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STREAM INDICATOR AND DESIGN WORKSHOP

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Environmental Monitoring and
Assessment Program

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STREAM INDICATOR AND DESIGN WORKSHOP

July 1993

Project Officer

D.P. Larsen
U.S. EPA Environmental Research Laboratory
200 SW 35th Street
Corvallis, Oregon 97333

Editor

R.M. Hughes
ManTech Environmental Technology, Inc.
U.S. EPA Environmental Research Laboratory
200 SW 35th Street
Corvallis, Oregon 97333

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EDITORS FOR WORKING GROUPS

Birds and amphibians: Sandra Thiele, ManTech Environmental Technology, Inc., U.S. EPA Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333.

Fish: Frank McCormick, U.S. EPA Environmental Monitoring Systems Laboratory, 3411 Church Street, Cincinnati, OH 45244.

Benthos: Phil Lewis, U.S. EPA Environmental Monitoring Systems Laboratory, 3411 Church Street, Cincinnati, OH 45244.

Periphyton: Barry Rosen, ManTech Environmental Technology, Inc., U.S. EPA Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333.

Metabolism: Brian Hill, U.S. EPA Environmental Monitoring Systems Laboratory, 3411 Church Street, Cincinnati, OH 45244.

Physical Habitat. Phil Kaufmann, Oregon State University, c/o U.S. EPA Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333.

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INTRODUCTION

The primary objective of the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program for Surface Waters (EMAP-SW) is to estimate—regionally and with known confidence—the status of, and trends in, indicators of the condition of U.S. lakes and streams. Given this objective, it is critical to document the process by which indicators are developed, evaluated, and eventually selected for implementation. The process includes technical workshops, examination of available databases, and local and regional pilot studies, all of which are documented by publications and peer reviews. The purpose of this report is to record the major conclusions reached in a workshop on stream indicators that was held in Cincinnati, Ohio, on February 26–28, 1992.

The indicators that are eventually selected by EMAP-SW will form the foundation for the information given to policy makers, aquatic scientists, and the public about the condition of lakes and streams in the United States. Effective indicators must be relevant to regional and national policies that ultimately determine the quality of lakes and streams, and they must be of sufficient interest to directly or indirectly stimulate policy makers and managers to act. Of course, they must also be ecologically relevant, scientifically credible, and related to biologically important characteristics of lakes and streams that are valued by the public.

We define an indicator as an ecological measurement, metric, or index that quantifies physical, chemical, or biological condition, habitat, or stressors. Indicators of biological condition are, of necessity, biological. We focus on biological indicators because we believe that they provide the most cost-effective assessments of the multiple physical, chemical, and biological stressors of streams and lakes. We are usually most interested in the biological components of lake and stream ecosystems; our interest in physical and chemical habitat is developed, as the word "habitat" implies, from its effects on the biota. Also, because we are interested in entire ecosystems, we expect that most of our biological indicators will be developed at the community or assemblage level, rather than at the genetic, population, or species level. However, it is the quantifiable forms (e.g., species richness, % introduced species), not the assemblages, that we call indicators.

In addition to EMAP participants, several scientists from universities and federal and state agencies were invited to participate in the workshop. Participants represented experience in the eastern, central, and western United States for each of seven stream attributes for which we wish

to develop indicators (birds, herptiles, fish, benthos, periphyton, metabolism, physical habitat structure). From an initial list of 89 non-EMAP candidates, 24 were able to participate. In addition, 8 scientists from the Cincinnati area and 17 from EMAP participated (Table 1).

On the first morning, participants received a brief overview of the EMAP-Surface Waters program. In the afternoon, they broke into three regional groups (west, central, east) to answer four questions:

1. **Are current ecological values appropriate for EMAP streams?** At present, EMAP-SW is addressing biological integrity, trophic state, and fishability as the ecological values of lakes and streams. We do not use "value" as an economic term. Rather, we are concerned with the intrinsic worth of the waterbody for its own sake, as well as with the broadly accepted (though ill-defined) societal goal of clean, productive, and healthy waters. We define biological integrity as the ability to support and maintain a balanced, integrated, adaptive community with a biological diversity, composition, and functional organization comparable to those of natural lakes and streams of the region (Frey, 1977; Karr and Dudley, 1981) at various levels of biological, taxonomic, and ecological organization (Noss, 1990). Trophic state is defined as the abundance or production of algae and macrophytes. By fishability, we mean the degree to which fish can be caught and safely eaten by humans and wildlife. We recognize that these three values may often be inharmonious; eutrophic waters may have exceptional biological integrity or fishability, but biological integrity and trophic state are often sacrificed to improve fishability for humans.

