Assessing Acid Mine Restoration Activities in the Henson Creek Watershed Using Aquatic Macroinvertebrate Assemblages

Report prepared by:
Eric Dinger, PhD and Mark Vinson, PhD
USDI Bureau of Land Management
National Aquatic Monitoring Center
Department of Watershed Sciences
Utah State University
Logan, UT 84322

14 August 2008

Introduction

Previous research on the impacts of mining on aquatic macroinvertebrates showed substantial impairment in the Henson Creek watershed (Vinson 2000). Restoration of Palmetto Gulch in the Henson Creek watershed, Hinsdale County, Colorado was undertaken in the fall of 2003, by sealing the entrance of the Roy Pray mine adit. To reduce or prevent acid water from draining from the mine the mine adit was sealed and the waste pile was relocated to reduce leaching of metals into the Palmetto Gulch stream. The Roy Pray mine is one of several mines in the Henson Creek Watershed and to date this site has received the most restoration. Aquatic macroinvertebrates have been shown to respond rapidly (within months to a single year) to restoration activities (e.g. Dinger and Marks 2007), and serve as bioindicators of overall ecosystem health (Rosenberg and Resh 1993; Merritt et al. 2008). The purpose of this report is to evaluate the effectiveness of the restoration activities at the Roy Pray mine site on aquatic macroinvertebrate assemblages. The Bureau of Land Management, Uncompahgre Field Office has been monitoring aquatic macroinvertebrate assemblages within the watershed for the past 8 years; 4 years of sampling before restoration of the Roy Pray mine began and 4 years since the restoration activities.

Methods

Site Selection

Aquatic macroinvertebrate samples have been collected at 20 sites within the the Henson Creek watershed (Vinson 2000, Dennis Murphy, personal communication). For this study, we focused on 5 sites above and below the restoration activities (Table 1). Sites were categorized as control and restored and either acid affected or unaffected. Due to the location of the study sites, that were unrestored, acid affected could still be considered as a control site.

Table 1. Locations, names and restoration status for sites used to assess restoration success.

Station ID	Name	Latitude	Longitude	Elevation	Restoration/impact status
Palm-01	Tributary above Palmetto Gulch upstream from mine	37° 58.00'	107° 34.00'	3828	Upstream from mine, control site
Palm-02	Tributary above Palmetto Gulch above mine, 100 meters below Palm-01	37° 58.00'	107° 34.00'	3822	Not restored, acid impacted by Sarah Woods mine
Palm-04	Palmetto Gulch, downstream from restored mine adit	37° 58.39'	107° 34.51'	3755	Immediately downstream from restoration
Palm-05	Palmetto Gulch upstream of north tributary	37° 57.78'	107° 34.03'	3572	About one mile downstream from restoration site
Palm-08	Henson Creek upstream from confluence with Palmetto Gulch	37° 59.00'	107° 33.54'	3493	Control site, not impacted

Site Descriptions

1. Palm-01 – A small tributary upstream from the restoration site. It is located within 100 meters of the mine plug. It is an unrestored, control site that is acid unaffected.
2. Palm-02 – A small tributary stream located just downstream from Palm-01. This site is located upstream of the restoration site. This site includes flow coming from the Sarah Woods mine. It is an unrestored, control site that is acid affected by the Sarah Woods mine.
3. Palm-04 – This site is located on Palmetto Gulch directly downstream from the Roy Pray mine restoration site. The adit was plugged in October 2003. It is a restored, impacted site that is acid affected.
4. Palm-05 – This site is located on Palmetto Gulch about one mile downstream from Palm-04. It is a restored impacted site that is acid affected.
5. Palm-08 – This site is located on Henson Creek just upstream of the confluence with the Palmetto Gulch. This site is an unrestored control site that is acid unaffected.

Field Methods

Aquatic macroinvertebrates were collected using Surber Nets (0.093 m^2, 250 µm mesh). At each site, 8 individual riffles within a 100 meter reach were sampled and composited into a single sample for a total sampling area of 0.744 m^2. Samples were preserved in 95% ethanol and sent to the U.S. Bureau of Land Management National Aquatic Monitoring Center for processing and identification.

Laboratory procedures are described in Cuffney et al. (1993) and Vinson and Hawkins (1996). Samples were sub-sampled to a minimum of 500 individuals using a float/lift/split method. In this, the sample was floated in a 250 µm sieve until the material was level in the pan. The sieve was then lifted out and split into equal portions. A random portion was then set aside and the process repeated until it appeared that 500 organisms remained. The sub-sample was then sorted under 7X magnification and sorted into order. After sorting, the entire sample was spread in a large, white enamel pan and the technician spent and additional 10 minutes searching for "big/rare" taxa that were missed in the sorted subsample. Insects were then identified to the lowest practical level, with the exception of Chironomidae (Diptera) which were identified to sub-family. Samples were archived in 70% ethanol and retained at the National Aquatic Monitoring Center, Logan, Utah.

