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F032 United States Department of Agriculture | [redacted]st Service | Manti-La Sal National Forest | [redacted]est Price River Dr. Price, Utah 84501 (801)637-2817

Reply to: 2600

Date: August 9, 1993

File ACT/007/006 #2
Copy Pam

Mr. Lowell Braxton
State of Utah Department of Natural Resources
Division of Oil, Gas, and Mining
355 West North Temple
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

RE: Aquatic Macroinvertebrate Sampling Justification for Addition to Federal Coal Lease UTU-64263, Cyprus-Plateau Mining Corporation, Star Point Mine, ACT/007/006, Folder #3, Carbon County, Utah

Dear Mr. Braxton:

Our meeting on July 28, 1993 with Susan White (DOGM) and Ben Grimes (Cyprus-Plateau Mining Corporation) resulted in an excellent discussion on the merits of aquatic macroinvertebrate monitoring in connection with coal mining activities. Baseline data on the macroinvertebrates was collected during the data adequacy requirements of the permit. To provide additional information on changes that have occurred within this drainage, the Forest Service is asking Cyprus-Plateau to do additional monitoring in Wild Cattle and Tie Fork Creeks in the June and September of 1994 and again in 1997 after subsidence is completed within these drainages at or near the sites where the initial monitoring has been done.

The Forest Service also requests that baseline monitoring for aquatic macroinvertebrates be done prior to the commencement of mining in the Nuckwoodward Drainage. The baseline monitoring, in Nuckwoodward Creek just below the confluence with Little Park Creek, should begin in September of 1993 and continue in June and September of 1994 and 1995. Followup monitoring at this site would occur in 1998 and again in 2000.

Enclosed you will find justification for monitoring macroinvertebrates beyond the required monitoring of water quality. This information was requested during our July 28, 1993 meeting. The Forest Service technical contact, Paul Burns, is willing to help Cyprus-Plateau with the selection of the monitoring sites and

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provide hands on demonstration and instruction if required to complete the monitoring. If additional information is required please contact him at the Forest Supervisor's Office in Price, Utah.

Sincerely,

/s/ George A. Morris

GEORGE A. MORRIS
Forest Supervisor

Enclosures

cc:
D-3
C.Reed (SO)

