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PLECOPTERA AND TRICHOPTERA SPECIES DISTRIBUTION RELATED TO ENVIRONMENTAL CHARACTERISTICS OF THE METAL-POLLUTED ARKANSAS RIVER, COLORADO

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ABSTRACT.—The Upper Arkansas catchment has been polluted with heavy metals from mining for almost 140 yr. Adult Plecoptera and Trichoptera species distributions were recorded from 22 stations along 259 km of main river during 1984–85 so that these could be related to metal deposition and other environmental characteristics. Chemically or physically perturbed sites had poor species richness compared with adjacent sites. There was no sequential downstream increase in species numbers. Filter-feeders proportionally increased downstream as predators declined; these proportions were reset at a high-energy site before the trend resumed. Using canonical correspondence analysis, we found that species composition was most strongly related to changes in distance/altitude and to temperature, particularly after regulatory flows entered the river. The proportion of biological variation explained by river measurements indicated that collected adults were largely derived from the main Arkansas River. Species tolerant of high sedimentary metal concentrations were identified while some other species appeared to be sensitive. The study provides a disturbed-state reference for monitoring effects of remedial actions begun in 1991, and for comparisons with other Colorado rivers.

Key words: Plecoptera, Trichoptera, multivariate analysis, adults, spatial distribution, sediments, species richness, heavy metals.

The Arkansas River in Colorado has been polluted by heavy metals since mining began in 1859. In 1983 serious metal pollution in the Upper Arkansas River affected sites up to 220 km downstream (Kimball et al. 1995). Emerging adult Plecoptera and Trichoptera were collected along this length of the Arkansas River during 1984–85 so that species distribution could be related to physical and chemical characteristics of the sampling sites. This study differed from other research on the Arkansas River by relating invertebrate distribution to sedimentary concentrations of heavy metals rather than water measurements. Kiffney and Clements (1993) found that metal concentrations in the Arkansas River underestimated the availability of metals to benthic macroinvertebrates. Bioaccumulated metal concentrations were better related to those measured in sedimentary minerals and periphyton. Remedial action on the worst affected sites began in 1991. Data provided here were collected during one of the river's most severe periods of metal pollution and could subsequently serve as a baseline measure for the effects of remediation.

METHODS

Study sites

Twenty-two sites were chosen along 259 km of the East Fork (sites EF1 and EF2) and Arkansas River (sites AR1–AR20) between Climax and Pueblo, east of the Continental Divide in central Colorado. A diagram and more complete description of sites can be found in the preceding paper (Ruse et al. 2000). The greatest source of metals to the catchment comes from Leadville Drain and California Gulch. This survey occurred between 2 major surges of metal sludge into California Gulch on 23 February 1983 and 22 October 1985. Water from the western slopes of the Continental Divide is diverted to Turquoise Lake and Twin Lakes, entering the Arkansas River above AR4 and AR9, respectively. The Arkansas River was impounded above AR19 by Pueblo Dam in 1974. The U.S. Environmental Protection Agency (EPA) declared the California Gulch catchment and the Arkansas River from above AR2 to below AR3 as a Superfund site in 1983. New water treatment plants on Leadville Drain and California Gulch were both in operation by June 1992.

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Sampling and Analysis

From May 1984 until September 1985 we collected adult Plecoptera and Trichoptera monthly using sweep net, beating sheet, water-skimming, hand-picking, and ultraviolet light traps. Adult Chironomidae were also collected and these data have been reported, together with pupal data, by Ruse et al. (2000). Numbers of collected adult Ephemeroptera were too few to warrant analysis.

We characterized sites using environmental data recorded on a single occasion, except for water temperature, which was recorded during each monthly visit to collect adult insects. The 3 most abundant superficial substratum types, among 5 size classes, were assessed visually and used to calculate mean particle size for each site (Ruse et al. 2000). Latitude, longitude, altitude, slope, and distance downstream from EF1 were obtained from maps. Copper, zinc, lead, manganese, iron, and cadmium concentrations were determined from 6 subsamples of submerged fine sand using a 25-mm-diameter PVC pipe inserted to a depth of 15 cm. We sampled each site during 18–19 October 1986, following the 2nd metal sludge surge into California Gulch. Metals were extracted using a sequence of hot digestions and evaporations (Ruse et al. 2000). An ordinal scale of zinc toxicity was calculated to account for the ameliorating effect of increased water hardness on metal toxicity to biota (Ruse et al. 2000).