Several sample summary indices were then calculated for each sample for evaluating the effects of restoration activities. The indices used were:

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). 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.

Hilsenhoff Biotic Index -. The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected, and changes in a site's HBI can be viewed as an indication of community change (Hilsenhoff 1987, Hilsenhoff 1988). This index is used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. 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. Shifts in HBI from low values to high values indicate a shift toward a more pollution tolerant assemblage, and a shift from high values to low values indicate a change towards a more intolerant assemblage.

EPT – This is a summary of the taxa richness and abundance among the insect Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are commonly considered sensitive to pollution.

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). A Shannon Diversity measurement of 0 indicates that the assemblage is composed of only one species, and increase upward with increasing species richness and eveness. Typical values range from 0 to 3.

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 impacts or pollutants. 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 decrease invertebrate abundance. Invertebrate abundance is presented as the number of individuals per square meter.

Analyses

Effects of restoration were assessed using two methods: 1) Graphical representation of trends over time and 2) Before-After/Control-Impact Paired Series (BACIPS). The value in graphical representation is that it allows the reader to gain a qualitative sense of changes of time relating to management actions, coupled with temporal variation of the study timeframe. In this sense, it offers relevant information on biological significance. The value of BACIPS is that it allows the testing of statistical significance in assessing restoration activities.

The premise of BACIPS is that the measure of interest (or measure of effect size) can be the difference of a response variable between a control and impact (in this case a restored site). This allows for inherent differences caused by habitat or spatial variation to be a minimal issue. The assumption, however, is that large-scale processes such as annual and seasonal variation are equal at both sites. Differences in the two sites were then compared using a t-test to evaluate a change in before-after periods. When there is a difference detected, interpretation was based on the graphical trends over time (i.e. positive or negative effect).

Results

There was no apparent change in invertebrate metrics at Palm-02, Palm-04 or Palm-05 after the adit was plugged in October 2003. The total number of taxa at Palm-04, immediately below the restored site, declined after the restoration, and has remained at or near pre-restoration levels (Figure 1A). There was also no apparent change in total taxa at Palm-05. Taxa levels at these impacted sites (but restored) remain similar to Palm-02, an impacted (unrestored) site just above the mine plug.

Invertebrate abundances showed similar patterns. Abundance at restored sites (Palm-04 and Palm-05) was less than that observed at control sites (Palm-01 and Palm-08, Figure 1B). Abundances at the restored sites were similar to that observed at the unrestored acid impacted site (Palm-02).

The number of EPT taxa observed at impacted restored sites was always less than that observed at control sites and on numerous dates no EPT taxa were collected at impacted sites

(Figure 1C). The unimpacted control site upstream from the mine plug (Palm-01) also tended to have low numbers of EPT taxa.

All sites had similar, but variable HBI scores (Figure 1D). There was a decline in HBI at Palm-05 immediately after restoration, but this was based on a sample collection of only 7 individuals.

Shannon diversity was variable during the study period for all sites sampled (Figure 1E). No pattern was discernable after restoration, although the all impacted sites (Palm-02, Palm-04, Palm -05) were similar to the unimpacted control site (Palm-01). The unimpacted site located on Henson Creek (Palm-08) always had higher Shannon Diversity than that found at all other sites.

The layout of the sites allowed for two separate comparisons using BACIPS: The restored site (Palm-04) versus the two upstream sites (Palm-01, upstream, not acid affected; and Palm-02, upstream, acid affected). Using Palm-01 site as a control, there was no significant effect of the restoration on any invertebrate metric (Table 2). However, using Palm-02 as a control site did provide 1 significant change in HBI values. However, examination of the average differences, before and after indicate that the change was responsible due to the restored site becoming *more similar* to the upstream Palm-02, which was still affected by the acid drainage from the Sarah Woods mine. Furthermore, the shift in HBI was more apparent in changes due to increased HBI in Palm-02, and not in the restored site.

Table 2. Results of Before-After/Control-Impact Paired Series (BACIPS) tests to determine restoration success of the Roy Pray adit plug. OTU = Operational taxonomic units, EPT = Ephemeroptera, Plecoptera and Trichoptera, and HBI = Hilsenhoff biotic index. * = significant at the α = 0.05 level.

