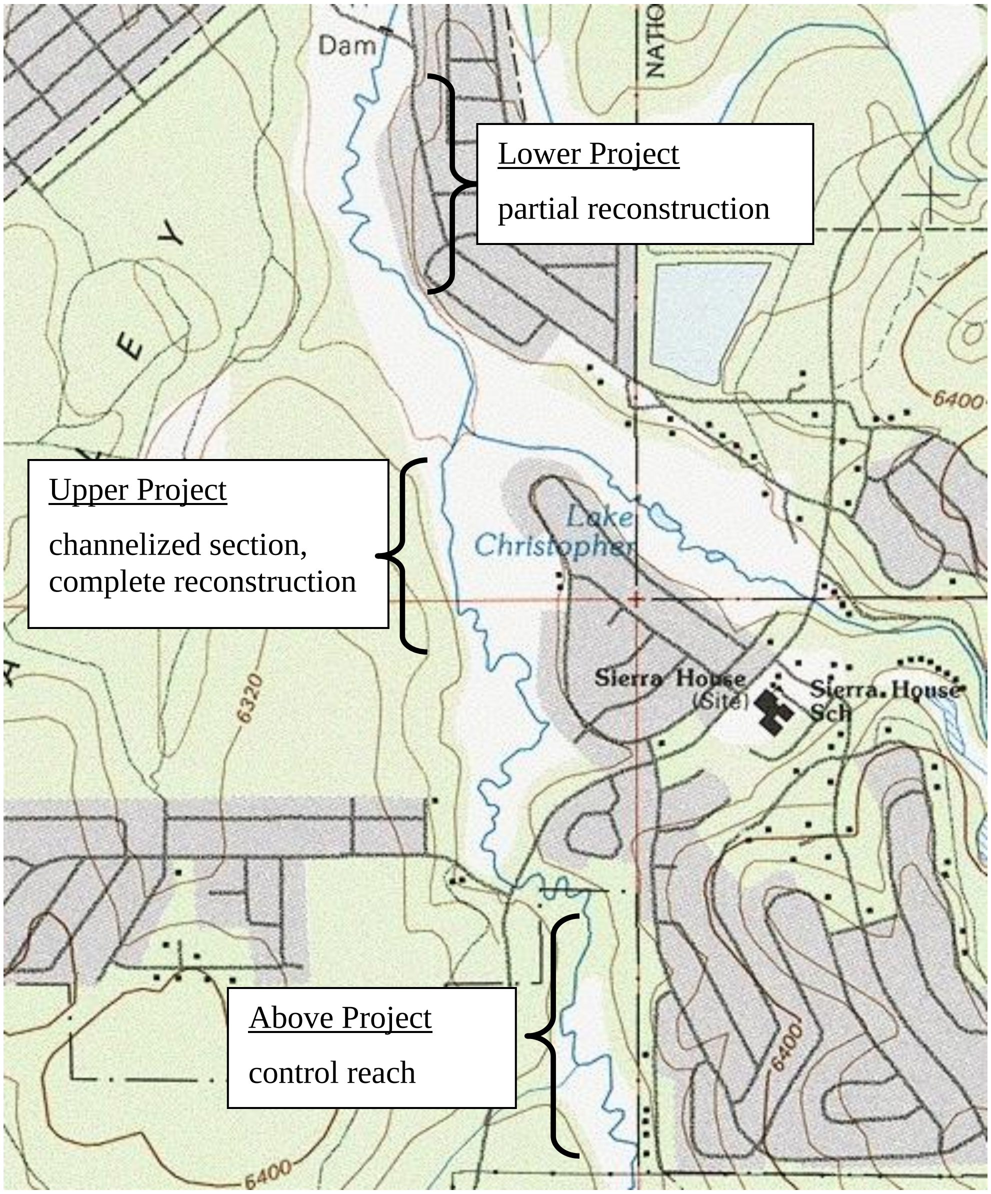

Lower Project

partial reconstruction

Upper Project

channelized section, complete reconstruction

Above Project

control reach

Figure 1.

MAP of TROUT CREEK RESTORATION MONITORING SITES

Figure 2. Restoration reaches on Trout Creek above and below the confluence of Cold Creek (coming in from the right side of the aerial photo).

Figure 3. Upstream control reach (above crossing of Pioneer Trail Road) on Trout Creek, sampled during post-project phase.

