The Ontario Benthos Biomonitoring Network

Chris Jones, Benthic Biomonitoring Scientist, Ontario Ministry of Environment, Dorset Environmental Science Centre, Dorset, Ontario, Canada, P0A 1E0
Brian Craig, Network Science Advisor, Environment Canada, Ecological Monitoring and Assessment Network Coordinating Office, Burlington, Ontario, Canada, L7R 4A6
Nicole Dmytrow, intern, Ontario Ministry of Environment, Dorset Environmental Science Centre, Dorset, Ontario, Canada, P0A 1E0

Abstract—*Canada's Ontario Ministry of the Environment and Environment Canada (Ecological Monitoring and Assessment Network) are developing an aquatic macroinvertebrate biomonitoring network for Ontario's lakes, streams, and wetlands. We are building the program, called the Ontario Benthos Biomonitoring Network (OBBN), on the principles of partnership, free data sharing, and standardization. This paper discusses the importance of biomonitoring, describes why benthos are commonly used as indicators of aquatic ecosystem condition, explains the complementarity of biological and chemical assessments, details OBBN components, and lists some research needs. The paper is framed by several themes: inclusiveness, partnerships, capacity building, and creating effective links between monitoring and decision-making.*

Traditionally there has been an individualistic approach to Biomonitoring in Ontario, with little communication between practitioners. This lack of coordination has limited the application of biomonitoring in the past, chiefly because no mechanism for sharing and comparing data existed, and because there was no consistent training. Based on approaches used in the U.K., Australia, and the U.S.A., the OBBN will overcome these difficulties by specifying standard methods (with options for tailoring programs to match expertise and financial resources), enabling data sharing between partners, automating assessments, and providing training.

Biological criteria for evaluating aquatic ecosystem condition are generally not available. The OBBN uses a reference-condition approach (RCA) to define biocriteria: samples from minimally impacted (reference) sites define an expectation (for example, the normal range) for biological condition at a test site. Assessments evaluate whether a test site's biological condition is within the normal range. The OBBN's automated analytical tools and a protocol that balances flexibility with standardization will allow the citizen scientist and university academic to do bioassessments of similar calibre. New partnerships, and the ability to generate local information on aquatic ecosystem condition, will build capacity for adaptive water management and enhance the link between science and decision making.

Introduction

Ontario Canada's Ministry of the Environment (MOE) and Environment Canada's Ecological Monitoring and Assessment Network Coordinating Office (EMAN CO) co-founded the Ontario Benthos Biomonitoring Network (OBBN). Once fully implemented, the OBBN will allow partners to evaluate aquatic ecosystem condition using the reference-condition approach and shallow-water benthos as indicators of environmental quality.

The purpose of this paper is to explain our vision of the Ontario Benthos Biomonitoring Network within the context of a complex mosaic of Canadian initiatives that together result in substantial capacity for adaptive environmental management and informed local decision-making. The common thread through this mosaic is a commitment to the fundamentals (Jones and others 2002): building partnerships, and providing information on ecosystem condition and management performance to local decision makers. We begin by discussing the importance of biomonitoring, explaining why benthos are commonly used as indicators of aquatic ecosystem condition, and highlighting the complementarity of biological and chemical assessments. We then describe the components of the OBBN and justify each in relation to their role in adaptive, community-based ecosystem management. The paper concludes with a list of research needs related to implementation.

Importance of Aquatic Biomonitoring

Monitoring supports adaptive water management; it provides feedback on the status of aquatic resources and the performance of policies, programs, and legislation (Jones and others 2002). Biomonitoring—the process of sampling, evaluating, and reporting on ecosystem condition using biological indicators—is an important part of aquatic ecosystem management. This is because management end-points are often biological (for example, protection of aquatic biota and their habitats), and because laws and policies typically stress the protection of aquatic biota.

Ontario's legislative basis for biomonitoring includes the Ontario Water Resources Act (R.S.O. 1990, CHAPTER O.40), which has a clearly biological definition of impairment. It states that "the quality of water shall be deemed … impaired if … the material discharged … causes or may cause injury to any person, animal, bird or other living thing …." Similarly, Ontario's Environmental Protection Act (R.S.O. 1990, CHAPTER E.19) has clearly biological elements of its definition of adverse impact, including: (a) impairment of the quality of the natural environment for any use that can be made of it, (b) injury or damage to property or to plant or animal life, (d) an adverse effect on the health of any person;, and (f) rendering any property or plant or animal life unfit for human use. Canada's federal Fisheries Act (R.S. 1985, c. F-14) provides further impetus for biomonitoring by stating that no person shall carry on any work or undertaking that results in the harmful alteration, disruption, or destruction of fish habitat (for example, spawning grounds; nursery, rearing, and migration areas; and food supply).

