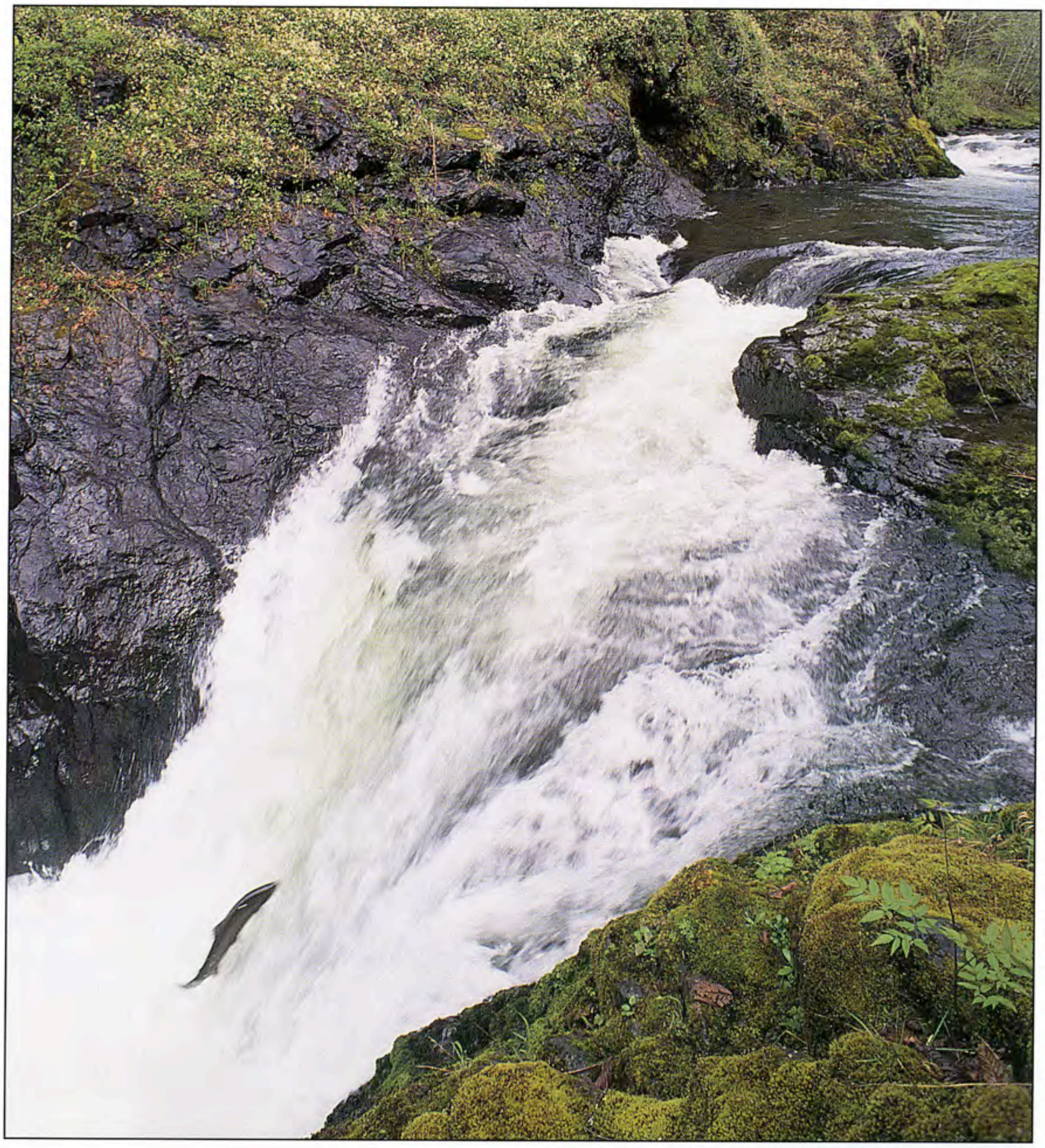
STREAMKEEPERS

Aquatic Insects as Biomonitors



Part Two

Biomonitoring

The Future Is Now: Biological Monitoring to Ensure Healthy Waters

Can we afford clean water? Can we afford rivers and lakes and streams and oceans which continue to make life possible on this planet? Can we afford life itself? . . . These questions answer themselves.

