IMPROVEMENTS IN BROWN TROUT AND INVERTEBRATE POPULATIONS IN THE ARKANSAS RIVER DURING RECLAMATION EFFORTS ON CALIFORNIA GULCH[1]

L.C. Bergstedt[2], J.W. Chadwick, D.J. Conklin, Jr., and S.P. Canton

Abstract: Aquatic biological data have been collected from the upper Arkansas River since 1994 to monitor aquatic biological conditions in the river relative to historic mining and recent remediation activities in the California Gulch drainage. California Gulch flows directly into the Arkansas River and has historically contained elevated levels of several metals. Reclamation efforts (capping of waste rock piles, interception and treatment of adit water, etc.) have eliminated surge flows from the adits and lowered concentrations of metals entering the Arkansas River. Monitoring of brown trout populations has shown increasing trends in both density and biomass since 1994. Brown trout density and biomass were historically low downstream of California Gulch. However, trout density and biomass have been comparable or better than the reference condition upstream of California Gulch since 2002. Numbers of young-of-year brown trout have also improved. For macroinvertebrates, density, total number of taxa, number of mayfly taxa, and number of metal intolerant taxa have shown increasing trends downstream of California Gulch since 1994. The percent of total density as heptageniid mayflies is still somewhat lower than the reference sites, indicating some residual effects of California Gulch are still occurring. These data indicate reclamation efforts have improved conditions for the aquatic biota in the Arkansas River downstream of California Gulch.

Additional Key Words: metals, Colorado, Superfund Site, biological monitoring, cadmium, copper, lead, zinc

---

[1]Paper presented at the 2005 National Meeting of the American Society of Mining and Reclamation, June 19-23, 2005. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502

[2]Lee C. Bergstedt, Fisheries Biologist, Chadwick Ecological Consultants, Inc. James W. Chadwick, Senior Aquatic Ecologist, Chadwick Ecological Consultants, Inc., Littleton, CO 80120. Don J. Conklin, Jr., Senior Aquatic Ecologist, Chadwick Ecological Consultants, Inc. Steven P. Canton, Senior Aquatic Ecologist, Chadwick Ecological Consultants, Inc.
Proceedings America Society of Mining and Reclamation, 2005 pp 54-70
DOI: 10.21000/JASMR05010054
https://doi.org/10.21000/JASMR05010054

Introduction

At an elevation of 3,097 m, Leadville is the highest incorporated town in the United States. California Gulch and the 43.7 km^2 around it form a mining district first developed in 1859. Miners worked the watershed extensively, looking for gold, silver, copper, zinc, manganese, and lead. A broad system of underground mines gave access to the ores (Roline, 1988; Costello, 2003). The Yak Tunnel, one of two tunnels that drain this mining district, is more than four miles long. It discharged approximately 190 metric tons of metals per year in the early 1980's (EPA 2000). Historic mining activities resulted in degradation of water quality and aquatic biota in the Arkansas River and its tributaries. One tributary, California Gulch, is a U.S. EPA Superfund Site. Elevated levels of cadmium, copper, lead, and zinc from California Gulch historically had detrimental effects on the macroinvertebrate (Clements, 1994) and fish (CEC, 2003) assemblages of the Arkansas River. The California Gulch Superfund Site covers approximately 4,774 ha and is divided into 12 Operable Units, each managed by a separate entity including the U.S. EPA, U.S. Bureau of Reclamation, the State of Colorado, ASARCO, Resurrection Mining Company, ASARCO-Resurrection joint venture (Costello, 2003).

Remediation Activities

Reclamation at the California Gulch Superfund Site includes water treatment plants, consolidation and stabilization of waste rock piles, surface water diversion, evaporation ponds, capping, and revegetation. Starting in 1990, the ASARCO-Resurrection joint venture agreed to design, build, and operate the Yak Treatment Plant. The treatment plan operates continuously and once it was built and put on-line in 1992, water quality in California Gulch improved greatly, but sources still affect both the water and soils. The treatment plant operates continuously and has improved the water quality of the Arkansas River. Although not Superfund related, a similar treatment plant was built on the Leadville Mine drainage tunnel, which flows into the East Fork of the Arkansas River. Once on-line, also in 1992, an improvement in water quality has also been found in the East Fork (Nelson and Roline 1996). Other reclamation efforts have focused on drainage controls for acid mine runoff, consolidation and capping of mine piles, cleanup of residential properties, and reuse of slag. Future site-wide water-quality improvements may include large-segment stream restoration, additional mine-pile consolidation and capping, runon-runoff control of mine-water discharge, and restoration and development of wetlands. Biosolids have also been applied to tailings deposits on the Arkansas River (Costello, 2003).

During these remediation efforts, Chadwick Ecological Consultants, Inc. (CEC) has collected aquatic biological data on behalf of the Resurrection Mining Company. This information has been collected to monitor aquatic biological conditions in the Arkansas River relative to mining reclamation activities in the California Gulch drainage. Aquatic biological sampling by CEC since 1994 has focused on fish populations and macroinvertebrate populations. Water quality data has been collected concurrently by MFG, Inc. since 1994.

Study Area

The study area is located in the upper Arkansas River in central Colorado, between the Sawatch and Mosquito Mountain Ranges, near the town of Leadville (Fig. 1). The study area is contained in the Southern Rocky Mountain ecoregion, which extends from southern Wyoming to northern New Mexico (Omernik, 1987). The Arkansas River begins at the confluence of the East Fork of the Arkansas River and Tennessee Creek, just west of Leadville. Flow is characterized by high late-spring and early summer snowmelt flows, which recede to base flow for the remainder of the year. Low flows typically occur in February and March.

Data from five monitoring sites were used to evaluate the effectiveness of reclamation activities in the California Gulch drainage. For California Gulch, water quality and macroinvertebrate data were analyzed from Site CG-6, which is located on California Gulch approximately 0.75 km upstream of the confluence with the Arkansas River, at an elevation of 2,915 m, to determine if concentrations of metals of concern have been decreasing in California Gulch and if the macroinvertebrate community has responded to reclamation activities.

Figure 1. Sampling sites on the upper Arkansas River and California Gulch, 1994-2004.