Use of Aquatic Macroinvertebrates as Bioindicators of Habitat Conditions

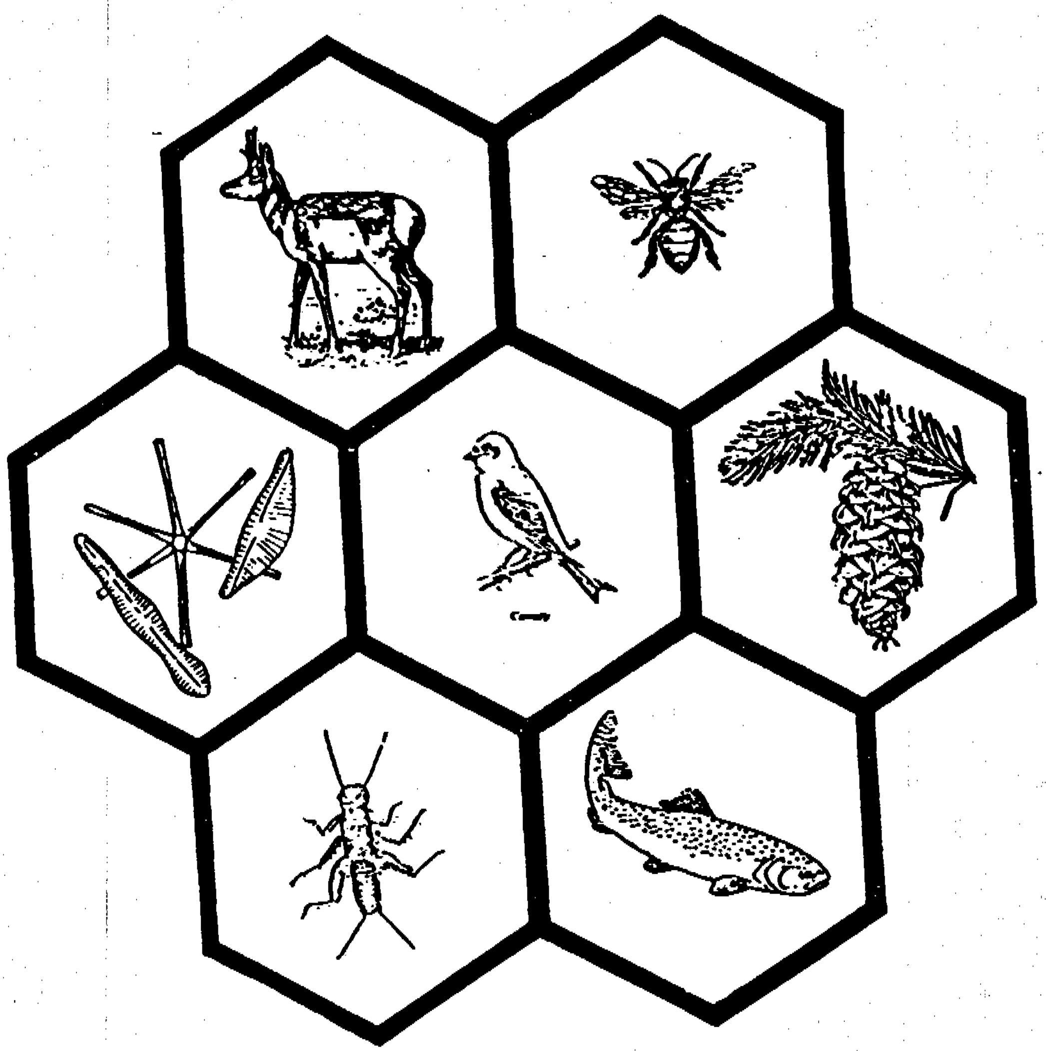
Fred A. Mangum

Intermountain Region USDA-Forest Service
Aquatic Ecosystem Analysis Laboratory
105 Page School, BYU
Provo, Utah 84602

ABSTRACT

As early as 1909 biologists R. Kolkwitz and M. Marsson made observations from stream studies concerning the ability of certain aquatic insect species to tolerate pollution. The insect species were thus categorized according to their abilities to live in clean waters, moderately polluted waters or polluted waters. In recent years the concept of using aquatic insect communities and species as bioindicators of habitat conditions has developed into a useful tool in monitoring and management of watersheds. Macroinvertebrates have shown measurable response to a wide variety and intensity of perturbations in aquatic ecosystems, including: organic enrichment, pesticides, sedimentation, heavy metals, thermal changes, acidification, petroleum spills and flow fluctuations. A model, Biotic Condition Index, developed to measure macroinvertebrate responses to perturbations is included.

BIOMONITORS, BIOINDICATORS, AND BIOASSAYS OF ENVIRONMENTAL QUALITY



A symposium held at the annual meeting of the American Association for the Advancement of Science, Pacific Division
Missoula, MT, June 10-11, 1985

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AQUATIC MACROINVERTEBRATES AS BIOINDICATORS

INTRODUCTION

Biologists have observed that environmental disturbances such as pollution induce changes in the structure and function of biological systems. These observations have prompted development of ways to judge the severity of pollution by analyzing changes in biological systems. The earliest extensive use of bioindicators in the United States was in the Illinois Natural History Survey under the direction of Dr. Forbes (1910).

Studies in recent years have emphasized species diversity and pollution tolerances of macroinvertebrates. Benthic macroinvertebrates are aquatic animals without backbones which can be seen with the naked eye and are particularly suitable as ecological indicators because their habitat preference and relatively low mobility cause them to be directly affected by substances that enter their environment. Natural and man influenced conditions can be monitored by macroinvertebrate bioindicators. Responses of macroinvertebrate taxa to various perturbations have been recorded, and aquatic fauna have become a reliable monitoring tool to assist in management of watersheds.

The following are examples of some of the ways in which macroinvertebrates have been used as indicators of specific types of perturbations. Most of the early studies were in waters polluted by organic enrichment, but in recent years the use of macroinvertebrates as bioindicators has been expanded to include nearly any form of perturbation that may be found in aquatic ecosystems.

ORGANIC ENRICHMENT

In 1956, Paine observed that aquatic insects can reveal present and past conditions in an aquatic ecosystem. Use of aquatic organisms as indicators of pollution is dependent upon a knowledge of their normal habits and their sensitivity to various environmental factors. One of the groups of aquatic macroinvertebrates found in all types of stream habitats, from the cleanest to the most polluted, are the dipterans, and thus they are an important indicator group.

Paine found that Chironomus riparius, Glyptotendipes sp., Eristalis bastardi, and Culex pipiens competed best in the septic zone and were indicators of organic pollution. Stictochironomus varius and Microtendipes pedellus were found in cleaner waters and Chironomus decorus seemed equally adapted for either clean or polluted waters. Species of Stratiomyidae and Tabanidae were found tolerant to pollution and associated low-dissolved oxygen.

In 1958 Gaufin made a year-round study of the Mad River, a trout stream in Ohio. The study was designed to determine effects of waste discharges on physical/chemical environment, benthic macroinvertebrate populations and value of macroinvertebrates as indicators of ecological changes produced by stream pollution. Within 60 miles the stream received effluents from two chlorpyrifos, temephos, and difluvenzuron as Chironomid control to residential/recreation lakes. These chemicals had various affects upon the Daphnia and Copepods in the zooplankton community and although Hyalella azteca was tolerant to temephos, it was severely reduced by chlorpyrifos and difluvenzuron. For several weeks Oligochaetes were not affected by the three chemicals.