2. **What stream classes or types should EMAP be sure to sample?** EMAP-SW currently ensures that a range of stream sizes is included for monitoring in all regions. Our concern in the workshop was to identify particular sizes or types of streams that are important, which a probability design might miss, and to suggest methods of including them.

3. **If used, how should reference sites be selected?** EMAP-SW has proposed using minimally disturbed regional reference sites as an objective way to estimate potential levels of biological integrity and trophic condition. These reference sites are also useful for developing, and evaluating the responsiveness of, potential indicators. However, their selection and evaluation requires considerable map study and field reconnaissance, as well as additional monitoring resources. If the reference condition can be determined in some other way, it could result in substantial savings.

Table 1. Participants in the EMAP Stream Indicator and Design Workshop

Bertin W. Anderson
201 South Palm Drive
Blythe, California 92225
Ph. 619-922-2541
Fx. 619-922-9581

Loren Bahls
Montana Dept. of Health & Environ. Sciences
Cogswell Bldg.
Helena, MT 59620
Ph. 406-444-5330
Fx. 406-444-1374

Mark B. Bain
New York Cooperative Fish & Wildlife
Research Unit
Fernow Hall, Cornell University
Ithaca, NY 14853-3001
Ph. 607-255-2840
Fx. 607-255-1895

John Baker
Lockheed - ESC
980 Kelly Johnson Drive
Las Vegas, NV 89119
Ph. 702-897-3253
Fx. 702-796-8367

Robert L. Beschta
College of Forestry
Oregon State University
Corvallis, OR 97331
Ph. 503-737-4292
Fx. 503-737-2668

Frank Borsuch
Ohio River Valley Water Sanitation
Commission
Dixie Terminal Bldg.
Cincinnati, OH

Thomas L. Bott
Stroud Water Research Center
Academy of Natural Sciences
512 Spencer Road
Avondale, PA 19311
Ph. 215-268-2153
Fx. 215-268-0490

Jeff Brawn
Illinois Natural History Survey
607 East Peabody
Champaign, IL 61820
Ph. 217-244-5937
Fx. 217-333-4949

Sandra Brewer
Technology Applications Inc.
3411 Church St.
Cincinnati, OH 45244

Janalee P. Caldwell
Oklahoma Museum of Natural History and
Dept. of Zoology
University of Oklahoma
Norman, OK 73019
Ph. 405-325-5022
Fx. 405-325-7771

Donald Charles
Patrick Center for Environmental Research
Academy of Natural Sciences
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103
Ph. 215-299-1090
Fx. 215-299-1028

Gary Collins
USEPA
26 West Martin Luther King Drive
Cincinnati, OH 45268-1525
Ph. 513-569-7325
FAX 513-569-7115

Susan Cormier
USEPA
26 W. Martin Luther King Dr.
Cincinnati, OH 45268-1525

Mary Jo Croonquist
Arizona Game and Fish Dept.
35325 North Stockton Hill Road
Kingman, AZ 86401
Ph. 602-692-7700, ext. 110
FX 602-692-1523

Table 1. Participants in the EMAP Stream Indicator and Design Workshop (continued)

Cliff Dahm
Department of Biology
University of New Mexico
Albuquerque, NM 87131
Ph. 505-277-2850
Fx. 505-277-0304

F. Bernard Daniel
USEPA
26 W. Martin Luther King Dr.
Cincinnati, OH 45268

Chris Faulkner
USEPA (WH-553)
401 M Street, SW
Washington, DC 20460
Ph. 202-260-6228
Fx. 202-260-7024

Joseph Freda
Environmental Resource Analysts
Route 2 Box 547
Notasulga, AL 36866
Ph. 205-257-4706

Joseph Furnish
Bureau of Land Management
1717 Fabry Road, SE
Salem, OR 97306
Ph. 503-375-5624
Fx. 503-375-5622

Stephen W. Golladay
Department of Zoology and Biological Station
University of Oklahoma
HC-71 Box 205
Kingston, OK 73439
Ph. 405-564-2463
Fx. 204-564-2479

Martin E. Gurtz
Water Resources Division
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, NC 27607
Ph. 919-571-4018
Fx. 919-571-4041

Charles P. Hawkins
Watershed Science Unit
Utah State University
Logan, UT 84322-5250
Ph. 801-750-2280
Fx. 801-750-3798

Alan Herlihy
Department of Fisheries and Wildlife
Oregon State University
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4442
Fx. 503-754-4716