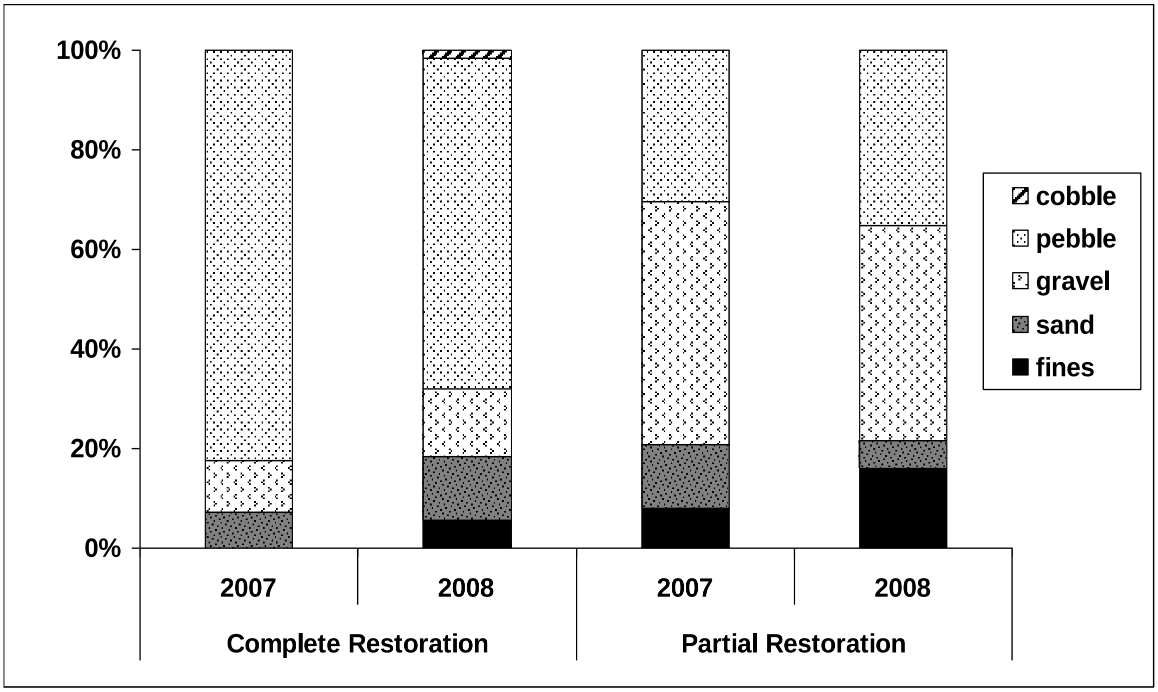

Figure 4. Substrate composition in riffles of reconstructed reaches of Trout Creek.