—Senator Edmund Muskie, 1972

Aquatic ecosystems embrace an interactive mosaic of environments extending from headwater streams and meadows through mainstem rivers to the sea. This mosaic includes small streams and large rivers, shorelines and streambeds, terrestrial watersheds and groundwater aquifers. Water, plants, animals, nutrients, debris, and byproducts of human society move among these environments no matter what the political boundaries or legal constructs established without regard for the connections.

Because rivers integrate everything in their landscapes, the living organisms found in rivers tell us about the status and quality of their watersheds. Unfortunately, the story told in North America's rivers today is one of damaged landscapes and the historical tendency to undervalue our rivers. Now is the time for citizens and agencies to reverse this trend.

Through most of the twentieth century, national efforts to protect water and associated resources were defined by the 1899 Rivers and Harbors (or Refuse) Act, which was passed to control sewage and oil spills in navigable waterways. By 1970, it was obvious that we needed a new approach. With passage of PL 92-500, the 1972 Water Pollution Control Act Amendments (now referred to as the Clean Water Act), hope for change came in the form of one explicit, wide-ranging, and visionary statement: "The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

Although progress has been made under this law in controlling point-source

An adult stonefly, *Perlesta* sp. (Plecoptera: Perlidae). Photographed in White Clay Creek, Pennsylvania by David H. Funk.

pollution (as from factories or wastewater treatment plants), other harm continues —nonpoint pollution (such as runoff from agricultural, forest, or urban areas); altered hydrological regimes; habitat destruction; and the introduction of exotic species. To break this pattern, we must now recognize and deal with the following facts:

- Water resources, especially their biological components, are in steep decline.

- Degradation stems from more than chemical contamination, yet conventional water-quality programs focus primarily on that one dimension. The biota of rivers offer a multidimensional view and a more effective analytical tool.

- Long-term success in protecting water resources means measuring their condition with biological criteria, that is, by monitoring the organisms (such as insects, fish, or plants) that inhabit our rivers and streams.

- The Clean Water Act establishes a clear objective, and science provides the tools, for protecting our waters, but the regulatory framework and its implementation have yet to catch up.

Because rivers integrate everything in their landscapes, the living organisms found in rivers tell us about the status and quality of their watersheds. The Nestucca River, photographed in Oregon by Dave Bohn.

We must begin to track the condition of aquatic systems the way Wall Street tracks the economy with gauges like the index of leading economic indicators. Our biological index should be sensitive to many different characteristics of living communities, as economic indicators describe many different aspects of economies. A good biological index should be much broader than an indicator of commodity production (e.g., water, fish, or shellfish) or a count of threatened and endangered species.

Using biological criteria to monitor and sustainably manage our aquatic resources is a vital necessity in the face of current trends. Native species are declining, and exotic species are invading waters throughout the United States. The proportion of aquatic organisms at risk of extinction is considerably higher than that of terrestrial organisms. For example, only 11 to 14 percent of birds, mammals, and reptiles are classed as rare to extinct, but *34 percent of the fish, 65 percent of the crayfish, and 75 percent of the freshwater mussels found in North America are included in that category.*

Fish consumption advisories continue to increase, affecting forty-five to forty-seven states each year. Shoreline, or riparian, corridors have been destroyed along most U.S. streams. Throughout North America, commercial fisheries that once produced tons of edible fish (salmon, bass, shad, etc.) for humans have declined—generally by more than 90 to 95 percent. In the Pacific Northwest, 214 native, naturally spawning Pacific salmon and steelhead stocks face a high or moderate risk of extinction, or are of special concern. Since 1910, naturally spawning salmon runs in the Columbia River have declined by more than 95 percent.

We now know that a principal reason for these widespread losses is landscape alteration; monitoring for chemical contaminants does not identify the consequences of these alterations. Priority lists of chemicals simply do not reflect ecological risks accurately. Point-source pollution controls do not effectively counter damages from nonpoint sources or the cumulative effects of multiple contaminants. Further, installing wastewater treatment and collector systems to comply with chemical standards may actually damage or even destroy many miles of stream channels and riparian corridors; the effects on local and regional biological integrity can be devastating.