For the Arkansas River, the reference sites were located upstream of the confluence with California Gulch. Site AR-1 is located on the Arkansas River approximately 3.9 km upstream of the confluence with California Gulch at an elevation of 2,960 m. Site AR-1 is used as the primary reference site for fish populations. Three sites were used for macroinvertebrate reference sites, Site AR-1, Site AR-12, which is located on the Arkansas River approximately 3.2 km upstream of the confluence with California Gulch at an elevation of 2,945 m, and Site AR-2, which is located on the Arkansas River approximately 0.3 km upstream of the confluence with California Gulch at an elevation of 2,905 m.

The downstream potentially impacted site was Site AR-3A, which is located on the Arkansas River approximately 0.5 km downstream of the confluence with California Gulch at an elevation of 2,895 m.

Methods

Concentrations of cadmium, copper, lead, and zinc from Sites AR-1, AR-3A, and CG-6 were obtained from MFG, Inc., which has monitored water quality on the Arkansas River and its tributaries on behalf of Resurrection Mining Company since 1994.

Fish population data has been collected in late summer or fall at Sites AR-1 and AR-3A by CEC alone or jointly with the Colorado Division of Wildlife (CDOW) in 1994, 1996, 1997, 1999, and 2001 through 2004. Sampling was conducted by making two sampling passes through the representative section of stream using electrofishing gear. Fish captured during each pass were kept separate to allow estimation of population density of each species using a maximum-likelihood estimator (Van Deventer and Platts, 1983, 1989). All fish sampled were identified to species, counted, measured for total length, weighed, and released. This sampling provided estimates of density (#/ha), biomass (kg/ha), condition (K) as described by Carlander (1969), relative weight (W_r) as described by Wege and Anderson (1978) and Anderson and Neumann (1996).

Benthic invertebrates have been sampled quantitatively at Sites AR-1, AR-12, AR-2, AR-3A, and CG-6 in spring and fall from 1994 through 2003 by CEC. Benthic invertebrate sampling entailed three replicate samples from similar riffle habitat using a modified Hess sampler (Canton and Chadwick, 1984), which encloses 0.086 m^2 and has a mesh size of 500 μm. Three samples have been shown to provide reliable estimates of density for benthic invertebrate communities in streams (Canton and Chadwick, 1988). In addition, to provide supplemental information on species composition, a qualitative sample from other habitat types (e.g., submerged logs, banks, pools, etc.) was taken at the study sites using a sweep net (500 μm mesh net). In the laboratory, organisms were sorted from debris, identified to the lowest practical taxonomic level, and counted.

This analysis provided the information required to calculate macroinvertebrate taxa richness parameters; total number of taxa, total number of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa (collectively referred to as EPT taxa), and total number of metal intolerant taxa, as well as four macroinvertebrate abundance parameters; density, mayfly relative abundance, and heptageniid mayfly relative abundance. The taxa richness parameters have been well documented to be consistent indicators of various types of anthropogenic stress, including metal stress (Clements et al., 1988; Lenat, 1988; Ohio EPA, 1988; Wiederholm, 1989; Klemm et al., 1990; Clements, 1991; Barbour et al., 1992; Clements, 1994; Kerans and Karr, 1994; DeShon, 1995; Fore et al., 1996; Lenat and Penrose, 1996; Wallace et al., 1996; Barbour et al., 1999; Karr and Chu, 1999; Clements et al., 2000; Fore, 2000; Karr, 2000; Lydy et al., 2000; CEC, 2001; Mebane, 2001; Clements et al., 2002; Jessup and Gerritsen, 2002). The abundance parameters have also been shown to be responsive to metal contamination in Colorado streams (Clements et al., 1988; Clements, 1991, 1994; Kiffney and Clements, 1994; Clements and Carlisle, 1998; Clements et al., 2000; Fore, 2000).

To determine long-term trends in biological parameters, simple linear regression (biological parameter by year) was used to determine if a significant positive or negative ($p < 0.05$) slope existed. To determine significant differences ($p < 0.05$) in macroinvertebrate parameters between sites, a three factor analysis of variance (ANOVA) was run. In addition to the site, the year and the season were also used as factors in the model in order to account for temporal variability.

Results

Water Quality

Mean concentrations of dissolved cadmium, copper, lead, and zinc have all shown declining trends ($p<0.01$ for all) in California Gulch (Fig. 2). This has mainly been due to a dampening of peak concentrations over the years. Mean dissolved cadmium, copper, lead, and zinc have declined by an average of 7.3, 23.0, 29.7, and 1,178.8 _g/L per year from 1994 through 2004, respectively.

Mean concentrations of dissolved cadmium, cooper, lead, and zinc have also shown declining trends ($p<0.01$ for all) in the Arkansas River downstream of California Gulch (Fig. 3). Mean dissolved cadmium, copper, lead, and zinc have declined by an average of 0.2, 0.5, 0.2, and 21.0 _g/L per year from 1994 through 2004, respectively. These average declines are not as dramatic as those observed in California Gulch, but average values in the Arkansas River are already orders of magnitude lower than those in California Gulch (Figs. 2 and 3).

By comparison, Site AR-1, the reference site upstream of California Gulch has not shown any significant trends in dissolved cadmium, copper, lead, or zinc levels ($p = 0.10$, 0.22, 0.52, and 0.20, respectively). This data suggests that the declines in metal concentrations at Site AR-3A are the result of reclamation activities in California Gulch, and not from other upstream sources.

Fish Populations

This analysis focuses specifically on brown trout (*Salmo trutta*) as they are the dominant species in the upper Arkansas River and its tributaries and comprise an average of 94% of the density and 95% of the biomass (CEC, 2003). Following construction of the treatment plants and initial remediation activities, the Arkansas River downstream of California Gulch continued to have low brown trout densities through 2001, when compared to the reference site (Fig. 4). Brown trout densities at sites AR-3A from 1994 through 1997 were below 500 brown trout/ha. However, densities increased steadily in 1999 and 2001, and then increased substantially in 2002. In 2003 and

2004, densities at Site AR-3A remained high and were higher than those observed at the reference site upstream of California Gulch (Site AR-1).