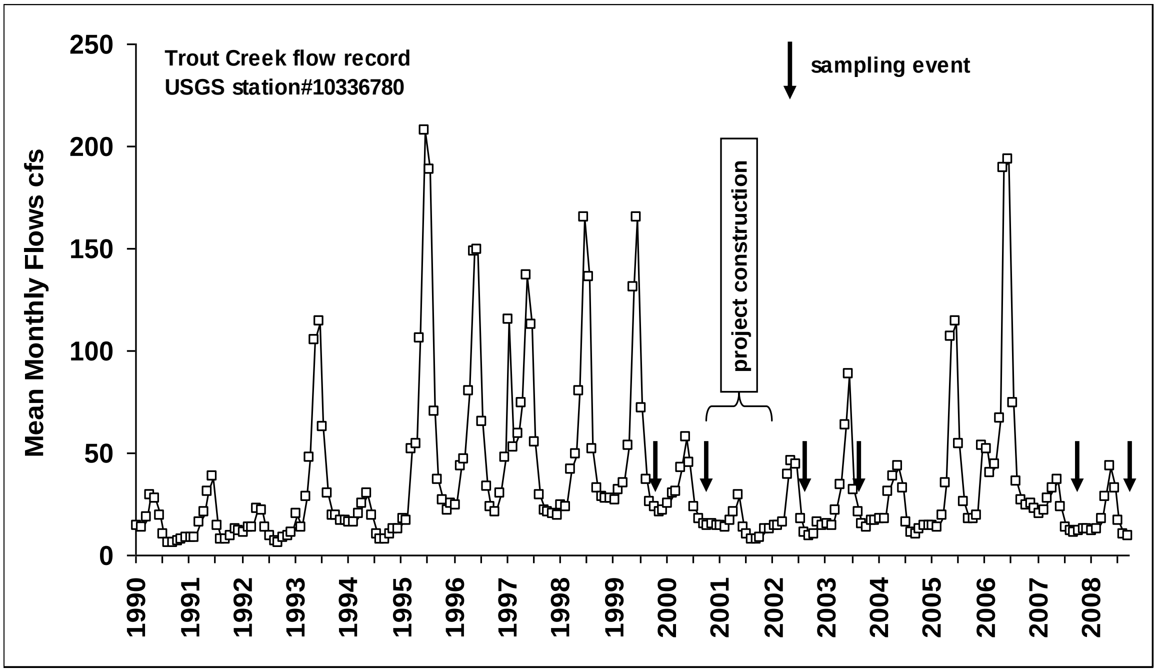

Figure 5. Record of monthly hydrograph from Trout Creek from 1990 into the fall of 2008. Peak flows typically occur in May-June, sampling occurred in late September of each year (at arrows). Gauge is located at Martin Avenue, below the project area (top of Figure 1).

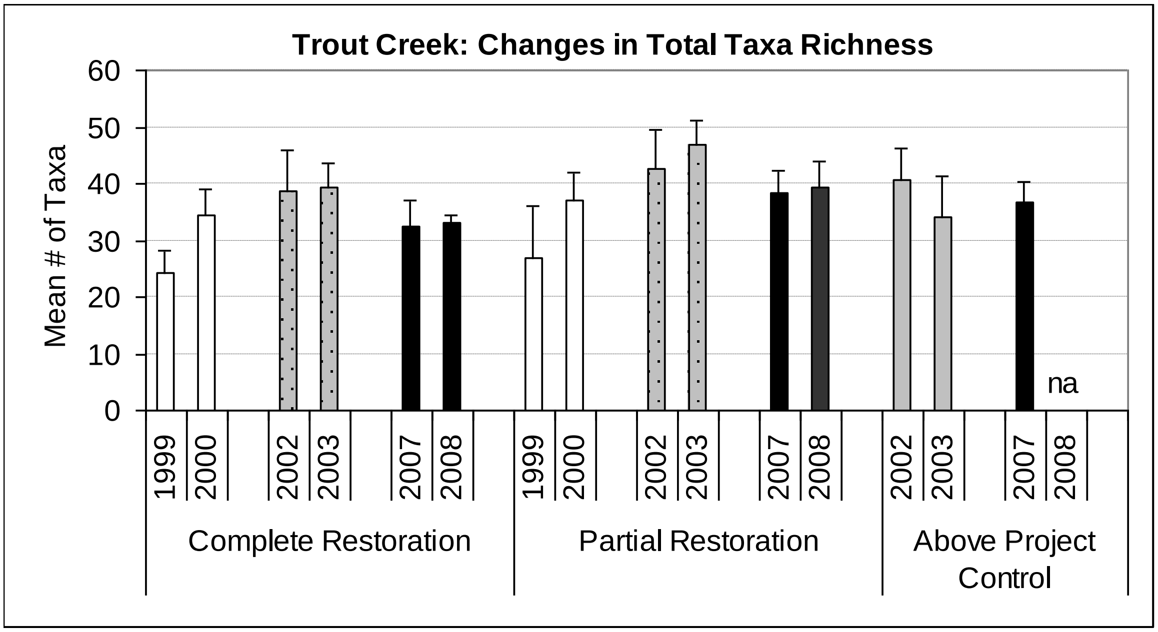

Figure 6. Total taxa richness diversity before restoration (open bars), initial post-restoration (grey bars), and after >5 years since project completion (black bars), for study sites on Trout Creek.