Brian Hill
USEPA
3411 Church Street
Cincinnati, OH 45244
Ph. 513-533-8114
Fx. 513-533-8181

Robert M. Hughes
ManTech Environmental
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4516
Fx. 503-754-4716

Mark R. Jennings
Department of Herpetology
California Academy of Sciences
1830 Sharon Avenue
Davis, Ca 95616
Ph. 916-753-2727
Fx. 916-758-5672

Philip R. Kaufmann
Department of Fisheries and Wildlife
Oregon State University
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4451
Fx. 503-754-4716

Table 1. Participants in the EMAP Stream Indicator and Design Workshop (continued)

Jim Lazorchak
USEPA
3411 Church Street
Newtown, OH 45244
Ph. 513-533-8114
Fx. 513-533-8181

David R. Lenat
North Carolina Division of Environmental Management
Water Quality Section
44-01 Reedy Creek Road
Raleigh, NC 27607
Ph. 919-733-6946

Philip A. Lewis
USEPA
3411 Church Street
Cincinnati, OH 45244
Ph. 513-533-8114
Fx. 513-533-8181

Frank H. McCormick
USEPA
3411 Church Street
Cincinnati, OH 45244
Ph. 513-533-8114
Fx. 513-533-8181

Ben McFarland
USEPA
3411 Church Street
Cincinnati, OH 45244

Lythia Metzmeier
Division of Water
18 Reilly Road
Frankfort, KY 40601
502-564-3410

G. Wayne Minshall
Department of Biological Sciences
Idaho State University
Box 8007
Pocatello, ID 83209
HPh. 208-236-2236
Fx. 208-236-4570

Steve Paulsen
University of Nevada
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4428
Fx. 503-754-4716

N. LeRoy Poff
Department of Zoology
University of Maryland
College Park, MD 20742
Ph. 301-405-6948
Fx. 301-314-9566

Edward Rankin
Ohio Environmental Protection Agency
1685 West Belt Drive
Columbus, OH 43228
Ph. 614-777-6264
Fx. 614-777-0975

Barry H. Rosen
ManTech Environmental
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4666
Fx. 503-754-4335

Robert L. Sinsabaugh
Biology Department
Clarkson University
Potsdam, NY 13699
Ph. 315-268-3798
Fx. 315-268-6670

Mark Smith
Technology Applications Inc.
3411 Church St.
Cincinnati, OH 45244

M. Kate Smith
USEPA
26 W. Martin Luther King Dr.
Cincinnati, OH 45268

Table 1. Participants in the EMAP Stream Indicator and Design Workshop (continued)

Karl Stein
U.S. Forest Service
P.O. Box 3623
Portland, Oregon 97208-3623
Ph. 503-326-4091
Fx. 503-326-7166

R. Jan Stevenson
Department of Biology
University of Louisville
Louisville, KY 40292
Ph. 502-588-5938
Fx. 502-588-0725

Sandra Thiele
ManTech Environmental
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4788
Fx. 503-754-4716

William Thoeny
Technology Applications Inc.
3411 Church St.
Cincinnati, OH 45244

Scott Urquhart
Department of Statistics
Oregon State University
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4475
Fx. 503-754-4716

Thom Whittier
ManTech Environmental
200 SW 35th Street
Corvallis, Oregon 97333
Ph. 503-754-4455
Fx. 503-754-4716

Roger Yeardley
Technology Applications Inc.
3411 Church St.
Cincinnati, OH 45244

Chris Yoder
Ohio Environmental Protection Agency
1685 West Belt Drive
Columbus, OH 43228
Ph. 614-777-6264
Fx. 614-777-0975

4. **What index periods are most suitable?** To conduct a cost-effective national survey, EMAP-SW must limit sampling to a single season or index period. The goal of EMAP is to make regional estimates of biological condition and trends in that condition for populations of streams. Year round sampling is unnecessary for evaluating biological trends or unacceptable changes (as opposed to natural fluctuations) in biological condition. Seasonal sampling, or multiple visits during an index period, effectively reduce the number of sites that can be monitored given a fixed budget, which also reduces our ability to detect and interpret regional patterns. Therefore, EMAP focuses its sampling on a single period when temporal variation is minimal and anthropogenic perturbations are maximized, thereby increasing the precision and accuracy of the population sample.

During the next two days, five questions were answered in sessions of the candidate indicator groups:

1. **What characteristics of the assemblage could serve as indicators?** With this question, we sought to determine the characteristics or variables that held the most promise for being developed into indicators by EMAP-SW scientists. In answering this question, the groups were also asked to evaluate a set of 15 indicator criteria adapted from Olsen (1992). The criteria provided a consistent set of attributes by which the various assemblages could be compared.