The chemical-contaminant approach fails to diagnose or correct water resource problems caused by other human influences. In the process of logging, grazing, urbanization, and recreation, we alter habitat structure by removing woody debris or destroying quiet pools. We disrupt flow patterns with dams or constructed channels. We remove organic material from riparian corridors, and we change relationships among organisms by introducing exotic species or overharvesting fish for sport or commerce.

Long-term protection of water resources requires that we focus on the living organisms that inhabit our rivers and streams, because the value of water resources to society comes from more than water quality and quantity. Humans depend on living waterways for many essential goods and services; waters that cannot support healthy biological communities are unlikely to support human society. Biological criteria provide the most effective markers of environmental quality and the most relevant guideposts for federal and state programs to protect society's economic and ecological interests.

One biological gauge is the index of biological integrity (IBI), first developed in 1981 for monitoring midwestern U.S. streams. Like economic indexes, an IBI consists of multiple measures (called metrics), each describing one aspect of a site's biological condition. IBIs have been developed for stream fishes and benthic (bottom-dwelling) invertebrates throughout the world; other IBIs are being developed to assess the condition of wetlands. Terrestrial IBIs using plants, insects, and birds are being tested for use at decommissioned nuclear weapons sites and to measure the health of forest ecosystems.

Researchers choose particular measures to incorporate into IBIs because those measures reflect specific and predictable responses of organisms to human activities across a landscape. These responses behave somewhat like the dose-response relationships measured by toxicologists. An organism's response to a toxic compound varies with dose; similarly, biological responses at a site reflect the cumulative impacts of disturbance affecting that site. When plotted on a graph, these measured responses demonstrate ecological dose-response curves. Considered together, they describe the health of complex ecological systems. They also enable decision makers, resource managers, and citizens to predict the ecological consequences of human activities (such as logging, grazing, urbanization, or recreation).

To be useful as metrics in an IBI, the biological responses that researchers choose to record should be relatively easy to measure and interpret. They must increase or decrease as human influence increases; they should be sensitive to a range of biological stresses. Most important, they must be able to discriminate human-caused disturbance from the background of natural variability. Historically, biologists tried to measure everything. But in addition to being expensive and logistically impossible, measuring everything fails to focus on clear signals of human-caused degradation.

Key biological features should be tracked to detect changes in species, including the identity and number of species present in standard samples; ecological processes such as nutrient dynamics and energy flow through food webs; and the health of individuals, which influences survival and reproduction. These features provide a comprehensive picture of water resource condition—one that goes beyond the toxicity or extent of chemical pollutants. Benthic invertebrates and fish are particularly appropriate for use in an IBI. Invertebrates are abundant and easily sampled, and the species living in virtually any water body represent a diversity of morphological, ecological, and behavioral adaptations to their natural habitat. As humans alter watersheds and water bodies, shifts occur in taxa richness (number of kinds), species composition (identity of species), individual health, and feeding and reproductive relationships of fish and invertebrates.

Samples of invertebrates from one of the best streams in rural King County, Washington, for example, contain twenty-seven taxa of invertebrates; similar samples from an urban stream in Seattle contain only seven. The rural stream has eighteen taxa of mayflies, stoneflies, and caddisflies, the urban stream only two or

Region	*Land Use*	*B-IBI*
King County, Washington	Rural	43
	Urban	9
Grand Teton Region, Wyoming	Little or no human activity	44
	Low to moderate recreation	41
	High recreation	28
	Urban	21

Benthic indexes of biological integrity (B-IBI) for streams in King County, Washington, and in and near Grand Teton National Park, Wyoming.

three. When these and other metrics are combined in an index based on invertebrates, the resulting "benthic index of biological integrity" (B-IBI) provides a numeric description of the condition, or health, of a stream (see the table above). The B-IBI for the rural stream in King County was 43 (the nine-metric index maximum is 45); that for the urban stream was 9 (the index minimum).

The B-IBI can also be used to compare sites in different areas. For example, nearly pristine areas in Grand Teton National Park have near-maximum B-IBIs. Streams with moderate levels of recreation in their watersheds have B-IBIs that are not significantly lower than those without human use, but places where recreation is heavy are clearly damaged. Urban streams in Jackson, Wyoming (near the National Park) are even more degraded, yet are not as bad as urban streams in Seattle.