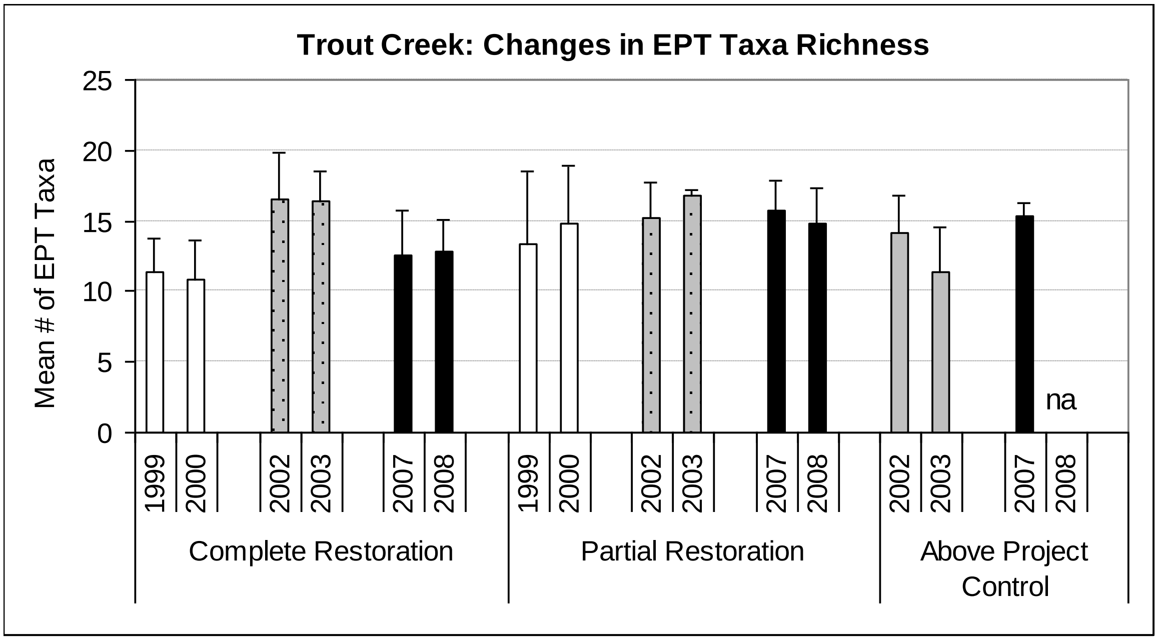

Figure 7. EPT taxa richness diversity before restoration (open bars), initial post-restoration (grey bars), and after >5 years since project completion (black bars), for study sites on Trout Creek.

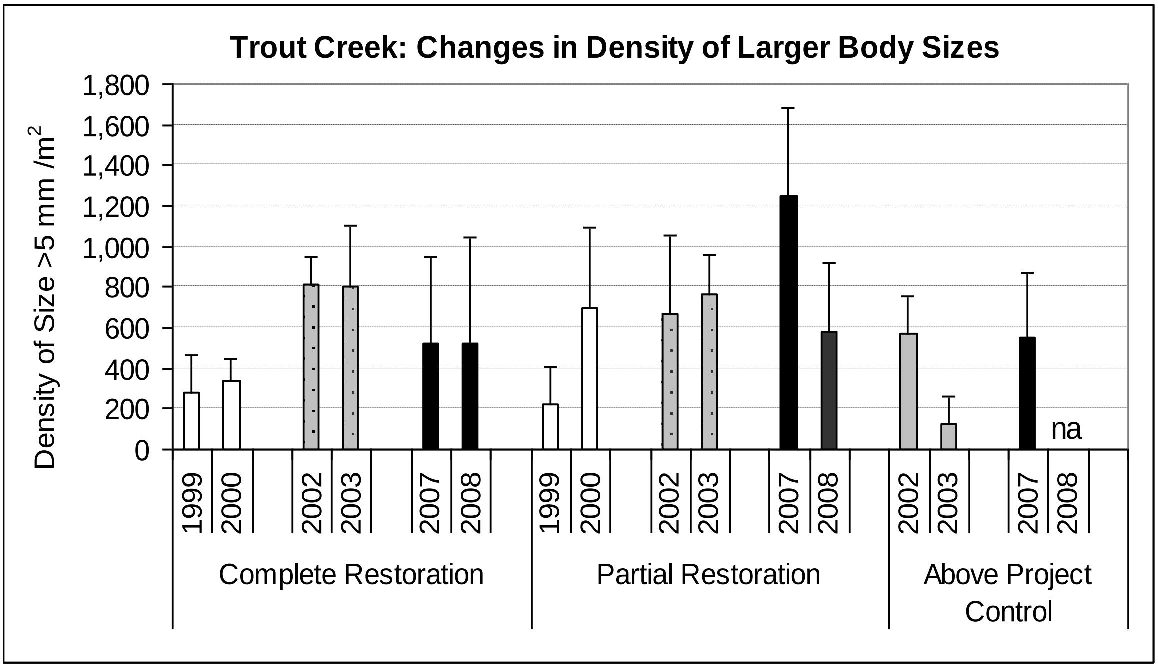

Figure 8. Density of larger benthic invertebrates (>5 mm) before restoration (open bars), initial post-restoration (grey bars), and after >5 years since project completion (black bars), for study sites on Trout Creek.