2. **Is the assemblage applicable to temporary streams?** Because most stream miles are temporary (ephemeral, or intermittent spatially, temporally, or both), we also considered how useful a candidate indicator would be when there was no water. Our objective was to assess whether the same indicator would be applicable in temporary and permanent streams. This is an important consideration in a national program where widespread applicability is essential.

3. **What should be the length of stream assessed?** The EMAP-SW sampling (site selection) design produces a single point on a set of 100 to 800 streams per year. Although water quality, and possibly those assemblages governed largely by water quality, can be reasonably assessed at a point, we did not feel this was true of most assemblages or of physical habitat quality. Thus, we wished to determine the amount or distance of the stream around the point that would produce a reliable index sample. That is, if a different team were to arrive at the same stream a day later, would it collect essentially the same taxa in the

same proportions? Or, would differences in orienteering and habitat in the vicinity produce markedly different samples? Another way of asking this question was: What level of sampling effort would produce a list of taxa that did not change markedly with increased sampling at a site? For EMAP-SW, and in this document, a site is the entire stream reach that is monitored. Within a site, samples may be taken at any number of stations (points, habitat units, macrohabitats, or microhabitats).

4. **What field and laboratory expertise is required?** We expect that field crews, in most cases, will not have to be highly trained specialists. In considering this question, we determined the level of training needed to sample all assemblages and to obtain high-quality data. We also assessed the level of laboratory expertise needed to correctly and consistently identify species and conduct analyses. Finally, we estimated the number of people and work hours required to collect and process the sample.

5. **What assessment metrics and analyses are appropriate?** In answering this final question, we wanted to list existing metrics, indices, and data analyses that were known, or expected, to be capable of assessing biological condition or physical habitat quality. We also tried to determine if those approaches were appropriate in various parts of the United States, or what modifications might be necessary to make them so.

This report is an aggregation of the consensus responses by the groups to the nine questions. In addition, the editor has added concluding remarks from the regional summaries of each of the first five questions, and assemblage editors have expanded on particular questions that were unevenly reported by the assemblage groups.

REGIONAL SESSIONS

1. Are current ecological values appropriate for EMAP streams?

East Region. This group maintained that the term *ecological integrity* would be preferable to *biological integrity*, because the former term incorporates physical, chemical, and biological integrity, and includes the riparian zone. Also, habitat structure and water quality are important management values in their own right. Some participants thought trophic state was not especially pertinent to streams, because streams naturally become nutrient enriched along the stream continuum rather than in a particular reach. Others felt that nutrient enrichment may be a more appropriate value for streams than trophic state. Fishability was considered likely to misrepresent fish assemblage health to the public unless it is clearly defined to include pathology and edibility. The group suggested aesthetic character, but felt this value would be difficult to assess, despite the ease of collecting data on conditions that are likely to change rapidly in the next few decades.

Central Region. The group stressed the importance of biological communities in evaluating the ecological integrity of a stream. Participants also agreed that biological integrity was weakly linked to water quality standards and regulations focusing on fishability and swimmability. Discussion centered on whether trophic state was a useful value or whether, in a stream context, it differed significantly from biological integrity. The group concluded that trophic state is largely a lake feature and that biological integrity incorporates the effects of nutrient enrichment. Other measures of water quality (turbidity, sedimentation, odor) would provide more useful information and are of greater concern to the public. Though it may represent a value of concern in the Clean Water Act, fishability by humans lacks a scientific basis and is too subjective, according to this group. The group viewed waterbody quality, or riparian and physical habitat quality, as more quantifiable than fishability and believed that this value would include information about the aesthetic qualities of a stream. The group also saw riparian and in-stream habitat as a valuable resource.

West Region. Participants agreed that biological integrity was a suitable value and recommended that it include stream and riparian components. The trophic state value engendered much more discussion. This group proposed dropping trophic state as a value, but including aspects of it in the biological integrity and waterbody character values. The terms *eutrophic, mesotrophic, and oligotrophic* are inappropriate for streams. The group judged trophic state to be a historic artifact of the limnological precursors to stream ecology and not as important a value for

streams as the other values. However, trophic problems do arise when velocities slow or macrophytes grow; also, low productivity is of concern to many fishery biologists. Although fishability is of great public concern, it often conflicts with biological integrity and lacks a scientific foundation. This value was not warmly accepted by ecologists, who felt fisheries quality or fish assemblage integrity, which would incorporate trophy fish, natural reproduction, and natives, would be preferred; but a change would require a major educational effort to enlighten those anglers who are simply interested in catching and consuming fish. Habitat integrity was offered as a value. It should include overall visual attractiveness of the waterbody and riparian area, sedimentation, anthropogenic alteration, and degree of decoupling from the riparian zone.