Thus this numeric index makes it possible to compare stream quality across geographic areas so that citizens as well as managers can establish priorities for protection and restoration. Multimetric biological monitoring recognizes that the quantitative biological conditions that constitute health vary geographically because the underlying chemical, physical, and biological properties of streams vary geographically. Properly used, IBI is calibrated to account for that variation.

Biological monitoring and assessment ultimately provide objective descriptions of the condition of our waters. They diagnose and integrate chemical, physical, and biological impacts as well as their cumulative effects; they can serve many kinds of environmental and regulatory programs when integrated with chemical analyses and single-species toxicity testing in the laboratory; and they are cost effective. Most important, because biological monitoring is sensitive to different impacts of human activity, it offers greater protection to water resources than chemical testing alone can provide.

Biological monitoring provides a more economical and effective method for accomplishing the broad objective articulated in the Clean Water Act. We no longer need to implement the act as if crystal clear distilled water running down concrete conduits were its objective. The tools for effective biological monitoring and assessment are now available.

Protecting water quality goes beyond clear water, beyond protecting single de-

A sexually mature adult mayfly. The males are distinguished by the large eyes on top of their heads, which aid them in locating females in a mating swarm. *Centroptilum* sp. (Ephemeroptera: Baetidae). Photographed by David H. Funk at Kitchen Creek, Rickett's Glen State Park, Pennsylvania.

sired species. Certain taxa may be valuable for commerce or sport, but these species do not exist in isolation. We cannot predict which organisms are critical to the persistence of commercial species or species important to us for other reasons. Failing to protect phytoplankton, zooplankton, insects, higher plants, bacteria, or fungi ignores the key contributions of these taxa to healthy biotic communities. *No matter how important a particular species is to humans, it cannot persist outside the biological context that sustains it.*

Water law that exists today still reflects the needs of a young, uncrowded nation moving into a limitless frontier. One hundred and fifty years ago there was less scientific knowledge, societal values were different, and ample water was available. Times have changed, and our attitudes must too. Only an integrative approach within each level of government (EPA, Forest Service, Fish and Wildlife Service, Geological Survey), across levels of government (local, state, regional, national, international), and among citizen groups can protect water resources.

Perhaps the most important step toward real protection of the nation's waters is to stop talking about water quality and start formulating policy that protects the biological integrity of our rivers, streams, lakes, wetlands, and oceans. Let us adopt a broader concept of water; redefine societal goals based on that concept; forge partnerships among scientists, policymakers, resource managers, and citizens to attain those goals; revise the legal framework guiding water resource policy; and redouble our efforts to protect high quality waters and to restore those that are degraded.

—James R. Karr

Macroinvertebrates as Indicators Of Stream Habitat Degradation

And in that webwork of water, in and around and gathered together by its flexuous body, a labyrinthine ecology connects our human lives to the least and greatest of the lives around us, an ecology we are only beginning to fathom and are unlikely ever to understand in its wholeness.

—John Daniel, *Oregon Rivers*

Stream ecologists have long recognized that macroinvertebrate species composition and abundance can be excellent monitors of ecosystem health. For example, early efforts to monitor and control pollution in European streams were motivated by a desire to protect human health. In the eighteenth century, the stench from untreated sewage in the Thames River was so bad that sheets soaked in vinegar were hung outside the Parliament Building in London in an attempt to counteract the smell. By the end of the nineteenth century, German aquatic ecologists had established a protocol for using macroinvertebrates to identify zones of habitat degradation, recovery, and clean water downstream of sewage outflows. Those zones were designated on the basis of indicator species—the type of macroinvertebrates that dominated the benthic (bottom-dwelling) fauna. Tubificid worms and aquatic insect midge larvae were associated with the most polluted water, due to their ability to withstand exceedingly low levels of dissolved oxygen, which gets consumed by the microorganisms decomposing sewage.

In the United States, benthic macroinvertebrates were also recognized as indicators of water quality by limnologists working in the Illinois River in the late nineteenth century. However, the European system of using indicator species to

Female midges laying eggs. An abundance of midge larvae can be an indication of poor water quality and habitat condition. (Diptera: Chironomidae). Photographed on the Deschutes River by Jim Schollmeyer.

classify stream ecosystem health was never widely accepted in this country. Here, the prevailing emphasis was to use water chemistry to determine water quality, because water chemistry provided a more precise indication of the exact nature of a pollutant. The Water Pollution Control Act Amendments of 1972 (also called the Clean Water Act) stimulated development of specific pollution indices and increased monitoring efforts to preserve the quality of the nation's water. With tighter restrictions on industry and the recognition that streams do not have an infinite capacity for receiving unwanted waste products, the relative importance of point-source chemical pollution has declined. Stream channel alterations and disruption of the riparian zone have become the most important threats to our streams.