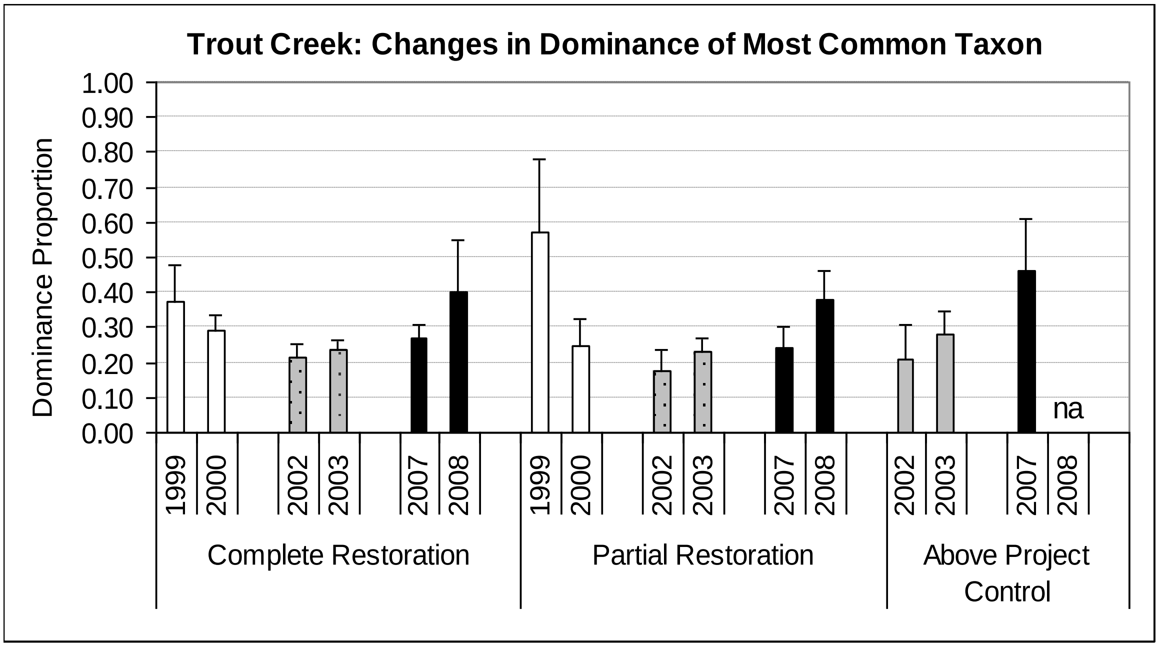

Figure 9. Dominance or proportion of total community comprised of a single taxon before restoration (open bars), initial post-restoration (grey bars), and after >5 years since project completion (black bars), for study sites on Trout Creek.