Conclusions: In general, the three groups suggested that EMAP should:

1. Retain the biological integrity value for streams.
2. Add a habitat integrity value.
3. Drop the trophic state and fishability values for streams, but incorporate the critical aspects of each (nutrient enrichment, development of filamentous mats and macrophyte beds, algal blooms, fish tissue contamination) as measurements for assessing biological and habitat integrity.

2. What stream classes or types should EMAP be sure to sample?

East Region. RF3 (the digitized USGS stream network) misses many small (temporary, spring, low order) streams, so EMAP should pilot this issue regionally. We are likely to miss pristine streams where they are rare, without additional effort to select them subjectively.

Central Region. The group listed no stream types in particular, but cautioned EMAP to remember that stream order classification does not work well in highly agricultural areas where channelization, ditching, and tiling are prevalent.

West Region. Spring creeks are very important in the arid and semi-arid West, often serving as refugia for rare or endangered species. They are poorly mapped and are themselves endangered (particularly geothermal springs). Spatially and temporally intermittent streams share some of the same characteristics. The grid should be augmented to ensure representation of all three types, or other frames (state maps, remote imagery) may be needed. The group also emphasized the

need to sample both high and low gradient streams in all ecoregions and urged EMAP to sample large rivers.

Conclusions: Based on these comments, the EMAP grid may need to be intensified to locate a sufficient number of spring and intermittent streams, or we may need a list frame, as for large rivers. Although such streams are of considerable importance in the West, EMAP must decide if they warrant additional effort in the eastern and central United States.

3. If used, how should reference sites be selected?

East Region. According to this group, many reference sites are needed, with a different set sampled each year of the four-year cycle. Sites should be selected by ecoregion and stream size; additional information on geology, soil type, and land use may be necessary where ecoregions are too heterogeneous. Reference sites should lack physical alterations and represent best management practices in their catchments, low chance of future perturbation, and riparian integrity. Sites with ongoing research, established databases, and especially healthy assemblages should also be sought.

Central Region. This group concluded that sites should be selected by their assemblage, physical habitat, and riparian integrity, but did not specify criteria. They also stated that professional judgement was important, but did not expand upon this.

West Region. The participants concluded that reference sites were absolutely critical to EMAP for assessing acceptable conditions (and desired future ones). Areas where pristine, least disturbed, and best attainable sites may be located include city water supply catchments, listed blue ribbon streams, and various state and federal reserves (wilderness areas, parks, research natural areas, etc.). The group cautioned that these areas may still be perturbed by fish stocking or dams. A final suggestion was to mail a questionnaire to all district, state, and regional biologists.

Conclusions: Apparently, current methods for reference site selection (Hughes et al., 1986) are appropriate, with some modifications to represent all major stream classes depicted by the grid sites.

4. What index periods are most appropriate?

The optimum time for indexing most attributes was May and June, but this would be less than optimal for fish. Base or low flow through leaf fall was also considered a suitable period for indexing all the aquatic attributes, but this would be an unsuitable index period for birds. Degree days, latitudinal and elevational gradients, peak runoff periods, and peak migratory periods must also be considered regionally and locally.

```
                                N   D   J   F   M   A   M   J   J   A   S   O
Birds                                               --------
Herptiles                                          ------------
Algae                                              --------------------
Metabolism                                             ---------
Benthos                                                ---------------
Fish                                                       -------------
Chemical and physical habitat                      --------------------
```

Conclusions: Both fish and birds can be optimally sampled only during a very short index period in much of the United States. If both are selected for sampling, however, several other indicators can be optimally or appropriately sampled at the same time.

ASSEMBLAGE/ATTRIBUTE SESSIONS

BIRD INDICATOR SUMMARY (Panelists: Jeff Brawn, Mary Jo Croonquist, Bertin Anderson, Bob Hughes)

Introduction

Of the semi-aquatic vertebrates, birds most closely meet the criteria used in the selection of EMAP response indicators. They also are more sensitive than purely aquatic assemblages to riparian disturbances (Brooks et al., 1991). Birds have been a focus of public concern and enjoyment; birdwatching and waterfowl hunting are major recreational activities contributing millions of dollars to the national economy (Payne and DeGraaf, 1975). In addition, an increasing segment of the public has become aware of the serious decline in bird populations, particularly waterfowl and neotropical migrants (Senner, 1986; Terborgh, 1989). The U.S. Fish and Wildlife Service's Breeding Bird Survey shows that more than 70% of migrant species have declined in the eastern United States since 1978. Radar tracking studies of migratory songbird flights over the Gulf of Mexico reveal that the volume of birds in the 1980s was half that in the 1960s (Ackerman, 1992). The connection to the biointegrity value of EMAP is clear.