Biota have the advantage over chemical indices of being less transient and more responsive to nonpoint pollution and other chronic disturbances. Thus, chemical indices of water quality have given way to the development of improved biological indices of ecosystem health. Furthermore, the Clean Water Act turned our attention back to the biota by calling for protection of the integrity of biological systems in our lakes, rivers, and streams.

Many types of biota (e. g., protozoa, algae, macroinvertebrates, and fish) are used to assess water quality in streams. The choice of taxon has historically depended on the expertise of the investigators involved in the assessment process. Ideally, however, one should weigh the costs and benefits of different taxonomic groups based on properties of an ideal indicator taxon. Taxa used as biotic indices of environmental health should:

- be easy to collect and identify;
- have cosmopolitan distributions and be present in a variety of habitat types;
- have a diversity of species that are responsive to a gradient of conditions ranging from degraded to healthy;
- be abundant enough so that reasonable sampling efforts do not deplete populations;
- have well-known natural histories and tolerances to environmental conditions;
- have limited mobility, so they do not move in and out of habitats seasonally;
- be relatively long-lived, so that chronic degradation can be detected; and
- be conducive to laboratory studies that could be designed to test mechanisms of effects.

While algae and protozoans are easy to collect, highly abundant, sedentary, have different levels of tolerance to degradation, respond quickly to changes in environmental conditions, and are conducive to laboratory study, species identification is difficult and scant natural historical information makes it difficult to translate data into meaningful values for decision-makers. Fish are relatively easy to identify and, as upper levels in the food chain, they integrate the impacts of disturbance on lower trophic levels. However, intense person-power required for collection, data misinterpretation due to natural patterns of migration independent of water quality, and danger of depleting small populations are disadvantages of using fish as bioindicators. The most rigorous monitoring program should involve multiple taxa in conjunction with assessment of the physiochemical aspects of the environment. However, funds are rarely available to accomplish the ideal study, and investigators often have to choose among the alternative methods of assessing ecosystem health. Macroinvertebrates have increasingly become the common choice of the optimal biological monitor, because they represent the best compromise among those characteristics of the ideal indicator taxon.

The earliest application of biomonitoring, such as studies implemented in Europe, simply used presence of certain indicator species that were chosen because they were either particularly tolerant or particularly intolerant of environmental degradation. While the presence of an indicator species assures that minimal habitat conditions exist for its survival, its absence is completely uninformative, and may be caused by factors independent of water quality (e.g., predation, competition, geographic barriers to dispersal, or availability of resources). For this reason, the indicator species concept was not widely accepted in this country. Subsequently, in about the 1970s in the United States and Europe, macroinvertebrate community indices were developed that incorporated some measure of species diversity to assess ecosystem health, assuming

Riffles on the Salmonberry River in Oregon's Coast Range. Riffle habitats are ideal for sampling because they support a high diversity of macroinvertebrates. Photograph by Dave Bohn.

that undisturbed communities are more diverse than disturbed ones. However, this assumption is also flawed, because very simple macroinvertebrate communities may exist in the purest of spring streams. Thus, ecologists soon recognized that they must consider the taxonomic composition of the community as well as its diversity when using biota to monitor water quality.

Recently, several different indices of biotic integrity have been devised that are highly effective tools in assessing the health of a stream. They incorporate a number of "metrics" including species richness and composition, abundance of local indicator species, and trophic composition of the macroinvertebrate fauna. These indices not only reflect interactions among organisms, but also between organisms and their chemical and physical environment. One common approach has been to use "rapid biological assessment protocols" that can be done cheaply and quickly, primarily in the field, and with little taxonomic expertise. However, if financial resources are available, more detailed analysis of the macroinvertebrate community generally produces a better indication of environmental quality.