We found it necessary to combine each species abundance for samples from the same site to relate their spatial variation to a site's environmental characteristics. Spatial variation in biological data was directly compared with environmental variation using canonical correspondence analysis (CCA; Ter Braak and Prentice 1988). The same procedures of forward selection and significance testing used by Ruse et al. (2000) were adopted here. Before analysis, species abundances were converted to percentages of total number of individuals collected from a site. Species recorded at a single site only were omitted from CCA to avoid spurious association with a coinciding extreme environmental measurement; their distributions are recorded in the Appendix. Environmental data were not transformed for CCA; measurements of temperature, slope, zinc toxicity, total manganese, and total iron were normally distributed. Latitude and longitude values were decimalized, and only the maximum water temperature recorded at each site was used. Environmental data were standardized to have a mean of zero and unit variance to remove arbitrary variation in units of measurement. CCA species scores were weighted mean sample scores (CANOCO version 3.1 scaling + 2). This analysis was sensitive to relative variation between sites, and it was not necessary to have precise particle size or water hardness data to relate these characteristics to spatial variation in species distribution.

RESULTS

Sampling provided 1809 adult Plecoptera, comprising 25 species, and 10,669 adult Trichoptera among 48 species. Species present at 2 or more sites are presented with their author's name in Table 1. Species have been arranged according to the primary axis of a correspondence analysis (Ter Braak and Prentice 1988) since this made the sequential downstream turnover in species composition readily apparent. Apart from the reversal of AR10 and AR11, there was a successive downstream replacement of species.

Stonefly species richness declined downstream of metal inputs from Leadville Drain and California Gulch (Fig. 1) and at sites AR6, AR10, and sites downstream of AR11 where water temperatures were high (environmental data provided in Ruse et al. 2000). No individuals were collected below Pueblo Reservoir. Chloroperlidae had an upstream distribution while Perlidae were collected from sites further downstream. Caddisfly species numbers were maintained throughout the study area, with slight reductions below the 2 major inputs of metal pollution (Fig. 2). Lowest species numbers occurred at AR10 and AR13. There was also a decline in species and family richness below Pueblo Reservoir compared with neighboring sites upstream. Most caddisfly families were well represented at all sites above the reservoir. Hydroptilidae had higher species richness at downstream sites, Psychomyiidae were present only downstream of AR10, and Leptoceridae were found only downstream of AR16.

Stonefly and caddisfly species were classified according to presumed feeding modes of their associated larvae (Table 1) and the data

TABLE 1. Proportions of species at each site: 1 = 0.1–4.9%, 2 = 5.0–9.9%, 3 = 10.0–19.9%, 4 = 20.0–39.9%, 5 = 40.0+%. G = Grazer, D = Detritivore, P = Predator, F = Filterer.