Bird assemblages reflect the condition of riparian areas. Riparian indicators are essential for diagnosing the probable causes of stream condition, because they link the waterbody to the catchment and offer a wider scale of spatial resolution than purely aquatic indicators. The EMAP-SW 1991 Pilot demonstrated the value of including the riparian area in studies of lake condition (Moors and O'Connor, 1992). Bird response data, along with physical habitat observations, indicated not only what habitat structure was available, but how it was used by birds. Moors and O'Connor showed that percent of foliage gleaners, insectivores, and neotropical migrants were inversely related to the percent of ground gleaners, omnivores, granivores, and level of disturbance. Pilot results also revealed that the percent of intolerant riparian bird species was strongly associated with the physical habitat quality of the riparian zone. Just as Croonquist and Brooks (1991) found in an earlier study, as the intensity of habitat alteration increased, the percent of neotropical migrant and intolerant species declined, whereas the percent of introduced species increased along streams. For many of these reasons, birds have been suggested for development as an indicator for all EMAP resource groups (David Bradford, U.S. EPA, Las Vegas).

Riparian indicators may have even more relevance to streams than to lakes. The physical habitat and western region groups at this workshop stressed the importance of riparian areas to streams. There is a smaller waterbody/riparian area ratio in stream systems than in lake systems. Also, birds and other semi-aquatic vertebrates remain an excellent source of information for intermittent or ephemeral streams, which usually lack water and aquatic biota during a summer index period. One of the panel members, Mary Jo Croonquist, observed during her work in Pennsylvania that there was no "stream effect" on the bird assemblage in forested and undisturbed headwater systems. However, in agricultural areas and in the arid southwest (Szaro, 1980), the riparian zone does act as a concentrator of birds.

The general consensus of the bird indicator panel was that birds as integrators of riparian condition would be a valuable indicator for streams because they capture the public interest and operate at scales humans can understand. Larger rivers would present sampling challenges similar to those that face other indicators.

Characteristics of assemblages that could serve as indicators

Not all birds are equally appropriate candidate indicators for streams. The focus most likely will be on those with small breeding ranges, such as shorebirds, pigeons, cuckoos, swifts, hummingbirds, kingfishers, woodpeckers, and perching birds. More orders would become candidates for rivers and lakes.

Societal Value: VERY HIGH. As stated earlier, birds have enormous societal value. Public interest in birds is high, particularly since bird assemblages representing significant portions of wetland, prairie, and forest ecosystems are declining.

Responsiveness: MODERATE. Avian response to various stressors is well documented. Bird assemblage changes that occur with anthropogenic impacts on a watershed scale have been documented in recent studies with response guilds (Croonquist and Brooks, 1991). Terborgh (1989) documented long-term trends in waterfowl numbers in Chesapeake Bay through the use of National Audubon Society Christmas Bird Count data over a 30-year span. He showed declines in dabbling and diving ducks linked to a decrease in underwater food plants, and a parallel increase in the numbers of geese, which have adapted to foraging in farm fields. See also Askins et al. (1990) for a discussion of declines in migratory birds.

Even though the direct response of bird assemblages to water quality is low, their value as an indicator lies in their great sensitivity to physical habitat alteration and land use changes in the riparian area and in the watershed. Their responsiveness to pesticide use is also high, though difficult to trace or document. Finally, if their aquatic insect prey are extirpated or severely reduced by stressors, bird populations are reduced.

There was some discussion of testing for tissue contamination in birds. Coordination with the U.S. Fish and Wildlife Service's contaminants monitoring program would be necessary to share data and to sample specific areas. Conducting nest searches to determine reproductive success would be another test of avian responsiveness to stress. Birds may be present, but not breeding, in habitats that are becoming degraded. However, both tissue contaminant work and nest searches would require more intensive sampling than that planned for EMAP surveys.

Ease of Sampling: LOW. The panel suggested that the point count method (i.e., recording all birds heard or seen at a series of timed stops) be employed by a two-member field crew. The survey should begin one half hour before sunrise and continue until four hours after sunrise. Though the sampling methodology is simple and the equipment needs are minimal, the high degree of training required for the birding crew and the 8 work hours of sampling prompt the low ranking.