A very important aspect of biomonitoring using macroinvertebrates or any other taxon is to determine whether observed changes in the fauna are due to environmental degradation or simply to natural fluctuations. Many environmental impact studies are implemented after some disaster has already struck, and therefore suffer from lack of knowledge of what the system was like before. Consequently, in stream systems we often sample upstream and downstream of some impacted site, but rarely before and after a disturbance event. However, with the advent of more rigorous environmental policies at both the national and state levels, more studies are actually including a pre-impact analysis of the system. According to statisticians and experts in experimental design, the best environmental impact studies include both a comparison of the impacted site to itself before the impact, and simultaneous comparisons to at least one, and better yet, several very similar non-impacted sites before and after the impact affects the target site. The most difficult part of this scheme is locating unimpacted sites that are similar enough to the impact site to serve as a reasonable "reference" against which to measure changes that occur in the impact site. Unless suitable reference sites can be identified for comparison, it is difficult to draw rigorous conclusions about causes of changes in streams that are often characterized by natural fluctuations.

The case studies that follow provide excellent examples of the application of some of these methods of "bugging" water quality with macroinvertebrates, especially the benthic index of biotic integrity or B-IBI. As you read these studies, you can evaluate the rigor with which the investigators have applied the approaches that I have presented within the constraints imposed by funding limitations or unpredictable events of environmental degradation. In this publication we hope to emphasize that the best approach, wherever possible, is a proactive one in which we continue to biomonitor even our healthy streams so that we can sustain, rather than be called upon to restore, their biotic integrity.

—Barbara L. Peckarsky

Part Three

Resources

Bibliography

General Reading

Adler, R. W., J. C. Landman and D. M. Cameron. *The Clean Water Act 20 Years Later*. Washington, D.C.: Island Press, 1993.

Berenbaum, May R. *Bugs in the System: Insects and their Impact on Human Affairs*. Reading, MA: Addison-Wesley Publishing Company, 1995.

Berners, Juliana. "The Treatise of Fishing with an Angle." In *Uncommon Waters: Women Write About Fishing*. Seattle, WA: The Seal Press, 1991.

Doppelt, B., M. Scurlock, C. Frissell and J. Karr. *Entering the Watershed: A New Approach to Save America's River Ecosystems*. Washington, D.C.: Island Press, 1993.

Frisch, Karl von and Otto von Frisch. *Animal Architecture*. New York, NY: Harcourt Brace Jovanovich, 1974.

Heinrich, Bernd. *A Year in the Maine Woods*. Reading, MA: Addison-Wesley Publishing Company, 1994.

Maclean, Norman. *A River Runs Through It*. Chicago, IL: University of Chicago Press, 1989.

Noss, Reed F. and Allen Y. Cooperrider. *Saving Nature's Legacy*. Washington, D.C.: Island Press, 1994.

Olson, Larry N. and John Daniel. *Oregon Rivers*. Englewood, CO: Westcliffe Publishers, 1997.

Quammen, David. *Natural Acts*. New York, NY: Nick Lyons Books, 1985.

Walton, Izaak and Charles Cotton. *The Compleat Angler*. London, England: Oxford University Press, 1974.

Wilkinson, C.F. *Crossing the Next Meridian: Land, Water, and the Future of the West*. Washington, D.C.: Island Press, 1992.

Zwinger, Ann. *Downcanyon: A Naturalist Explores the Colorado River Through the Grand Canyon*. Tucson, AZ: University of Arizona Press, 1995.

General Biomonitoring References

Abate, T. "Environmental Rapid Assessment Programs Have Appeal and Critics." *BioScience* 42 (1992):486-9.

Angermeier, P. L. and J. R. Karr. "Biological Integrity Versus Biological Diversity As Policy Directives." *BioScience* 44 (1994): 690-7.

Barbour, M. T., J. L. Plafkin, B. P. Bradley, C. G. Graves and R. W. Wisseman. "Evaluation of EPA's Rapid Bioassessment Benthic Metrics: Metric Redundancy and Variability Among Reference Stream Sites." *Environmental Toxicology and Chemistry* 11 (1992):437-49.

Courtemanch, P. L. "Bridging the Old and New Science of Biological Monitoring." *Journal of the North American Benthological Society* 13 (1994):117-21.

Hart, D. D. "Building a Stronger Partnership Between Ecological Research and Biological Monitoring." *Journal of the North American Benthological Society* 13 (1994):110-6.