Greeff (1978) tested the sensitivity of indicator groups of aquatic invertebrates to Fenthion, an aviside used to control red-billed finches which roost in trees along rivers in South Africa. Concern was expressed about the slow degradation of the aviside and possible hazard to humans and thus the study was made. The best indicators were dragonfly nymphs, particularly Pseudagrion sp. which showed a measurable effect and then recovery. Hemiptera and Ephemeroptera (mainly baetis sp.) are also sensitive to this aviside and take much longer to recover from contamination.

In 1973 Wallace found the insecticides Abate, Dursban, and Methoxychlor effective for removal of blackflies (Simuliids). Drift of non-target aquatic insects was increased by the use of these insecticides but none of the groups of insects including Ephemeroptera, Plecoptera, Trichoptera, and Chironomidae were severely affected or eradicated by the low concentrations (1ppm for 15 min.) of the insecticide found effective for control of blackfly populations. The selectivity of these insecticides may have been partly due to the habit of Simuliids to frequent the upper gravel layers while the other taxa were protected in deeper gravel layers of the Canadian streams tested.

Muirhead (1971) found Baetid mayflies susceptible to Abate and possibly even more sensitive than Simuliium larvae to Dursban. Caddis larvae, particularly Hydropsyche sp., have been reported as the most important predators on blackfly larvae.

Gaufin (1965) reported laboratory studies on effects of ten organic insecticides on various aquatic invertebrates. The TL_{50} (concentration of chemical that kills 50 percent of the test organisms) was determined for two caddisfly species, Arctopsyche grandis and Hydropsyche californica. Arctopsyche and Hydrophsyche were most sensitive to Parathion and their TL_{50} was attained at .00043 and .007 mg/l, respectively. For Malathion the TL_{50} chemical concentrations were .02250 and .032 mg/l for Hydropsyche and Arctopsyche, respectively. DDT was less toxic; the TL_{50} concentrations were .0480 and .175 mg/l for Hydropsyche and Arctopsyche, respectively.

In addition to this study, the four-day TL_{50} concentrations for ten pesticides including DDT, Aldrin, Dieldrin, Endrin, Parathion, Malathion, Di-syston, Dylox, and Bayer 29493 were shown for Pteronarcys californica, Acroneuria pacifica, Ephemerella grandis and Gammarus lacustris. Of the stoneflies, Acroneuria was more sensitive to organic insecticide than Pteronarcys. Acroneuria was most sensitive to Endrin and Parathion and least sensitive to DDT and Aldrin. Pteronarcys was most sensitive to Endrin and Guthion, and least sensitive to DDT and Aldrin. Gammarus died at concentrations of all insecticides below that used in the field to control insect pests. Gammarus was most sensitive to Guthion and Malathion and least sensitive to Aldrin and Dieldrin. The mayfly, Ephemerella grandis, was most sensitive to Parathion and Endrin and least sensitive to Dylox and Malathion. The best indicators of insecticide pollution were determined to be Gammarus lacustris and Ephemerella grandis.

DeJoux (1978) found that the insecticide, Abate, used to control the blackfly Simuliim damnosum in the Volta Basin, Ghana, often kills up to 50

HEAVY METALS

Macroinvertebrates as bioindicators have been widely used for monitoring heavy metals in our aquatic ecosystems, particularly from mining operations. The sensitivities and tolerances of various macroinvertebrate taxa to heavy metals gives us a good yardstick to measure the severity of pollution from mining activities. These studies have been carried out in the laboratory and under field conditions for many of the heavy metals found in aquatic ecosystems.

Moore (1979) found that macroinvertebrate diversity indices and indicator species were effective in monitoring metal contamination. There was also a strong negative correlation between concentration of metals and abundance of benthic organisms. Nehring (1976) found that the Silver TL_{50} for Ephemerella grandis was .001 mg/l and for Pteronarcys californica was .004 to .009 mg/l, which indicates silver is toxic in very low concentrations.

Zanella (1982) found Hydropsyche sp. apparently more tolerant to copper concentrations than Brachycentrus americanus in the Sacramento River. Wimmer (1975) metered copper sulfate into an experimental stream reach in Ohio over a 2.5-year period after which chemical and macroinvertebrate samples were taken. Copper concentrations were measured by atomic absorption spectroscopy. Mayflies were eliminated from the community where copper concentrations were 66 ppb. Chironomids were still present and found dominating the community.

Butcher (1946) found that Chironomid larva were the first to reappear in an English stream that had been grossly polluted with copper from an industrial source. He found all macroinvertebrates were eliminated by copper concentrations of 600 ppb, with Chironomids reappearing when the concentration was 120 ppb. He did not sample the concentrations between these extremes.