Code	Species name	Trophic group	Site																					
			E 1	E 2	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 11	A 10	A 12	A 13	A 14	A 15	A 16	A 17	A 18	A 19	A 20
CACO	*Capnia confusa* Claassen	D	1	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PAVE	*Paraleuctra vershina* Gaufin & Ricker	D	1	1	–	–	1	1	1	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–
AMBA	*Amphinemura banksi* Baumann & Gaufin	D	1	2	1	3	1	1	1	–	1	1	–	1	1	–	–	–	–	–	–	–	–	–
PODE	*Podmosta delicatula* (Claassen)	D	1	2	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PRBE	*Prostoia besametsa* (Ricker)	D	–	–	–	1	3	1	1	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–
SUPA	*Suwallia pallidula* (Banks)	P	2	4	1	3	5	3	2	4	3	3	1	1	2	–	–	–	–	–	–	–	–	–
SWCO	*Sweltsa coloradensis* (Banks)	P	3	–	2	1	1	1	1	–	1	1	1	1	–	–	–	–	–	–	–	–	–	–
TRPI	*Triznaka pintada* (Ricker)	P	1	1	1	1	1	2	3	–	1	1	1	1	–	–	–	–	–	–	–	–	–	–
SKPA	*Skwala parallela* (Frison)	P	–	–	–	1	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–
KOMO	*Kogotus modestus* (Banks)	P	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PTBA	*Pteronarcella badia* (Hagen)	D	1	–	–	–	–	1	1	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–
GLVR	*Glossosoma verdona* Ross	G	1	2	3	1	–	1	2	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
ARGR	*Arctopsyche grandis* (Banks)	P	1	1	1	1	1	1	1	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–
AGSA	*Agraylea saltesea* Ross	G	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
AMCA	*Amphicosmoecus canax* (Ross)	D	1	2	1	1	1	1	1	1	1	1	1	1	–	–	–	–	–	–	–	–	–	–
LIAB	*Limnephilus abbreviatus* Banks	D	–	–	–	–	1	1	–	1	1	1	1	–	–	–	–	–	–	–	–	–	–	–
OLMI	*Oligophlebodes minutus* (Banks)	G	1	1	1	4	2	5	2	2	1	1	–	–	–	–	–	–	–	–	–	–	–	–
PHQU	*Philarctus quaeris* (Milne)	D	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RHAN	*Rhyacophila angelita* Banks	P	3	3	4	1	1	1	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
RHBR	*Rhyacophila brunnea* Banks	P	3	1	1	1	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
RHPE	*Rhyacophila pellisa* Ross	P	3	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
ISFU	*Isoperla fulva* Claassen	P	–	–	–	1	–	1	1	1	1	1	2	1	1	1	–	–	–	–	–	–	–	–
TRSI	*Triznaka signata* (Banks)	P	–	–	–	–	–	–	–	–	1	1	1	3	–	1	–	–	–	–	–	–	–	–
BRAM	*Brachycentrus americanus* (Banks)	F	–	1	2	2	2	1	2	2	3	1	2	1	2	1	–	1	1	–	–	–	–	–
MIBA	*Micrasema bactro* Ross	D	–	–	1	1	–	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–
AGBO	*Agapetus boulderensis* Milne	G	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–
OCLO	*Ochrotrichia logana* (Ross)	D	1	–	–	–	–	–	–	1	1	1	1	1	–	–	–	1	–	–	–	–	–	–
UTLO	*Utacapnia logana* (Nebeker & Gaufin)	D	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
LEPL	*Lepidostoma pluviale* (Milne)	D	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	1	–	–	–	–	–	–
ONUN	*Onocosmoecus unicolor* (Banks)	D	–	1	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–
BROC	*Brachycentrus occidentalis* Banks	F	–	1	1	1	1	1	2	3	3	4	5	2	4	1	–	1	–	1	2	–	–	–
GLPA	*Glossosa parvulum* Banks	G	–	–	–	–	–	2	4	3	4	1	2	5	3	4	3	1	1	1	1	–	–	–
RHCO	*Rhyacophila coloradensis* Banks	P	3	3	4	2	–	–	1	3	1	3	1	1	5	3	3	5	4	3	1	–	–	–
HYOS	*Hydropsyche oslari* Banks	F	–	–	–	–	–	–	–	–	–	1	–	1	1	1	1	1	1	–	–	1	–	–
PSFL	*Psychomyia flavida* Hagen	D	–	–	–	–	–	–	–	–	–	–	–	1	–	4	5	3	4	1	1	–	1	1
HEPA	*Hesperoperla pacifica* (Banks)	P	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	–	1	1	1	–	–	–
ISMO	*Isoperla mormona* Banks	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	1	1	–	–
ISQU	*Isoperla quinquepunctata* (Banks)	P	–	–	–	–	–	1	1	1	1	1	1	1	–	1	1	1	1	3	1	–	–	–
ISEL	*Isogenoides elongatus* (Hagen)	P	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–
CUTH	*Culoptila thoracica* (Ross)	G	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	1	2	1	1	1	–	–
GLVN	*Glossosoma ventrale* Banks	G	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–	–
HYCO	*Hydropsyche cockerelli* Banks	F	–	–	–	1	1	1	1	1	2	4	4	1	1	1	3	3	4	4	3	2	–	1
LEPI	*Leucotrichia pictipes* (Banks)	G	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	3	1	1	–	1	–
CLSA	*Claassenia sabulosa* (Banks)	P	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–
AGMU	*Agraylea multipunctata* Curtis	G	–	–	–	–	–	1	1	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–
MEFR	*Mesocapnia frisoni* (Baumann & Gaufin)	D	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
CHPE	*Cheumatopsyche pettiti* (Banks)	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	2	3
HYOC	*Hydropsyche occidentalis* Banks	F	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	2	1	3	5	5	4	5
HYAJ	*Hydroptila ajax* Ross	G	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	3	3
HYAR	*Hydroptila argosa* Ross	G	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
HYPE	*Hydroptila pecos* Ross	G	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	1
MAAY	*Mayatrichia ayama* Mosely	G	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	1	–
OCST	*Ochrotrichia stylata* (Ross)	D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	4	2
NELA	*Nectopsyche lahontanensis* Haddock	D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–
OEIN	*Oecetis inconspicua* (Walker)	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–
LIDI	*Limnephilus diversus* (Banks)	D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	1
LITA	*Limnephilus taloga* Ross	D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1