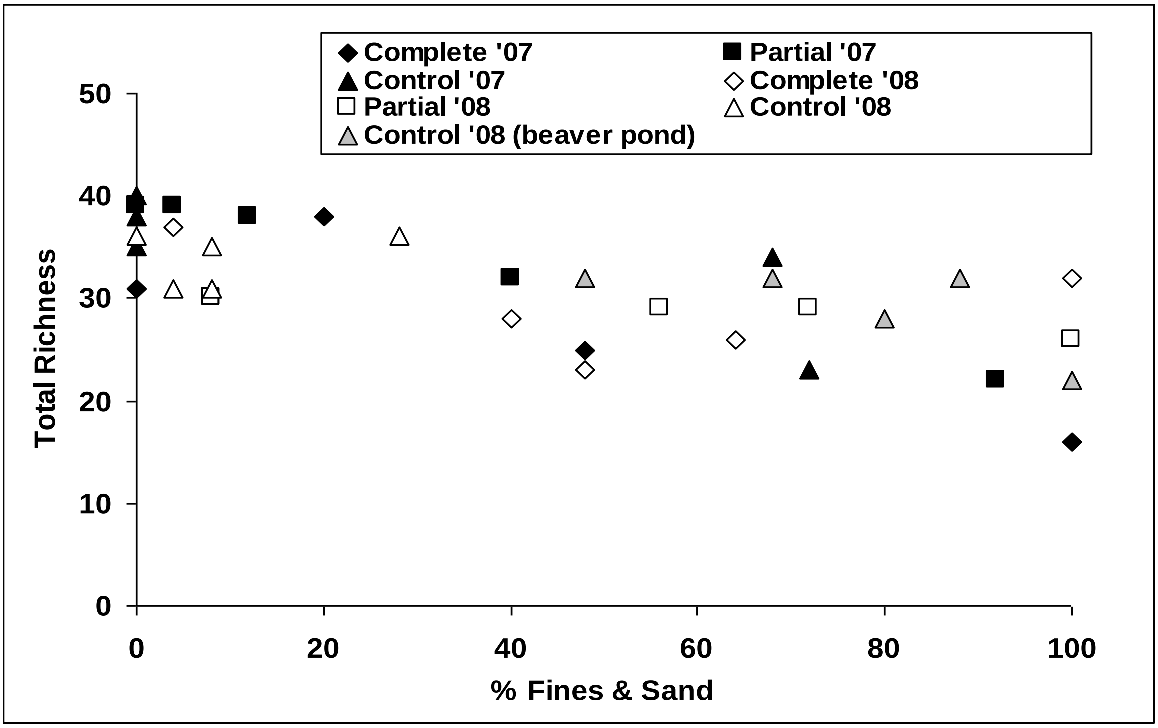

Figure 10. Richness diversity of total taxa from quadrat samples with grid-frame counts of FS cover. Samples taken from a range of conditions in all reaches in 2007 and 2008.

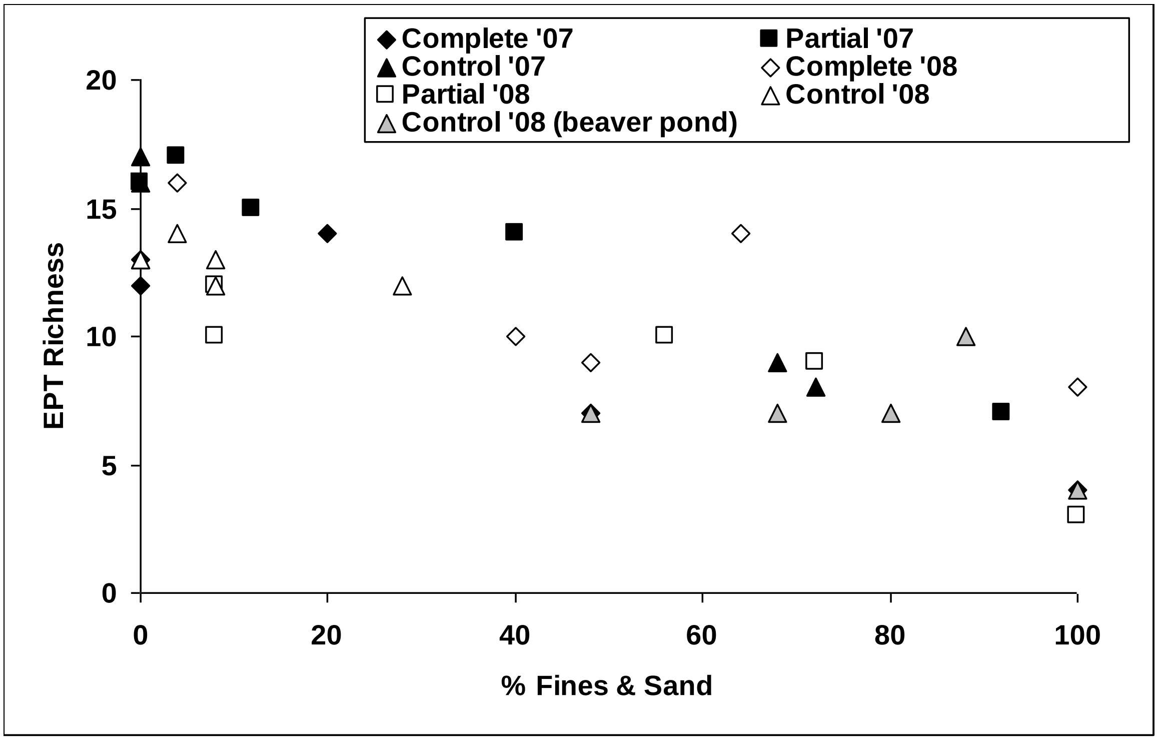

Figure 11. EPT taxa richness diversity from quadrat samples with grid-frame counts of FS cover. Samples taken from a range of conditions in all reaches in 2007 and 2008.