In samples from Panther creek, a Salmon River tributary receiving effluents from an old copper mine, Chironomids were found in abundance where copper concentrations were between 45 and 163 ppb but were missing from the community in Big Deer Creek where the copper concentration was 364 ppb. Atherix sp., a Dipteran, found tolerant to 134 ppb, was severely limited by 163 ppb and missing at 364 ppb copper concentrations. Other species found at the control station above the toxic effluents were missing or appeared to be drifters collected at stations with copper concentrations over 38 ppb (Mangum, 1977).

Graney (1983) found that the Asiatic clam, Corbicula fluminea, is a good bioindicator of cadmium, copper and zinc. Among other requirements, a good indicator must not be killed by the metal or toxicant but will normally accumulate the metal in its tissues over time. Maximum accumulation of cadmium occurred in 11 days, whereas copper and zinc accumulations continued through the 28-day exposure period. Copper showed the greatest degree of tissue uptake, cadmium was intermediate, and zinc had the lowest potential for concentration.

Ahsanullah (1976) found that the cadmium TL_{50} for marine organisms tested ranged from 0.2 to 16 mg/l for cadmium. Arthropod was 0.2 to 0.4 mg/l and for Militus, a bivalve molluscan, the TL_{50} was between 1 and 5 mg/l. For crabs, Paragrapsus sp. the 168 hr TL_{50} was 14 to 16.7 mg/l cadmium and for Neanthes, a marine Polychaete, the 168 hr TL_{50} was 6.4 mg/l.

The pattern of invertebrate mortality during the experiments indicated azteca was 33.2 degrees C. and for *Gammarus fasciatus* was 34.6 degrees C.

Lehmkuhl (1974) observed that although releases of low temperature waters from reservoirs may not kill aquatic insect nymphs or larvae, they can disrupt or destroy temperature triggered phases in the life cycle of many insects. Summer cool and winter warm waters were observed to have nearly eradicated the benthic insect community below a large reservoir on the Saskatchewan River in Canada. Martin (1976) found that critical thermal maximum for dragonfly nymphs acclimated to 16 degrees C., 24 degrees C. and 32 degrees C. was 42.8, 43.6, and 44.8 degrees C., respectively; thus, increasing the acclimation temperature increased the organisms' thermal tolerance.

ACIDIFICATION

Macroinvertebrates have been extremely useful as bioindicators, particularly in the eastern United States, in streams known to be polluted by acid waters from mining operations. Pollutants from industry are now known to be carried great distances in upper air streams and their possible deposition in lakes and streams throughout the United States and other countries is a phenomenon to be investigated. It is increasingly important that we utilize the aquatic macroinvertebrates as bioindicators of possible acidic trends in aquatic ecosystems.

Napier (1976) observed that mayfly nymphs were abundant and diverse in riffles of three control streams (pH 7.7 - 8.4) in southeastern Ohio and missing from three streams (pH 2.9 - 3.0) with current or past histories of mine acid pollution. The only species present in the acidic waters were in the orders Hemiptera, Coleoptera, and Megaloptera.

Parsons (1968) indicated the biotic community was the best indicator of acid conditions since acid levels fluctuated over time and between the stations sampled in Missouri streams associated with strip mining. At pH values of 2.8, 3.7, 4.0, and 4.2 macroinvertebrates present included a dragonfly nymph, Chironomids, Psychodids, and the alderfly *Sialis sp.*. A horsefly larva, *Tabanus sp.*, caddisfly, *Cheumatopsyche sp.* and dragonfly *Ophiogomphus sp.* were added to the list in another stream with a pH of 4.2. In a stream with pH 6.0 a mayfly, *Hexagenia limbata*, snail *Physa sp.*, and caddis *Chimmara obscura* were found in the community. Parsons stressed the importance of basing ecological evaluations upon communities rather than single indicators. In a stream reach with pH 6.8 additional benthos in the community were a mayfly *Stenomema sp.*, a stonefly *Isogenus sp.* and a caddisfly *Polycentropus sp.*. At a pH of 7.3 there were 25 taxa in the community.

Orciari and Hummon (1975) studied two lakes in southeastern Ohio and found that acid mine water effluent reduced the diversity of Oligochaetes in the lake receiving pollution. Warner (1973) reported that Roaring Creek in West Virginia, which was polluted by mine acid drainage (pH 2.8-3.8), was inhabited by low diversities of 3 to 12 benthic invertebrate taxa. Stream reaches with pH 4.5 and higher supported communities of 25 or more invertebrate taxa. Heavy metals accompanying waters with low pH often make the ecosystem even less inhabitable by stream biota.