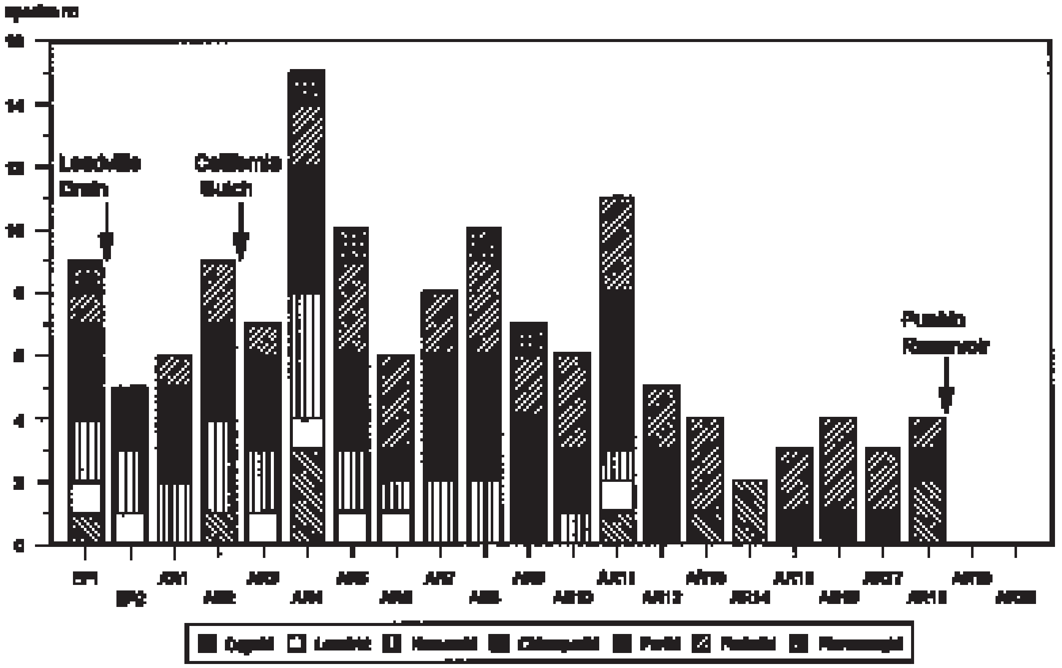

Fig. 1. Distribution of Plecoptera families.

combined with that of adult species of Chironomidae collected with them (Ruse et al. 2000). This provided a better perspective of stream function since these were the 3 dominant groups of emerging insects. Including midges in the analyses did not greatly alter relative composition of the 4 trophic classes. Proportions of predators at the first 3 sites were reduced by including midges, proportions of grazers were increased at all sites, detritivores remained about the same, and filterers were reduced at the last 4 sites. For the 3 insect groups combined, proportions of predators were highest at EF1, AR3, and AR10 and almost absent below Pueblo Reservoir (Fig. 3). Grazer proportions were lowest below California Gulch at AR3, and at AR8 and AR9, recovering downstream to peak at AR4 and AR11. Detritivores (shredders and collector-gatherers) declined downstream from EF1 to AR10, recovered by AR13, and then declined again. In contrast, proportions of filterers increased below the outflows of regulatory lakes downstream to AR9, declined by AR12, and mostly increased downstream.

Ordination

Stepwise regression progressively selected distance downstream, latitude, and maximum temperature as significantly correlated with variation in species composition among sites. Altitude was also significant but highly negatively correlated with distance and was excluded to prevent multicollinearity (variation inflation factor = 189; Ter Braak 1990). Total copper concentration was the 4th most explanatory variable but did not have a significant relationship with species data after the previous variables had been selected ($P = 0.09$). The 3 selected variables explained 37.5% of biological variation in CCA. The species-environment relationship was significantly different from random for the first 2 CCA axes ($P = 0.01$), accounting for 32.9% of all biological variation and 87.7% of explained variation.

