OGMCOAL - Fwd: Crandall Canyon Mine Macroinvertebrate Study - June 2010

From: Daron Haddock
To: Ingrid Campbell
Date: 1/31/2011 10:12 AM
Subject: Fwd: Crandall Canyon Mine Macroinvertebrate Study - June 2010
Attachments: june 2010 complete macro report.pdf

Forwarded FYI-

>>> "Marrelli, Dana" <dmarrelli@coalsource.com> 1/25/2011 9:29 AM >>>
Hello,
I have attached the Crandall Canyon Mine Macroinvertebrate Study for June 2010.
The field work has been done for the Fall 2010 study, but we do not have the results back from the lab.
I will forward the report as soon as I receive it.
Thank you,

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Crandall Canyon Mine Macroinvertebrate Study June 2010

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January 17, 2010

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Crandall Canyon Mine Macroinvertebrate Study June 2010

1.0 Introduction

On June 7, 2010, JBR Environmental Consultants, Inc. (JBR) collected benthic macroinvertebrate samples from Crandall Creek, which is located near Huntington, Utah. The samples were collected both upstream and downstream of an underground coal mine operated by Genwal Resources, Inc. (Genwal) and permitted by the Utah Division of Oil, Gas and Mining (DOGM) through its coal mining program. The mine, known as the Crandall Canyon Mine, has been idle for more than three years. However, intercepted groundwater continues to discharge from the sealed portals and Crandall Creek is the receiving stream for the discharged water.

In 2009, Genwal hired JBR to sample the creek's benthic macroinvertebrates and assess the resultant data to determine whether or not the mine discharge is affecting Crandall Creek's aquatic community. JBR collected the first set of samples on September 16, 2009 and reported the study results in early 2010 (JBR 2010). In that report, we recommended some changes to the sampling methodology. Those recommendations were implemented during the June 7, 2010 monitoring event, results of which are reported herein. After giving some relevant background information, this report goes on to describe the June 2010 data collection and analysis methodology, provides the laboratory data, and discusses the study results to date.

1.1 Background

The Crandall Canyon Mine began discharging groundwater in late 1995, and did so more or less continuously for 12 years. While the mine was operating, groundwater entering the underground mine had to be collected and pumped to the surface to ensure safe operating conditions. Except for some passive in-mine settling, this groundwater was not treated prior to being released to Crandall Creek. Its discharge was regulated by the Utah Division of Water Quality (DWQ) through the Utah Pollutant Discharge Elimination System (UPDES) permit program, and water quality limits were imposed to ensure that Crandall Creek and downstream water resources were protected. With very few exceptions, those permit limits were met during the 12 years of near-continuous pumped groundwater discharge.

Subsequent to mine closure in mid-2007, the pumps and other infrastructure were removed from underground and the portals were sealed. Without active pumping, groundwater discharge ceased. The UPDES permit continued to be in effect, and the "no discharge" status was reflected on the monthly discharge monitoring reports. Genwal projected that recovering groundwater levels would never reach the portal elevations and, therefore, this water would never again discharge from the mine. However, after about three months with no discharge, groundwater unexpectedly began flowing out of the mine from beneath the portal seals. It has continued without interruption since that time.

While the more recent gravity-flow rates have been similar to the flow rates that prevailed during the operational pumping, water quality changed once the discharge resumed in early 2008. After several weeks during which samples collected from the initial gravity discharge contained elevated total dissolved solids (TDS) and certain metals (zinc, nickel, iron), concentrations of most of the measured constituents diminished and soon returned to a near-normal level. Iron concentrations were the exception – total iron increased from <0.05 mg/L, which was a typical concentration during the active mining and groundwater pumping activities, to about 1.0 to 2.0 mg/L immediately after the gravity discharge began. After several months, total iron concentrations appeared to stabilize at about 0.5 mg/L, but in September 2008, iron again began to climb to a concentration that reached as high as 5.1 mg/L. (The discharge water's pH remained near-neutral or slightly alkaline throughout this period and no other metals were found to be elevated.) The iron-laden discharge also resulted in iron-stained streambed substrate along an approximate 3,000-foot reach of Crandall Creek immediately downstream of where the groundwater discharge enters the stream. In early 2010, Genwal began operating an iron treatment system, and total iron concentrations have consistently been kept at less than 1.0 mg/L since March 2010. However, the iron-stained substrate is still present.

Crandall Creek is a small perennial stream that drains a 2,500-acre watershed located within the bounds of the Manti-La Sal National Forest and conveys flow to Huntington Creek. Genwal's intercepted groundwater enters Crandall Creek approximately 1.5 miles upstream of the confluence of those two streams (Figure 1). Both Crandall Creek and Huntington Creek support aquatic resources, and Huntington Creek is a noted trout fishery. These fish rely in part upon a healthy and abundant macroinvertebrate community as a food source. The Utah Division of Wildlife Resources (DWR), in a 1995 letter to Genwal, indicated that Crandall Creek had a small resident cutthroat population and was also important spawning habitat for trout in Huntington Creek (Moretti 1995).

Iron is an essential element for both fish and the macroinvertebrates upon which they rely as a food source, as well as all other terrestrial and aquatic biota. However, in the aquatic environment, iron can be harmful or even toxic depending upon its chemical form and its concentration. Largely as a function of the water's pH and dissolved oxygen content, iron is typically present in either an insoluble ferric form or a soluble ferrous form. It can also be present as an integral component of individual sediment particles whose parent rock contains iron. While the chemistry of iron in water can be complex and is not fully discussed here, it is important to note a couple of key points. Commonly, iron found in groundwater is in the ferrous form, but when exposed to the atmosphere, this dissolved iron often oxidizes to the ferric form and then precipitates (Hem 1985). These iron precipitates can physically degrade aquatic habitat by covering bed substrate and organic matter; the covering can also reduce food sources for both fish and macroinvertebrates. The particulates (either from precipitates or fine sediments) can clog an organism's gills or filtering apparatus, and thereby hinder oxygen intake. Iron can also precipitate directly onto an organism's body, physically harming its body structure and function. In its soluble (dissolved) form, iron can also be toxic when ingested by aquatic life; this is commonly the mechanism of impact in waters where acid mine drainage often elevates the dissolved concentrations of numerous heavy metals including iron. Peplow and Edmunds (1999) provide a comprehensive review of acid mine drainage and its effects on macroinvertebrates.

Taking all of these things into account, EPA has conservatively recommended a (nationwide) criterion (chronic) of 1.0 mg/L iron, as part of their published National Recommended Water Quality Criteria for the protection of aquatic life (EPA 2009). Following EPA's recommendation, Utah, in its Water Quality Standards given at U.A.C. R317-2-14, adopted a maximum dissolved iron criterion of 1.0 mg/L for all streams that are classed for aquatic wildlife beneficial uses. DWQ set the Crandall Canyon Mine's UPDES permit limit at 1.0 mg/L total iron to provide protection at an even more conservative level than the stream standard without accounting for any dilution effects.

1.2 Purpose of Study

In 2009, due to ongoing elevated iron concentrations associated with Genwal's permitted groundwater discharge, the relevant regulatory (DWQ, DOGM) and management (U.S. Forest Service (USFS), DWR) agencies became concerned about the potential impacts of the discharge on aquatic life. In mid-August, 2009, DOGM issued a Citation for Non-Compliance (#10044) that required Genwal to engage a qualified biologist to collect macroinvertebrate samples from Crandall Creek twice each year (in June and September) and prepare comprehensive reports that describe and evaluate each study's results.

This report is intended to continue to meet the DOGM requirements for the biannual sampling and reporting. Its purpose is to assess both the spatial and temporal variation in the macroinvertebrate community of Crandall Creek with the goal of determining what, if any, iron-caused impacts have occurred in that community and whether or not improvements follow with the discharge of treated water.

In addition, study results can be used to assess the overall health of Crandall Creek. Because they are sensitive to water quality and respond quickly to stressors, including water pollutants, and also because they are fairly stationary within a given stream feature, benthic macroinvertebrates integrate variations in water quality or other habitat components (Davis et al 2001). Numerous indices and metrics such as diversity, taxa ratios, richness, and the like can be calculated and used to assess the macroinvertebrate community at a given site in regard to its ability to tolerate environmental pollution. The presence or absence of a specific macroinvertebrate taxon can indicate a perturbation that may not have been captured by grab samples analyzed for specific water chemistry. Ideally, this study may provide insight on the general condition of Crandall Creek as well as the iron-specific impact (if any) of Genwal's discharge on the creek's aquatic community.

2.0 Previous Studies

The macroinvertebrate samples that JBR collected on September 16, 2009 (JBR 2010) in response to the previously noted DOGM citation were not the first such samples collected in Crandall Creek. In 1980, prior to the mine start-up, macroinvertebrate samples were collected at several locations along Crandall Creek. A follow-up macroinvertebrate study was conducted in 1994, after several years of mine operations; at the time of sampling, groundwater had not been intercepted in a quantity sufficient to require surface discharge. In addition, the USFS samples benthic macroinvertebrates in Huntington Creek every five years. Brief descriptions of each of these other studies were given in the previous study report (JBR 2010).

For the more recent study, intended to comply with DOGM Citation #10044, macroinvertebrate samples were collected both upstream and downstream of the Crandall Canyon Mine in September 2009 (JBR 2010). The uppermost sampling reach (CRANDUP-01) was upstream of any influence of the mine's groundwater discharge, thus serving as a reference reach. The middle reach (CRANDMD-02) included the area immediately downstream of the discharge location where flow mixing, aeration, and iron precipitation were occurring. The downstream reach (CRANDLWR-03) was a short distance upstream of the confluence with Huntington Creek, outside of the area with a visibly impacted substrate. Sample collection methodology was generally based upon the reach-wide, multi-habitat sample methodology outlined in the (EMAP) Field Operations Manual for Wadeable Streams (EPA 2001), slightly modified as per discussions with the Manti-La Sal National Forest fisheries biologist.

Overall, the study results indicated that the Crandall Creek macroinvertebrate community downstream of the mine's discharge appeared to have been negatively impacted. Further, results indicated that the impact may not have been confined to immediately downstream of the discharge; instead it appeared to have occurred as far down as the lowermost sampled site near the mouth of Crandall Creek. However, both downstream reaches of the creek were still supporting a variety of macroinvertebrates, indicating that the discharge had not completely decimated macroinvertebrate populations. Last, the study results indicated that even Crandall Creek upstream of the mine discharge was in less than optimum condition, based on the sampled macroinvertebrate community.

3.0 Site Locations and Descriptions

3.1 Site Locations

The June 2010 macroinvertebrate samples were collected at the same three sites as were identified for the September 2009 sampling event (Figure 1). The uppermost site (CRANDUP-01) is near the upstream edge of the upper parking lot and outside of any influence of the mine's groundwater discharge. Its downstream endpoint is approximately 2 meters above the flow measurement flume and the reach extends upstream approximately 150 meters. The middle site (CRANDMD-02) includes the area immediately downstream of the discharge location where flow mixing, aeration, and iron precipitation are occurring. Its upstream endpoint (Transect K) is approximately 5 meters downstream of the discharge point, with the reach extending downstream approximately 150 meters. The downstream site (CRANDLWR-03) was chosen to be approximately 2 meters upstream of the mine road crossing near the confluence of Crandall Creek and Huntington Creek, and its reach extended upstream from that point approximately 150 meters.

As per EMAP protocol, during the September 2009 study 11 cross-section transects were established at regular intervals within each of these reaches, and were flagged and marked (JBR 2010). These same transects were used in the June 2010 study.

3.2 Site Descriptions

The report that presented the 2009 study results (JBR 2010) described stream morphology, substrate, and riparian vegetation. During the June 2010 sampling, general stream morphology and riparian vegetation was observed to be the same as in September 2009. However, high flow accompanied by high water turbidity as a result of spring runoff was obscuring the channel substrate and submerging certain morphological features. Despite the high flow, it was possible to make some general observations on substrate based upon the area of substrate that was physically disturbed for each subsample.

The substrate at CRANDUP-01 appeared typical of a comparable small mountain stream. Fine sediment was present in all slow water areas (i.e., beaver ponds), with a mix of small cobble and gravel at other sites. Of the five samples taken for the multi-habitat sample (see Section 4.1.1 for methodology), the substrate was dominated by fine sediment (<2 mm) at two locations, coarse substrate (64-4,000 mm) at two locations, and gravel (2-64 mm) at a single location. Of the eight targeted riffle samples (see Section 4.1.2), five had a gravel substrate, and three had a coarse substrate. Although embeddedness was not measured, substrate particles at all sample locations appeared to generally have a low degree of embeddedness.

The substrate at CRANDMD-02 was similar to CRANDUP-01, with substrate in the five multi-habitat samples dominated by gravel (three locations), with coarse substrate and fine sediment at one location each. At the eight targeted riffle samples, substrate was dominated by gravel (seven locations), with only one location having coarse substrate. However, iron-stained, filamentous algae were present to some degree on the substrate at four of the five multi-habitat samples and seven of the eight targeted riffle samples. The degree to which filamentous algae covered the substrate at the locations noted above was difficult to discern due to the turbid water, but it could be felt on the substrate and was present in the kick net after sampling. Also, iron staining was present on the substrate at two of the five multi-habitat samples and three of the eight targeted riffle samples.

The substrate types at CRANDLWR-03 were generally similar to the other two sites, with gravel, coarse particles (two locations each), and fine sediment (one location) at the multi-habitat sample locations. There were three targeted riffle locations with coarse substrate and five with gravel. However, unlike the two upstream sites, the substrate particles at CRANDLWR-03 sample locations were generally calcified and cemented in place.

June 7, 2010 view of CRANDUP-01, looking upstream

As already mentioned, the most noticeable change in site conditions between the September 2009 and the June 2010 sampling events was the much higher flow rate. Although there is not a stream gage on Crandall Creek, it appears that peak flow for the year likely occurred on the same day as sampling. This is supported by data from the stream gage on Huntington Creek below the Huntington power plant (approximately 8 miles downstream of the Crandall Creek – Huntington Creek confluence), where peak flows occurred on June 6, 2010. The following photos provide a visual description of the site conditions at the time of sampling.

June 7, 2010 view of CRANDMID-02, looking downstream

June 7, 2010 view of CRANDLWR-03, looking downstream

4.0 Methods

JBR collected two macroinvertebrate samples, a multi-habitat sample and a riffle sample, from each of the locations described above. Sample collection for the multi-habitat sample was the same as described in JBR 2010 and was based upon the reach-wide sample methodology outlined in the (EMAP) Field Operations Manual for Wadeable Streams (EPA 2001). The specific application of this sample methodology was modified as per discussions with the Manti-La Sal National Forest fisheries biologist who is responsible for USFS macroinvertebrate sampling on the Forest. Section 4.1.1 below describes the modified methodology. The riffle sample was collected following the EMAP targeted riffle sample methodology. Section 4.1.2 below describes the targeted riffle methodology.

The collected and preserved samples were then delivered to the National Aquatic Monitoring Center (the BugLab) in Logan, Utah for processing and taxonomic identification. The BugLab is a cooperative venture between the U.S. Bureau of Land Management (BLM) and Utah State University. Its focuses on processing macroinvertebrate samples, and processes a large percentage of the samples collected on federal land in the western U.S. The DWQ Monitoring Manual (DWQ 2006) specifies that macroinvertebrate samples be processed by the BugLab. DWQ's methodology is described in Section 4.2., and the BubLab's complete report (Miller 2009) is attached as Appendix 1.

4.1 Sample Collection Methods

4.1.1 Modified Multi-Habitat Sample Collection

The EMAP methodology for the multi-habitat sample specifies that one macroinvertebrate subsample is taken at each of the eleven transects within the delineated reach. These subsamples are then combined into a composite sample. The sample location at the first transect is randomly selected using a six sided dice (i.e., sample is taken at a location 25, 50, or 75 percent of the distance from the channel's left edge depending upon the roll of the dice), with the sampling point at subsequent transects chosen systematically. However, the Manti-La Sal National Forest regularly collects only 4-5 macroinvertebrate subsamples within each reach, which are then combined into a single composite sample. The 4-5 subsamples are collected from as many habitat types as possible in order to sample the full range of habitat types present within the reach. In order to be more consistent with the methodology used by the Forest, the EMAP reach-wide, multi-habitat sample methodology was modified to only include five samples. However, to keep the modified methodology as similar to EMAP procedure as possible (which improves consistency and keeps the samples as replicable as possible), the five samples were collected at every other transect starting with Transect B, where possible. The exceptions were at CRANDUP-01 and CRANDMD-02. At CRANDUP-01, the furthest upstream sample was moved to the uppermost transect (transect "K") due to high flow at transect "J". At CRANDMD-02, one of the samples was taken at an adjacent transect in order to sample a large run that was different than other habitat types within the reach. At CRANDLWR-03, sampling at every other transect sufficiently captured the range of habitat types present in the reach.

As Crandall Creek is a narrow stream at all sites, and particularly CRANDUP-01, sample location at each transect was not chosen randomly or systematically, rather the site that was most suitable to sampling was chosen (i.e., the location that allowed placement of the sampler). All sampling was conducted using a 500-micron mesh D-frame kick net. In cases where a transect directly intersected a beaver dam, the sample was taken in the same location as in 2009 (i.e., below the beaver dam, as sampling the lentic environment behind the dam would not have been feasible using a Surber sampler). None of thetransects directly intersected a beaver pond. The samples were collected in a downstream-to-upstream order to avoid including organisms dislodged from upstream samples.

For sampling transects the following procedures were utilized.

1. The kick net was quickly and securely positioned on the bottom of the channel with the opening facing upstream. Gaps between the frame and substrate were minimized.