Laboratory Ease: HIGH. Only data entry and analyses are needed; confirmations of recordings (if taken) are likely only for very unusual species.

Measurement Stability: HIGH. Measurement error is minimized by training field crews to a 90% accuracy using taped calls. Trained crew members record only what they can confidently identify. Any unrecognized call or sighting is listed as unknown (i.e., unknown duck or unknown flycatcher). Having a tape-recorded record of the day's transect will help in corroborating field identifications. If taping the full transect is impractical, the tape recorder could be used to record the unfamiliar calls and songs.

Index Period Stability: MODERATE. Index periods will vary by region. Within a region, the index period will be chosen to correspond with the peak of avian breeding activity. Measurement variability is lowest for birds that are calling within a territory. Doing surveys during breeding season also limits the recording of transient migrants. Conducting the survey from south to north within a region will compensate for latitudinal delays in nesting activities. An index period of June should

be acceptable for the northern half of the United States, using the south to north strategy, and May-June will be appropriate for the southern half of the nation. Index period stability will be lowest in alpine areas, where entry will depend upon snowmelt, and in arid areas, where water may be limiting.

In many regions of the country, the breeding season index period for birds may not coincide with the index period chosen for other EMAP indicators—fish, for example. This may make bird surveys too costly to conduct past the pilot stage. However, this topic is worthy of more discussion before a July-August sampling period is finalized. In the regional discussions, all indicators but fish suggested a May-June index period. It is true that there are advantages to sampling in-stream organisms during low flow when the systems are most stressed. However, as Dave Lenat stated during the discussion, "Good streams and bad streams can be indistinguishable when they both crash in late summer."

Among-Site/Among-Year Variation: HIGH. The variability in observations between sites differing in vegetative cover and habitat condition is greater than the variability in year-to-year observations at a particular site. Species at a site are consistent among years, but population sizes may vary markedly as discussed above.

Among-Site/Within-Site Variation: HIGH. Variability among sampling points of different habitat quality or character along a reach are both quite high, but compositing data from multiple sampling points at a site (within-site variation) effectively reduces the within-site variation. Also, habitat quality and character among sites is expected to be much greater than within sites.

Available Database: HIGH. Three long-term databases already exist for birds: (1) the National Audubon Society Christmas Count established circa 1900, (2) the Breeding Bird Census, sponsored by the Audubon Society and established in 1946, and (3) the U.S. Fish and Wildlife Service Breeding Bird Survey begun in 1965. Of the three, the Breeding Bird Survey with its random, single visit sampling scheme and nationwide scope, most closely approximates the EMAP framework. Breeding Bird Survey volunteers cover a route 25 miles long along rural roads, stopping every one-half mile to record all birds seen and heard within three minutes. In 1977, volunteers ran 1,832 routes in 48 states and in all the provinces of Canada (Robbins et al., 1986; Terborgh, 1989). These databases are excellent for trend and variance analyses, although they are not specific for surface waters.

Expected Taxonomic Richness per Reach: MODERATE. About 25–50 species; varies with region and habitat.

Macrohabitat Use: MODERATE. Several in the riparian zone, a few in the stream.

Guild Information: HIGH. See "Possible assessment metrics and analyses," page 16.

Diagnostic Power: MODERATE. High for habitat structure and terrestrial pesticides, low for water quality.

Signal/Noise Ratio: MODERATE. The emphasis of point count bird surveys is on territorial passerine birds (singing males recorded during breeding season). Under normal conditions, the variability in observations from year to year should be low. Territories will be reestablished yearly in good habitat. However, the numbers of migrant birds do fluctuate from year to year depending upon the severity of winter or early spring climatic conditions, or habitat conditions in wintering areas. These population changes add variability to trends assessment.

Information/Cost ratio: MODERATE. A normal stream transect is likely to produce 25–50 species, depending upon the region of the country and the local habitat diversity. Much published information about bird species ecology and zoogeography is available, meaning that when a species is identified, there is a large body of ancillary information about each species' niche and habitat to aid in interpretation and analysis.

The information/cost ratio for bird survey data is moderate. Although costs for the degree of training and the quality assurance effort may be relatively high, the low cost of equipment and a simple sampling methodology compensate for these costs. The early morning sampling period also allows time for bird crew members to assist with other field efforts in the afternoon.