Warner observed a decline in the number of taxa at pH below 6.0 with a

Winget (1979) found heavy grade oil and gasoline spills from dam construction equipment eliminated the most sensitive macroinvertebrate species in the community in Current Creek below the spills. The toxicity was more severe directly below the oil spills, with impacts decreasing downstream. Some species of Chironomids and Oligochaetes appeared to be tolerant to the oil spills.

REGULATED FLOWS

Flow manipulations have been shown to impact macroinvertebrate communities. Long periods of low flows tend to enhance tolerant species and limit sensitive species. The spring flushing flows often missed by rivers below reservoirs are important to the maintenance of instream habitat (Williams, 1980). Winget (1984) observed that macroinvertebrate community composition was modified by the presence of a dam. At the filter feeding collector/gatherers and scrapers gained advantage over the shredders. Insect taxa eliminated from stream reaches near the dam were Rhithrogena robusta, Pteronarcella badia, and Ephemerella doddsi; whereas, Arctopsyche grandis, Chironomidae and Simuliidae increased in numbers. Small instar larvae were negatively impacted by unnaturally high July and August flows.

DIVERSITY INDICES

The main motivation for developing environmental indices in the early 1970's was the National Environmental Policy Act (NEPA) of 1969 which requires the President of the United States to report to Congress on the status and condition of the major natural, manmade, and altered environmental classes in the Nation. The Council of Environmental Quality (CEQ) was responsible for development of required yardsticks. CEQ decided to develop indices in six areas, including water pollution. Environmental impact statements could be strengthened by inclusion of predicted shifts in a water quality index.

The most commonly employed judicial standard for the allowable deterioration of water quality by users is the amount associated with 'reasonable use' in light of the circumstances. This and other legal tests cannot be expressed numerically but a numerical quality index certainly would have evidenciary value in determining whether the activity in question exceeded the common law standard. This would be particularly helpful if monitoring data were available to show trends over time. Some professionals want an objective method for reporting water quality but prefer not to sacrifice any technical detail. The general public and elected officials want to understand their environment and environmental indices.

Thomas (1977) says living organisms provide convenient fulltime monitors of all pollutants, including their synergistic effects; thus biological indicators like the miners canary measure the actual responses of organisms to environmental quality. The physiological and ecological diversity of species allows a wide choice of indicator species for various environmental factors and situations. Because ability to support life is a prime predicted by the CTQa, or actual community tolerance quotient - which yields a decimal fraction. This times 100 equals the BCI. The stream evaluation is based upon its own potential, not that of another similar stream.

The BCI value is easily understood because it is like a score on a test. If in the 90's, the condition of the aquatic ecosystem is close to its potential. A BCI of 80 indicates that the aquatic ecosystem is in good condition but could be better. A BCI score of 70 indicates water and habitat degradation and less than 70, severe aquatic ecosystem impacts, requiring long-term restoration.

BIOINDICATORS IN ACTION

Macroinvertebrates and the BCI have helped land managers in state and federal agencies make decisions concerning aquatic ecosystems and associated drainages. The following are some examples where the BCI and macroinvertebrate analysis have helped land managers.

Williams Creek, Plumas National Forest, in California had excellent conditions in both water quality and habitat quality. The BCI was 106.

Mill Creek is a Tributary to Upper Provo River in Utah. This stream had fairly good water quality and habitat quality but some dominance among taxa tolerant to sediment and organic enrichment. The BCI was 82.

Panther Creek, a tributary to Middle Fork Salmon River in Idaho, receives high concentrations of toxic copper and iron from a mine at the head of Big Deer Creek. Panther Creek can support only the most tolerant insects and even they are not able to maintain resident populations. The instream substrate could support an excellent biota but the toxic water will not permit it. The BCI was 61.

Cottonwood Creek is a stream with broken banks and devastated water and habitat quality. Severe overgrazing had eliminated the potential for supporting the necessary phases in the life cycle of a trout population in the reach of stream sampled. Grazing had eliminated instream and riparian habitat and sharply reduced the value of this resource for multiple use. The BCI was 64.

A negative trend was shown in 1983 by the macroinvertebrate communities in Lolo Creek, which had been monitored over a 5-year period. Some of the moderately tolerant stoneflies disappeared and tolerant species became numerous. The BCI had declined from 94 to 86 and the total number of taxa from 41 to 31. This evidence helped the Lolo National Forest fishery biologist gain a commitment from logging industry officials to take action to reduce sedimentation from their operations.

Rock Creek on the Lolo National Forest provides some excellent trout fishing. Sediment from natural and man-influenced sources and organic enrichment from ranch activities along the stream pose some threat, but as of August, 1984, macroinvertebrate community composition did not show severe impacts. The BCI was 85.