2. The sample area was checked for heavy organisms, such as mussels and snails. Any such organisms were placed into the composite sample bucket. All substrate particles larger than golf balls and that were at least halfway into the sample area were picked up and rubbed with hands or a brush to dislodge organisms into the net. Particles that were more than halfway outside the sample area were pushed aside and not sampled. After particles were washed, they were placed outside of the sample area.

3. Starting at the upstream end of the sample area, the remaining substrate was kicked vigorously for 30 seconds. The water was allowed to clear before removing the net from the water column.

4. The net was lifted out of the water then quickly immersed several times to concentrate sample material in the end of net. Care was taken not to further disturb channel substrate with the net, or allow for organisms to escape.

5. The net was inverted into the composite bucket, which had been ¼ to ½ filled with stream water. The net was inspected for clinging organisms and forceps were used to place these organisms into the bucket.

6. The net was rinsed in the stream before moving to the next transect.

7. The dominant substrate and habitat type were recorded on the field data sheet.

After sampling was completed at the five transects, the following procedures were employed to prepare a multi-habitat composite index sample to be sent to the lab.

1. The contents of the sample bucket were manually swirled to separate organisms from the sample material. The sample material was poured through a 300-micron mesh sieve and the inside of the bucket was inspected for organisms. Organisms were rinsed off any large objects (rocks, organics, etc.) with a spray bottle filled with stream water before discarding the objects. Additional serial bucket rinses were employed until no remaining organisms were noted in the sample bucket.

2. Using the spray bottle, the sample material inside the sieve was rinsed to one side and transferred into the sample container using as little water as possible. The sieve was carefully examined for clinging organisms and these were placed into the sample bottle using forceps.

3. The sample container was completely filled with 95-percent ethanol so that the final concentration was between 75 and 90 percent. The container was slowly tipped horizontally and rotated to allow complete mixing of the ethanol and sample.

4. Sample containers were labeled with the information listed below. A duplicate of this label was written on ethanol-safe paper and placed inside of the container. Samples were then delivered to the BugLab for analysis.

    * Type of Sample (e.g., multi-habitat or riffle)
    * Stream Name
    * Site I.D.
    * Forest (Manti-La Sal National Forest)
    * Date and Time of Collection
    * Number of Jars

4.1.2 Targeted Riffle Sample Collection

The EMAP methodology for the targeted riffle sample specifies that eight macroinvertebrate subsamples be taken within available riffle macrohabitat units within the delineated reach. These subsamples are then combined into a composite targeted riffle sample. The sample locations are identified by surveying the delineated reach prior to sampling to visually estimate the number and area of riffle units. If the reach contains more than one distinct riffle macrohabitat unit but less than eight, the eight sampling points are allocated among the units to spread the effort throughout the reach as much as possible, with it possible to collect more than one kick sample from a single riffle unit. If the number of riffle macrohabitat units is greater than eight, one or more habitats is skipped at random. At all sites in June 2010, the number of riffle macrohabitat units was between one and eight. As a result, several samples were taken within the same unit at each site. Within each riffle unit, EMAP specifies that the sample locations be chosen at random from nine equal quadrats (visually estimated). However, as already noted, Crandall Creek is a narrow stream at all sites, and particularly CRANDUP-01.

As a result, the riffle samples from each macrohabitat unit were not chosen randomly, rather the site that was most suitable to sampling was chosen (i.e., the location that allowed placement of the sampler). The samples were collected in a downstream-to-upstream order to avoid including organisms dislodged from upstream samples.

Once locations were chosen, samples were collected and composited following the same procedures outlined for the modified multi-habitat sample.

4.2 Analysis Methods

As noted above, the BugLab identified the taxa represented in the macroinvertebrate samples that JBR collected. The lab processed the samples using methods similar to those recommended by the United States Geological Survey (Cuffney et al 1993, as referenced in Judson and Miller 2010). Because the samples contained fewer than 600 organisms, 100 percent of the sample material was processed (if more than 600 organisms had been present per sample, a sub-sampling procedure would have been used). Generally, organisms were removed under a dissecting microscope at 10-30 power and separated into taxonomic orders. Organisms were then identified to a lower taxonomic level (family, genus, and/or species, as feasible). Once identified and counted, samples were placed in 20-ml glass scintillation vials with polypropylene lids in 70% ethanol, given a catalog number, and retained. The results report (Judson and Miller 2010) includes a complete list of taxa and the number of organisms by taxa (see Appendix 1).

The BugLab also provided data summaries and calculated various indices and metrics (Judson and Miller 2010), many of which will be discussed in the results discussion. These include: abundance, total taxa richness, EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa richness, Ephemeroptera taxa richness, Plecoptera taxa richness, Trichoptera taxa richness, percent EPT abundance, percent Ephemeroptera abundance, percent Chironomidae abundance, Intolerant taxa richness, percent tolerant organisms, Hilsenhoff Biotic Index, percent contribution of the dominant taxon, clinger taxa richness, percent clinger abundance, percent collector-filterer abundance, and percent scraper abundance. Definitions/descriptions of these individual metrics and their usefulness are provided below and are taken almost verbatim from the BugLab's data report (Judson and Miller 2010). More detail and references for how calculations were made are also given in their report, which can be found in Appendix 1.

Taxa richness - Richness is a component and estimate of community structure and stream health based on the number of distinct taxa. Taxa richness normally decreases with decreasing water quality. In some situations organic enrichment can cause an increase in the number of pollution tolerant taxa. Taxa richness was calculated for operational taxonomic units (OTUs) and the number of unique genera, and families. The values for operational taxonomic units may be overestimates of the true taxa richness at a site if individuals were the same taxon as those identified to lower taxonomic levels or they may be underestimates of the true taxa richness if multiple taxa were present within a larger taxonomic grouping but were not identified. All individuals within all samples were generally identified similarly, so that comparisons in operational taxonomic richness among samples within this dataset are appropriate, but comparisons to other data sets may not. Comparisons to other datasets should be made at the genera or family level.

Abundance - The abundance, density, or number of aquatic macroinvertebrates per unit area is an indicator of habitat availability and fish food abundance. Abundance may be reduced or increased depending on the type of impact or pollutant. Increased organic enrichment typically causes large increases in abundance of pollution tolerant taxa. High flows, increases in fine sediment, or the presence of toxic substances normally cause a decrease in invertebrate abundance. Invertebrate abundance is presented as the number of individuals per square meter for quantitative samples and the number of individuals collected in each sample for qualitative samples.

EPT - A summary of the taxonomic richness and abundance within the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are commonly considered sensitive to pollution (Karr and Chu 1998, as referenced in Judson and Miller 2010).

Percent contribution of the dominant family or taxon - An assemblage largely dominated (>50%) by a single taxon or several taxa from the same family suggests environmental stress. Habitat conditions likely limit the number of taxa that can occur at the site.

Shannon Diversity Index - Ecological diversity is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances. The Shannon Diversity Index was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations.

Evenness - Evenness is a measure of the distribution of taxa within a community. Value ranges from 0-1 and approach zero as a single taxa becomes more dominant.

Clinger taxa - The number of clinger taxa have been found by Karr and Chu (1998, as referenced in Judson and Miller 2010) to respond negatively to human disturbance. These taxa typically cling to the tops of rocks and are thought to be reduced by sedimentation or abundant algal growths.

Long-live taxa - The number of long-lived taxa was calculated as the number of taxa collected that typically have 2-3 year life cycles. Disturbances and water quality and habitat impairment typically reduces the number of long-lived taxa (Karr and Chu 1998, as referenced in Judson and Miller 2010).

Biotic indices - Biotic indices use the indicator taxa concept. Taxa are assigned water quality tolerance values based on their tolerance to pollution. Scores are typically weighted by taxa relative abundance. In the USthe most commonly used biotic index is the Hilsenhoff Biotic Index (Hilsenhoff 1987 and 1988, as referenced in Judson and Miller 2010). The USFS and BLM throughout the western U.S. have also frequently used the USFS Community Tolerance Quotient.

Hilsenhoff Biotic Index - The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. It is best at detecting organic pollution. Families were assigned an index value from 0 (taxa normally found only in high quality unpolluted water) to 10 (taxa found only in severely polluted waters). Family level values were taken from Hilsenhoff (1987 and 1988, as referenced in Judson and Miller 2010) and a family level HBI was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. Sampling locations with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. Rather than using mean HBI values for a sample, taxon HBI values can also be used to determine the number of pollution intolerant and tolerant taxa occurring at a site. In this report, taxa with HBI values $\leq$2 were considered intolerant clean water taxa and taxa with HBI values $\geq$8 were considered pollution tolerant taxa. The number of tolerant and intolerant taxa and the abundances of tolerant and intolerant taxa were calculated for each sampling location.

USFS community tolerant quotient - Taxa are assigned a tolerant quotient from 2 (taxa found only in high quality unpolluted water) to 108 (taxa found in severely polluted waters). The dominance weighted community tolerance quotient (CTQd) was calculated. Values can vary from about 20 to 100, in general the lower the value the better the water quality.

Functional feeding group measures - A common classification scheme for aquatic macroinvertebrates is to categorize them by feeding acquisition mechanisms. Categories are based on food particle size and food location, e.g., suspended in the water column, deposited in sediments, leaf litter, or live prey. This classification system reflects the major source of the resource, either within the stream itself or from riparian or upland areas and the primary location, either erosional or depositional habitats. The number of taxa and individuals of the following feeding groups were calculated for each sampling location.

Shredders - Shredders use both living vascular hydrophytes and decomposing vascular plant tissue - coarse particulate organic matter. Shredders are sensitive to changes in riparian vegetation. Shredders can be good indicators of toxicants that adhere to organic matter.

Scrapers - Scrapers feed on periphyton - attached algae and associated material. Scraper populations increase with increasing abundance of diatoms and can decrease as filamentous algae, mosses, and vascular plants increase, often in response to increases in nitrogen and phosphorus. Scrapers decrease in relative abundance in response to sedimentation and higher levels of organic pollution or nutrient enrichment.

Collector-filterers - Collector-filterers feed on suspended fine particulate organic matter. Collector-filterers are sensitive to toxicants in the water column and to pollutants that adhere to organic matter.

Collector-gatherers - Collector-gatherers feed on deposited fine particulate organic matter. Collector-gatherers are sensitive to deposited toxicants.

Predators - Predators feed on living animal tissue. Predators typically make up about 25% of the assemblage in stream environments and 50% of the assemblage in still-water environments.

Unknown feeding group - This category includes taxa that are highly variable, parasites, and those that for which the primary feeding mode is currently unknown.

In addition, JBR used the BugLab's data set to calculate several other metrics that various literature sources consistently indicate as being potentially useful for macroinvertebrate analysis, particularly in regard to potential metals pollution. These are described below.

Ratio of Specialist Feeders to Generalist Feeders - Specialist feeders include shredders and scrapers and generalist feeders include filterers and gatherers. Generalists are typically more tolerant to environmental stressors, so their proportion often increases in response to degraded water quality or stream habitat. This ratio has been used successfully to assess impacts from mining (Mize and Deacon 2002).

Ratio of EPT to Chironomidae - Ideally, communities have a near-even distribution among all four of these major groups. The Chironimid Family, in general, is more tolerant than most of the taxa in the Ephemeroptera, Plecoptera, and Trichoptera orders (Barbour et al 1999). Therefore, this ratio can indicate environmental stress when it shows disproportionate numbers of Chironomidae (Davis et al 2001).

Percent *Baetis*, Hydropsychidae, and Orthocladinae; Ratio of *Baetis* to all Ephemeroptera – These two similar measures express the documented higher tolerances of *Baetis*, Hydropsychidae, and Orthocladinae, than other members of their families. Mize and Deacon (2002) among others have used the presence of these taxa when assessing environmental conditions specific to mining (some studies have found the opposite conclusion with *Baetis*; however, the majority appear to consider it one of the more tolerant of the mayflies).

Percent Heptageniidae, Chloroperlidae, and *Rhyacophila*; Ratio of Heptageniidae to all Ephemeroptera – Similarly to the above-noted tolerant taxa, Heptageniidae, Chloroperlidae, and *Rhyacophila* were considered by Mize and Deacon (2002) when assessing elevated trace metals impacts. Heptageniidae, Chloroperlidae, and *Rhyacophila* were chosen due to their apparent sensitivity to such elements, thus their absence can indicate poor water quality. Many other authors have associated a lack of Heptageniidae organisms, in particular, with heavy metals pollution (i.e. Kiffney and Clements 1994).

As with analysis of any set of macroinvertebrate data, multiple metrics and their predicted response to perturbations (as given by EPA (2009a) and others in the scientific community) will be relied upon to make a finding of impact or nonimpact in regard to Genwal's groundwater discharge and Crandall Creek. Whether looking at data from an individual sample, comparing data from different sites for a spatial assessment, or examining temporal changes, no one metric can ever be presumed to tell the whole story. First, there is typically some natural variability in community makeup, so reliance on a single metric can be misleading. Further, some metrics are better at ascertaining specific conditions than others (i.e., organic pollution versus metals pollution). For these reasons, most researchers use a variety of metrics and would expect to see similar indications in several of them before making a conclusion regarding impact to a given site. In contrast, there is some redundancy among metrics because they use at least some of the same data. EPA (Barbour et al 1999) and others have developed techniques for combining various metrics into a single index, and also for ranking sites based upon individual metrics in a way that a potentially impacted site can be compared to reference sites (known to be unimpacted). In this study, the low number of sample sites, lack of replicates, and inadequate information on historical baseline make these techniques impossible or impractical to use. Further, the natural variability of any of one these metrics is not known, so it is difficult to determine whether a difference between sites as shown by one metric is due to degraded conditions or simply a reflection of natural variability. While a data set conducive to statistical handling (assigning confidence limits, assessing significance, etc.) would be ideal, and may be available as sampling continues in the future, those types of data do not currently exist.

Instead, individual metrics were calculated for each site and graphed to provide an easy visual means of comparison (Appendix 2). Although some metrics are not independent of each other, there was a specific intent to choose metrics that are of different types (i.e., tolerance as measured by CTQd, community composition as measured by EPT abundance, feeding mechanism as measured by specialist-to-generalist ratio), as recommended by EPA (Barbour et al 1999). Metrics that would be expected to decrease as site conditions worsen (i.e., richness) are shown in blue and those that would be expected to increase as site conditions worsen (i.e., HBI) are shown in green, further facilitating visual interpretation. Comparisons between CRANDUP-01 and CRANDMD-02, across matrices, allow an assessment of whether conditions are degraded below Genwal's discharge. The presumption is that if multiple matrices indicate the same trend (i.e., impact), there is a greater likelihood that (1) there is a degradation between sites; and (2) the mine discharge is responsible for the degradation. Similarly, comparisons between CRANDMD-02 and CRANDLWR-03 can be made to assess whether there is a spatial limit to the degradation (recovered conditions downstream).

5.0 Results and Discussion

The laboratory results report that was prepared by the BugLab (Judson and Miller 2010) is provided in full as Appendix 1. That report includes the raw data (taxonomic lists of organisms that were sampled, counts, etc.) as well as numerous tables giving various metrics and indices that the lab calculated based upon the data. The BugLab's report (Judson and Miller 2010) does not discuss or interpret the study results. This section focuses on those tasks, beginning with a brief summary of the data and a general discussion of the results.

A total of 65 operational taxonomic units (OTUs) were identified in the 6-sample sets, compared to a total of 57 OTUs identified in the September 2009 3-sample set. The number of families (28) was the same in both the 2009 and 2010 sample sets, but the number of genera increased from 33 to 46. All of the insect orders most commonly found in macroinvertebrate communities (Coleoptera, Diptera, Ephemeroptera, Plecoptera, and Tricoptera) as well as individuals from some non-insect classes were represented in both sample sets.

The greater number of genera found in the June 2010 sampling event may be attributed to the fact that targeted riffle samples were collected in addition to the multi-habitat ones. First, collecting both targeted riffle and multi-habitat samples resulted in sample collection over a larger area, which could increase the odds of collecting members of a less abundant genus. And, second, riffles and runs generally have a greater diversity of macroinvertebrates than other habitat features (Barbour, et al 1999). However, in June 2010, total abundance (average 523 organisms per square meter over the 6-sample set) dropped even lower than the already low 660 sampled in September 2009. One of the suppositions in the previous study report (JBR 2010) was that the low abundance in the fall 2009 samples may have, in part, been due to the use of a 1,000 micron mesh size instead of a finer 500-micron mesh. However, the June 2010 samples (collected with a finer, 500-micron mesh) had an even lower abundance. Flow conditions, time of year, and macroinvertebrate life cycles may all have contributed to the overall lower numbers.

As was also the case in September 2009, none of the three Crandall Creek sites was in optimum shape at the time of the June 2010 sampling. As the first graph in Appendix 2 shows, all sites were dominated by members of the order Diptera (although the upstream (CRANDUP-01) targeted riffle sample was less so). Dominance of any single order often indicates an unbalanced system. Further, most Diptera are quite tolerant to perturbations and thus are often a sign of a stressed environment. The two tolerance indices calculated by the BugLab also indicate a less than ideal aquatic community throughout Crandall Creek. HBI results, when rated according to the scale provided in Section 4.2 under the HBI description, were at best "slightly enriched" and at worst "enriched"; none of the three sites would be categorized as "clean" by this measure. CTQd, which can range from about 20 in the best quality streams up to about 100 in the poorest, was between 67 and 92 in the Crandall Creek June 2010 samples, which also indicates a stream that is providing less than ideal aquatic habitat.