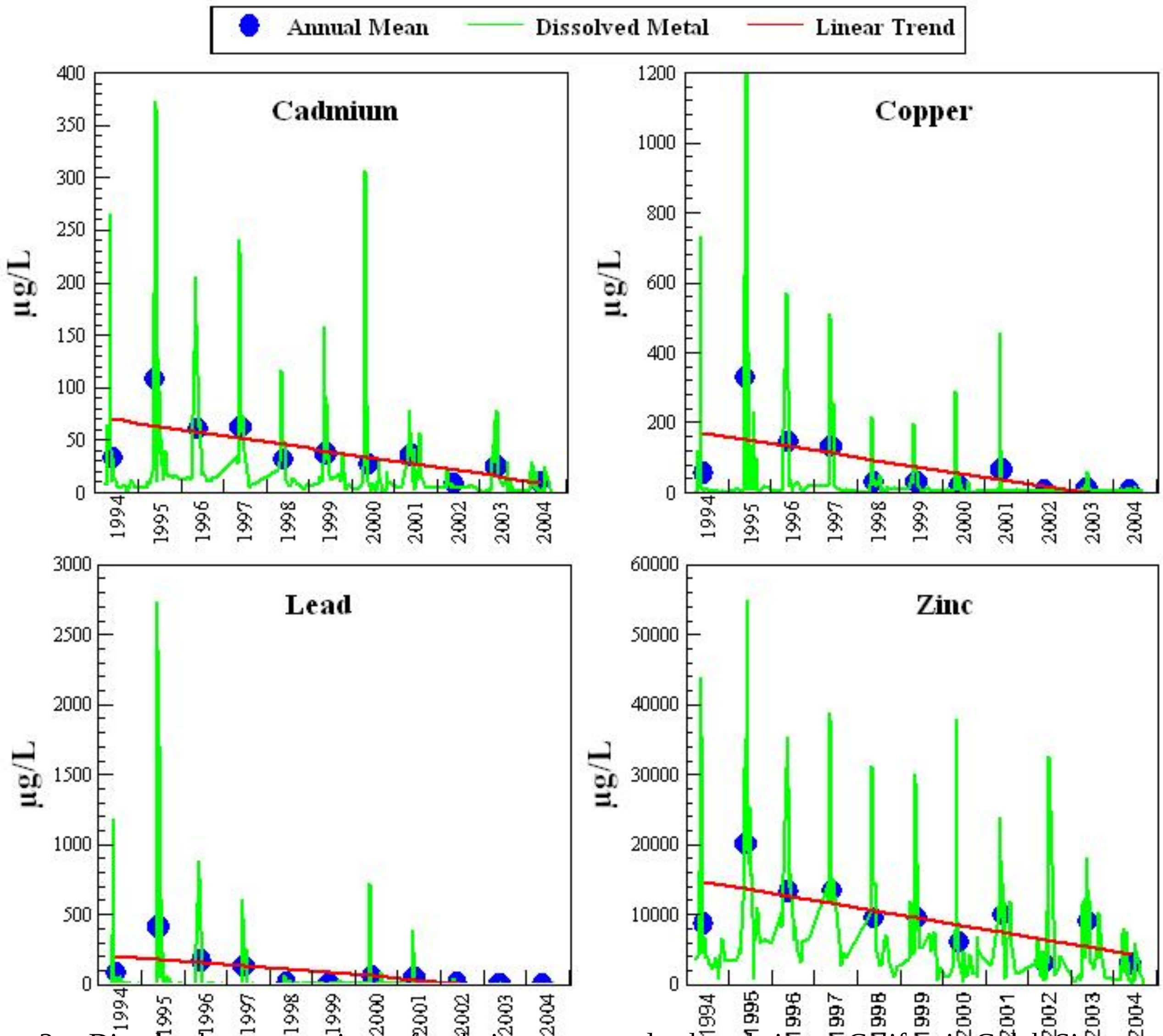

Figure 2. Dissolved concentrations of cadmium, copper, lead, and zinc at California Gulch Site CG-6, 1994-2004.

Fish biomass in late summer and fall followed a very similar pattern to that seen for fish density. Biomass at Site AR-1 upstream of California Gulch has been fairly consistent throughout the monitoring period, except for a substantial increase in 2002 (Fig. 4). Site AR-3A downstream of California Gulch historically exhibited lower biomass until 2002. Site AR-3A has shown a substantial increase in biomass and has had higher biomass estimates than the reference site from 2002 through 2004.