In 1984 West Fork Butte Creek on the Lolo National Forest had 48 taxa in the macroinvertebrate community including 14 species of mayflies. There was good balance among the trophic groups. All of the analysis elements indicated excellent water and habitat quality and stability in this aquatic ecosystem. The BCI was 102.

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COVER PHOTO
Clark Fork Valley
Missoula, Montana
Dave Thomas

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MONTANA FOREST AND CONSERVATION EXPERIMENT STATION

Benjamin B. Stout, Station Director

The Montana Forest and Conservation Experiment Station was established by the Montana State Legislature in 1937 as a nonprofit organization devoted to scientific investigation of natural resource problems. The station serves as the research unit of the University of Montana School of Forestry with the Dean functioning as station director. The station seeks, through this magazine and other publications, to enhance public understanding of forestry and conservation and contribute to wise use of our nation's forest, water, range, wildlife and recreation resources.

ISSUES

TOPICS

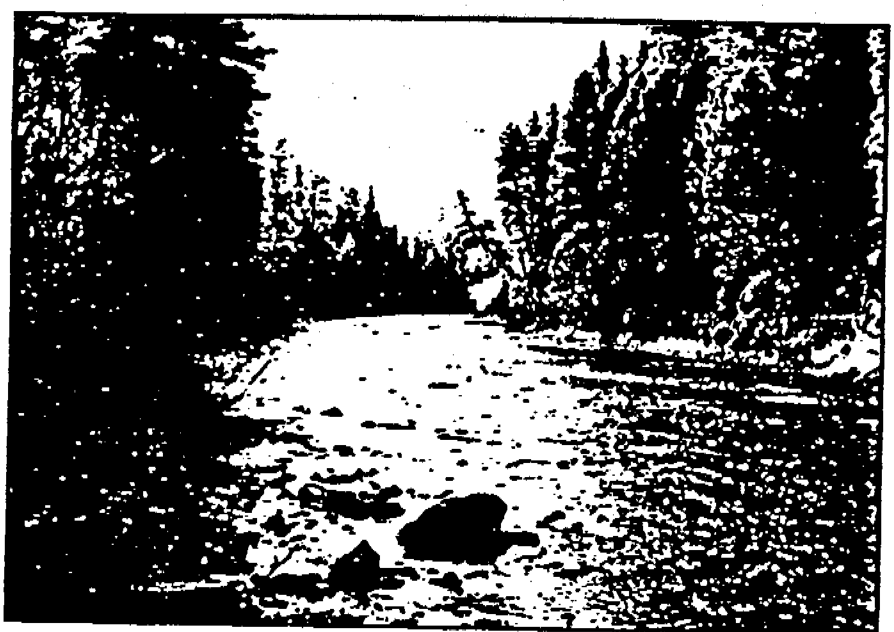
DEPARTMENTS

Use of Macroinvertebrates To Monitor Forest Management Activities

Gregory L. Munther

"Macro what?" is the most common response when a biologist begins to elaborate on the benefits of using aquatic organisms to monitor the biological health of a stream in mixed company of foresters, engineers, miners or others involved in forest management.

Land managers have become increasingly aware that the health of a stream's biota reflects the way adjacent lands in the drainage are being managed. There are often many concurrent activities in a single drainage, each with the potential to alter stream conditions. For example, in a western Montana drainage such as Lolo Creek on the Lolo National Forest, logging and road building may raise water temperatures and sediment levels. Livestock grazing can cause organic enrichment because of concentrated excrement adjacent to the stream, and future mining projects in the area may add chemical pollutants. In addition, a major federal highway parallels the stream, heavy traffic along the road was once responsible for a spill of thousands of gallons of diesel oil into an stream. Managers have long searched for a technique that could be used not only to monitor the relative health of streams such as Lolo Creek but to isolate the sources of any pollution that causes a decline in the biota.



The U.S. Forest Service uses macroinvertebrates and other methods to monitor sediment level changes in western Montana's Rock Creek. Photo/Greg Munther

In the past, one of the ways managers have monitored streams is by directly measuring the pollutants believed released by particular activities. For example, sediment may be the suspected pollutant in the case of road building or logging, while a metal or processing compound may be monitored in areas affected by mining. These physical measurements can be used to assess whether pollutant levels have changed over time. One disadvantage of relying only on these measurements is that most sampling procedures rely on one or more instantaneous measurements, assuming that these samples also represent other, unmeasured time periods. However, in the case of non-point pollution sources, the pollution levels may vary greatly from day to day, either because a particular management activity is more intensive at specific times or because of uncontrolled events such as heavy precipitation.