Although Crandall Creek as a whole may provide less-than-ideal habitat, all of the sites had at least a somewhat diverse assemblage of taxa, and all supported at least some taxa that are considered intolerant to pollution or other habitat alterations. All three sites had individuals the least tolerant taxa, which is useful information because it indicates that, while not ideal, there is adequate water quality and aquatic habitat in Crandall Creek, including at the CRANDMD-02 location immediately below Genwal's discharge point. Whatever effects the discharge may have had, the stream at that location is not devoid of macroinvertebrate life, and in fact is still supporting some sensitive taxa.

Knowing that (1) Crandall Creek overall has an aquatic community that is not optimum, and (2) in spite of Genwal's previous iron-laden discharge, the creek is still supporting aquatic life provides a useful context for the remainder of the results discussion. Those two things being said, by most of the metrics discussed below, there is a less healthy macroinvertebrate community at both CRANDMD-02 and CRANDLWR-03, which are downstream of the discharge, than at CRANDUP-01, which is upstream of the discharge. Whether this is due to current discharge water quality, previous elevated iron concentrations in the discharge water, or other habitat differences is not clear.

Habitat differences among the three sites (described above in Section 3.2) could be at least partially reflected in the results and their interpretation. For example, CRANDUP-01 and CRANDLWR-03 have similar substrate size compositions, but at the latter much of the substrate is embedded and cemented. This lack of interstitial spaces results in poor physical habitat for macroinvertebrates at CRANDLWR-03. Therefore, the site comparisons in Section 5.2 must consider that habitat is degraded at this site due to characteristics unrelated to any that have potentially occurred due to the discharges of iron-laden water. Additionally, the substrate at CRANDMD-02 is similar to that at the other two sites, but proportionally has more graveled riffle reaches than the other two sites. These features generally offer the best physical habitat for macroinvertebrates, but at CRANDMD-02, much of this high-quality substrate is now iron-stained and covered filamentous algae. This must be considered in both the sample type comparisons (Section 5.1) and in the spatial comparisons (Section 5.2).

Seasonal differences, primarily reflected in the flow rate, could also have a bearing on the results interpretation, as discussed further in Section 5.3.

5.1 Comparison of Targeted Riffle and Multi-Habitat Samples

As with the September 2009 analysis, numerous metrics and indices have been calculated and graphed for the June 2010 samples. These graphs are included in Appendix 2. They provide a visual means to determine whether there were differences between the samples collected from targeted riffle sites and those collected from the multi-habitat sites. (As with all analysis, data are insufficient to determine statistical significance of any noted differences.)

One of the reasons that the previous study report (JBR 2010) recommended that targeted riffle samples should be collected along with the multi-habitat ones during future monitoring events was based upon the observation that habitat types varied somewhat between each reach. It was felt that the spatial data comparison would be more robust using the results of targeted riffle sampling. In addition, Utah's DWQ monitoring program calls for macroinvertebrate samples to be collected using only a targeted riffle method (DWQ 2006). Collecting targeted riffle samples in Crandall Creek, as well as continuing to collect multi-habitat samples, would allow a broader means of data interpretation in the future, as the data set grows.

The graphs in Appendix 2 indicate that, for sites CRANDMD-02 and CRANDLWR-03, differences between the targeted riffle and the multihabitat samples were generally fairly small. At CRANDUP-01, in contrast, more often than not, there were larger differences between these two sample types. One reason may be that the multi-habitat sample for CRANDUP-01, as noted in Section 3.2, included only a single subsample from a graveled riffle (in contrast to three at CRANDMD-02).

For numerous indices, CRANDMD-02 looked comparatively better using the multi-habitat samples than when using the targeted riffle samples. Perhaps most telling, Shannon's Diversity was very low in the targeted riffle at this site, but the multi-habitat sample at CRANDMD-02 had a higher Shannon's Diversity than all but the CRANDUP-01 targeted riffle sample. This could reflect the proportionally greater number of riffle subsamples comprising the multi-habitat sample at the CRANDMD-02 than at the other two sites.

In time, as the data set grows, more definitive discussions on these differences or lack thereof can be had. Meanwhile, for the remainder of this report, the targeted riffle sample results will be used for the discussion of spatial variation (Section 5.2) and the multi-habitat sample results will be used for the discussion of temporal variation (Section 5.3). In the first instance, using targeted riffles eliminates some of the potential bias due varying substrate characteristics among the sites. In the second instance, because multi-habitat samples were the only ones collected in both 2009 and 2010, they are the only appropriate means of temporal comparisons.

5.2 Spatial Variation in Macroinvertebrate Community

As noted above, numerous metrics and indices based upon the June 2010 sampling at CRANDUP-01, CRANDMD-02, and CRANDLWR-03 have been calculated and graphed. These graphs are included in Appendix 2 and provide a visual aid for analyzing the spatial variation in the macroinvertebrate community along Crandall Creek. As noted above in 5.1, only the targeted riffle samples will used for the spatial comparisons. CRANDUP-01 is upstream of any potential impact from Genwal's discharge, CRANDMD-02 is immediately below the discharge where impacts would presumably be the greatest, and CRANDLWR-03 is further downstream where impacts could presumably be either similar those seen at CRANDMD-02 or reduced, thus indicating a spatial limit to the impact.

Out of the 20 targeted riffle sample metrics graphed in Appendix 2, 80 percent (16) indicate a decline in macroinvertebrate community health between CRANDUP-01 and CRANDMD-02. It is important to reiterate that the data for any one metric are insufficient to make a statistical significance determination of the differences between sites. Some difference would be expected simply due to natural variations in the measurements and this cannot be determined for any single metric with the available data. Further, each metric is, at best, simply a likely indicator of a condition or trend rather than definitive proof. It is also important to note that some of these metrics are not independent of each other. All that being said, however, the fact that such a high percentage of the metrics showed the same trend between these two sites substantiates a finding of difference and increases the likelihood that the difference is not simply due to natural variation.

The 16 metrics that point towards a decline in the aquatic community between sites CRANDUP-01 and CRANDMD-02 encompass a range of tolerance, community composition, diversity, and feeding group metrics. Both the CTQd Index, which is a weighted community tolerance index, and Shannon's Diversity Index, which is a measure of variety in the macroinvertebrate community, indicated significantly poorer conditions at CRANDMD-02 than at CRANDUP-01. Several metrics assessing various taxa (Chironomids, *Baetis*, Hydropsychidae, and Orthocladiinae) that can withstand poor water quality showed a higher relative abundance of those organisms at CRANDMD-02 than at CRANDUP-01, supporting the contention of degraded conditions at the former. Also supporting that contention were several metrics assessing taxa sensitive to poor water quality (Heptageniidae, Chloroperidae, and *Rhyacophila*, specifically, and all EPT taxa generally). Last, feeding group measures also support the conclusion of these other metrics. Therefore, based upon the number and variety of metrics that indicate at least some level of decline in the macroinvertebrate community between these two sites, it appears that CRANDMD-02 continues to show the results of some type of perturbation.

Similarly, based upon almost all of the various targeted riffle sample metrics (Appendix 2), CRANDUP-01 has a healthier macroinvertebrate community than does CRANDLWR-03, seemingly indicating that CRANDLWR-03 has also been subject to some type of perturbation. Differences between CRANDMD-02 and CRANDLWR-03 are generally less significant than between CRANDUP-01 and CRANDLWR-03. In some cases, the graphs show better conditions immediately below the discharge (CRANDMD-02) than further downstream (CRANDLWR-03) and in some cases show the opposite. Overall, analysis of the targeted riffle samples shows that CRANDUP-01 is in better health than the other two sites. As mentioned in Section 5.0, the poor condition of the macroinvertebrate community at CRANDLWR-03 may be due to poorer physical habitat conditions (i.e. embeddedness and cementation) at this site.

As described in Sections 3.2 and 5.0, the physical habitat at CRANDMD-02 would actually be quite good if it were not for the iron-staining and algae. All else being equal, it perhaps could be argued that this site should be able to support the best macroinvertebrate community of the three sites sampled. The fact that most of the metrics reflect it as the least able to support a healthy macroinvertebrate community lends support to a contention that the mine discharge has had an impact.

5.3 Temporal Variation in Macroinvertebrate Community

As previously mentioned, macroinvertebrate studies were conducted in Crandall Creek in 1980 and 1994. However, those data are of limited use for temporal comparisons due to unknowns in either sampling locations and/or collection methodology. In addition, the more recent fall 2009 data (JBR 2010) can only provide a limited basis for comparisons with the June 2010 data because of the differences expected due to flow conditions, seasonality and macroinvertebrate life cycles.

Examining the multi-habitat sample metrics in Appendix 2 and comparing them with the same from the fall 2009 study (JBR 2010) indicates that all three sites seemed to reflect poorer macroinvertebrate conditions in the spring than in the previous fall. Again, this may simply reflect difference due to high flow conditions at the time of sampling and should not be taken as an overall decline in Crandall Creek, either upstream or downstream of the discharge.

In general, the same types of macroinvertebrates were present in both spring and fall, though there were some differences in the dominant taxa between the two seasons. Whether this is due to life cycle/seasonality, or normal variability, or truly defines a trend, cannot be determined. In any case the two data sets, taken over two different seasons, cannot be used to determine trend; like-season data in coming years will be more conducive for determining temporal changes.

5.4 Indication of Iron-specific Impacts

As described above, the data indicate that there is some degradation in the aquatic community between CRANDUP-01 and CRANDMD-02. That degradation also appears to continue downstream to CRANDLWR-03. Attributing the degradation directly to the previously elevated iron in Genwal's groundwater discharge continues to be problematic, as was discussed in the previous study report (JBR 2010). Further, although the discharge water is no longer iron-laden, the stream bed continues to be visibly altered by iron precipitates. Degradation noted in the June 2010 samples could be the result of populations not yet recovered from the water quality perturbations, continuing impacts resulting from the precipitated iron, and/or causes unrelated to iron (such as physical habitat problems at CRANDLWR-03).

6.0 Recommendations for Future Study

JBR recommends that the 2011 sampling events use the same methodology and equipment as was used in 2010. Samples should include both a multi-habitat sample at each site and a targeted riffle sample at each site. As more data are collected, analysis of spatial and temporal differences will become more meaningful.

7.0 Summary and Conclusions

In June 2010, benthic macroinvertebrate samples were collected from three reaches of Crandall Creek. One reach was located upstream of Genwal's Crandall Canyon Mine groundwater discharge while the other two reaches were located downstream of the discharge. One of the primary goals of the study was to determine whether the previously elevated iron concentrations have impacted Crandall Creek's macroinvertebrate population. Macroinvertebrate community composition at these three reaches was determined by taxonomic identification of the organisms collected during the June sampling, and numerous indices and metrics were calculated for ease in interpreting results.

Overall, the study results indicate that the Crandall Creek macroinvertebrate community immediately downstream of the mine discharge continues to show signs of having been negatively impacted. Although the downstream reach of Crandall Creek also has a degraded macroinvertebrate community, its poor substrate condition (embedded and cemented) is likely a contributing (if not dominating) factor affecting macroinvertebrate community health at that site. However, both downstream reaches of the creek are still supporting a variety of macroinvertebrates, indicating that the past iron-laden discharge has not completely eliminated macroinvertebrate habitat.

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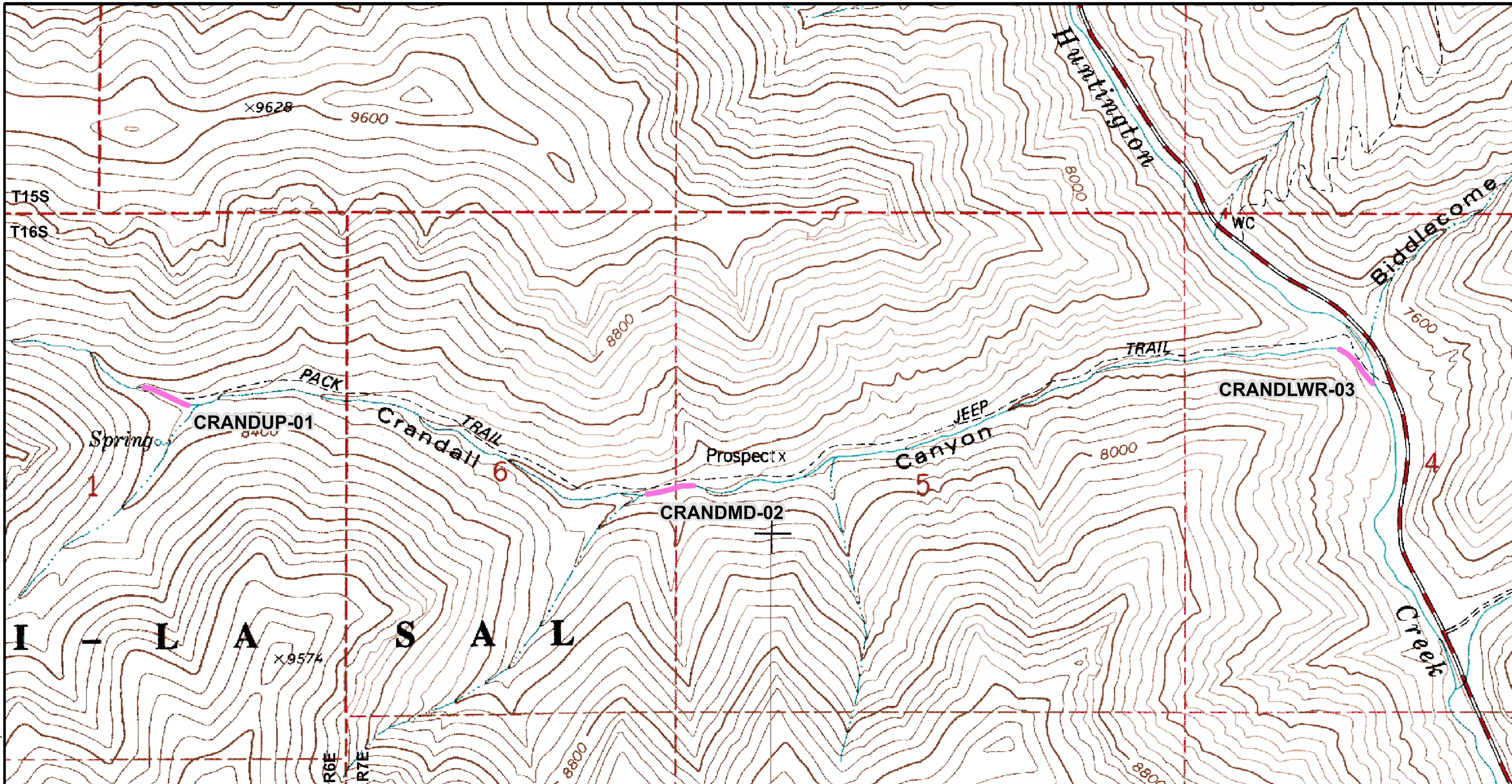

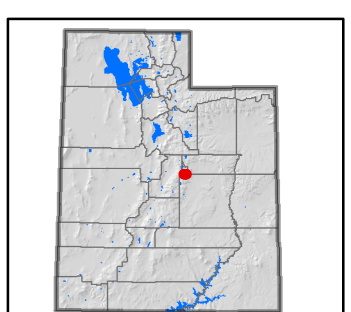

BASE MAP: UTAHUSGS 7.5 MINUTE QUADRANGLE, RILDA CANYON, UTAH

Legend

Macroinvertebrate Study Sites

N

1,000 500 0 1,000 Feet

CRANDALL CANYON MINE
MACROINVERTEBRATE STUDY
JUNE 2010

FIGURE 1
LOCATION MAP

JBR

DRAWN BY: CP | DATE DRAWN: 01/17/2011
SCALE: 1:12,000

drawings\CrandallCanyonMine_Macroinvertebrate Study.mxd

APPENDIX 1
BUGLAB REPORT

Aquatic Invertebrate Report For Samples Collected By Jbr Environmental Consultants

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8 November 2010

Sampling Locations

Table 1. Sampling site locations

Station	Location	Latitude	Longitude	Elevation (meters)
CRANDLWR-03	Crandall Creek, Lower, Emery County, Utah	39.464	111.146	2363
CRANDMD-02	Crandall Creek, Middle, Emery County, Utah	39.460	111.165	2384
CRANDUP-01	Crandall Creek, Upstream, Emery County, Utah	39.460	111.168	2389

Methods

Field sampling

Samples were collected on June 7, 2010 (Table 2). Aquatic invertebrates were collected quantitatively from all available habitats with a kick net with a 500 micron mesh net.

Laboratory methods

General procedures for processing invertebrate samples were similar to those recommended by the United States Geological Survey (Cuffney et al. 1993) and are described in greater detail and rationalized in Vinson and Hawkins (1996). Samples were sub-sampled if the sample appeared to contain more than 600 organisms. Sub-samples were obtained by pouring the sample into an appropriate diameter 500 micron sieve, floating this material by placing the sieve within an enamel pan partially filled with water and leveling the material within the sieve. The sieve was then removed from the water pan and the material within the sieve was divided into two equal parts. One half of the sieve was then randomly chosen to be processed and the other half set aside. The sieve was then placed back in the enamel pan and the material in the sieve again leveled and split in half. This process was repeated until approximately 600 organisms remained in one-half of the sieve. This material was placed into a Petri dish and all organisms were removed under a dissecting microscope at 10-30 power. Additional sub-samples were taken until at least 600 organisms were removed, All organisms within a sub-sample were removed, and separated into taxonomic Orders. When the sorting of the sub-samples was completed, the entire sample was spread throughout a large white enamel pan and searched for 10 minutes to remove any taxa that might not have been picked up during the initial sample sorting process. The objective of this "big/rare" search was to provide a more complete taxa list by finding rarer taxa that may have been excluded during the sub-sampling process. These rarer bugs were placed into a separate vial and the data entered separately from the bugs removed during the sub-sampling process. All the organisms removed during the sorting process were then identified using appropriate identification keys (see literature cited list for list of taxonomic resources used). Once the data had been entered into a computer and checked, the unsorted portion of the sample was discarded. The identified portion of the sample was placed in a 20 ml glass scintillation vial with polypropylene lids in 70% ethanol, given a catalog number, and retained. In this report, metrics were calculated using data from the sub-sampled and big/rare portions of the sample. Abundance data are presented as the estimated number of individuals per square meter for quantitative samples and the estimated number per sample for qualitative samples.