Reflecting our legislation, Ontario's policies also suggest a need for biomonitoring. The document, "Water Management: Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy [sic]" (Ontario Ministry of Environment and Energy 1994) states, "With respect to surface water quality, the goal is to ensure that … water quality is satisfactory for aquatic life…" Similarly, Ontario's Provincial Policy Statement (PPS) (R.S.O. 1990, CHAPTER P.13), an extension of the Planning Act, states, "the quality and quantity of ground water and surface water and the function of sensitive ground water recharge/discharge areas, aquifers, and headwaters will be protected, or enhanced." The PPS further states that development and site alteration is only permitted in significant habitats if no negative impacts on the natural features or the ecological functions will result.

Although the above are Ontario examples, similar legislation- and policy-based justifications for biomonitoring can be made in many countries. An international example includes the EU Water Framework Directive, which requires both good ecological status (based on the reference condition approach, see below) and good chemical status of surface water (EU Commission 2003). In the U.S., the concept of biological integrity has been included in water legislation (for example, the Water Pollution Control Act) since 1972 and "is now an integral component of water resource programs at state and federal levels" (U.S. EPA 2002).

Benthos as Indicators

Benthos are large, bottom dwelling insects, crustaceans, worms, mollusks and related aquatic animals. They are good indicators of aquatic ecosystem health because they are sedentary, their life cycles range in length from months to years (compares well with typical 1-3 year business planning and budgeting horizons typically applied in environmental management), they are easy to collect and identify, they are responsive to changes in water and sediment quality, they are ubiquitous, and they are not typically seen as an economic or recreational resource themselves (Mackie 2001). Benthos have been used extensively to assess water quality in streams and lakes (Rosenberg and Resh 1993 and 1996).

Complementarity of Biological and Physical-Chemical Monitoring

Physical-chemical (stressor-based) and biological (effect-based) monitoring approaches are complementary (table 1). An example of a stressor-based index is a water chemistry analyte (in other words, a surrogate for the toxicity of water to fish). An example of an effect-based index is age class abundance of smallmouth bass (in other words, a surrogate for reproductive success and mortality of fish exposed to a chemical stressor).

A case study for the Pretty River, Collingwood, Ontario shows the complementarity of these two types of indicators. Table 2 shows benthos data between 1996 and 2001 for Pretty River while figures 1 and 2 show water quality for the same stream and time period. The majority of the distribution of data for phosphorus and zinc (stressor-based indicators) were well below

Table 1. Complementarity of stressor- and effect-based aquatic monitoring (adapted from Roux and others 1999).

	Stressor-based Approach	Effect-based Approach
Monitoring focus	Stressors causing environmental change, i.e., chemical and physical inputs	Effects (responses) of natural and/or anthropogenic disturbances, e.g., changes in the structure and function of biological communities
Management focus	Water quality regulation: controlling stressors through regulations	Aquatic ecosystem protection: managing ecological integrity
Primary indicators	Chemical and physical habitat variables, e.g., pH, dissolved oxygen, copper concentration	Structural and functional biological attributes (e.g., relative taxa abundances, frequency of deformities)
Assessment end points	Degree of compliance with a set criterion or discharge standard	Degree of deviation from a benchmark or desired biological condition

Table 2. Species abundances for each listed benthos taxon collected during a 5 minute kick and sweep sample for the Pretty River, Collingwood, Ontario.