Species turnover among samples was strongly related to change along the longitudinal axis of the river. Dominance of the 1st CCA axis compared with the 2nd resulted in an archlike configuration of sites in Figure 4. Gradient lengths for the first 2 unconstrained axes (biological data alone) were 5.72 and 2.78

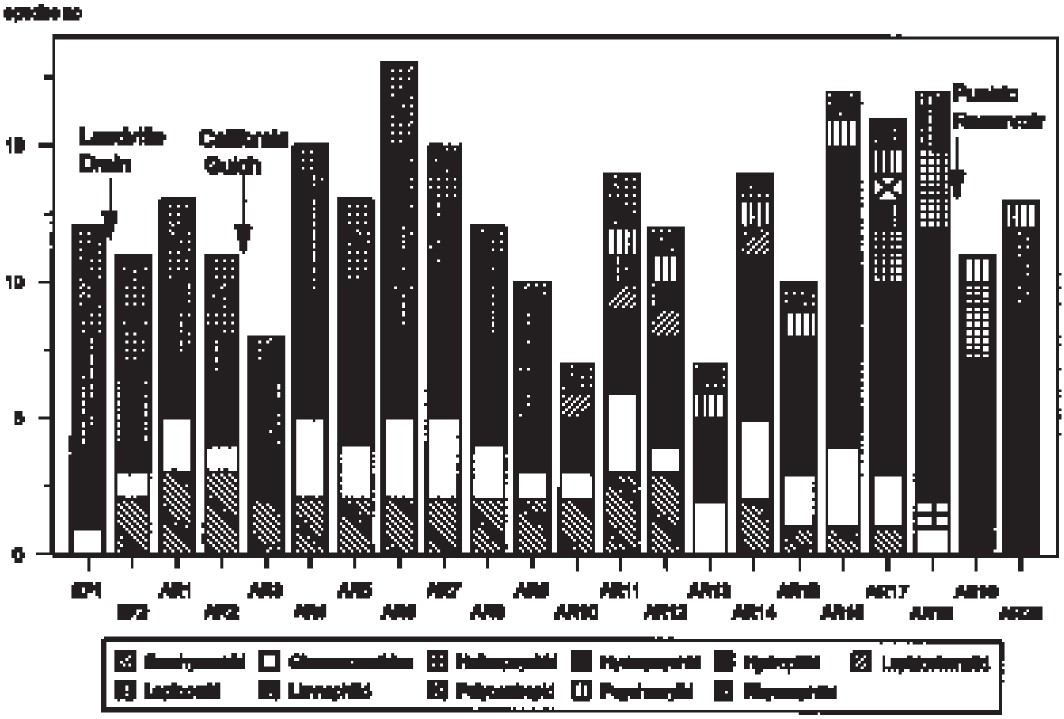

Fig. 2. Distribution of Trichoptera families.

s units, respectively. Detrending or reduction of environmental variables did not remove the arching trend, and separation into 2 data sets was impractical for the small number of samples. The 1st CCA axis was most significantly related to downstream distance (canonical coefficient *t*-value 6.26, interset correlation 0.97). The 2nd axis was principally related to variations in maximum temperature (*t*-value 3.51, correlation 0.32), and latitude (*t*-value 7.8, correlation –0.28). The dominant relationship between species distribution and distance resulted in proximity of sites upstream of AR11 and the 2 sites below Pueblo Reservoir along axis 1. The clusters of sites, AR4–AR5 and AR9–AR10, were the 1st and 2nd sites, respectively, downstream of outflows from Turquoise Lake and Twin Lakes. Sites AR6, AR7, and AR8, together with AR5, had the highest sedimentary levels of heavy metals, with the exception of copper at AR3 (Ruse et al. 2000).

Species in Figure 4 are placed close to modes of their distribution among sites. Species at the extreme bottom left of Figure 4, such as the caddisfly *Rhyacophila pellisa* and the stonefly *Podmosta delicatula,* were associated with sites on the East Fork and the most upstream Arkansas River sites. *Rhyacophila pellisa* reappeared below the most metal-polluted sites at AR11. The nemourid *Prostoia besametsa* and the chloroperlid *Suwallia pallidula* had their highest abundances at AR3, the 1st site below California Gulch. Other species that thrived at sites with high sedimentary levels of heavy metals, AR3–AR8, were the chloroperlid *Triznaka pintada,* the limnephilid *Oligophlebodes minutus, Brachycentrus americanus, B. occidentalis, Glossosoma parvulum,* and *Hydropsyche cockerelli.* The last 4 species were widely found at sites down to Pueblo Reservoir while the first 2 species had a more upstream distribution. *Rhyacophila coloradensis* also appeared to be tolerant of high sedimentary metal concentrations and to have a wide distribution above the impoundment; however, it was absent at the first 2 sites below California Gulch. *R. angelita* was the only rhyacophilid present at sites AR3 and AR4, but its distribution was limited in range of altitude.