	Palm-01 (control) versus -04 (restored)			Palm-02 (Control) versus -04 (restored)		
	Average difference			Average difference		
	Before	After	*p*	Before	After	*p*
OUT	14	9.6	0.308	1	-0.67	0.61
Abundance	1631	801	0.154	6	0.67	0.78
Shannon diversity	0.46	0.567	0.527	-0.046	0.52	0.135
EPT taxa	4	2	0.527	0.67	-1.67	0.135
HBI	-1.19	0.11	0.143	-1.67	0.25	0.044*

Discussion

There appeared to be no effect of restoration activities on aquatic macroinvertebrate assemblages in Palmetto Gulch. Densities of macroinvertebrates in restored sites remained as low as measurements from pre-restoration activities. There was also no improvement in indicators of ecosystem integrity (e.g. HBI, EPT, Shannon Diversity). Measurements of aquatic macroinvertebrate assemblage density and ecosystem integrity were likewise similar to other unrestored, acid impacted streams.

The lack of any improvement in the macroinvertebrate assemblage was likely due to two potential sources: 1) the continued degradation of the water quality from the Sarah Woods mine, and 2) continued heavy metal inputs from the Roy Pray mine, despite plugging.

The Sarah Woods mine is the third largest source of mining pollution in the Palmetto Gulch (Krabacher et al. 2006). Of particular note, there is a substantial amount of copper pollution (270 µg/L) from the mine. Copper is known to be highly toxic to aquatic macroinvertebrates (Wiederholm 1984), and the values measured from the Sarah Woods mine are well above values known to be chronically toxic to macroinvertebrates (Krabacher et al. 2006). Without successful restoration of pollution sources located higher in the watershed, there is unlikely to be any successful invertebrate recolonization lower in the watershed where impacts are still present.

Another possibility is that the reservoir created behind the plug of the Roy Pray mine continues to seep through the rock layers, eventually infiltrating the stream some distance below the plug (Krabacher et al. 2006). In essence, the mine associated pollution of the Roy Pray mine is still present in the sites located downstream from the restoration activities. The evidence for this is continued measurements of increased Aluminum, Cadmium, Copper, Manganese, and Zinc from water quality measurement above the Roy Pray mine and 2000 feet downstream of the mine. In some cases (especially Aluminum and Copper), the concentration of these metals is 2 – 3.5 times greater downstream from the adit plug. Further restoration activities for the Roy Pray mine may be necessary to improve water quality and biotic assemblages downstream from the Roy Prat mine.

Krabacher et al. (2006) raise the possibility that some amount of heavy metal leaching into the water maybe from natural sources. In this case, invertebrate assemblages may naturally be depauperate and in low abundances. However, the pollution levels and difference in abundances and diversity in the furthest upstream site versus the site immediately downstream from the mine was of such a high magnitude that it is more likely the result of continued acid mine drainage from the mine.

Continued restoration activities are planned for the Palmetto gulch, including the prospect of increased restoration of the Roy Pray mine (e.g. geosynthetic liner of mine waste, different management options for sediment ponds). We recommend the inclusion of restoration activities to the Sarah Woods mine and continued monitoring of aquatic invertebrates to determine long-term trends and assessment of any new or future restoration activities.

Report cover photo credits:
Left – Palmetto Gulch, upstream from the Roy Pray mine, from Krabacher et al. 2006.
Right – Roy Pray mine bulkhead, from Krabacher et al. 2006.

Literature cited

Cuffney, T.F., Gurtz, M.E. and Meador, M.R. 1993. Methods for collecting benthic invertebrate samples as part of the National Water Quality Assessment Program: United States Geological Survey Open File Report 93-406.

Dinger, E.C. and J.C. Marks. 2007. Effects of high levels of Antimcyin A on aquatic invertebrates in a warm-water Arizona stream. North American Journal of Fisheries Management 27: 1243-1256.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical ecology: a primer on methods and computing. John Wiley and Sons. New York.

Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family level biotic index. The Journal of the North American Benthological Society. 7:65-68.

Hilsenhoff, W.L. 1987. An improved index of organic stream pollution. The Great Lakes Entomologist. 20:31-39.

Krabacher, P., Herron, J., Graves, J. and K. Brown. 2006. Reclamation Feasibility Report: Henson Creek Watershed. Colorado Department of Natural Resources, Division of Minerals and Geology. Denver, Colorado. 171 pages.

Merritt, R.W., K.W. Cummins, and M.B. Berg, editors. 2007. An Introduction to the Aquatic Insects of North America. 4th Ed., Kendall/Hunt Publishing Co., Dubuque, Iowa.

Rosenberg, D., and V. Resh, editors. 1993. Freshwater biomonitoring and benthic invertebrates. Chapman and Hall, Inc. New York, New York. 488 pages.

Vinson, M.R. and C.P. Hawkins. 1996. Effects of sampling area and subsampling procedures on comparisons of taxa richness among streams. Journal of the North American Benthological Society 15:393-400.