Qualitative Sample	Kick 1 (~5 min)	Number	Kick 2 (~5 min)	Number
Molophilus	Hydropsyche	37	Hydropsyche	4
Caenis	Stenelmis	3	Optioservus	1
Stenonema femoratum	Optioservus	2	Stenonema (imm.)	1
Stenonema (imm.)	Antocha	12	Fossaria	1
Caecidotea	Hemerodromia	1	Paracapnia	4
Hydropsych	Stenonema (imm.)	13		
Stenelmis (l)	Orthocladiinae	1		
Hesperocorixa	Tanypodinae	1		
Agnetina	Chironomini	1		
Taenioteryx	Tanytarsini	6		
Paracapnia	Ephemerella	1		

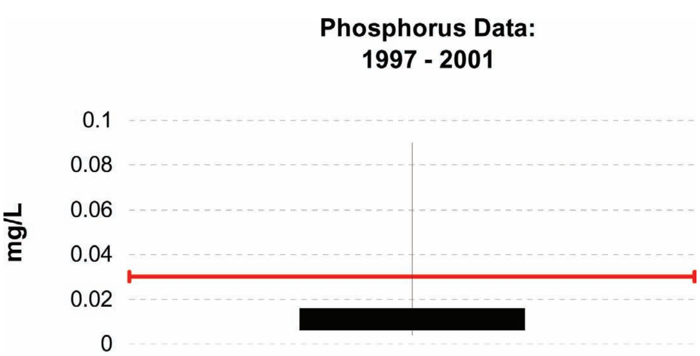

Figure 1. Phosphorus data from Pretty River, Collingwood, ON. The central 50 percent of the data is shown as the box, with vertical bars extending to the maximum and minimum observed values. Unpublished data.

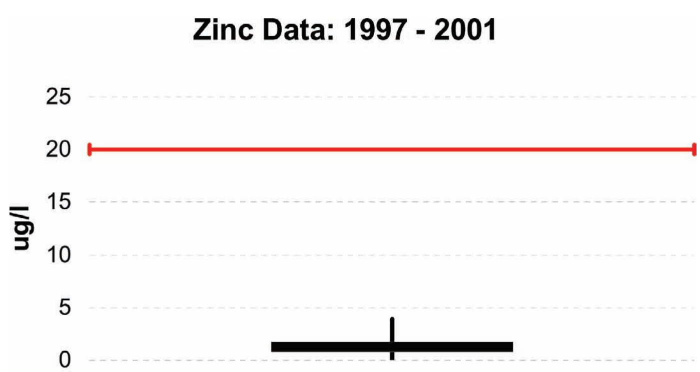

Figure 2. Zinc data from Pretty River, Collingwood, ON. The central 50 percent of the data is shown as the box, with vertical bars extending to the maximum and minimum observed values. Unpublished data.

Provincial Water Quality Objectives (MOEE 1994), suggesting good water quality conditions; however, in comparison to local minimally impacted stream communities, the very low overall abundance and the relative scarcity of sensitive benthos (effect-based indicator) suggested a strong effect of habitat degradation (which was consistent with the site's history as a man-made bedrock floodway channel). In this case, seemingly contradictory water chemistry and biological monitoring results can be combined to make a more complete assessment of aquatic ecosystem condition than either approach could on its own, in other words, to conclude that water quality is good but that biota are suppressed by habitat degradation.

Ontario Benthos Biomonitoring Network Vision

Herein we describe OBBN components and reinforce the connection of each component to adaptive community-based ecosystem management.

Background

Even though the need for benthos biomonitoring is well known, its application has not been widespread in Ontario for several reasons: although regulatory guidelines for water chemistry are available, no analogous biocriteria exist for biomonitoring; bioassessment is complex due to a number of confounding factors (for example, biota respond to factors other than water quality); no standard sampling protocol exists; benthos identification requires special expertise; experts disagree on interpretation; and traditional methods are costly.

A historical patchwork approach to biomonitoring in Ontario created three main barriers to wider application: no standard protocol, no mechanism for sharing data, and no consistent training. The OBBN will remove these barriers by specifying standard methods, enabling data sharing between partners, automating analysis using a reference-condition approach, and providing training. With the direction of a multi-partner Technical Advisory Committee, we are developing the network according to the principles of partnership, free data sharing, and standardization. EMAN sees the OBBN as a pilot project for a Canada-wide aquatic biomonitoring program that is accessible to volunteer "citizen scientists" and professional research scientists alike.

The Ontario Benthos Biomonitoring Network has four objectives:

1. To enable the assessment of lakes, streams, and wetlands using benthic macro-invertebrates as indicators of environmental quality.
2. To provide a biological performance measure related to management of aquatic ecosystems.
3. To provide a biological complement to Ontario's provincial surface water chemistry monitoring program.
4. To facilitate a reference condition approach to bioassessment in which minimally impacted sites are used to derive a community expectation for a test site.