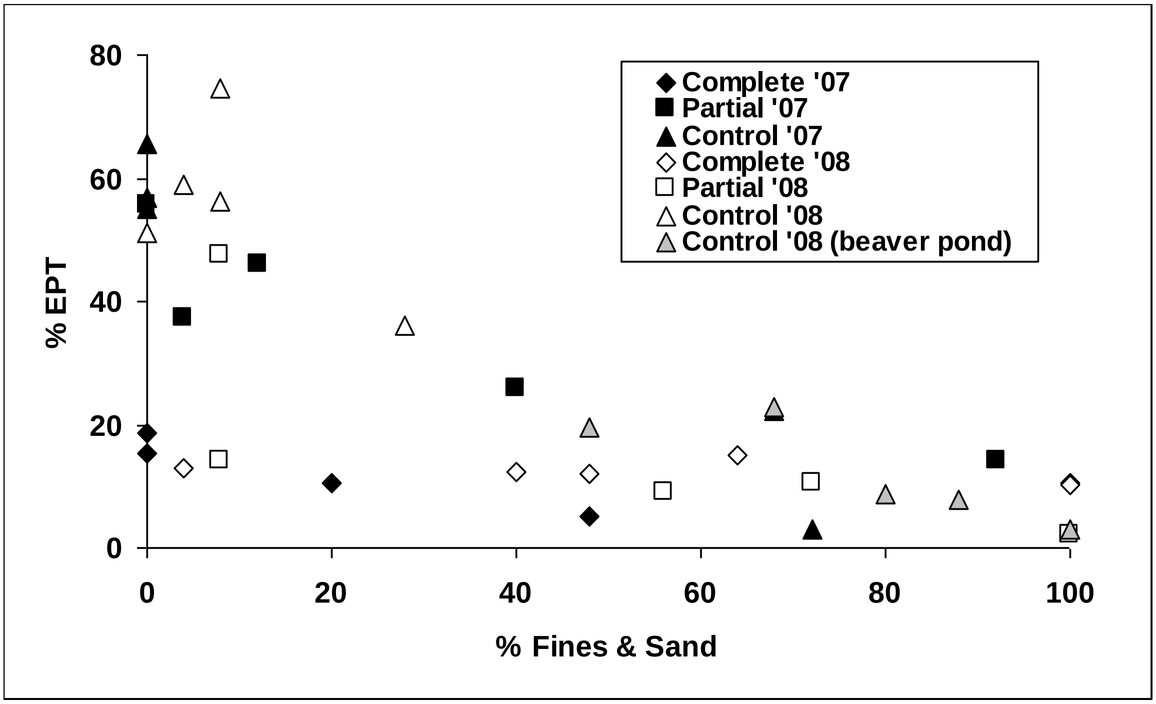

Figure 12. Percent EPT from quadrat samples with grid-frame counts of FS cover. Samples taken from a range of conditions in all reaches in 2007 and 2008.