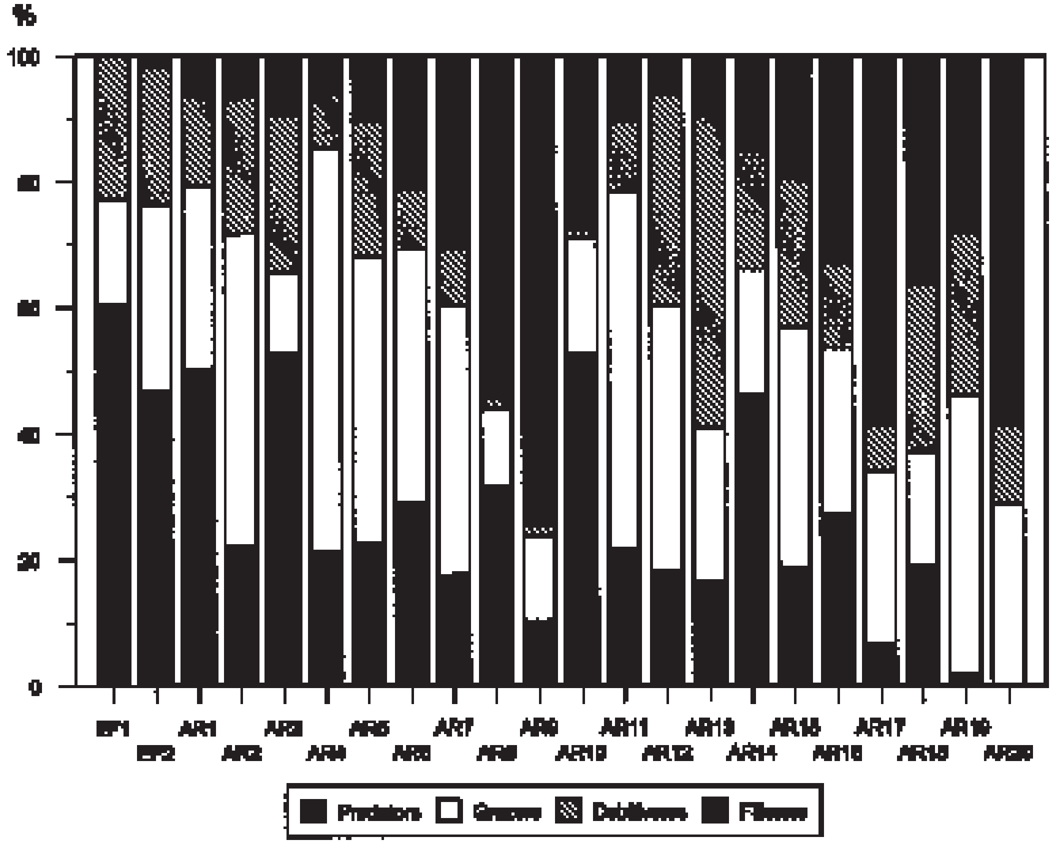

Fig. 3. Distribution of trophic classes of adult Chironomidae, Plecoptera, and Trichoptera.

Middle-elevation sites, AR11–AR14, draining soft sedimentary and carbonate rocks were particularly suitable to the caddisflies *Lepidostoma pluviale* and *Psychomyia flavida,* although the latter species was also present downstream to AR20. Species associated with lower-gradient downstream sites appear in the bottom right corner of Figure 4. *Isoperla quinquepunctata* and *I. mormona* were the stoneflies most successful at colonizing these sites while *Mesocapnia frisoni* (male) was found at AR18. Although no stoneflies were collected downstream of Pueblo Reservoir, the hydropsychids *Cheumatopsyche pettiti* and *Hydropsyche occidentalis* and the hydroptilids *Hydroptila ajax* and *Ochrotrichia stylata* were dominant at AR19 and AR20.

DISCUSSION

Ruse et al. (2000) concluded that collections of adult Chironomidae included individuals derived from habitats beyond the main Arkansas River. Part of the evidence for this conclusion was the relatively low proportion of adult species variation explained by river-related environmental variables within a CCA, 22.3% compared to 43.4% for pupal species data. With CCA, 37.5% of adult stonefly and caddisfly species variation was explained by river-related variables, suggesting that they were more likely to have been derived from the main river than were adult chironomids collected in the same samples. In terms of significant CCA axes, 32.9% of stonefly and caddisfly species distribution was explained, precisely the same as for pupal chironomids collected directly from the river.