We expect to fully implement the OBBN by 2005. Coordinating partners, MOE and EMAN CO, are providing scientific guidance and limited sampling equipment. Partners (federal, provincial, and local governments; conservation authorities [Ontario's watershed-based quasi-governmental water management agencies]; universities; non-governmental groups; and volunteers) are sampling lakes, streams, and wetlands, using and reporting information according to their own mandates, and participating in collaborative research to refine protocols and analytical methods.

Reference Condition Approach

We recommend a reference condition approach (RCA) to bioassessment (fig. 3), in which minimally impacted reference sites are used to define "normal" and set an expectation for community composition at test sites where water and habitat quality are in question (Wright and others 2000, Bailey and others 2004). Using the RCA, we consider test sites unusual if their communities fall outside of the normal range. Unusual sites warrant further study to determine if human activities are responsible for the deviant community composition.

The first step in the RCA is to sample reference sites. Because no objective, quantitative criteria for "minimally impacted" exist, we ask partners to sample sites that are not obviously exposed to any human impacts (such as point-source contamination, regulation of water level, water impoundment, deforestation, habitat alteration, development, agriculture, or acidification), and that represent best local conditions. Test site sampling will commence once a reasonable amount of reference site data is available.

OBBN Protocol

Providing standard operating procedures is vital to wide implementation of aquatic benthos biomonitoring in Ontario. Some degree of standardization is important in any monitoring program to ensure comparability of results over time and across jurisdictions, and this is particularly true when using a reference condition approach; however the OBBN protocol (Jones and others 2004) also recognizes that some degree of flexibility is equally vital in a program that is founded on partnerships. OBBN partners differ with respect to their financial resources and expertise, and standard methods must have options that can accommodate these differences. Table 3 summarizes OBBN protocol recommendations. Approximately 400 sites have been sampled to-date in Ontario using these protocols.

OBBN Database and Automated Analytical Tools

The OBBN includes an internet-accessible database for storing and sharing reference site and test site data. The database is being jointly developed by EMAN CO and the National Water Research Institute of Environment Canada and will be integrated with a proposed national

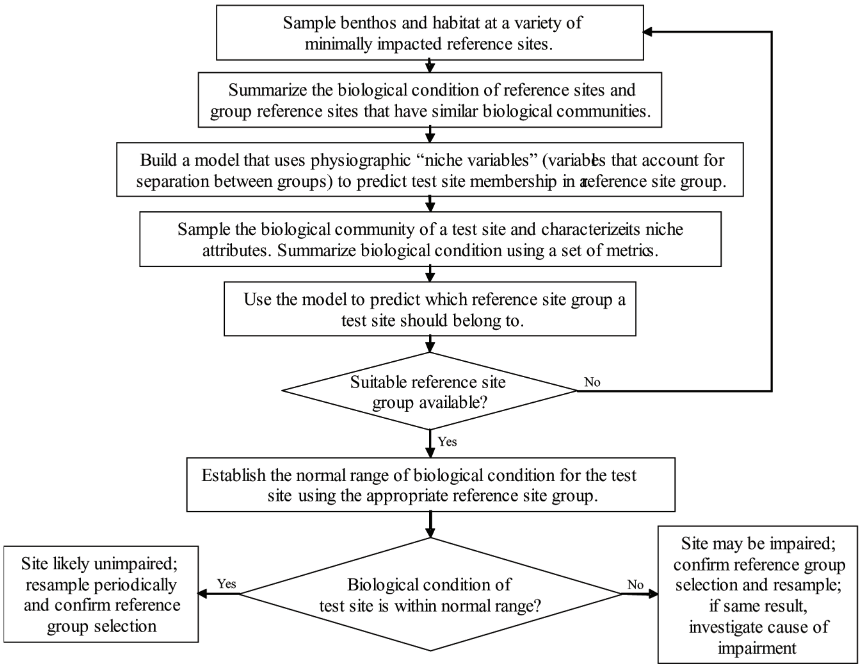

Figure 3. Steps in the reference condition approach to bioassessment.

biomonitoring program. Several automated analytical database modules are currently under development: a test site and reference site selection utility, a mapping utility, a summary metrics calculator, and a statistical module for hypothesis testing. These modules are critical to the success of the program because they mean that sophisticated bioassessments can be done equally by volunteer citizen scientists and professional research scientists alike; they will allow partners to generate readable, custom, nearly-instantaneous assessment reports that represent a considerable increase in available information for local community-based decision making in Ontario. These assessment tools are a substantial innovation in light of many other programs in which community volunteers merely collect, submit data to a central warehouse, and receive little or no feedback on what the data mean.