Relying on physical measurements alone to monitor the health of an aquatic ecosystem's biological components forces land managers to attempt to link lethal or stress limits of a particular pollutant developed in a laboratory for one or more organisms. Although this kind of data can be useful when judging the relative risks of a proposed project, the manager may not be able to accurately extrapolate laboratory results to field conditions. For example, the toxicity of many polluting chemicals may be more acute in mountain waters than in other study areas: The alkalinity, or hardness, of mountain water is frequently low, and chemicals may therefore not be buffered as they often are in lowland waters. In addition, other stresses, such as abnormally high water temperature during hot, dry periods, can combine with pollutants to co[illegible] the threat to aquatic organisms. For th[illegible]y reason, organisms living in a stream can provide a reliable indication of habitat conditions — they are fulltime monitors of activities affecting aquatic habitats in a drainage.

Once managers decide to monitor components of a biological system, their choice of trophic levels will depend on their objectives. For example, if a manager is interested in the long-term effects of a pollutant on fish populations, he or she would find it difficult to extrapolate effects based on the results of an algae study. On the other hand, information about algae community composition may provide a more exact interpretation of the biological mechanisms limited by a particular pollutant.

Diatoms and other periphyton (attached or sessile organisms) are all useful as monitoring organisms, depending on monitoring objectives. Monitoring of diatoms and periphyton gives researchers the opportunity to use the simplest forms of plant life found in essentially all surface waters. Diatoms are used most extensively because they are more common, encompass many species and are easy to identify. They are most useful when monitoring nutrient enrichment, dissolved oxygen depletion and pollutant toxicity, including heavy metals, pH and salinity. These organisms are easy to collect — only a bottle and a scraping device such as a knife are needed -- and it is easy to gather enough for statistical purposes because of their relative abundance.

Another opportunity for biomonitoring exists at the top of the aquatic trophic pyramid -- in fish populations. Because the general public often takes an interest in fish abundance and habitat, measurements of these organisms provide direct feedback to the public and to land managers about how forest activities are affecting fish populations.

However, there are limitations on using these organisms as the *sole* method of monitoring a stream. A diatom or periphyton community may take a matter of days to recover from a severe perturbation; therefore, frequent sampling may be necessary if the pollution being monitored reaches the stream at irregular interval[illegible] rather than at a steady flow.

One disadvantage of monitoring fish populations is that often only a few indigenous species may be present in a particular area, and their tolerance to specific pollutants may be quite narrow. Thus, although monitoring may show that a fish population has changed, it may be difficult to pinpoint the responsible pollutant or mechanism if there are no other species with more tolerance to the pollutant. For example, if a stream with rainbow and cutthroat trout as well as whitefish were subjected to elevated temperatures, chemicals and sediment from a mining operation, the population of each species would probably decline. [illegible]owever, it would be difficult to assess which of the three polluting mechanism was most responsible for the decline because all of the species present were affected.

Another factor limiting fish population sampling is a slow response rate: Pollutants that affect only one life stage of a fish may not be detected in a population study for some time. For example, a pollutant that affects spawning success may not show up until the eggs affected become mature, catchable trout — a matter of two to four years.

The answer to these limitations may well be a combination of monitoring techniques. In combination with any or all of the monitoring tools described above,

Above: a relatively pristine streambed. Below: sediment has filled in the spaces between rocks, thus displacing the insects that rely on these spaces for habitat. Photo/Greg Munther

Gregory L. Munther is zone fisheries biologist for the Lolo, Bitterroot and Deer Lodge National Forests in western Montana. He was previously a fisheries biologist on the Sawtooth National Forest and also worked for the Forest Service in Utah and Wyoming. He holds a BS in forestry and an MS in fisheries management, both from the University of Idaho.

The underside of a rock in a stream riffle can support an abundant and diverse invertebrate population. *Photo/Greg Munther*

macroinvertebrates can provide valuable interpretive opportunities for a variety of pollutants. These organisms are becoming an increasingly popular monitoring tool for land managers concerned about the effect of their monitoring activities on the aquatic ecosystem. The U.S. Forest Service, for example, formalized its use of macroinvertebrates in 1974 by establishing the Aquatic Ecosystem Analysis Lab in Provo, Utah. Since that time, the demand for macroinvertebrate analysis and interpretation has grown from 200 samples from two national forests in 1975 to 1,000 samples from 20 national forests in 1984. The lab also processes 900 samples annually from Bureau of Land Management districts.

Macroinvertebrates were first used to monitor pollution from point sources, such as sewage treatment and industrial discharges into surface waters. Researchers discovered that clean-water macroinvertebrate species decreased below sewage treatment outfalls, and species composition shifted toward aquatic worms and other burrowing forms that thrive in organic sludges and matts of aquatic plants.

Macroinvertebrates have become an important management tool for a number of reasons. They are more abundant than fish and include many species, numbering up to 80 species in a given stream, and may exceed 1,000 organisms per square foot of streambed. Each species has individual tolerances to particular pollutants, so the absence or abundance of one species or a group of species can provide biological evidence of the water's quality.