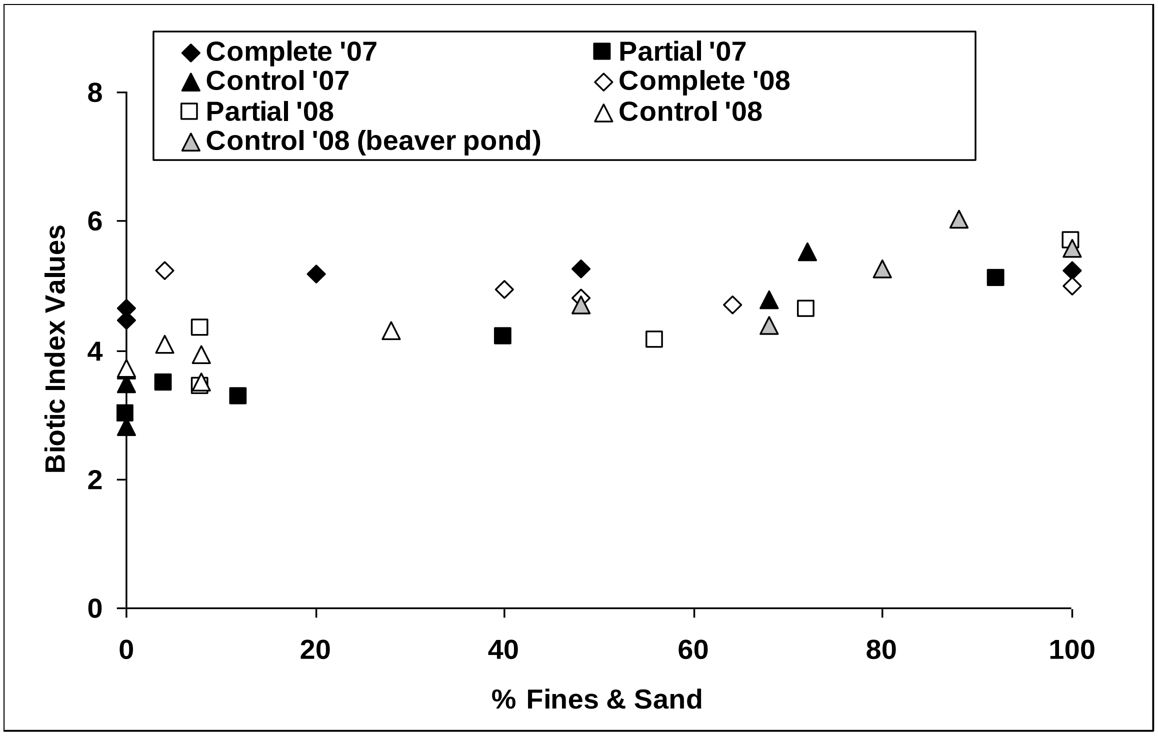

Figure 13. Biotic index of community tolerance from quadrat samples with grid-frame counts of FS cover. Samples taken from a range of conditions in all reaches in 2007 and 2008.

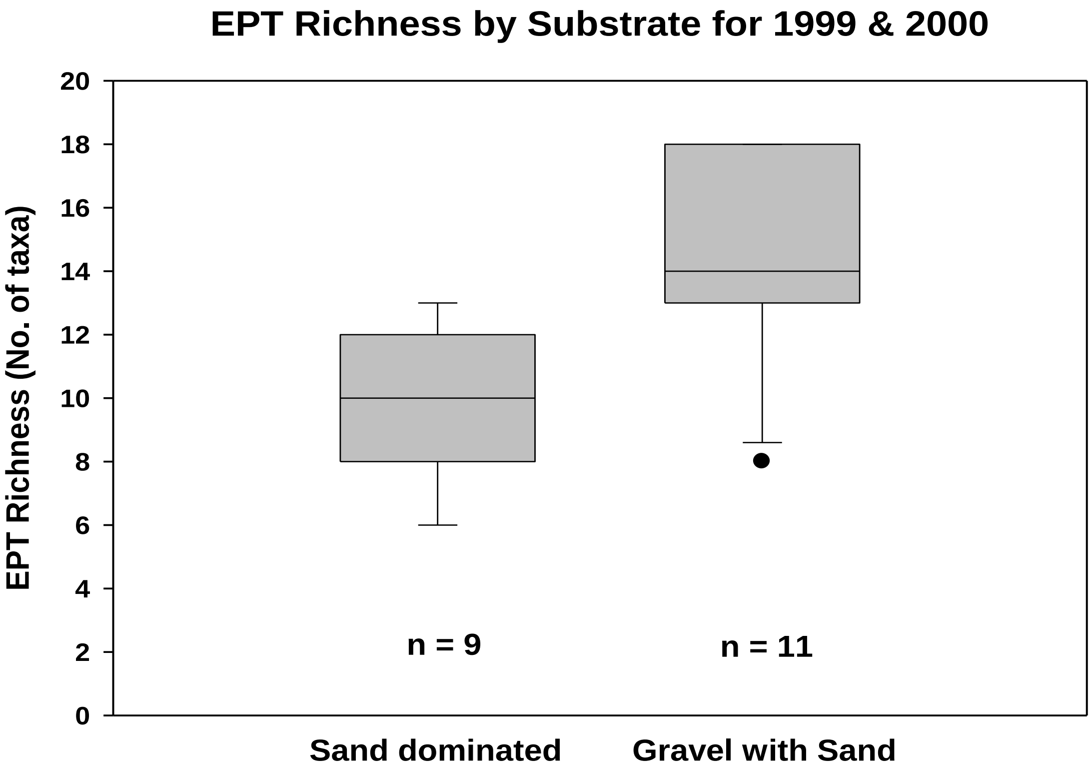

Figure 14. Richness diversity of EPT taxa on different substrate types sampled in the pre-project channelized stream segments (above and below Cold Creek) in 1999 and 2000 shown in box (25th-75th percentiles, median line) and whisker plots.