Generating a custom report with the automated analytical tools requires an OBBN partner to proceed through six steps:

1. Log-in to the database with a client password (passwords are coded to training certification level and effectively limit data entry fields and forms a user has access to based on training received).
2. Enter site location, benthos, and habitat data for test site (site photo optional).
3. Execute the reference site selection tool (runs a predictive model that predicts a test site's reference site group membership based on site- and catchment-scale physiographic information, and queries the database for records associated with reference sites in the predicted group).
4. Execute the Metrics Calculator (calculates a user-defined set of benthos community summary metrics for both the test site and reference sites).
5. Execute the hypothesis testing tool (automates the statistical calculations associated with a multivariate t-test, which determines if the test site is within or outside the normal range considering all summary metrics [and redundancies among metrics] simultaneously).
6. Execute the reporting tool (which compiles products from each of the above modules into a simple output).

Table 3. Summary of OBBN protocol recommendations.

Biomonitoring Component	Recommendation
Benthos Collection Method	Traveling kick and sweep (other optional methods are available for special studies or atypical habitats)
Mesh Size	500 µm
Time of Year	Any season; assessment comparisons are made using data from the same season
Picking	In lab (preferred) or in field (optional); preserved (preferred) or live (optional), microscope (preferred) or visually unaided (optional); random sub-sampling to provide a fixed count per sample
Taxonomic Level	Mix of 27 Phyla, Classes, Orders and Families (minimum detail); more detailed identifications are optional and are recommended for reference sites
Analysis	Reference condition approach: community composition summarized using a variety of user-defined indices and hypothesis testing based on generalized distance (Bowman and Somers 2004)

Training

Training is a critical component of the OBBN for two main reasons. First, it ensures that protocols are followed correctly so that partners have confidence in the quality of reference and test site data shared through the network. Second, it fosters interest in monitoring and better use of monitoring information in the environmental decision making process.

The large number of OBBN participants and relatively few full-time staff administering the network (one government scientist and one recent graduate intern) necessitated a train-the-trainer approach, which is still under development. To-date, training has been offered at a series of multi-day courses that cover all aspects of the program, with emphasis on the reference condition approach, sample collection and processing procedures, and benthos identification. So that deficiencies in OBBN methods can be corrected, the training workshops will be augmented with short protocol-audit workshops, in which exercises will determine if participants are applying techniques as written and if difficulties are arising.

To-date, several hundred partners have attended training courses and their feedback will enable refinements to the training program. A future training focus will be benthos identification. Rather than developing a unique taxonomic certification for Ontario, we plan to implement the North American Benthological Society taxonomic certification program, which is still under development (North American Benthological Society 2003).

Collaborative Research

The OBBN includes a collaborative research component that is aligned with program implementation, principally the refinement of methods. Collaborative research opportunities ensure efficiency, assist with the delivery of the resulting information, and allow partners to get more involved in monitoring science than they would otherwise be able to. Studies investigating high priority questions related to collection methods and timing of benthos sampling are underway. These studies will determine where optional methods can be applied, if sufficient numbers of animals are collected, and whether different collection methods yield similar relative abundance estimates for a site. A temporal stream study is investigating seasonal patterns of benthos community composition and may allow us to refine sampling windows specified in our protocol manual.

We list several OBBN research questions below. Studies to answer each question will be undertaken in priority sequence with results being reported using media appropriate to our audience, typically peer reviewed literature and government technical bulletins.

- Is the reference site mean plus/minus 2 standard deviations a reasonable definition of the normal range? Does this definition reflect what we consider to be an ecologically significant effect, in other words, the minimum effect size we wish to detect?
- How many groups of reference sites are there? How many sites are required to define a group? How minimally impacted must a site be to be considered a reference site? Does this threshold change depending on location in the province?
- How accurately can we predict a test site's reference group membership? What are the best attributes on which to build our predictive model?
- What is the ideal ratio of reference sites to number of metrics used in the analysis?
- Does the detail of benthos identification (for example. Order-level vs. Genus-level) affect the sensitivity of a bioassessment and the amount of diagnostic information provided? Does the selection of a sampling method affect sensitivity or diagnostic resolution? Can we use "response signatures" to identify certain types of impairment? Which indices contribute the most information to bioassessments in different parts of Ontario?
- How many samples are enough for whole lake, whole river, or whole wetland assessments?