Vinson, M.R. 2000. Mining impacts on aquatic macroinvertebrates in the Henson Creek watershed. Report to the Bureau of Land Mangament, Uncompaghre Field Office, Montrose, Colorado. 21 pages.

Widerholm, T. 1984. Responses of aquatic insects to environmental pollution. Pages 508- 557 In Resh, V. and D. Rosenberg, editors, The Ecology of Aquatic Insects. Praeger Publishers, New York, New York.

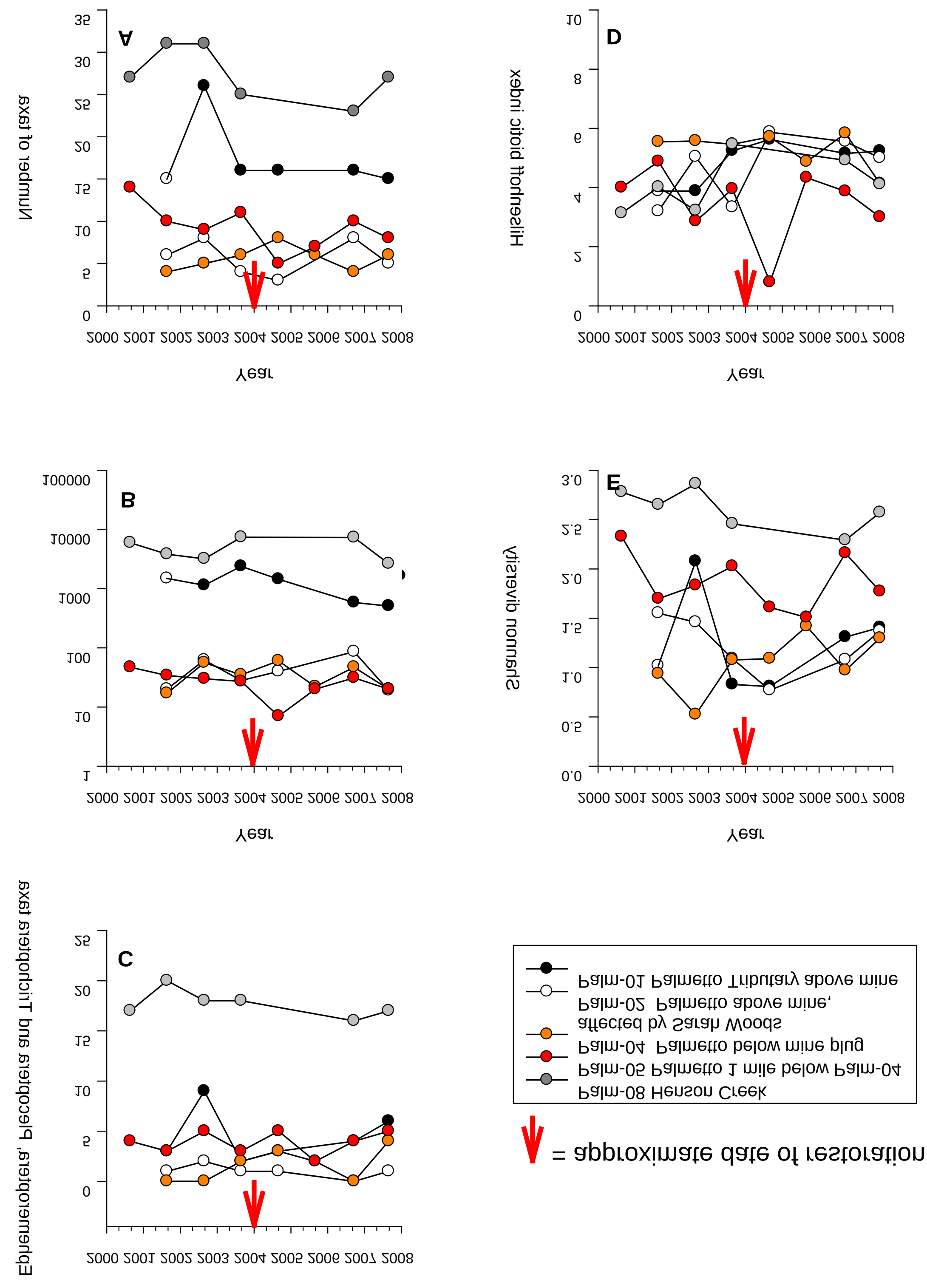

Figure 1. Patterns of 5 measures of invertebrate ecosystem health for 5 sites in the Henson Creek Watershed: A – Number of Taxa, B – Abundance, C – Ephemerotpera, Plecoptera and Trichoptera taxa, D – Hilsenhoff Biotic index, and E – Shannon diversity.