Species Richness and Function

Assuming these adults were representative of the main river, total stonefly and caddisfly species richness in the Colorado section of the Arkansas River did not conform to a trend of

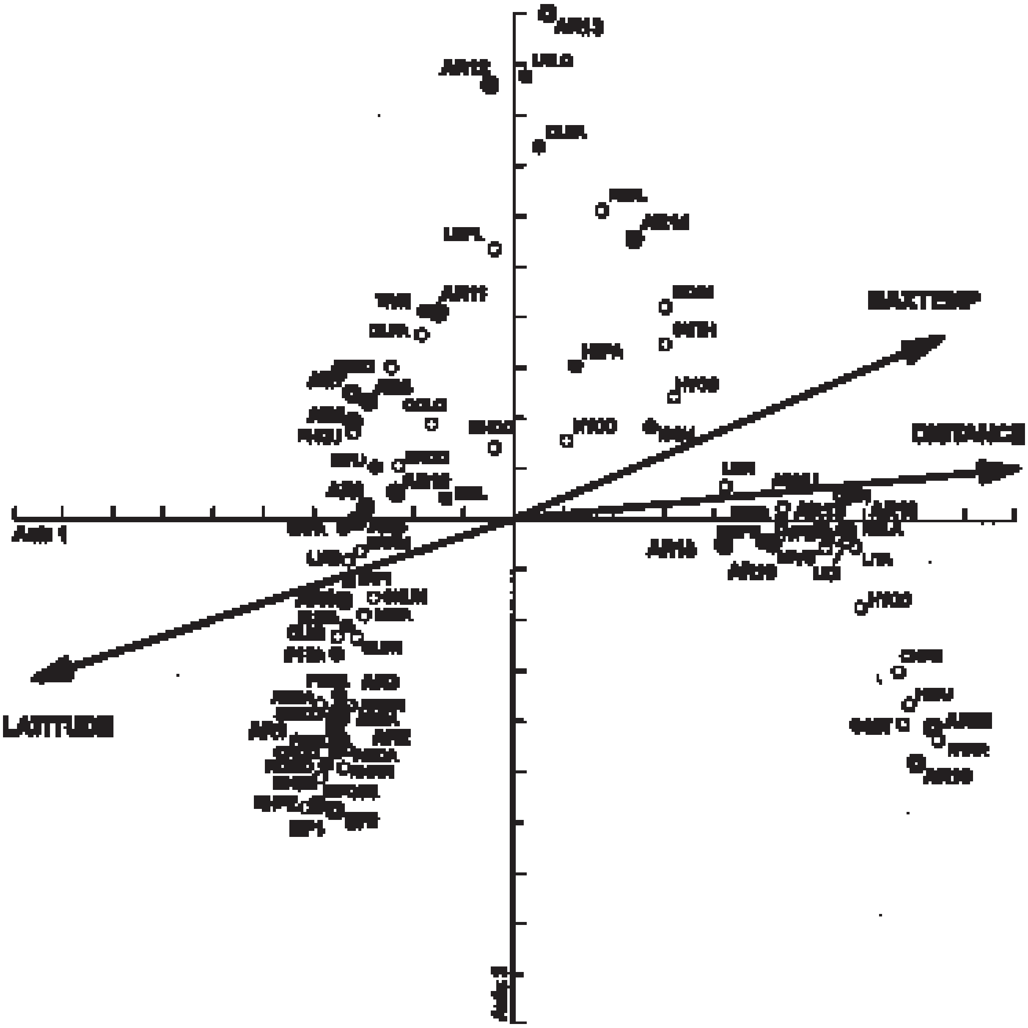

Fig. 4. CCA ordination of Plecoptera (●) and Trichoptera (○) species. Arrows indicate importance and direction of maximum change in species composition among samples as the variable increases. Bold circles used for sites. Species codes from Table 1.

downstream increase. Allan (1975) and Ward (1986) demonstrated progressively increasing numbers of species down smaller Rocky Mountain streams in Colorado. Adult Chironomidae from the Arkansas River have also failed to reveal a sequential downstream trend in species numbers (Ruse et al. 2000). Stonefly species numbers were lowest at sites with a maximum recorded temperature above 19°C, all downstream of AR12, and were absent below Pueblo Dam. The negative effect of heavy metal inputs from Leadville Drain and California Gulch on stonefly or caddisfly species richness was less than that of Pueblo Reservoir. Physical stress of site AR10 appeared to cause a decline in species numbers, just as it did for Chironomidae (Ruse et al. 2000). Downstream trends became more apparent at the family or trophic level. The inclusion of adult chironomids with stoneflies and caddisflies in the trophic classification accounted for nearly all adult insects collected during the survey. This should have accounted for a large part of the macrobenthic community since Ward (1986) found that adult insects accounted for nearly all macroinvertebrate abundance and biomass of a neighboring Colorado stream. Proportions of predators and detritivores declined from site EF1 to AR9 as grazers and/or filterers increased. Trends in trophic groups appeared to be reset at site AR10, possibly due to its hydraulic stress or to the reduction in sedimentary concentrations of heavy metals compared with sites upstream (Ruse et al. 2000). Perturbations imposed by California Gulch also upset this trend, and regulatory outflows from the 2 lakes were considered responsible for the dominance of filterers downstream. Following the resetting of proportions of trophic classes that occurred at sites AR10–AR12, a similar downstream reduction in predators and detritivores resumed as proportions of filterers or grazers increased.