Summary

Monitoring is important to adaptive environmental management because it provides feedback to managers on the status of resources and the performance of management activities. Biomonitoring is required to support legislative and policy direction in many jurisdictions, and provides effect-based results that are relevant in management schemes that aim to protect biota. Benthos, bottom dwelling invertebrates that live in most aquatic systems, have many traits that make them excellent indicators of aquatic ecosystem condition.

The Ontario Benthos Biomonitoring Network will enable partners ranging from volunteers to research scientists to reliably conduct benthos bioassessments on lakes, streams, and wetlands. The result will be a marked increase in the amount of locally available information on aquatic ecosystem condition for consideration in environmental management decisions. The OBBN has five components that have been built specifically to promote comprehensive bioassessment coverage of the province: a database that enables reference and test site data sharing, a standard protocol (which contains options so procedures can be tailored to partners' expertise and financial resources), training, automated analytical tools, and a research program. The network will be fully implemented by 2005 on the principles of partnership, free data sharing, and standardization and is part of a mosaic of Canadian programs that are delivering effective information to local environmental decision makers.

References

Bailey, R. C.; R. H. Norris; T. B. Reynoldson. 2004. Bioassessment of freshwater ecosystems using the reference condition approach. Norwell, MA: Kluwer Academic Publishers. 167 pp.

Bowman, M. F.; K. M. Somers; R. A. Reid. 2003. A Simple Method To Evaluate Whether A Biological Community Has Been Influenced By Anthropogenic Activity. In: Hedley, K.; S. Roe; A.J. Niimi, eds. Proceedings for the 30th Annual Aquatic Toxicity Workshop: September 28 to October 1, 2003, Ottawa, ON: 62-72.

EU Commission. 2003. EUROPA European Commission: Introduction to the new EU Water Framework Directive. http://europa.eu.int/comm/environment/water/water-framework/overview.html.

Jones, C.; R. M. Palmer; S. Motkaluk; M. Walters. Watershed Health Monitoring: Emerging Technologies. Boca Raton: Lewis Publishers. 248 p.

Jones, C.; K.M. Somers; B. Craig; T. B. Reynoldson. 2004. Ontario Benthos Biomonitoring Network protocol manual, version 1.0. Ontario Ministry of Environment. (may be downloaded at http://obbn.eman-rese.ca/obbn/).

Ontario Ministry of Environment and Energy. 1994. Water Management: Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy. Toronto, ON: Queen's Printer for Ontario. 67 p.

Mackie, G. L. 2001. Applied Aquatic Ecosystem Concepts. Dubuque: Kendall-Hunt Publishing. 744 p.

North American Benthological Society. 2003. A Proposal for a Taxonomic Certification Program. http://www.benthos.org/Business/Archives/NABSTaxCertPropsl10-10-03.pdf.

Rosenberg, D. M.; V. H. Resh, eds. 1993. Introduction to Freshwater Biomonitoring and Benthic Macroinvertebrates. New York, NY: Chapman and Hall. 488 p.

Rosenberg, D. M.; V. H. Resh. 1996. Use of aquatic insects in biomonitoring. In Merritt, R.W.; K.W. Cummins., eds. An introduction to the aquatic insects of North America (Third Edition). Dubuque: Kendall-Hunt Publishing: 87-97.

Roux, D. J.; P. L. Kempster; C. J. Kleynhans; H. R. Van Vliet; H. H. Du Preez. 1999. Integrating stressor and response monitoring into a resource-based water-quality assessment framework. Environmental Management. 23:15-30.

U.S. EPA. 2002. Biological Indicators of Watershed Health. http://www.epa.gov/bioindicators/html/biointeg.html.

Wright, J. F.; D. W. Sutcliffe; M.T. Furse, eds. 2000. Assessing the biological quality of fresh waters: RIVPACS and other techniques. Ambleside: Freshwater Biological Association. 400 p.