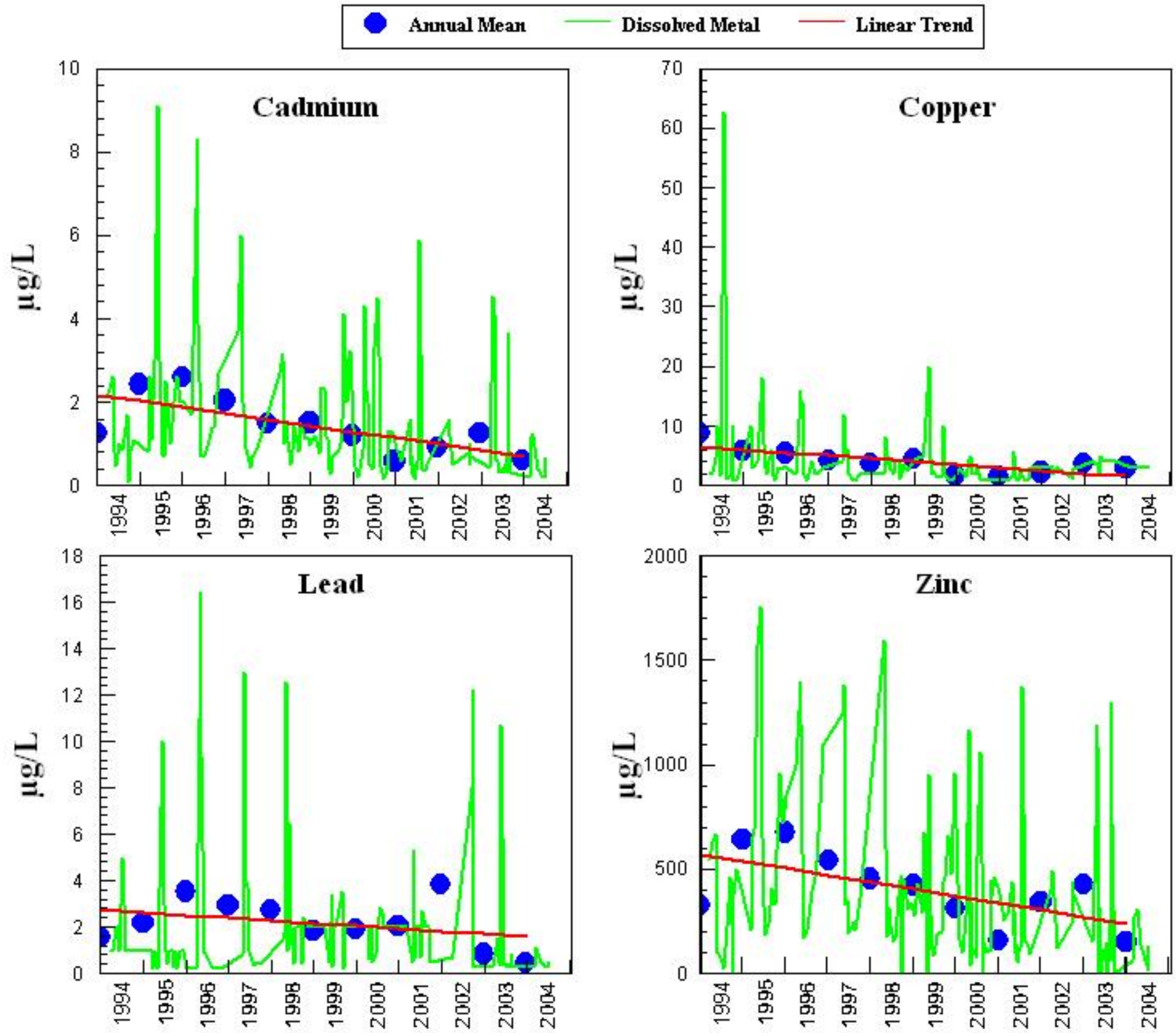

Figure 3. Dissolved concentrations of cadmium, copper, lead, and zinc from the Arkansas River Site AR-3A, 1994-2004.

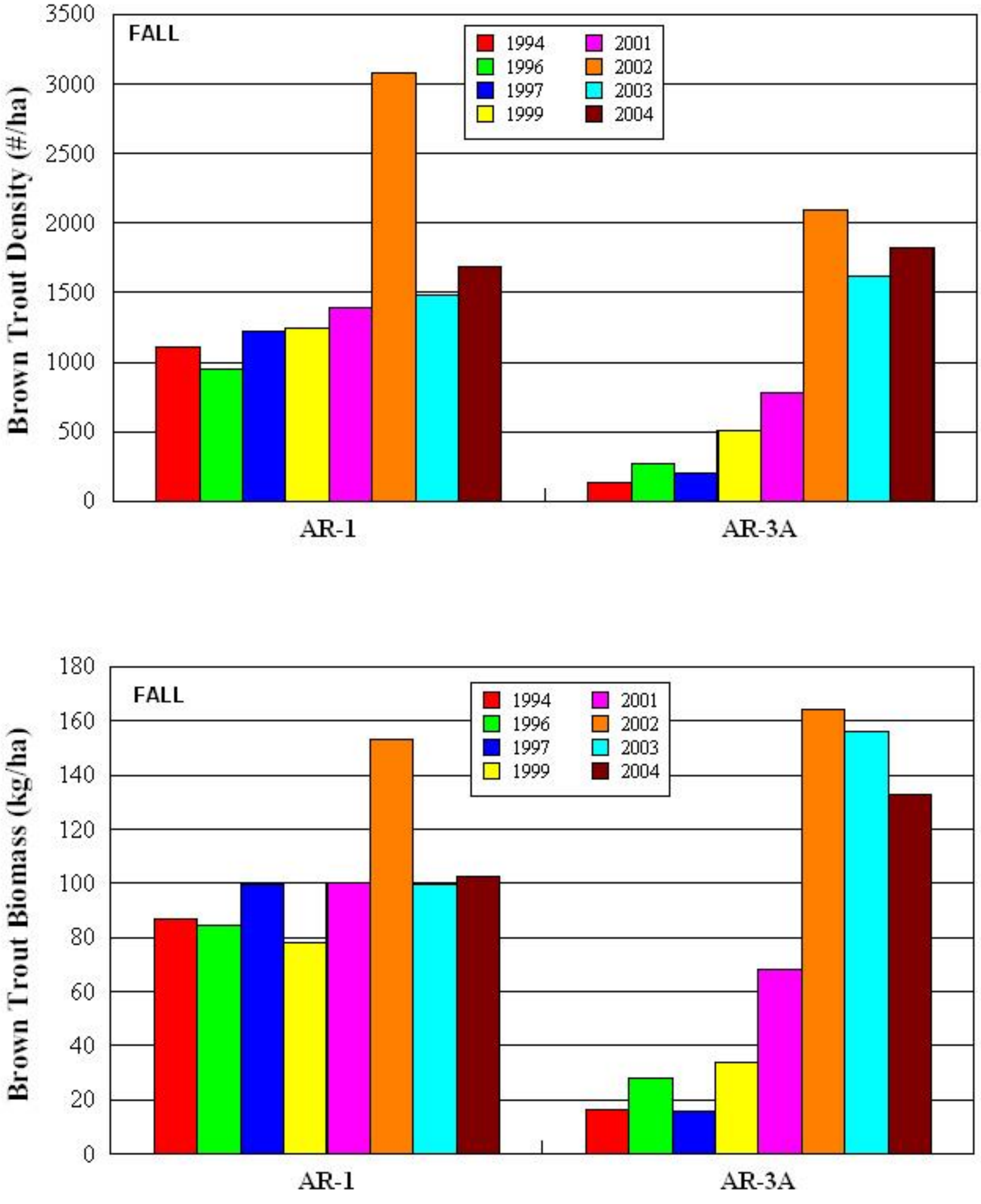

Figure 4. Brown trout biomass and density from the Arkansas River Sites AR-1 and AR-3A, 1994-2004.