Table 2. Field comments and laboratory processing information.

Sample	Station	Sampling Date	Habitat Sampled	Sampling Method	Sampling Area Sqmts	% of sample processed	Number of individuals identified	Field Comments
143613	CRANDUP-01	06/07/2010	Riffle	Kick net	0.74	100	563	
143614	CRANDUP-01	06/07/2010	Multiple	Kick net	0.46	100	138	
143615	CRANDMD-02	06/07/2010	Riffle	Kick net	0.74	100	437	
143616	CRANDMD-02	06/07/2010	Multiple	Kick net	0.46	100	404	
143617	CRANDLWR-03	06/07/2010	Riffle	Kick net	0.74	100	276	
143618	CRANDLWR-03	06/07/2010	Multiple	Kick net	0.46	100	119	

Data summarization

A number of metrics or ecological summaries can be calculated from an aquatic invertebrate sample. A summary and description of commonly used metrics is available in Barbour et al. (1999, http://www.epa.gov/owow/monitoring/rbp/index.html#Table%20of%20Contents) and Karr and Chu (1998). Both of these publications suggest use of the following metrics for assessing the health of aquatic invertebrate assemblages: Total taxa richness, EPT taxa richness, Ephemeroptera taxa richness, Plecoptera taxa richness, Trichoptera taxa richness, % EPT abundance, % Ephemeroptera abundance, % Chironomidae abundance, Intolerant taxa richness, % tolerant organisms, Hilsenhoff Biotic Index, % contribution of the dominant taxon, clinger taxa richness, % clinger abundance, % collector-filterer abundance, and the % scraper abundance. Assessments are best made by comparing samples to samples collected similarly at reference sites or from samples collected prior to impacts or management actions at a location. In this report, the following metrics were calculated for each sample.

Taxa richness - Richness is a component and estimate of community structure and stream health based on the number of distinct taxa. Taxa richness normally decreases with decreasing water quality. In some situations organic enrichment can cause an increase in the number of pollution tolerant taxa. Taxa richness was calculated for operational taxonomic units (OTUs) and the number of unique genera, and families. The values for operational taxonomic units may be overestimates of the true taxa richness at a site if individuals were the same taxon as those identified to lower taxonomic levels or they may be underestimates of the true taxa richness if multiple taxa were present within a larger taxonomic grouping but were not identified. All individuals within all samples were generally identified similarly, so that comparisons in operational taxonomic richness among samples within this dataset are appropriate, but comparisons to other data sets may not. Comparisons to other datasets should be made at the genera or family level.

Abundance - The abundance, density, or number of aquatic macroinvertebrates per unit area is an indicator of habitat availability and fish food abundance. Abundance may be reduced or increased depending on the type of impact or pollutant. Increased organic enrichment typically causes large increases in abundance of pollution tolerant taxa. High flows, increases in fine sediment, or the presence of toxic substances normally cause a decrease in invertebrate abundance. Invertebrate abundance is presented as the number of individuals per square meter for quantitative samples and the number of individuals collected in each sample for qualitative samples.

EPT - A summary of the taxonomic richness and abundance within the insect Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are commonly considered sensitive to pollution (Karr and Chu 1998).

Percent contribution of the dominant family or taxon - An assemblage largely dominated (>50%) by a single taxon or several taxa from the same family suggests environmental stress. Habitat conditions likely limit the number of taxa that can occur at the site.

Shannon diversity index - Ecological diversity is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances. The Shannon diversity index was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. The calculations were made following Ludwig and Reynolds (1988, equation 8.9, page 92).

Evenness - Evenness is a measure of the distribution of taxa within a community. The evenness index used in this report was calculated following Ludwig and Reynolds (1988, equation 8.15, page 94). Value ranges from 0-1 and approach zero as a single taxa becomes more dominant.

Clinger taxa - The number of clinger taxa have been found by Karr and Chu (1998) to respond negatively to human disturbance. Clinger taxa were determined using information in Merritt et al. (2008). These taxa typically cling to the tops of rocks and are thought to be reduced by sedimentation or abundant algal growths.

Long-live taxa - The number of long-lived taxa was calculated the number of taxa collected that typically have 2-3 year life cycles. Disturbances and water quality and habitat impairment typically reduces the number of long-lived taxa Karr and Chu (1998). Life-cycle length determinations were based on information in Merritt et al. (2008).

Biotic indices - Biotic indices use the indicator taxa concept. Taxa are assigned water quality tolerance values based on their tolerance to pollution. Scores are typically weighted by taxa relative abundance. In the United States the most commonly used biotic index is the Hilsenhoff Biotic Index (Hilsenhoff 1987, Hilsenhoff 1988). The USFS and BLM throughout the western United States have also frequently used the USFS Community Tolerance Quotient.

Hilsenhoff biotic index - The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. It is best at detecting organic pollution. Families were assigned an index value from 0- taxa normally found only in high quality unpolluted water, to 10- taxa found only in severely polluted waters. Family level values were taken from Hilsenhoff (1987, 1988) and a family level HBI was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. Sampling locations with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. Rather than using mean HBI values for a sample, taxon HBI values can also be used to determine the number of pollution intolerant and tolerant taxa occurring at a site. In this report, taxa with HBI values $\leq$ 2 were considered intolerant clean water taxa and taxa with HBI values $\geq$ 8 were considered pollution tolerant taxa. The number of tolerant and intolerant taxa and the abundances of tolerant and intolerant taxa were calculated for each sampling location.

USFS community tolerant quotient - Taxa are assigned a tolerant quotient (TQ) from 2 - taxa found only in high quality unpolluted water, to 108 - taxa found in severely polluted waters. TQ values were developed by Winget and Mangum (1979). The dominance weighted community tolerance quotient (CTQd) was calculated. Values can vary from about 20 to 100, in general the lower the value the better the water quality.

Functional feeding group measures - A common classification scheme for aquatic macroinvertebrates is to categorize them by feeding acquisition mechanisms. Categories are based on food particle size and food location, e.g., suspended in the water column, deposited in sediments, leaf litter, or live prey. This classification system reflects the major source of the resource, either within the stream itself or from riparian or upland areas and the primary location, either erosional or depositional habitats. The number of taxa and individuals of the following feeding groups were calculated for each sampling location. Functional feeding group designations were from Merritt et al. (2008).

Shredders - Shredders use both living vascular hydrophytes and decomposing vascular plant tissue - coarse particulate organic matter. Shredders are sensitive to changes in riparian vegetation. Shredders can be good indicators of toxicants that adhere to organic matter.

Scrapers - Scrapers feed on periphyton - attached algae and associated material. Scraper populations increase with increasing abundance of diatoms and can decrease as filamentous algae, mosses, and vascular plants increase, often in response to increases in nitrogen and phosphorus. Scrapers decrease in relative abundance in response to sedimentation and higher levels of organic pollution or nutrient enrichment.

Collector-filterers - Collector-filterers feed on suspended fine particulate organic matter. Collector-filterers are sensitive to toxicants in the water column and to pollutants that adhere to organic matter.

Collector-gatherers - Collector-gatherers feed on deposited fine particulate organic matter. Collector-gatherers are sensitive to deposited toxicants.

Predators - Predators feed on living animal tissue. Predators typically make up about 25% of the assemblage in stream environments and 50% of the assemblage in still-water environments.

Unknown feeding group - This category includes taxa that are highly variable, parasites, and those that for which the primary feeding mode is currently unknown.

Results

Abundance data and taxa richness are reported as the estimated number of individuals per square meter for quantitative samples and the number per sample for qualitative samples. NC = Not calculated. * = unable to calculate. EPT = totals for the insect orders, Ephemeroptera, Plecoptera, Trichoptera. QL = qualitative sample.

Sample	Sampling date	Station	Total abundance	EPT abundance	Dominant family	% contribution dominant family
143613	06/07/2010	CRANDUP-01	758	429	Chironomidae	25.73
143614	06/07/2010	CRANDUP-01	297	56	Chironomidae	65.99
143615	06/07/2010	CRANDMD-02	588	137	Chironomidae	51.53
143616	06/07/2010	CRANDMD-02	870	108	Chironomidae	42.76
143617	06/07/2010	CRANDLWR-03	371	63	Chironomidae	35.31
143618	06/07/2010	CRANDLWR-03	256	26	Chironomidae	54.69
Mean			523.3	136.5		46.00

Diversity indices

Sample	Sampling Date	Station	Total taxa richness	Total genera richness	Total family richness	EPT taxa richness	Shannon diversity index	Evenness
143613	06/07/2010	CRANDUP-01	35	25	21	15	2.650	0.750
143614	06/07/2010	CRANDUP-01	21	12	14	5	2.030	0.670
143615	06/07/2010	CRANDMD-02	36	25	20	12	2.030	0.570
143616	06/07/2010	CRANDMD-02	31	19	20	9	2.590	0.750
143617	06/07/2010	CRANDLWR-03	24	16	17	6	2.210	0.700
143618	06/07/2010	CRANDLWR-03	22	15	15	4	2.210	0.710
Mean			28.2	18.7	17.8	8.5	2.290	0.690

Genera richness by major taxonomic group.

Sample	Sampling Date	Station	Coleoptera	Diptera	Ephemerotpera	Heteroptera	Megaloptera	Odonata	Plecoptera	Trichoptera	Annelida	Custacea	Mollusca
143613	06/07/2010	CRANDUP-01	1	14	8	0	0	0	2	5	1	0	1
143614	06/07/2010	CRANDUP-01	0	13	3	0	0	0	0	2	1	0	0
143615	06/07/2010	CRANDMD-02	2	19	4	0	0	0	3	5	0	0	0
143616	06/07/2010	CRANDMD-02	3	11	4	0	0	0	3	2	1	0	1
143617	06/07/2010	CRANDLWR-0	2	12	1	0	0	0	2	3	0	0	1
143618	06/07/2010	CRANDLWR-0	2	11	1	0	0	0	1	2	0	0	1
Mean			**1.7**	**13.3**	**3.5**	**0.0**	**0.0**	0.0	**1.8**	**3.2**	0.5	**0.0**	**0.7**

Total abundance by major taxonomic group.

Sample	Sampling Date	Station	Coleoptera	Diptera	Ephemerotpera	Heteroptera	Megaloptera	Odonata	Plecoptera	Trichoptera	Annelida	Custacea	Mollusca
143613	06/07/2010	CRANDUP-01	4	291	295	0	0	0	44	90	7	0	3
143614	06/07/2010	CRANDUP-01	0	235	24	0	0	0	0	32	2	0	0
143615	06/07/2010	CRANDMD-02	23	362	102	0	0	0	4	31	0	0	0
143616	06/07/2010	CRANDMD-02	24	493	60	0	0	0	13	34	32	0	84
143617	06/07/2010	CRANDLWR-0 3	3	199	39	0	0	0	9	15	0	0	4
143618	06/07/2010	CRANDLWR-0 3	4	187	15	0	0	0	2	9	0	0	4
Mean			9.7	294.5	89.2	0.0	0.0	0.0	12.0	35.2	6.8	0.0	15.8

Biotic Indices

Sample	Sampling date	Station	Hilsenhoff Biotic Index		USFS Community CTQd
			Index	Indication	
143613	06/07/2010	CRANDUP-01	3.95	Possible slight organic pollution	67
143614	06/07/2010	CRANDUP-01	5.01	Some organic pollution	81
143615	06/07/2010	CRANDMD-02	4.53	Some organic pollution	86
143616	06/07/2010	CRANDMD-02	4.11	Possible slight organic pollution	92
143617	06/07/2010	CRANDLWR-03	3.49	No apparent organic pollution	84
143618	06/07/2010	CRANDLWR-03	4.51		89
Mean			4.27		83.2

Taxa richness and relative abundance values with respect to tolerance or intolerance to pollution were based on the Hilsenhoff Biotic Index (HBI). Intolerant taxa have HBI score <= 2. Tolerant taxa have a HBI score >= 8. Data are presented as estimated count per square meter for quantitative samples and total number per sample for qualitative samples.

Sample	Sampling date	Station	Intolerant taxa				Tolerant Taxa			
			Richness		Abundance		Richness		Abundance	
143613	06/07/2010	CRANDUP-01	7	(20)	159	(21)	1	(3)	24	(3)
143614	06/07/2010	CRANDUP-01	3	(14)	37	(12)	1	(5)	13	(4)
143615	06/07/2010	CRANDMD-02	8	(22)	28	(5)	1	(3)	7	(1)
143616	06/07/2010	CRANDMD-02	5	(16)	22	(3)	1	(3)	58	(7)
143617	06/07/2010	CRANDLWR-0	3	(13)	13	(4)	0	(0)	0	(0)
143618	06/07/2010	CRANDLWR-0	2	(9)	4	(2)	0	(0)	0	(0)
Mean			4.7	(16)	43.8	(8)	0.7	(2)	17.0	(3)

Functional feeding groups

Taxa richness by functional feeding group. The percent of the total is shown in parentheses.

Sample	Sampling date	Station	Shredders		Scrapers		Collector-filterers		Collector-gatherers		Predators		Unknown	
143613	06/07/2010	CRANDUP-01	4	(11)	4	(11)	3	(9)	11	(31)	12	(34)	1	(3)
143614	06/07/2010	CRANDUP-01	1	(5)	2	(10)	0	(0)	7	(33)	11	(52)	0	(0)
143615	06/07/2010	CRANDMD-02	4	(11)	3	(8)	3	(8)	9	(25)	15	(42)	2	(6)
143616	06/07/2010	CRANDMD-02	1	(3)	3	(10)	2	(6)	9	(29)	13	(42)	3	(10)
143617	06/07/2010	CRANDLWR-0	2	(8)	1	(4)	2	(8)	5	(21)	14	(58)	0	(0)
143618	06/07/2010	CRANDLWR-0	0	(0)	0	(0)	2	(9)	4	(18)	14	(64)	2	(9)
Mean			2.0	(6)	2.2	(7)	2.0	(7)	7.5	(26)	13.2	(49)	1.3	(5)

Invertebrate abundance by functional feed group. The percent of the total is shown in parentheses.

Sample	Sampling date	Station	Shredders		Scrapers		Collector-filterers		Collector-gatherers		Predators		Unknown	
143613	06/07/2010	CRANDUP-01	44	(6)	117	(15)	5	(1)	402	(53)	184	(24)	4	(1)
143614	06/07/2010	CRANDUP-01	6	(2)	6	(2)	0	(0)	228	(77)	56	(19)	0	(0)
143615	06/07/2010	CRANDMD-02	12	(2)	5	(1)	13	(2)	417	(71)	118	(20)	22	(4)
143616	06/07/2010	CRANDMD-02	28	(3)	6	(1)	93	(11)	512	(59)	205	(24)	26	(3)
143617	06/07/2010	CRANDLWR-0	5	(1)	1	(0)	13	(4)	198	(53)	153	(41)	0	(0)
143618	06/07/2010	CRANDLWR-0	0	(0)	0	(0)	11	(4)	161	(63)	80	(31)	4	(2)
Mean			15.8	(2)	22.5	(3)	22.5	(4)	319.7	(63)	132.7	(27)	9.3	(1)

The 10 metrics thought to be most responsive to human induced disturbance (Karr and Chu 1998).

Sample	Sampling Date	Station	Total taxa	Ephemeroptera taxa	Plecoptera taxa	Trichoptera taxa	Long-lived taxa	Intolerant taxa	Clinger taxa	% tolerant individuals	% contribution dominant taxon	% predators
143613	06/07/2010	CRANDUP-01	35	7	2	5	2	7	11	3.17	19.53	24.27
143614	06/07/2010	CRANDUP-01	21	3	0	2	0	3	4	4.38	33.33	18.86
143615	06/07/2010	CRANDMD-02	36	4	2	4	2	8	10	1.19	50.17	20.07
143616	06/07/2010	CRANDMD-02	31	4	1	1	3	5	8	6.67	30.46	23.56
143617	06/07/2010	CRANDLWR-03	24	1	0	2	2	3	5	0.00	35.31	41.24
143618	06/07/2010	CRANDLWR-03	22	1	0	2	2	2	4	0.00	44.53	31.25
Mean			28.2	3.3	0.8	2.7	1.8	4.7	7.0	2.57	35.55	26.54

Taxonomic list and counts for 6 samples collected on June 7, 2010. Count is the total number of individuals identified and retained. Samples heading refers to the number of samples containing that taxon.