Another advantage of using macroinvertebrates is that these organisms will repopulate a river section within three months after pollution decimates a population. This characteristic is important to land managers because macroinvertebrate populations reflect not only water quality degradation, but the stream's recovery after the pollution has been eliminated. On the other hand, even the briefest perturbation can eliminate particularly sensitive species, and subsequent sampling can detect the change up to three months later, thus providing a continuous monitoring device that requires samples only a few times a year.

These common organisms are now often used in wildland management. The Lolo National Forest, for example, began macroinvertebrate monitoring in 1977 and is currently monitoring about 35 streams, primarily for potential sedimentation effects. Baseline study sites are established at least two or three years before the beginning of a ground-disturbing project such as logging. Each fall, at least three samples are collected from each stream site, a process that provides background data on natural population levels and annual variability. Monitoring continues as a project is developed. If significant changes are noted in population numbers, individual species abundance or community diversity, monitoring continues until the watershed recovers. Other parameters, such as sediment deposition and transport and streamflow data, are also studied during the monitoring. Although most sampling is done to monitor the impacts of individual projects in a drainage, some sites are maintained to evaluate the cumulative effects of many activities in the watershed.

After collection, many Forest Service units send their samples out for analysis. Many of those in the West use the services provided by the Aquatic Ecosystems Analysis Lab. Lab staff sort samples by taxa and, if some species are abundant, subsample part of the sample. Lab director Dr. Fred Mangum's interpretation includes a number of analyses of the sorted taxa. Each identified taxa is quantified, and the invertebrate community is described as a Dominance and Taxa Index (DAT), which is a measure of both the dominance of species in the community and the number of species present.

Another index incorporates strea[illegible]t. water quality and environmental tolerances of invertebrate taxa. Termed the Biotic Condition Index (BCI), it evaluates the stream's condition in relation to its own potential water quality, not that of a theoretical stream.

The above analysis allows Dr. Mangum to describe the condition of a stream, even when he has never seen it. Robert Hammer, forest hydrologist for the Bitterroot National Forest, testified that one year of invertebrate sampling provided better documentation of a stressed stream than several years of physical water sampling techniques. In the mid-1970s, Bitterroot Forest personnel sent Dr. Mangum four invertebrate samples from the East Fork of the Bitterroot River. One was from the Anaconda Pintlar Wilderness, one from a tributary with extensive clearcuts, one from private land with an intensive feedlot operation and the last downstream from all of these sources. Mangum, who had not seen the drainage, described high levels of sediment stress from the clearcut drainage, organic enrichment from the feedlot operation, and stress from both sediment and organic enrichment from the sample taken at the downstream site. His comparison of the upstream and downstream samples yielded clues that the stream had changed substantially in a short distance. The dominance and taxa index was 21.3 at the upstream site, indicating a healthy community but was only 10.7 downstream. At the upper station, clean water species were present in numbers representative of a resident population, but downstream they were either missing or present in very low numbers. Pollution-tolerant species such as the Baetid mayflies and chironomids dominated the downstream populations. These changes in the relative numbers of particular species allowed Dr. Mangum to conclude that sediment and organic pollution from domestic livestock were the likely causes of significant changes in the stream.

The key to interpretation of invertebrates is understanding of the physical and chemical requirements of each taxa analyzed. Fauna diversity in a stream is similar to that found in terrestrial systems. Each invertebrate species has a specialized niche. When that niche is damaged, a negative population response will soon follow. For example, many invertebrate species depend on the intersticial spaces between rocks to shelter them from the current velocities common to mountain stream riffles. If these spaces are filled by sediment, the number of associated species may decrease. However, there may be a corresponding increase in species that burrow into sedimen[illegible] Thus, a land manager who notes a shift in community composition toward those species tolerant of sediment can conclude that sediment is accumulating in the stream substrates. This change in composition is important to fish populations because it causes a shift in food sources; it may also indicate changing conditions for fish spawning and overwintering habitat because both are adversely affected by increased sediment accumulation.

Invertebrates can be used to monitor changes along a stream as well as in it. One group of taxa are called shredders because they use leaf and litter in a stream as food. An abundance of these taxa can indicate ample streamside vegetation, while a scarcity [illegible]may point to a perturbation that has reduced or eliminated streamside plants.

Although biologists and hydrologists will continue to use a variety of monitoring tools to define changes in aquatic systems, macroinvertebrates are a cost effective addition and can provide a reliable link between positive or negative biological changes and land management activities. They have been used to evaluate both source and nonpoint source pollution, and their use will undoubtedly increase as future use and mangement of water become more intense. It is increasingly possible that macroinvertebrate collections may be seen in courtrooms as evidence in disputes about water pollution and the need to maintain viable aquatic ecosystems.

A collection basket holding natural substrate used to collect invertebrates. Photo/Greg Munther