The reference site (Site AR-1) upstream of California Gulch did not exhibit a significant upward or downward trend for brown trout density ($p = 0.14$) or biomass ($p = 0.22$). In contrast, Site AR-3A has shown increasing trends for brown trout density ($p < 0.01$) and biomass ($p < 0.01$). The lack of significant trends at the reference site suggests that the increases seen at Site AR-3A downstream of California Gulch are not the result of natural variation, but rather reflect improved water quality as a result of reclamation activities.

Analysis of length-frequency data indicate multiple age classes of brown trout at both Site AR-1 and AR-3A (Fig. 5). The consistent presence of at least four age classes at Site AR-1 and Site AR-3A over the years indicate the presence of resident, self-sustaining, brown trout populations in the Arkansas River. Site AR-3A had an especially strong young-of-year age class in 2004 (Fig. 5), once again indicating improving biological conditions at this site.

Macroinvertebrate Populations

At Site AR-3A, the total number of macroinvertebrate taxa, number of EPT taxa, and number of metal intolerant taxa showed a generally increasing trend since 1994 (Fig. 6), and this increasing trend is significant for both spring and fall data ($p < 0.01$ for all). Additionally, macroinvertebrate density has shown significantly increasing trends since 1994 for fall data (p э 0.02).

When the reference sites for invertebrates (Sites AR-1, AR-12, and AR-2 combined) were analyzed, all three taxa richness parameters and all three abundance parameters demonstrated significant increasing trends (p#0.02 for all) over time for both spring and fall data. This increasing temporal trend at the reference sites complicates our ability to determine the level of improvement in the Arkansas River downstream of California Gulch. It appears that some factor or factors upstream of California Gulch have also changed since 1994.

All six macroinvertebrate parameters were compared between the reference sites upstream of California Gulch (Sites AR-1, AR-12, and AR-2) to Site AR-3A downstream of California Gulch. To determine differences in macroinvertebrate parameters between Site AR-3A and the reference sites (pooled), a three factor (site, year, season) ANOVA was run for each macroinvertebrate parameter. For the taxa richness parameters, the total number of taxa, number of EPT taxa, and number of metal intolerant taxa were all significantly lower at site AR-3A than the reference sites (p # 0.04). In general, recent sampling years (2000-2004) were significantly lower ($p < 0.05$) than early sampling years (1994-1999). Fall sampling had significantly higher ($p < 0.01$) values than spring sampling values for total number of taxa and number of EPT taxa, but not for metal intolerant taxa ($p = 0.10$).

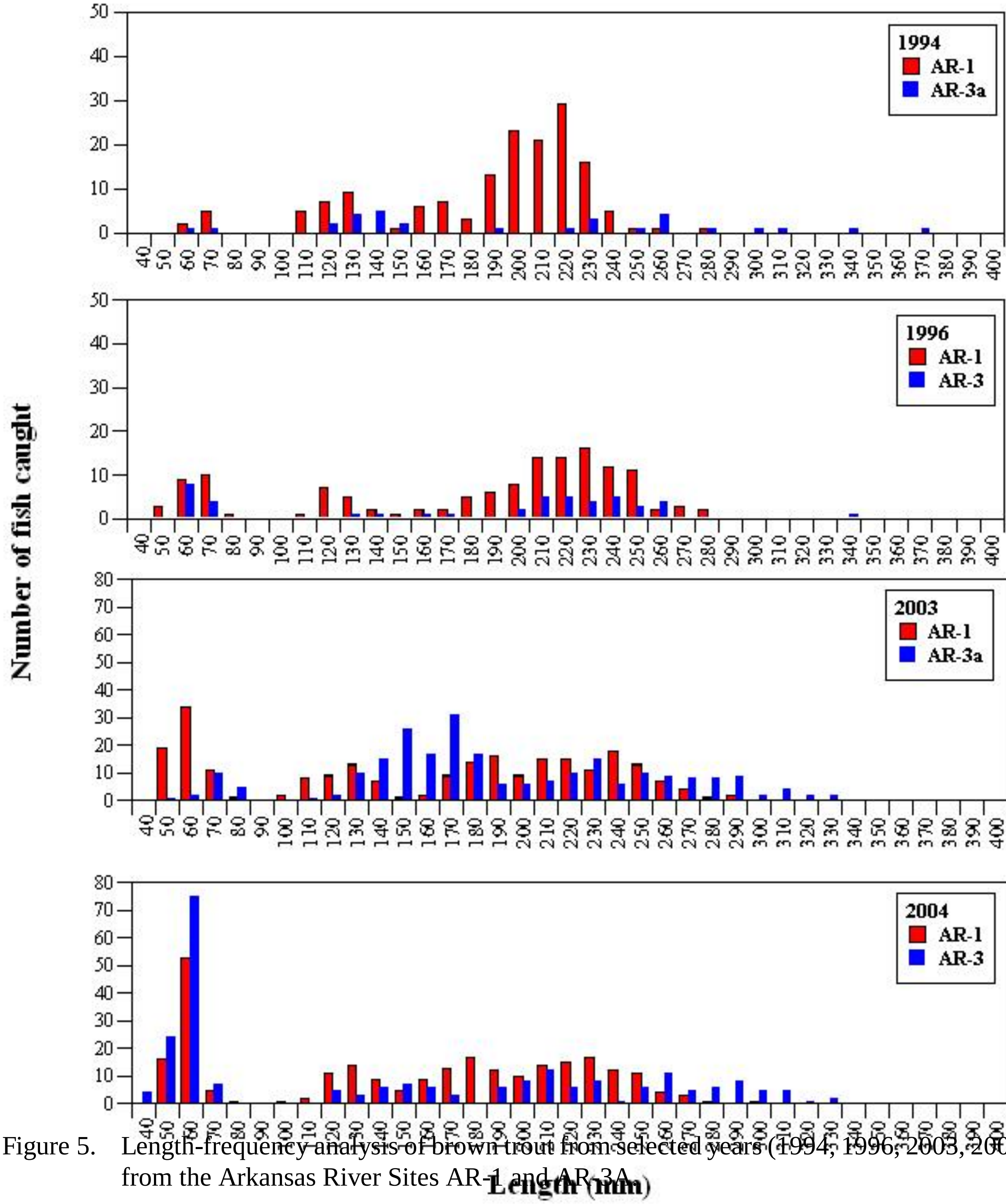

Figure 5. Length-frequency analysis of brown trout from selected years (1994, 1996, 2003, 2004) from the Arkansas River Sites AR-1 and AR-3A.