Order	Family	Subfamily/Genus/Species	Samples	Count
Phylum: Annelida				
Class: Clitellata	SubClass: Oligochaeta			
			3	21
Phylum: Arthropoda				
Class: Arachnida	SubClass: Acari			
Trombidiformes			5	28
Trombidiformes	Arrenuridae	Arrenurus	2	2
Trombidiformes	Lebertiidae	Lebertia	6	139
Trombidiformes	Sperchonidae	Sperchon	5	47
Class: Insecta	SubClass: Pterygota			
Coleoptera	Dytiscidae		1	1
Coleoptera	Elmidae		1	1
Coleoptera	Elmidae	Narpus concolor	3	25
Coleoptera	Elmidae	Optioservus	3	4
Coleoptera	Elmidae	Optioservus quadrimaculatus	2	4
Diptera	Ceratopogonidae		4	6
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	6	16
Diptera	Ceratopogonidae	Forcipomyiinae Atrichopogon	1	1
Diptera	Chironomidae		4	41
Diptera	Chironomidae	Chironominae	5	95
Diptera	Chironomidae	Orthocladiinae	6	648
Diptera	Chironomidae	Tanypodinae	3	12
Diptera	Dixidae	Dixa	2	3
Diptera	Dolichopodidae		1	1
Diptera	Empididae	Clinocera	1	1
Diptera	Empididae	Hemerodromiinae Hemerodromiini	1	8
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	6	71
Diptera	Empididae	Neoplasta	4	9
Diptera	Muscidae		1	1
Diptera	Psychodidae	Pericoma	4	56
Diptera	Simuliidae	Simuliinae Prosimuliini Helodon	2	6
Diptera	Simuliidae	Simuliinae Prosimuliini Helodon	1	1
Diptera	Simuliidae	Simuliinae Simuliini Simulium	2	8
Diptera	Stratiomyidae	Caloparyphus	4	10
Diptera	Stratiomyidae	Euparyphus	1	1
Diptera	Tabanidae		1	1
Diptera	Tipulidae		1	1
Diptera	Tipulidae	Dicranota	5	8
Diptera	Tipulidae	Hesperoconopa	1	1
Diptera	Tipulidae	Hexatoma	1	3
Diptera	Tipulidae	Limoniinae Antocha monticola	2	25
Diptera	Tipulidae	Limoniinae Eriopterini Ormosia	1	1
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	5	9
Diptera	Tipulidae	Pedicia	1	1
Diptera	Tipulidae	Tipulinae Tipula	3	13
Ephemeroptera	Ameletidae	Ameletus	3	4
Ephemeroptera	Baetidae	Baetis	6	236

Ephemeroptera	Baetidae	Diphetor hageni	1	1
Ephemeroptera	Ephemerellidae	Drunella	2	3
Ephemeroptera	Ephemerellidae	Drunella coloradensis/flavilinea	1	13
Ephemeroptera	Ephemerellidae	Drunella grandis	1	6
Ephemeroptera	Heptageniidae		1	1
Ephemeroptera	Heptageniidae	Cinygmula	3	73
Ephemeroptera	Heptageniidae	Epeorus	3	33
Plecoptera	Chloroperlidae		4	8
Plecoptera	Chloroperlidae	Sweltsa	1	1
Plecoptera	Nemouridae	Zapada	2	25
Plecoptera	Perlodidae		2	5
Plecoptera	Perlodidae	Isoperlinae Isoperla	2	11
Trichoptera	Hydropsychidae	Arctopsychinae Parapsyche elsis	1	1
Trichoptera	Hydropsychidae	Hydropsychinae Hydropsyche	2	10
Trichoptera	Limnephilidae		3	20
Trichoptera	Limnephilidae	Chyrandra centralis	1	1
Trichoptera	Limnephilidae	Limnephilinae Limnephilini Hesperophylax	2	2
Trichoptera	Rhyacophilidae	Rhyacophila	5	35
Trichoptera	Rhyacophilidae	Rhyacophila angelita group	2	6
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	3	61
Phylum: Mollusca				
Class: Bivalvia	SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	4	46
Phylum: Nemata				
Class:	SubClass:			
			1	2
Phylum: Platyhelminthes				
Class: Turbellaria	SubClass:			
			2	3

Total: OTU Taxa : **65** Genera : **46** Families : **28** Individuals : **1937**

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Taxa Lists for Individual Samples

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDUP-01, Crandall Creek, Upstream, Emery county, Utah. The sample was collected from riffle habitat using a kick net. The total area sampled was 0.743 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 563 individuals were removed, identified and retained. The sample identification number is 143613. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			adult	6.73	
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes			adult	4.04	U
Trombidiformes	Lebertiidae	Lebertia	adult	17.49	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae	Optioservus quadrimaculatus	adult	4.04	
Diptera	Ceratopogonidae		pupae	2.69	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	5.38	
Diptera	Chironomidae		pupae	28.26	
Diptera	Chironomidae	Chironominae	larvae	18.84	
Diptera	Chironomidae	Orthocladiinae	larvae	148.00	
Diptera	Dixidae	Dixa	larvae	2.69	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	43.06	
Diptera	Empididae	Neoplasta	larvae	2.69	
Diptera	Psychodidae	Pericoma	larvae	24.22	
Diptera	Simuliidae	Simuliinae Prosimuliini Helodon	larvae	1.35	
Diptera	Stratiomyidae	Caloparyphus	larvae	1.35	
Diptera	Tipulidae	Dicranota	larvae	1.35	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	1.35	
Diptera	Tipulidae	Tipulinae Tipula	larvae	9.42	
Ephemeroptera	Ameletidae	Ameletus	larvae	2.69	
Ephemeroptera	Baetidae	Baetis	larvae	138.59	
Ephemeroptera	Baetidae	Diphetor hageni	larvae	1.35	
Ephemeroptera	Ephemerellidae	Drunella coloradensis/flavilinea	larvae	17.49	
Ephemeroptera	Ephemerellidae	Drunella grandis	larvae	8.07	
Ephemeroptera	Heptageniidae		larvae	1.35	
Ephemeroptera	Heptageniidae	Cinygmula	larvae	95.53	
Ephemeroptera	Heptageniidae	Epeorus	larvae	29.60	
Plecoptera	Nemouridae	Zapada	larvae	32.29	I
Plecoptera	Perlodidae	Isoperlinae Isoperla	larvae	12.11	
Trichoptera	Hydropsychidae	Arctopsychinae Parapsyche elsis	larvae	1.35	
Trichoptera	Limnephilidae	Chyrandra centralis	larvae	1.35	
Trichoptera	Limnephilidae	Limnephilinae Limnephilini Hesperophylax	larvae	1.35	
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	26.91	I
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	larvae	59.20	
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	2.69	
Phylum: Platyhelminthes					
Class: Turbellaria		SubClass:			
			adult	2.69	

Total:	OTU Taxa :	**35**	Genera :	**27**	Families :	**21**		757.51

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDUP-01, Crandall Creek, Upstream, Emery county, Utah. The sample was collected from multiple habitat using a kick net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 138 individuals were removed, identified and retained. The sample identification number is 143614. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			adult	2.15	
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes	Lebertiidae	Lebertia	adult	2.15	
Trombidiformes	Sperchonidae	Sperchon	adult	2.15	
Class: Insecta		SubClass: Pterygota			
Diptera	Ceratopogonidae		pupae	2.15	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	4.31	
Diptera	Chironomidae		pupae	6.46	
Diptera	Chironomidae	Chironominae	larvae	88.26	
Diptera	Chironomidae	Orthocladiinae	larvae	99.03	
Diptera	Chironomidae	Tanypodinae	larvae	2.15	
Diptera	Dolichopodidae		larvae	2.15	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	2.15	
Diptera	Muscidae		larvae	2.15	
Diptera	Psychodidae	Pericoma	larvae	12.92	
Diptera	Tipulidae	Limoniinae Eriopterini Ormosia	larvae	2.15	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	4.31	
Diptera	Tipulidae	Tipulinae Tipula	larvae	6.46	
Ephemeroptera	Baetidae	Baetis	larvae	17.22	
Ephemeroptera	Ephemerellidae	Drunella	larvae	4.31	I
Ephemeroptera	Heptageniidae	Cinygmula	larvae	2.15	
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	6.46	I
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	larvae	25.83	
Total: OTU Taxa : **21**		Genera : **13**	Families : **14**	297.08	

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDMD-02, Crandall Creek, Middle, Emery county, Utah. The sample was collected from riffle habitat using a kick net. The total area sampled was 0.743 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 437 individuals were removed, identified and retained. The sample identification number is 143615. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes			adult	5.38	
Trombidiformes	Lebertiidae	Lebertia	adult	44.40	
Trombidiformes	Sperchonidae	Sperchon	adult	16.15	U
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae	Narpus concolor	larvae	20.18	
Coleoptera	Elmidae	Optioservus	larvae	2.69	
Diptera	Ceratopogonidae		larvae	1.35	I
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	4.04	
Diptera	Ceratopogonidae	Forcipomyiinae Atrichopogon	larvae	1.35	
Diptera	Chironomidae		pupae	6.73	
Diptera	Chironomidae	Chironominae	larvae	1.35	
Diptera	Chironomidae	Orthocladiinae	larvae	294.66	
Diptera	Dixidae	Dixa	larvae	1.35	
Diptera	Empididae	Clinocera	larvae	1.35	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	10.76	
Diptera	Empididae	Neoplasta	larvae	4.04	
Diptera	Psychodidae	Pericoma	larvae	6.73	
Diptera	Simuliidae	Simuliinae Prosimuliini Helodon	larvae	6.73	
Diptera	Simuliidae	Simuliinae Prosimuliini Helodon onychodactylum	pupae	1.35	
Diptera	Simuliidae	Simuliinae Simuliini Simulium	larvae	5.38	
Diptera	Stratiomyidae	Caloparyphus	larvae	5.38	
Diptera	Stratiomyidae	Euparyphus	larvae	1.35	
Diptera	Tipulidae		larvae	1.35	I
Diptera	Tipulidae	Dicranota	larvae	4.04	
Diptera	Tipulidae	Pedicia	larvae	1.35	
Ephemeroptera	Ameletidae	Ameletus	larvae	1.35	
Ephemeroptera	Baetidae	Baetis	larvae	91.49	
Ephemeroptera	Ephemerellidae	Drunella	larvae	1.35	
Ephemeroptera	Heptageniidae	Epeorus	larvae	8.07	
Plecoptera	Chloroperlidae		larvae	1.35	I
Plecoptera	Chloroperlidae	Sweltsa	larvae	1.35	
Plecoptera	Nemouridae	Zapada	larvae	1.35	U
Trichoptera	Limnephilidae		larvae	8.07	I
Trichoptera	Limnephilidae	Limnephilinae Limnephilini Hesperophylax	larvae	1.35	
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	10.76	I,U
Trichoptera	Rhyacophilidae	Rhyacophila angelita group	larvae	4.04	
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	larvae	6.73	
Total: OTU Taxa : **36**	Genera : **28**	Families : **20**		587.98	

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDMD-02, Crandall Creek, Middle, Emery county, Utah. The sample was collected from multiple habitat using a kick net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 404 individuals were removed, identified and retained. The sample identification number is 143616. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			adult	32.29	
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes			adult	23.68	U
Trombidiformes	Arrenuridae	Arrenurus	adult	2.15	
Trombidiformes	Lebertiidae	Lebertia	adult	86.11	
Trombidiformes	Sperchonidae	Sperchon	adult	10.76	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae	Narpus concolor	larvae	19.38	
Coleoptera	Elmidae	Optioservus	larvae	2.15	
Coleoptera	Elmidae	Optioservus quadrimaculatus	adult	2.15	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	10.76	
Diptera	Chironomidae		pupae	25.83	
Diptera	Chironomidae	Chironominae	larvae	64.58	
Diptera	Chironomidae	Orthocladiinae	larvae	264.79	
Diptera	Chironomidae	Tanypodinae	larvae	17.22	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	25.83	
Diptera	Psychodidae	Pericoma	larvae	58.13	
Diptera	Simuliidae	Simuliinae Simuliini Simulium	larvae	4.31	
Diptera	Stratiomyidae	Caloparyphus	larvae	8.61	
Diptera	Tipulidae	Dicranota	larvae	2.15	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	6.46	
Ephemeroptera	Ameletidae	Ameletus	larvae	2.15	
Ephemeroptera	Baetidae	Baetis	larvae	45.21	
Ephemeroptera	Heptageniidae	Cinygmula	larvae	2.15	
Ephemeroptera	Heptageniidae	Epeorus	larvae	10.76	
Plecoptera	Chloroperlidae		larvae	2.15	I
Plecoptera	Perlodidae		larvae	6.46	I
Plecoptera	Perlodidae	Isoperlinae Isoperla	larvae	4.31	
Trichoptera	Limnephilidae		larvae	27.99	I
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	6.46	I
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	83.96	
Phylum: Nemata					
Class:		SubClass:			
			adult	4.31	
Phylum: Platyhelminthes					
Class: Turbellaria		SubClass:			
			adult	2.15	

Total: OTU Taxa : **31** Genera : **20** Families : **20** 869.72

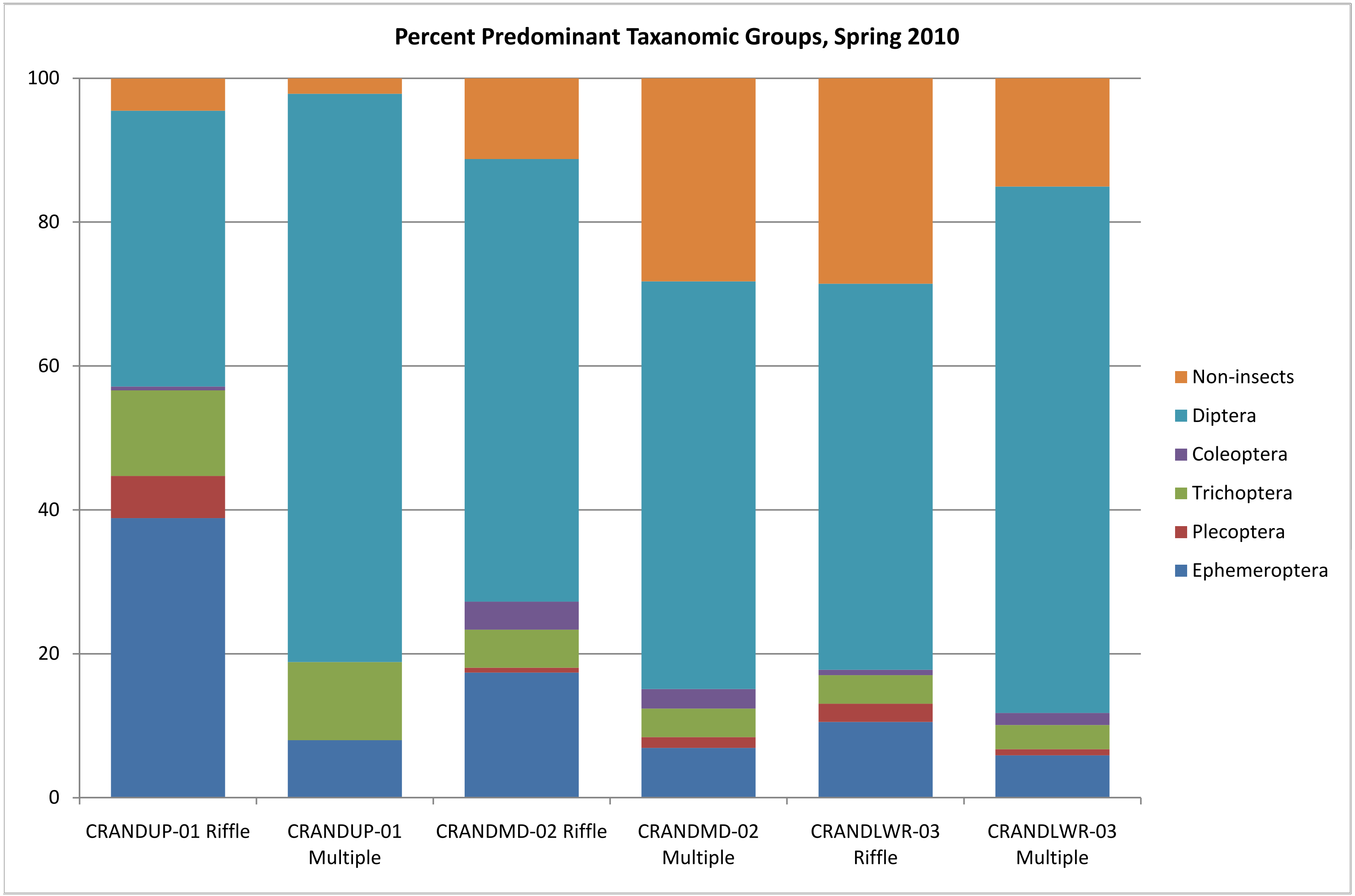
Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDLWR-03, Crandall Creek, Lower, Emery county, Utah. The sample was collected from riffle habitat using a kick net. The total area sampled was 0.743 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 276 individuals were removed, identified and retained. The sample identification number is 143617. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