Species Compositional Change

Trends in species turnover were most correlated with the sequential downstream order of sites. Altitude, highly negatively correlated with distance downstream, was positively correlated with latitude. The ultimate cause of correlation between species spatial distribution and distance downstream could be related to changes in hydraulic stress (Statzner and Higler 1986). This has already been suggested, in the previous paragraph, as the cause of changes in functional groups around site AR10. Water temperature was also revealed, by CCA, as being a distinct contributor to biological variation. Sequential downstream change in water temperature was believed to be a controlling factor in hydropsychid caddisfly distribution in a study by Hildrew and Edington (1979). In contrast to adult and pupal chironomid data, sedimentary metals concentrations had no significant explanatory value to caddis- and stoneflies, although copper was significant at the 10% probability level. At high-altitude sites, however, there were species tolerant of ambient concentrations of heavy metals while a few species appeared to be metal sensitive. These responses occurred immediately below Leadville Drain and California Gulch, in contrast to the Chironomidae which were most affected at sites of greatest metal deposition, AR5–AR8 (Ruse et al. 2000). The metal-tolerant chloroperlid *Suwallia pallidula* was described as a euryzonal mountain species by Ward (1986). It was found from 3042 m down to 2338 m in the Arkansas River. Another tolerant stonefly, the nemourid *Prostoia besmetsa,* was classified as a lower-montane/foothills species (below 2500 m) but was not found below 2748 m (AR8). The perlodid *Isoperla quinquepunctata,* recorded by Ward (1986) as a plains species (<1700 m), was present at high-altitude sites on the Arkansas River (up to 2865 m) with high sedimentary metal concentrations. *I. quinquepunctata* did have a more downstream distribution than most other stoneflies collected. Clements (1994) suggested that *Rhyacophila* was tolerant of metals in the Upper Arkansas River. We found 4 species of *Rhyacophila* that appeared to differ in their tolerances to metals. Only *R. angelita* was found at the next 2 sites downstream of California Gulch. All 4 species declined in relative abundance below this discharge, or below Leadville Drain in the case of *R. pellisa*. *Rhyacophila* species distribution was also related to altitude. The altitude range of *R. coloradensis* in the Arkansas River was wider than suggested for this species by Allan (1975) for another Colorado river, based on its site-to-microhabitat niche breadths. Among species found in abundance below Pueblo Reservoir, the hydropsychid *Cheumatopsyche pettiti* was reported to be a plains (<1700 m) species by Ward (1986). These differences in findings between studies of neighboring Colorado streams could be due to variation in river size and habitat characteristics of the sites and to improvements in taxonomic keys. It is also possible that the presence of high concentrations of heavy metals in the Arkansas River was responsible for such differences.

Major mining operations in the Leadville area ceased in January 1999. Adult stoneflies and caddisflies, together with midge pupal skins, are sensitive to immediate impacts of the most polluted tributaries and their downstream deposits of metals. A repeat survey of these organisms would be an effective monitor of the changes in the macrobenthos of the Arkansas River following clean-up operations and the cessation of mining.

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APPENDIX. Species found at only 1 site.

Species name	Stonefly/Caddisfly	Site
Capnia gracilaria Claassen	S	AR18
Malenka coloradensis (Banks)	S	AR4
Sweltsa lamba (Needham & Claassen)	S	AR4
Isogenoides zionensis Hanson	S	AR10 (4 males)
Helicopsyche borealis (Hagen)	C	AR18
Hydropsyche bronta Ross	C	AR20
Hydroptila waubesiana Ross	C	AR16
Neotrichia halia Denning	C	AR16
Stactobiella brustia (Ross)	C	EF1
Triaenodes tarda Milne	C	AR18
Asynarchus nigriculus (Banks)	C	AR1
Hesperophylax occidentalis (Banks)	C	AR6
Limnephilus externus (Hagen)	C	AR6
Psychoglypha subborealis (Banks)	C	EF1
Polycentropus halidus Milne	C	AR17