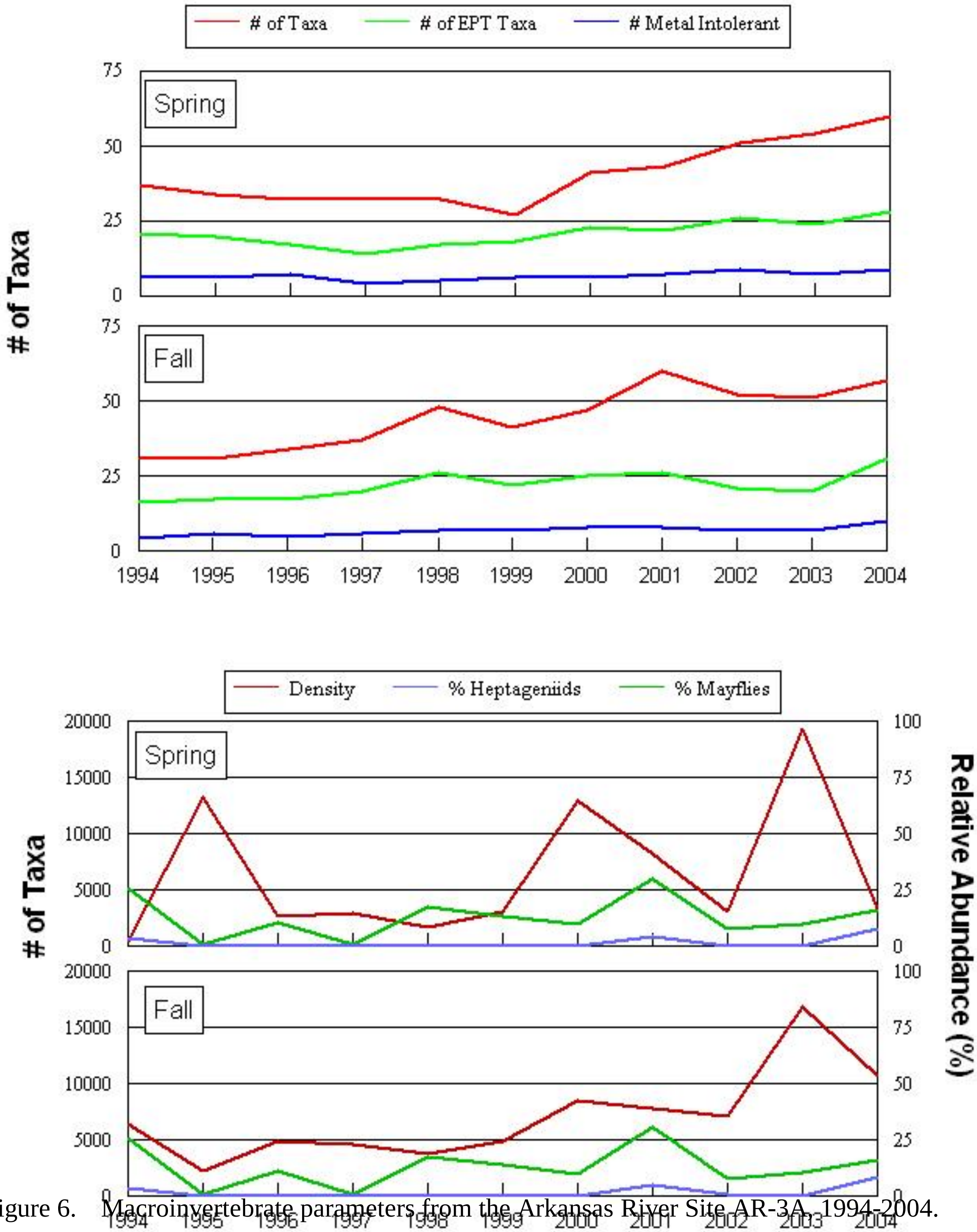

Figure 6. Macroinvertebrate parameters from the Arkansas River Site AR-3A, 1994-2004.