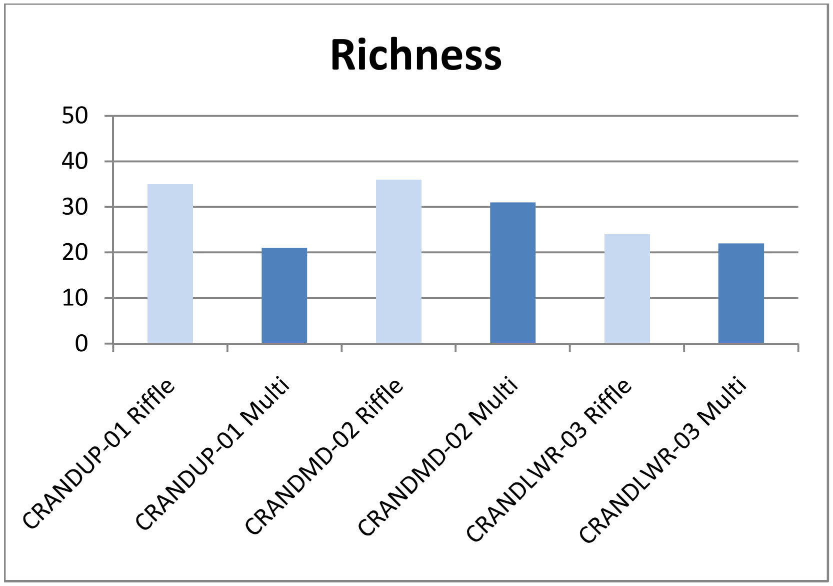
Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes			adult	8.07	U
Trombidiformes	Lebertiidae	Lebertia	adult	63.24	
Trombidiformes	Sperchonidae	Sperchon	adult	30.95	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae		larvae	1.35	I
Coleoptera	Elmidae	Optioservus	larvae	1.35	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	1.35	
Diptera	Chironomidae	Orthocladiinae	larvae	130.51	
Diptera	Empididae	Hemerodromiinae Hemerodromiini	larvae	10.76	I
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	14.80	
Diptera	Empididae	Neoplasta	larvae	1.35	
Diptera	Stratiomyidae	Caloparyphus	larvae	1.35	
Diptera	Tabanidae		larvae	1.35	
Diptera	Tipulidae	Dicranota	larvae	2.69	
Diptera	Tipulidae	Hexatoma	larvae	4.04	
Diptera	Tipulidae	Limoniinae Antocha monticola	larvae	25.56	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	1.35	
Diptera	Tipulidae	Tipulinae Tipula	larvae	4.04	
Ephemeroptera	Baetidae	Baetis	larvae	39.02	
Plecoptera	Chloroperlidae		larvae	6.73	D
Plecoptera	Perlodidae		larvae	2.69	I,D
Trichoptera	Hydropsychidae	Hydropsychinae Hydropsyche	larvae	9.42	
Trichoptera	Limnephilidae		larvae	1.35	I
Trichoptera	Rhyacophilidae	Rhyacophila angelita group	larvae	4.04	
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	4.04	
Total: OTU Taxa : **24**		Genera : **17**	Families : **17**	371.35	

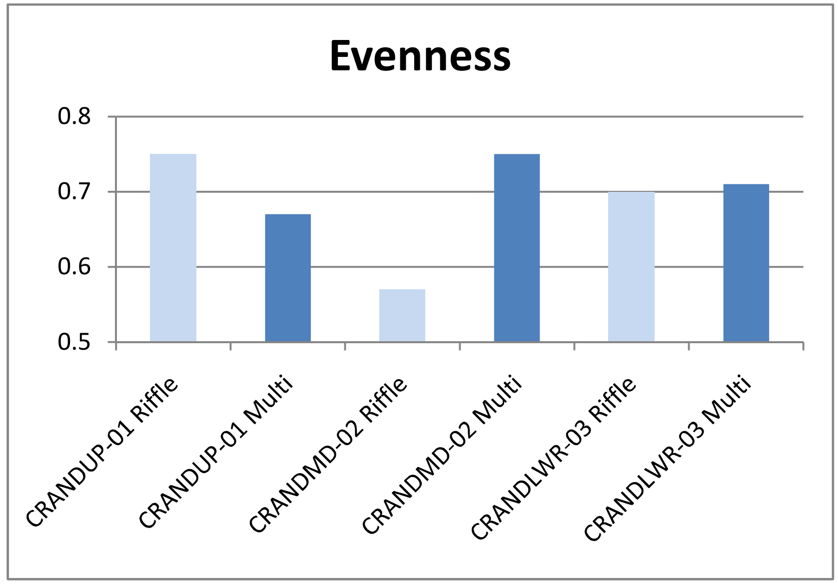
Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected June 7, 2010 at station CRANDLWR-03, Crandall Creek, Lower, Emery county, Utah. The sample was collected from multiple habitat using a kick net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 119 individuals were removed, identified and retained. The sample identification number is 143618. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

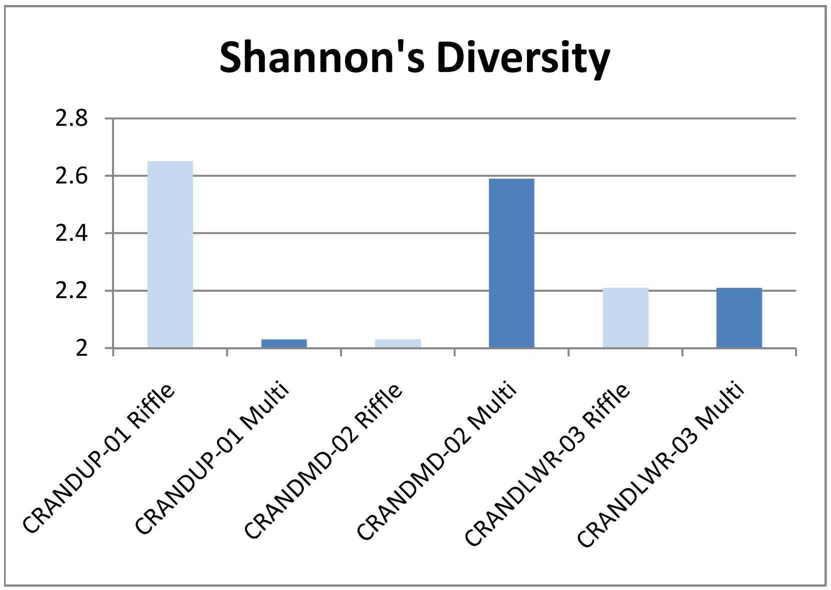
Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes			adult	8.61	U
Trombidiformes	Arrenuridae	Arrenurus	adult	2.15	
Trombidiformes	Lebertiidae	Lebertia	adult	10.76	
Trombidiformes	Sperchonidae	Sperchon	adult	12.92	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Dytiscidae		larvae	2.15	D
Coleoptera	Elmidae	Narpus concolor	larvae	2.15	
Diptera	Ceratopogonidae		larvae	2.15	I
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	2.15	
Diptera	Chironomidae	Chironominae	larvae	19.38	
Diptera	Chironomidae	Orthocladiinae	larvae	114.10	
Diptera	Chironomidae	Tanypodinae	larvae	6.46	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	15.07	
Diptera	Empididae	Neoplasta	larvae	6.46	
Diptera	Tipulidae	Dicranota	larvae	2.15	
Diptera	Tipulidae	Hesperoconopa	larvae	2.15	
Diptera	Tipulidae	Limoniinae Antocha monticola	larvae	12.92	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	4.31	
Ephemeroptera	Baetidae	Baetis	larvae	15.07	
Plecoptera	Chloroperlidae		larvae	2.15	D
Trichoptera	Hydropsychidae	Hydropsychinae Hydropsyche	larvae	6.46	
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	2.15	D
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	4.31	
Total: OTU Taxa : **22**	Genera : **15**	Families : **15**		256.18	

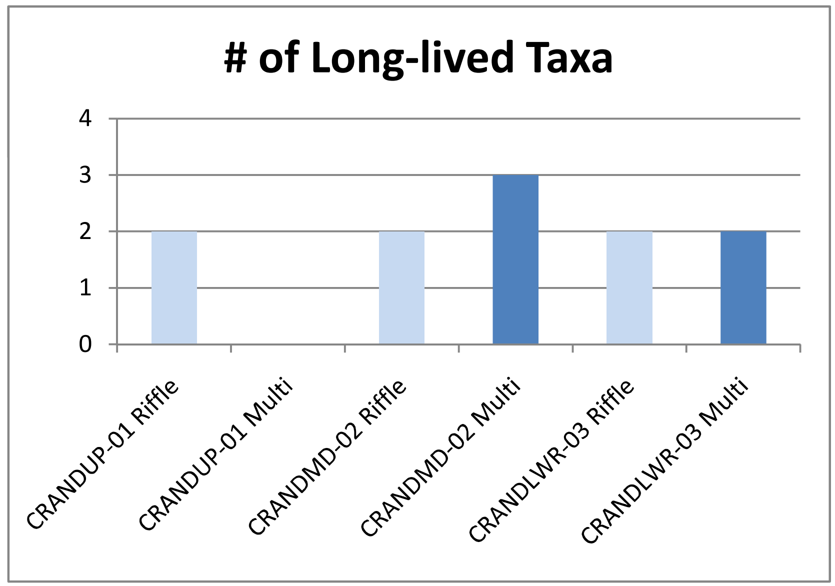
APPENDIX 2
MACROINVERTEBRATE METRICS

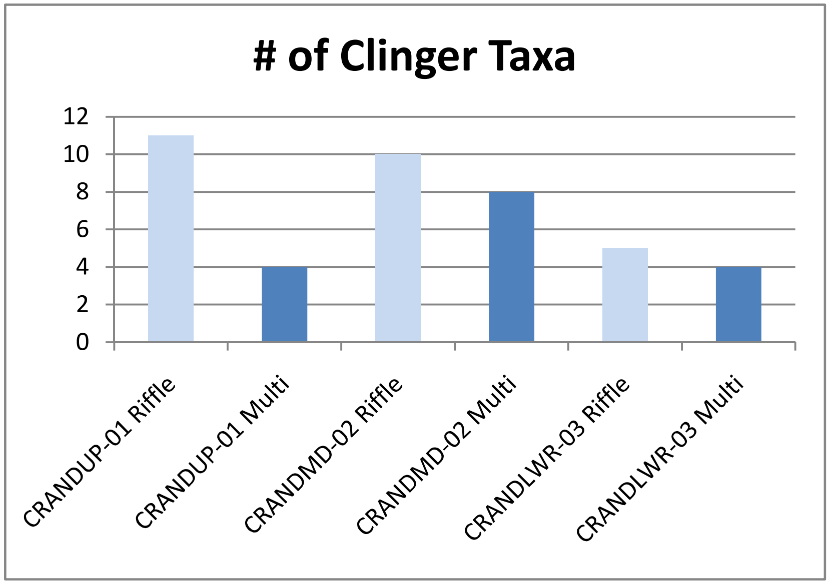

Percent Predominant Taxonomic Groups, Spring 2010
100
80
60
40
20
0
CRANDUP-01 Riffle
CRANDUP-01 Multiple
CRANDMD-02 Riffle
CRANDMD-02 Multiple
CRANDLWR-03 Riffle
CRANDLWR-03 Multiple
Non-insects
Diptera
Coleoptera
Trichoptera
Plecoptera
Ephemeroptera


Richness
50
40
30
20
10
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

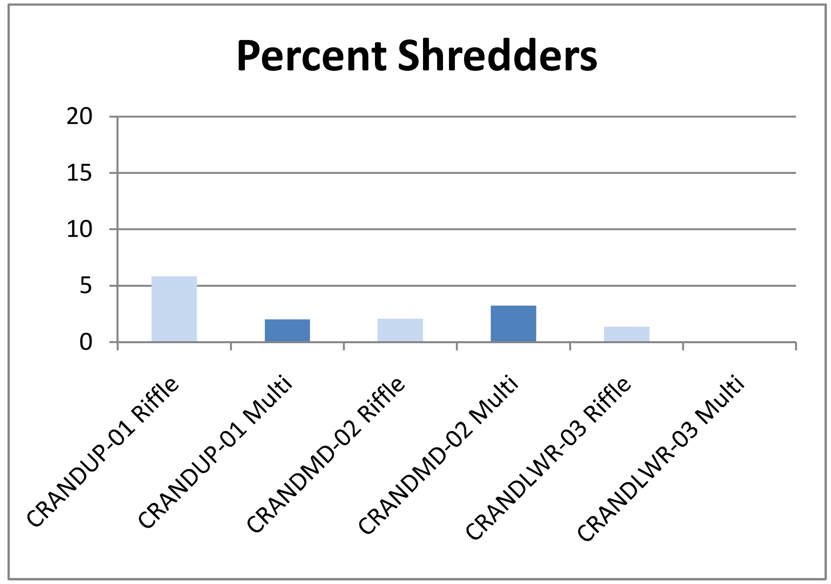

Evenness
0.8
0.7
0.6
0.5
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi


Shannon's Diversity
2.8
2.6
2.4
2.2
2
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

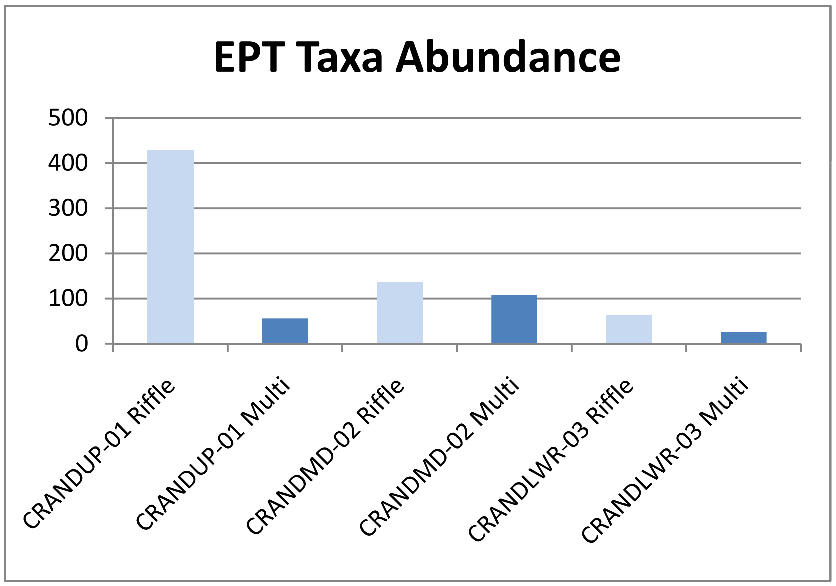

# of Long-lived Taxa
4
3
2
1
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi



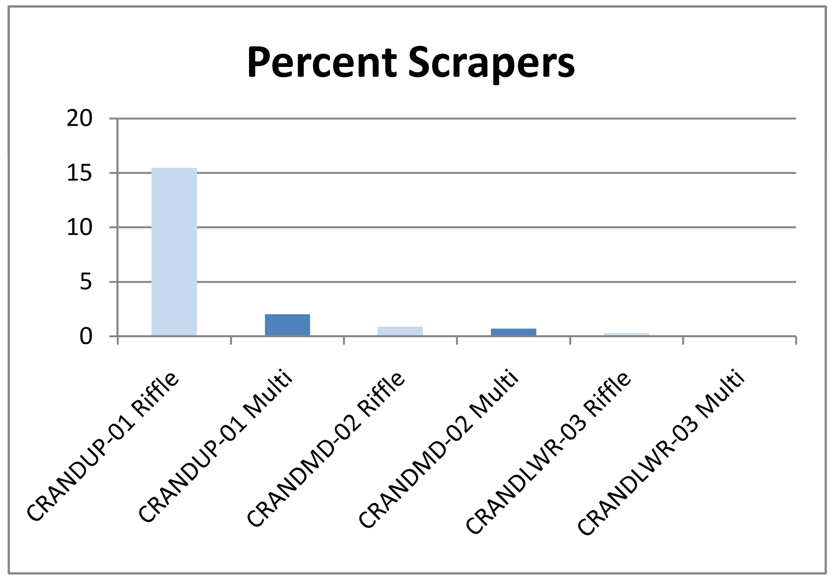
# of Clinger Taxa
12
10
8
6
4
2
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi



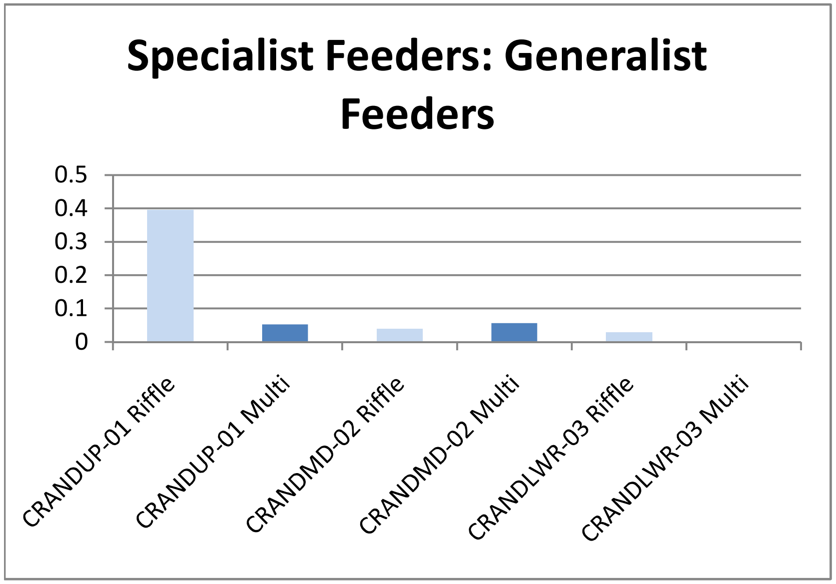
Percent Shredders
20
15
10
5
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