Hayslip, G. A., ed. *Region 10 In-Stream Biological Monitoring Handbook—For Wadable Streams in the Pacific Northwest.* Seattle, WA: U.S. Environmental Protection Agency, 1993.

Hughes, R. M., D. P. Larsen and J. M. Omernik. "Regional Reference Sites: A Method for Assessing Stream Potentials." *Environmental Management* 10, no. 5 (1986): 629-35.

Karr, J .R. "Biological Integrity: A Long Neglected Aspect of Water Resource Management." *Ecological Applications* 1 (1991): 66-84.

Karr, J. R. "Biological Integrity and the Goal of Environmental Legislation: Lessons for Conservation Biology." *Conservation Biology* 4 (1990):244-50.

Loeb, S. L. and A. Spacie, eds. *Biological Monitoring of Aquatic Systems*. Boca Ratan, FL: Lewis Publishers, 1994.

Omernik, James M. and Alisa L. Gallant. *Ecoregions of the Pacific Northwest,* EPA/600/3-86\033; 1-39. U.S. Environmental Protection Agency, 1986.

Pascoe, D. and R. W. Edwards, eds. *Freshwater Biological Monitoring*. Oxford, England: Pergamon Press, 1984.

Scrimgeour, Garry J. and Dan Wicklum. "Aquatic Ecosystem Health and Integrity: Problems and Potential Solutions." *Journal of the North American Benthological Society* 15, no. 2 (1996):254-61.

Macroinvertebrate References

Angradi, Ted R. and Mark R. Vinson. *Status of and Attitudes Toward Aquatic Macroinvertebrate Monitoring on National Forests and Districts of the Bureau of Land Management*, NE 200; 1-14. USDA Forest Service Dept. of the Interior, 1995.

Davis, W. S. and T. P. Simon, eds. *Biological Assessment and Criteria*. Boca Raton, FL: Lewis Publishers, 1995.

Fore, Leska S., James R. Karr and Robert W. Wisseman. "Assessing Invertebrate Responses to Human Activities: Evaluating Alternative Approaches." *Journal of the North American Benthological Society* 15, no. 2 (1996):212-31.

Hafele, Rick and Steve Hinton. *Guide to Pacific Northwest Aquatic Invertebrates*. Portland, OR: Oregon Trout, 1996.

Jackson, J. K. and V. H. Resh. "Sequential Decision Plans, Benthic Macroinvertebrates and Biological Monitoring Programs." *Environmental Management* 13 (1989):455-68.

Kerans, B. L., James R. Karr and Steven A. Ahlstedt. "Aquatic Invertebrate Assemblages: Spatial and Temporal Differences Among Sampling Protocols." *Journal of the North American Benthological Society* 11, no. 4 (1992):377-90.

Lenat, D. R. "Water Quality Assessment of Streams Using a Qualitative Collection Method for Benthic Invertebrates." *Journal of the North American Benthological Society* 7 (1988):222-33.

McCafferty, W. Patrick. *Aquatic Entomology*. Boston MA: Science Books International, 1981.

Merritt, Richard W. and Kenneth W. Cummins, eds. *An Introduction to the Aquatic Insects of North America*. Dubuque, IA: Kendall/Hunt Publishing Company, 1996.

Mulvey, M., L. Caton and R. Hafele. *Oregon Nonpoint Source Monitoring Protocols Stream Bioassessment Field Manual: For Macroinvertebrates and Habitat Assessment*. Portland, OR: Oregon Department of Environmental Quality Laboratory Biomonitoring Section, 1992.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross and R. M. Hughes. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish*, EPA-444/4-89-001. Washington, D.C.: U.S. Environmental Protection Agency, 1989.

Plotnikoff, R. W. and J. S. White. *Taxonomic Laboratory Protocol for Stream Macroinvertebrates Collected by the Washington State Department of Ecology*, Publication 98-323. Olympia, WA: Washington State Department of Ecology, 1996.

Rosenberg, D. M. and V. R. Resh, eds. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. New York, NY: Chapman and Hall Publishing, 1993.

Vinson, Mark R. and Charles P. Hawkins. "Effects of Sampling Area and Subsampling Procedure on Comparisons of Taxa Richness Among Streams." *Journal of the North American Benthological Society* 15, no. 3 (1996):392-9.