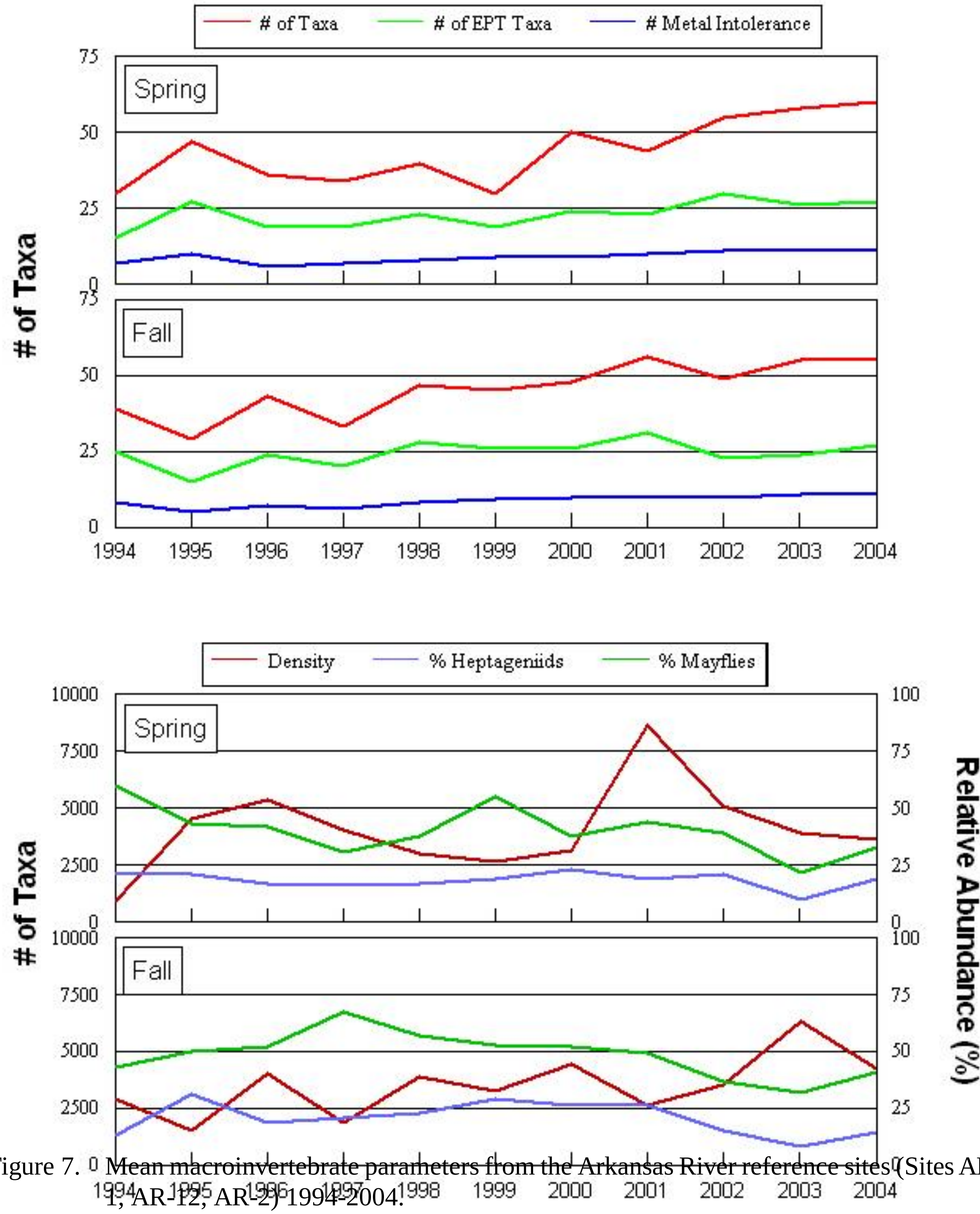

Figure 7. Mean macroinvertebrate parameters from the Arkansas River reference sites (Sites AR-1, AR-12, AR-2) 1994-2004.

For density, Site AR-3A was significantly higher than the reference sites ($p < 0.01$) and fall sampling had significantly higher values than spring ($p = 0.01$). No differences were observed between most years but mean values generally followed the same pattern seen for taxa richness parameters. For relative abundance of mayflies and relative abundance of heptageniid mayflies, Site

AR-3A was significantly lower than the reference sites ($p < 0.01$) and fall samples were significantly higher ($p < 0.04$) than spring samples. No differences were observed between most years and there was no temporal patterns that were observed for the other parameters.

This analysis also showed that most of the interaction terms between site, year, and season were significant. This demonstrates the complex nature of the factors structuring the aquatic community in the Arkansas River, both upstream and downstream of California Gulch. In general, most parameters are significantly lower at Site AR-3A and this differences are more common during the spring sampling. However, most parameters have shown higher values in recent years indicating that the macroinvertebrate assemblage is improving over time.

Conclusions

Mean concentrations of dissolved cadmium, cooper, lead, and zinc have all shown declining trends in California Gulch and at Site AR-3A on the Arkansas River downstream of California Gulch from 1994 through 2004. Site AR-1, the reference site upstream of California Gulch, has not shown any significant trends in dissolved cadmium, cooper, lead, or zinc levels, suggesting that the declines in metal concentrations at Site AR-3A are the result of decreased loads from California Gulch and not from other upstream sources.

Fisheries data from 1994 through 2004 supports the conclusion that fish populations have improved at Site AR-3A downstream of California Gulch. Brown trout biomass and density estimates have shown an increasing trend since 1994. Brown trout biomass and density have both been higher at Site AR-3A than Site AR-1 in the past two years.

Macroinvertebrate data indicates that conditions are improving in California Gulch and downstream of California Gulch. In recent years (2000 to present), Macroinvertebrate parameters at Site AR-3A have not differed significantly as often as in past years (1994 - 1998). Based on macroinvertebrate community data, it appears that some residual effects of the inflow of California Gulch remain, but is seen only in the more metal sensitive components of the community.

This study provides strong evidence that reclamation activities in the California Gulch watershed are helping to improve water quality in the Arkansas River.

Acknowledgments

The authors wish to thank the Resurrection Mining Company for its continued funding and support of biological monitoring efforts in the upper Arkansas River basin. We also thank the Colorado Division of Wildlife for aiding in the collection of fisheries data.

Literature Cited

Anderson, R.O., and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482. IN: Murphy, B.R., and D.W. Willis (eds.). *Fisheries Techniques*, 2nd Edition. American Fisheries Society, Bethesda, MD.

Barbour, M.T., L. Plafkin, B.P. Bradley, C.G. Graves, and R.W. Wisseman. 1992. Evaluation of EPA=s rapid bioassessment benthic metrics: Metric redundancy and variability among reference stream sites. Environmental Toxicology and Chemistry 11:437-449.http://dx.doi.org/10.1002/etc.5620110401.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates and Fish*, 2nd Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Canton, S.P., and J.W. Chadwick. 1984. A new modified Hess sampler. Progressive Fish-Culturist 46:57-59.http://dx.doi.org/10.1577/1548-8640(1984)46<57:ANMHS>2.0.CO;2.

Canton, S.P., and J.W. Chadwick. 1988. Variability in benthic invertebrate density estimates from stream samples. Journal of Freshwater Ecology 4:291-297. http://dx.doi.org/10.1080/02705060.1988.9665178.

Carlander, K.D. 1969. *Handbook of Freshwater Fishery Biology*, Vol. 1. Iowa State University Press, Ames, IA.

Chadwick Ecological Consultants, Inc. 2001. *Evaluation of the Aquatic Biological Communities of Thompson and Squaw Creek Using the Idaho Department of Environmental Quality Water Body Assessment Guidance Document*. Prepared for Thompson Creek Mining Company, Challis, ID.

Chadwick Ecological Consultants, Inc. 2003. *Preliminary Report on the Biological Data for the Upper Arkansas River 1994-2002*. Report prepared for Resurrection Mining Company, Denver, CO.

Clements, W.H. 1991. Community responses of stream organisms to heavy metals: A review of observational and experimental approaches. Pages 363-391. IN: Newman, M.C., and A.W. McIntosh (eds.). *Metal Ecotoxicology: Concepts and Applications*. Lewis Publishing, Inc., Chelsea, MI.