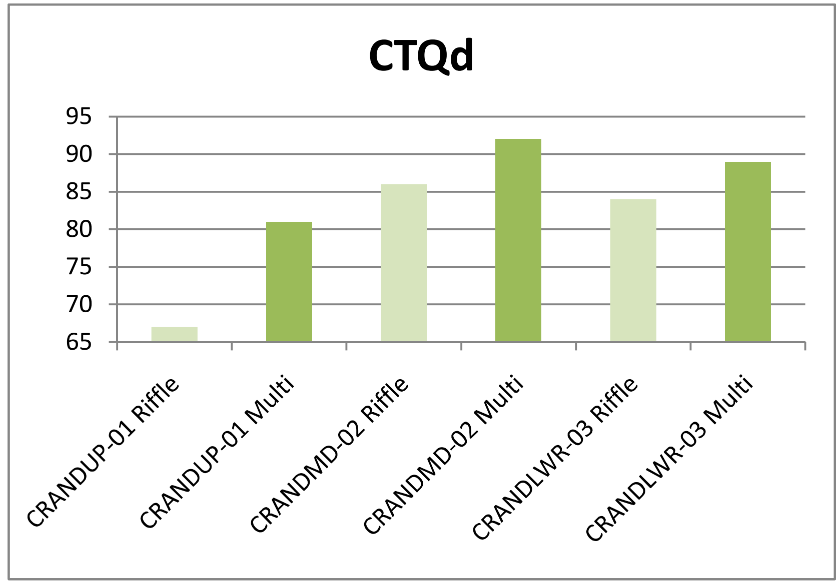


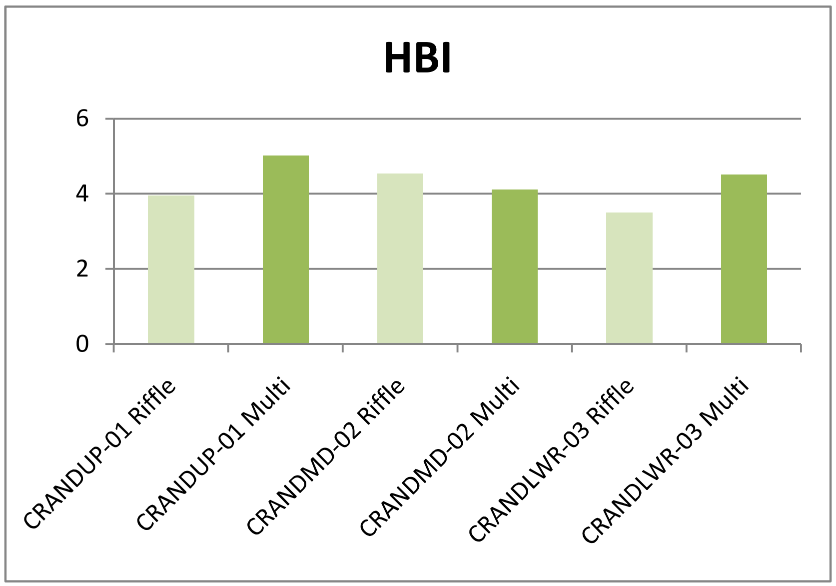
EPT Taxa Abundance
500
400
300
200
100
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

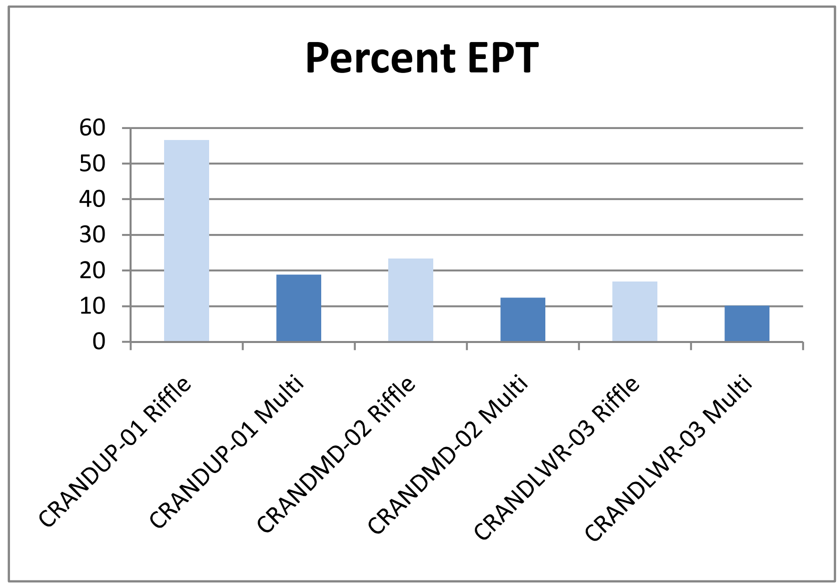


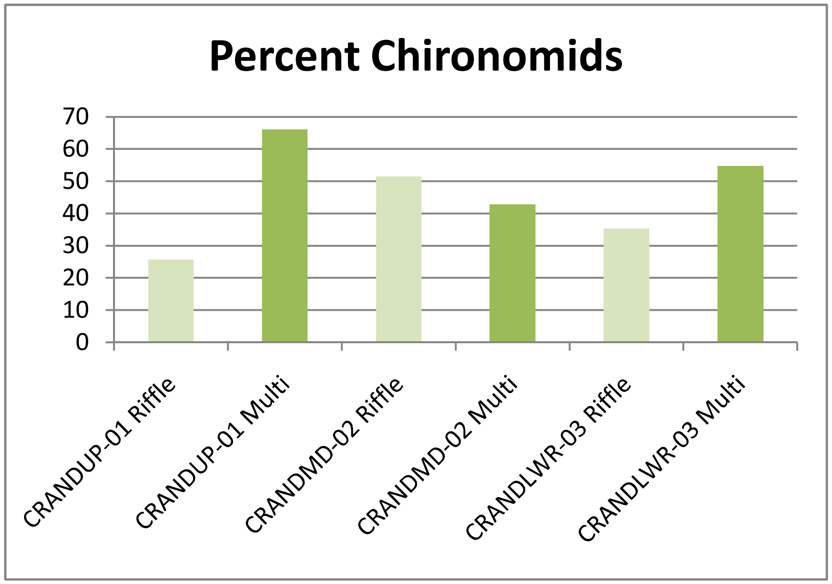
Percent Scrapers
20
15
10
5
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

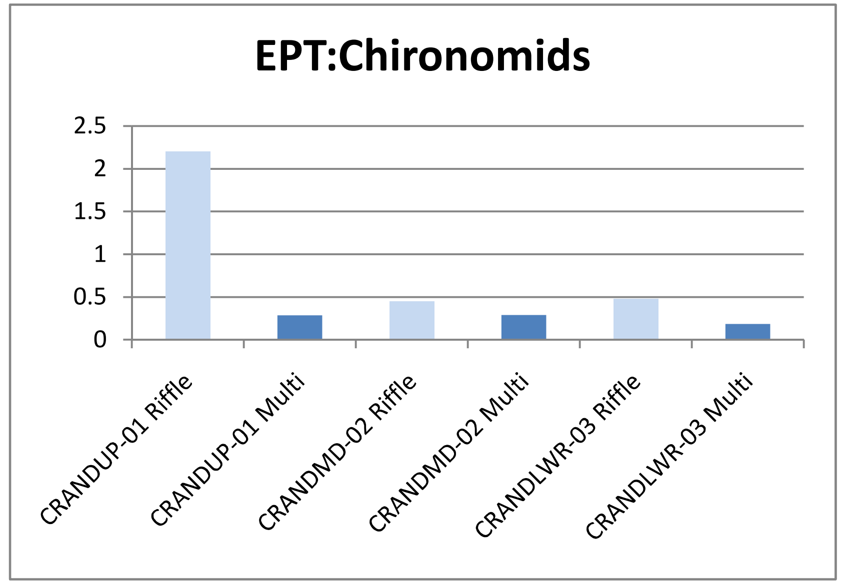

Specialist Feeders: Generalist Feeders
0.5
0.4
0.3
0.2
0.1
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

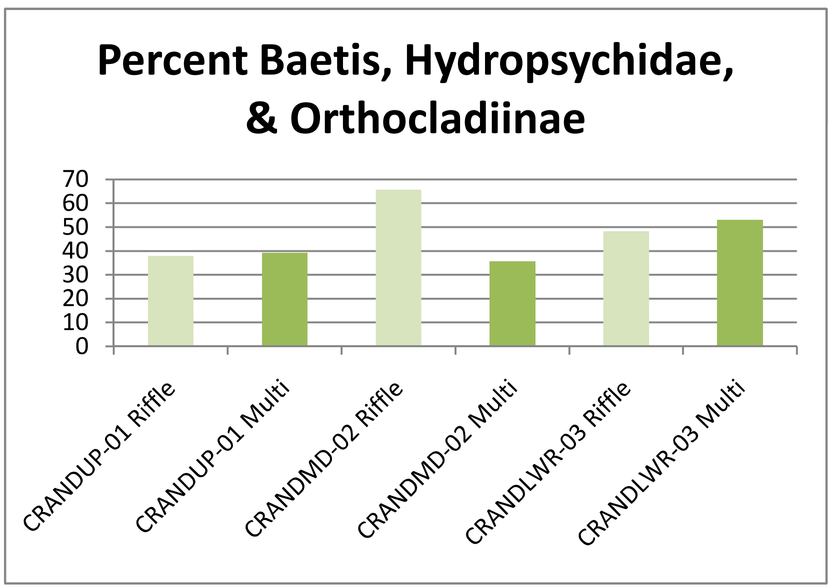

CTQd
95
90
85
80
75
70
65
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

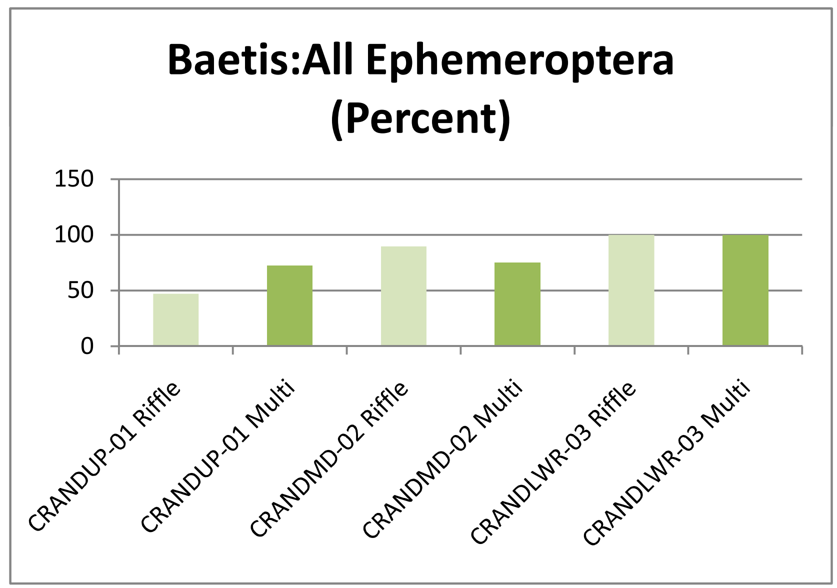

HBI
6
4
2
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

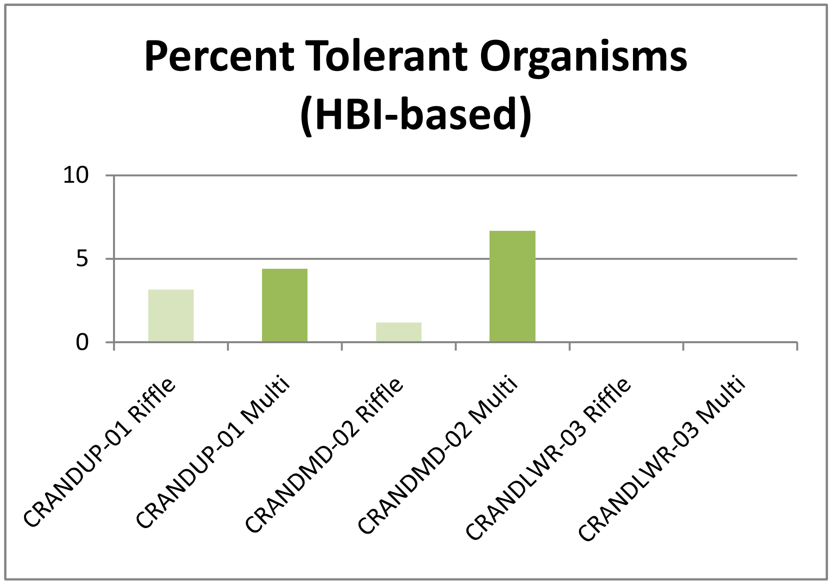

Percent EPT
60
50
40
30
20
10
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

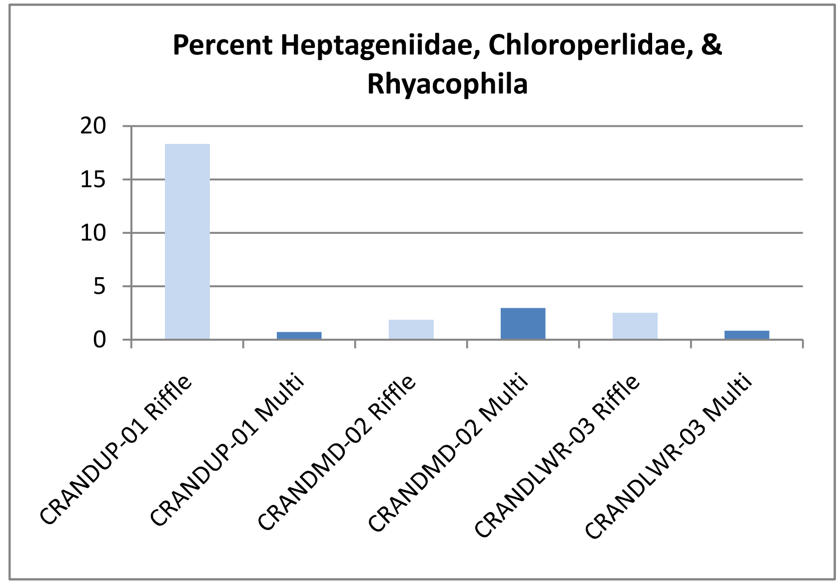

Percent Chironomids
70
60
50
40
30
20
10
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

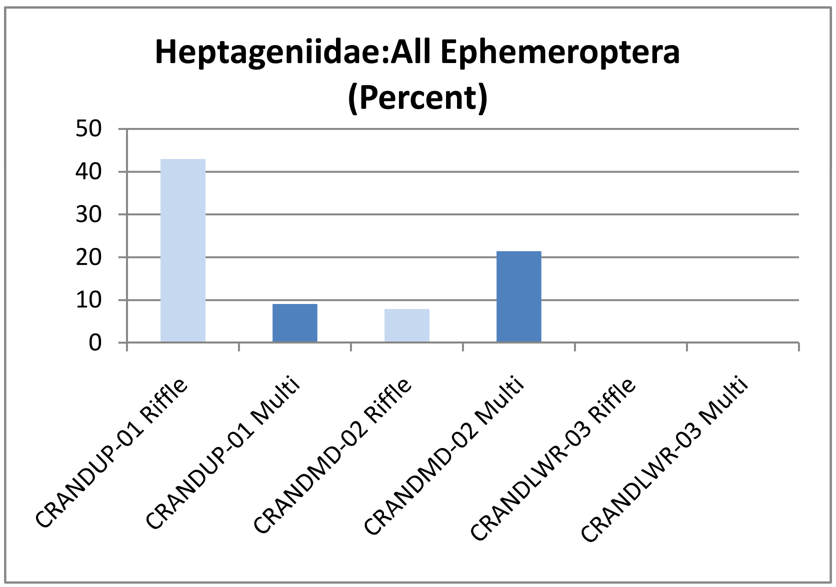

EPT:Chironomids
2.5
2
1.5
1
0.5
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

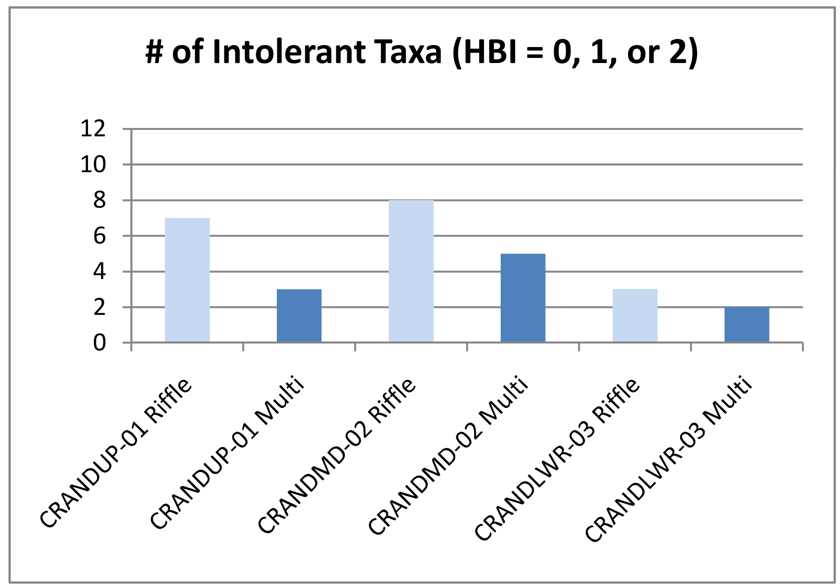

Percent Baetis, Hydropsychidae, & Orthocladiinae
70
60
50
40
30
20
10
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi


Baetis:All Ephemeroptera (Percent)
150
100
50
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

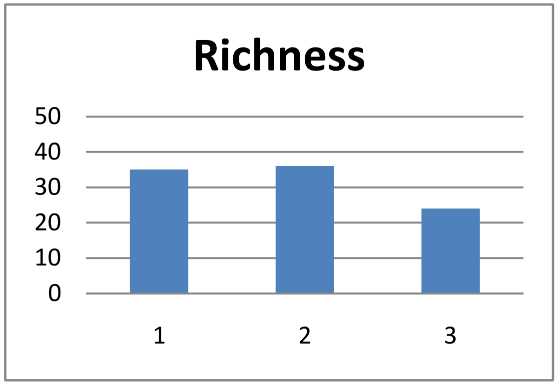

Percent Tolerant Organisms (HBI-based)
10
5
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

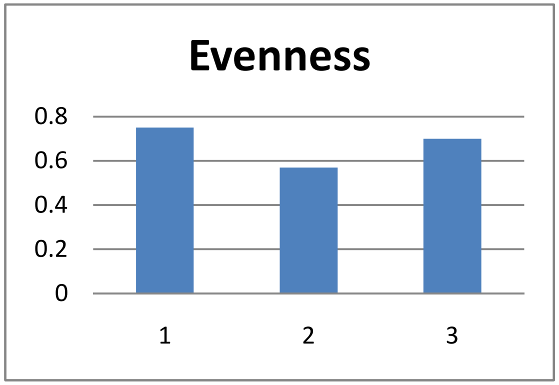

Percent Heptageniidae, Chloroperlidae, & Rhyacophila
20
15
10
5
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

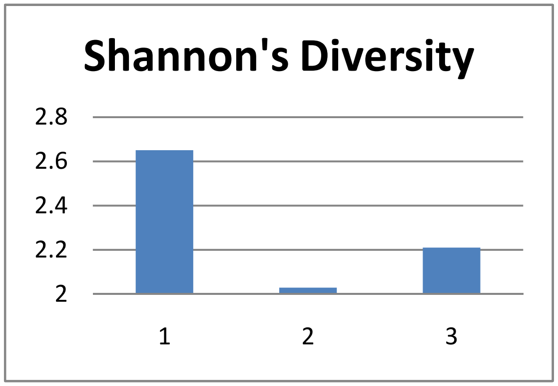

Heptageniidae:All Ephemeroptera (Percent)
50
40
30
20
10
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

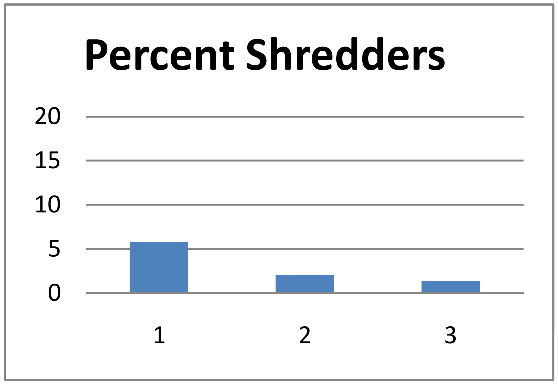

# of Intolerant Taxa (HBI = 0, 1, or 2)
12
10
8
6
4
2
0
CRANDUP-01 Riffle
CRANDUP-01 Multi
CRANDMD-02 Riffle
CRANDMD-02 Multi
CRANDLWR-03 Riffle
CRANDLWR-03 Multi

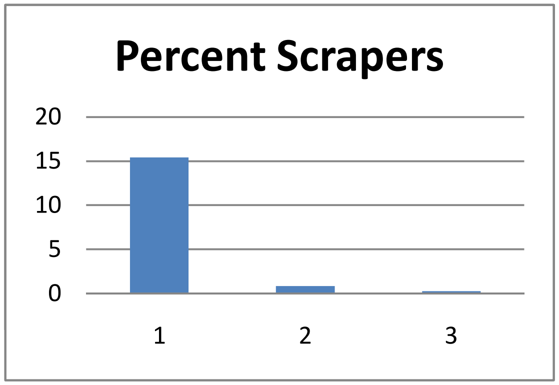
June 2010 Riffle Samples

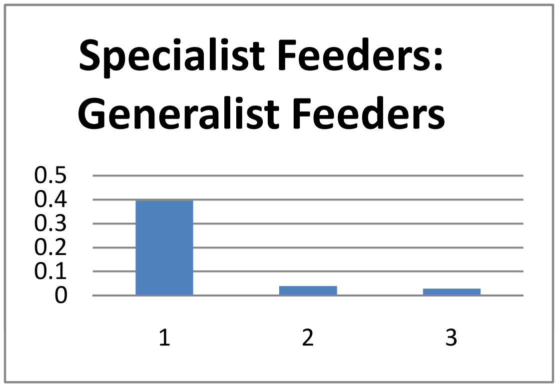


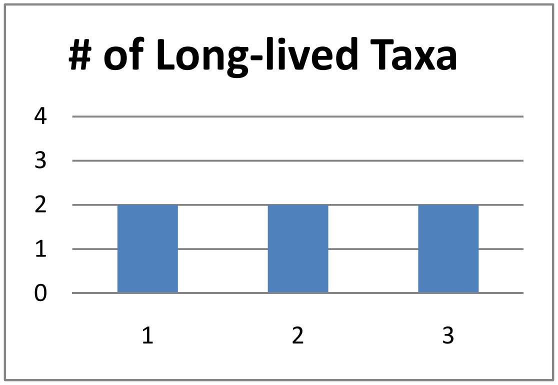


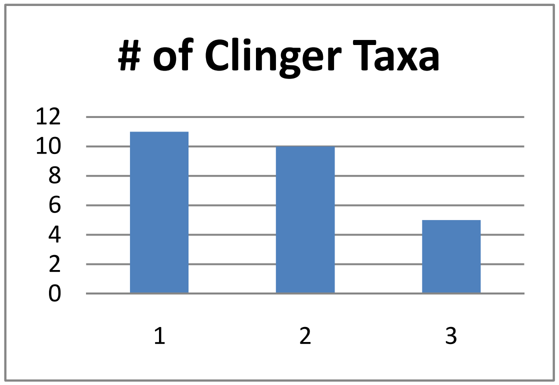


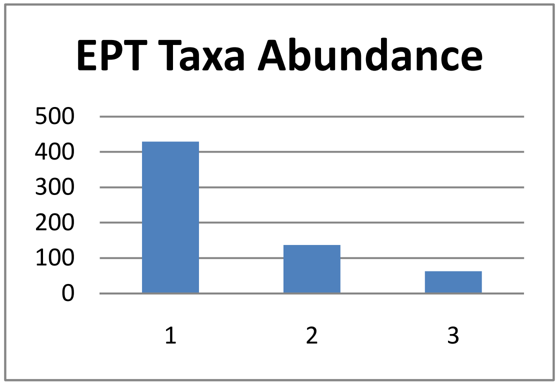




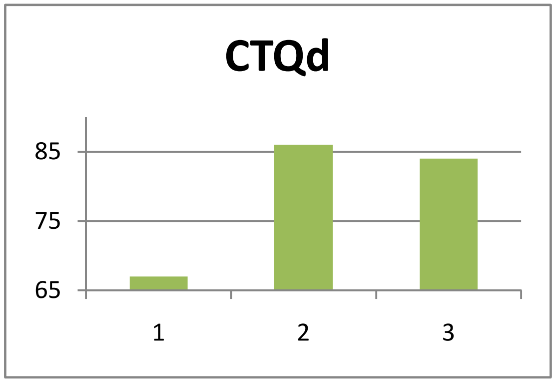


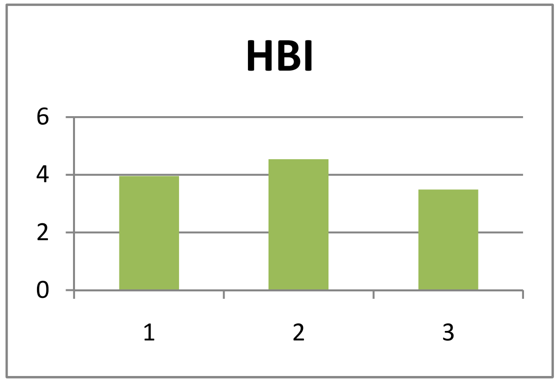


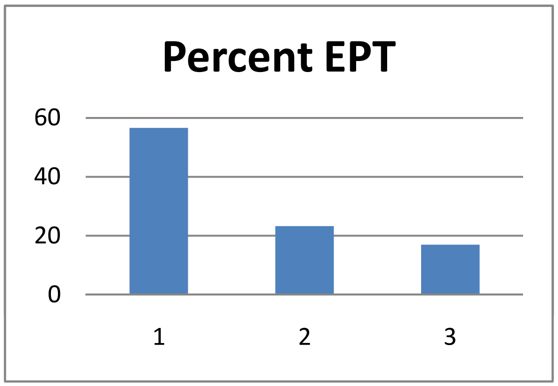


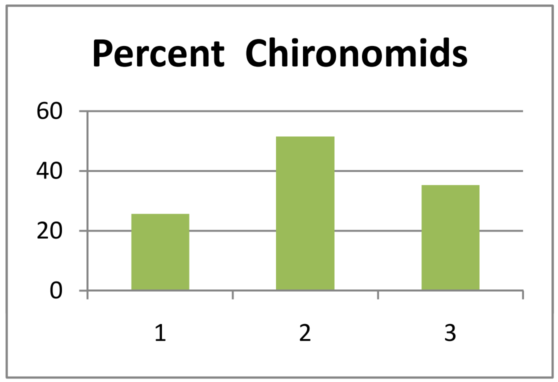


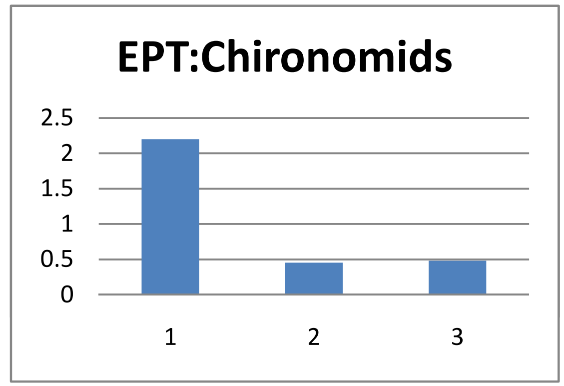
June 2010 Riffle Samples



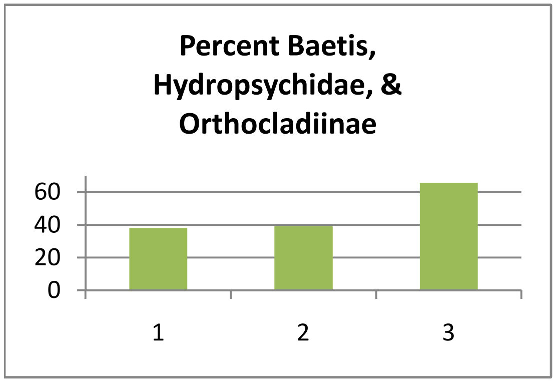


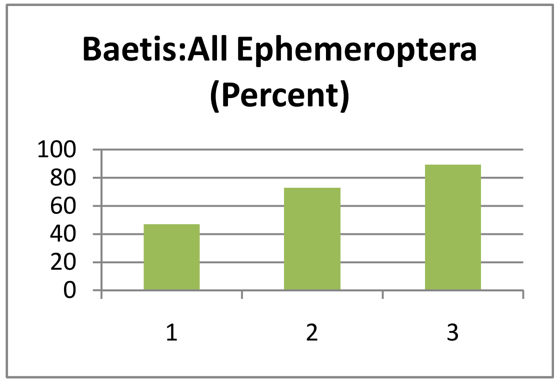


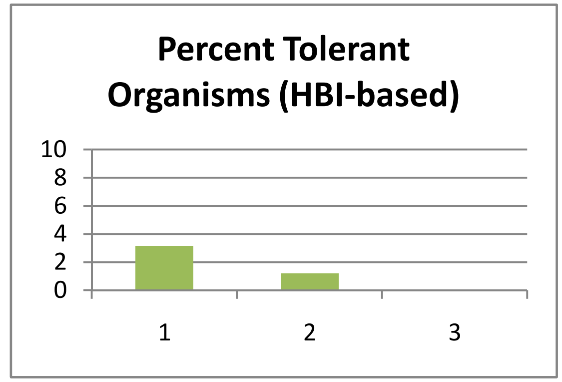


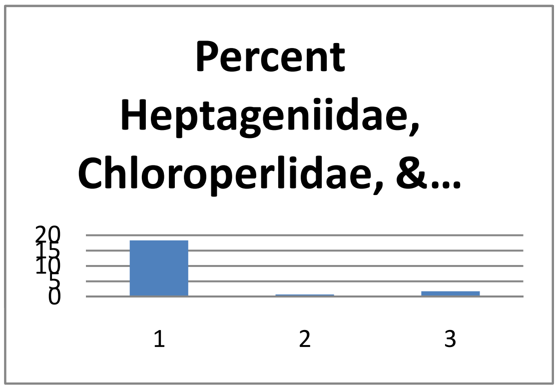


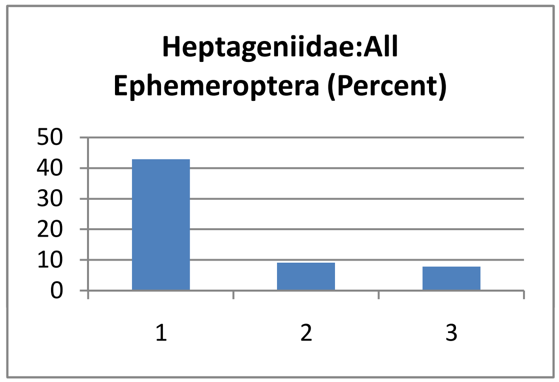
June 2010 Riffle Samples

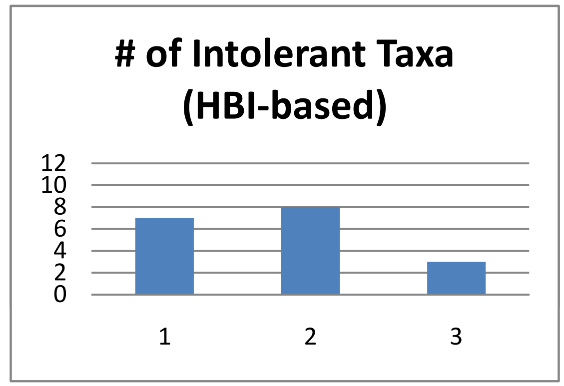






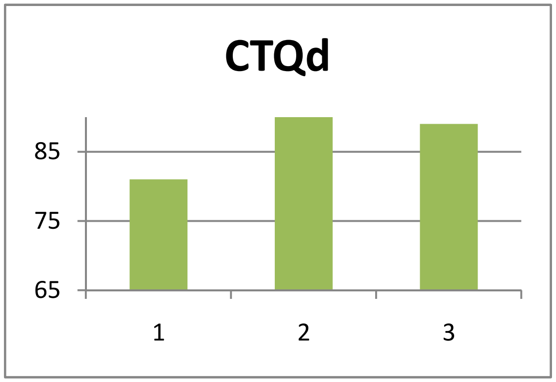


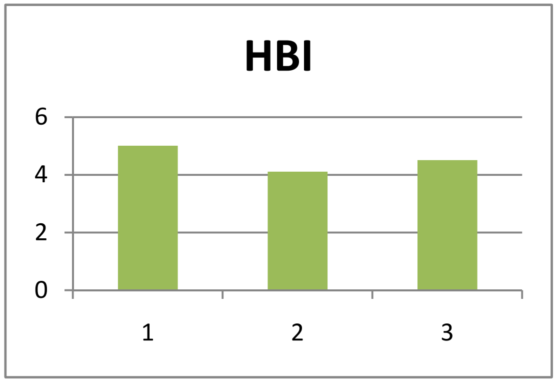


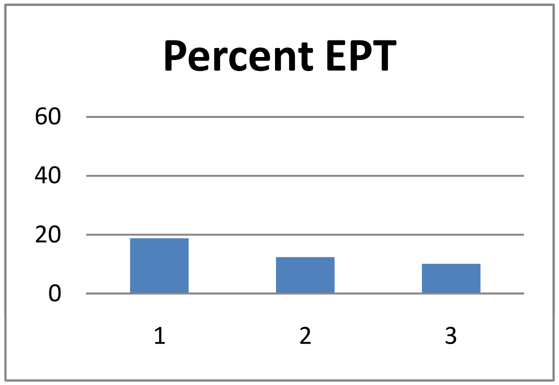


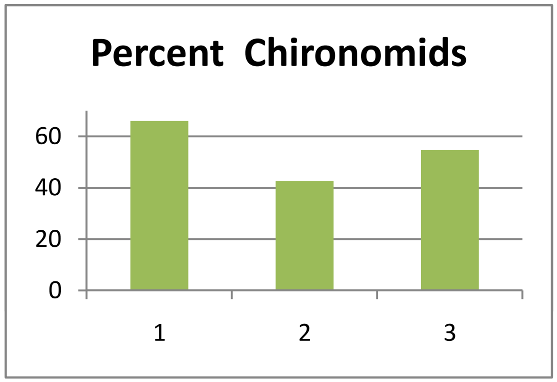
June 2010 Multi-Habitat Samples

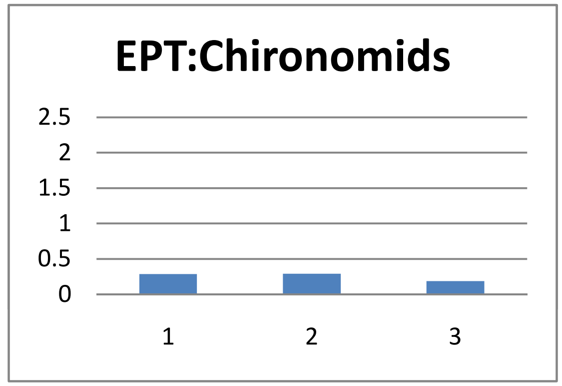
June 2010 Multi-Habitat Samples











June 2010 Multi-Habitat Samples