Clements, W.H. 1994. Benthic invertebrate community response to heavy metals in the Upper Arkansas River basin, Colorado. Journal of the North American Benthological Society 13:30-44. http://dx.doi.org/10.2307/1467263.

Clements, W.H., D.S. Cherry, and J. Cairns, Jr. 1988. Impact of heavy metals on insect communities in streams: A comparison of observational and experimental results. Canadian Journal of Fisheries and Aquatic Sciences 45:2017-2025. http://dx.doi.org/10.1139/f88-235.

Clements, W.H., and D.M. Carlisle. 1998. *Development and Validation of a Regional Biotic Index to Assess the Effects of Heavy Metals on Headwater Streams of the Southern Rocky Mountain Ecoregion*. Final Report to the U.S. Environmental Protection Agency, Region 8, Denver, CO.

Clements, W.H., D.M. Carlisle, J.M. Lazorchak, and P.C. Johnson. 2000. Heavy metals structure benthic communities in Colorado mountain streams. Ecological Applications 10:626-638. http://dx.doi.org/10.1890/1051-0761(2000)010[0626:HMSBCI]2.0.CO;2.

Clements, W.H., D.M. Carlisle, L.A. Courtney, and E.A. Harrahy. 2002. Intergrating observational and experimental approaches to demonstrate causation in stream biomonitoring studies. Environmental Toxicology and Chemistry 21:1138-1146. http://dx.doi.org/10.1002/etc.5620210605 PMid:12069296.

Costello, C. 2003. *Acid Mine Drainage: Innovative Treatment Technologies*. Report prepared for the U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

DeShon, J.E. 1995. Development and application of the invertebrate community index (ICI). Pages 217-244. IN: Davis, W.S., and T.P. Simon (eds.). *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis, Boca Raton, FL.

Fore, L.S. 2000. *Development and Application of a Biological Index to Assess the Influence of Heavy Metals on Stream Invertebrates in Mineralized Areas of Colorado*. Prepared for the U.S. Environmental Protection Agency, Region 8, Denver, CO.

Fore, L.S., J.R. Karr, and R.W. Wisserman. 1996. Assessing invertebrate responses to human activities: Evaluating alternative approaches. Journal of the North American Benthological Society 15:212-231. http://dx.doi.org/10.2307/1467949

Jessup, B., and J. Gerritsen. 2002. Stream macroinvertebrate index. Chapter 3. IN: Grafe, C.S. (ed.). *Idaho Small Stream Ecological Assessment Framework and Integrated Approach*. Idaho Department of Environmental Quality, Boise, ID.

Karr, J.R. 2000. Defining and measuring river health. Freshwater Biology 41:221-234. http://dx.doi.org/10.1046/j.1365-2427.1999.00427.x.

Karr, J.R., and E.W. Chu. 1999. *Restoring Life in Running Waters: Better Biological Monitoring*. Island Press, Washington, DC.

Kerans, B.L., and J.R. Karr. 1994. Development and testing of a benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768-785. http://dx.doi.org/10.2307/1942007.

Kiffney, P.M., and W.H. Clements. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a Rocky Mountain stream in experimental microcosms. Journal of the North American Benthological Society 13:511-523. http://dx.doi.org/10.2307/1467847.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters*. EPA/600/4-90/030. U.S. Environmental Protection Agency.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7:222-233. http://dx.doi.org/10.2307/1467422.

Lenat, D.R., and D.L. Penrose. 1996. History of EPT taxa richness metric. *Bulletin of the North American Benthological Society* 13:305-307.

Lydy, M.J., C.G. Crawford, and J.W. Frey. 2000. A comparison of selected diversity, similarity, and biotic indices for detecting changes in benthic-invertebrate community structure and stream quality. Archives of Environmental Contamination and Toxicology 39:469-479. http://dx.doi.org/10.1007/s002440010129 PMid:11031307.

Mebane, C.A. 2001. Testing bioassessment metrics: Macroinvertebrate, sculpin, and salmonid responses to stream habitat, sediment, and metals. Environmental Monitoring and Assessment 67:293-322. http://dx.doi.org/10.1023/A:1006306013724 PMid:11334445.

Nelson, S.M., and R.A. Roline. 1996. Recovery of a stream macroinvertebrate community from mine drainage disturbance. Hydrobiologia 339:73-84. http://dx.doi.org/10.1007/BF00008915.

Ohio Environmental Protection Agency. 1988. *Biological Criteria for the Protection of Aquatic Life*, Volumes 1 - 3. Ecological Assessment Section, Division of Water Quality Monitoring and Assessment, Ohio Environmental Protection Agency, Columbus, OH.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118-125. http://dx.doi.org/10.1111/j.1467-8306.1987.tb00149.x.

Roline, R.A. 1988. The effects of heavy metal pollution of the upper Arkansas River on the distribution of aquatic macroinvertebrates. Hydrobiologia 160:3-8. http://dx.doi.org/10.1007/BF00014273

U.S. Environmental Protection Agency. 2002. *Abandoned Mine Site Characterization and Cleanup Handbook*. EPA 910-B-00-001. U.S. Environmental Protection Agency, Seattle, WA.

Van Deventer, J.S., and W.S. Platts. 1983. Sampling and estimating fish populations from streams. *Transactions of the North American Wildlife and Natural Resources Conference* 48:349-354.

Van Deventer, J.S., and W.S. Platts. 1989. *Microcomputer Software System for Generating Population Statistics from ElectroFishing Data - User=s Guide for MicroFish 3.0.* General Technical Report INT-265/1989. U.S. Forest Service.

Wallace, J.B., J.W. Grubaugh, and M.R. Whiles. 1996. Biotic indices and stream ecosystem processes: results from an experimental study. Ecological Applications 6:140-151. http://dx.doi.org/10.2307/2269560

Wege, G.J., and R.O. Anderson. 1978. Relative Weight (W_r): A new index of condition for largemouth bass. Pages 79-91. IN: Novinger, G.D., and J.G. Dillard (eds.). *New Approaches to the Mangement of Small Impoundments*. Special Publication 5. North Central Division, American Fisheries Societty.

Wiederholm, T. 1989. Response of aquatic insects to environmental pollution. Pages 508-557. IN: Resh, V.H., and D.M. Rosenberg (eds.). *The Ecology of Aquatic Insects*. Praeger Scientific, New York, NY.