Applicability to temporary streams

HIGH. Bird surveys from riparian areas along intermittent and ephemeral streams would provide indicator data in areas where in-stream data may be lacking. The indicator criteria discussed for perennial streams, such as societal value and responsiveness, would be similarly ranked for temporary streams, except for the information/cost ratio, which would increase. If in-stream

indicator information is incomplete or unavailable due to a lack of water, riparian and semi-aquatic vertebrate indicator information will be necessary to assess condition.

Length of stream segment assessed

HIGH. The point count method, or circular plot method, is appropriate for estimating bird assemblage composition in patchy habitats (Reynolds et al., 1980). Using this method, the crew walks parallel to the streambank, stopping every 100 m for 5 or 6 minutes to observe, listen, and record all sightings and bird calls. The advantage over a transect technique is that a stationary observer has less effect on bird activity and is more effective in detecting birds when not constantly watching the path of travel, especially in rough, heavily vegetated terrain (Anderson and Ohmart, 1981). Should the water noise be too loud, the observer would walk farther from the bank. The field crew could sample at 100-m intervals for 4 hours, or do 15 stations at 100-m intervals, or sample the entire stream segment at 100-m intervals, depending upon its length. Allowing time for recording and walking between stations, a crew would walk about 2 km during a 4-hour sampling time. In areas of rough terrain, the distance would be shortened during the 4-hour sampling window. Physical habitat information would be recorded at each stop. If habitat type changes markedly within an observation circle at a station, bird type should be matched to habitat type.

Deciding on the most efficient sampling time per stop during a point count survey means striking a balance between achieving the maximum number of detections without counting the same birds more than once. Manuwal and Carey (1991) conducted pilot studies in the western Washington Cascade Mountains to determine an optimum sampling time for point count surveys. They found that detections increased steadily until 8 minutes had elapsed, after which the number of observations remained constant. Variable interstation distances were tested during the same study. The results showed very little difference in the number of detections at interstation distances of 150, 200, and 300 meters. The major consideration for optimum distance between sampling points is that the distances match in scale bird territories and distribution across the landscape.

Field and lab expertise required

HIGH.

Crew: The ideal crew would have two members, both trained birders with a full range of hearing acuity. From the experience of the lake survey field crew, only one skilled birder was necessary; the second person recorded habitat observations. However, the trained birders were subject to rigorous QA testing. They sampled side by side to determine if their detection skills were identical. The panel believed that two skilled birders were preferable to one, for QA reasons and for double detection power; however, costs may preclude this option. They also discussed the possibility of using a tape recorder during the survey as a cross reference for post-sampling accuracy checks. We can probably manage with one trained birder and another nonbirding crew member to do physical habitat measurements or other EMAP field tasks.

Training: Birders should be subject to rigorous training, working with tapes of bird calls. QA tests will be given regularly, including tests for measurement error and crew variability. Several dry runs at representative stream sites will be necessary before each field season. Simultaneous transects run by crew members will ensure equivalent skills.

Labor Hours: 8 (2 persons x 4 hours each).

Gear: Binoculars, tape recorder, microphone, machetes, flagging, clipboards, bird tapes. A parabolic recorder could be used for recording bird songs for quality control checks if costs are not prohibitive.

Total Field and Lab Hours: 8 field hrs/site. Training by a qualified trainer for at least 2 weeks for 4 persons, or 400 hours (5 persons X 80 hours); this would equal 100 hours for each of 4 crews. The lake survey crews were trained during a month-long university ornithology course, which concentrated on bird songs and calls; it required over 100 hours. Training costs decline with more crews. Assuming that a crew samples 30 sites, training hours would be at least 3/site. Total hours = 11/site. This does not include reconnaissance or setting up of the sampling transect.

Possible assessment metrics and analyses

1. Number of species
2. Number of detections/station
3. % neotropical migrants of total species
4. % exotic species of total species
5. Trophic guilds – carnivorous, herbivorous, omnivorous

6. Foraging guilds — bark gleaners, flycatchers, foliage gleaners, ground gleaners. Foraging information may be subdivided into several categories, such as methods of search and attack, foraging sites, type of food, and food handling strategies. Use of the various categories depends upon the detail required to answer the research questions (Remsen and Robinson, 1990).
7. Habitat specificity – forest interior, second growth, young seral stage, prairie, grassland, pasture, water, wetland

Although there is no bird assemblage index as advanced as Karr's Index of Biotic Integrity for fish, much work has been done with bird assemblages and guilds (Croonquist and Brooks, 1991; Moors and O'Connor, 1992; Short and Burnham, 1982; Verner, 1984). In fact, Root (1967) coined the guild concept while working with bird assemblages. Brooks and associates have developed response guilds using metrics based on a species' wetland dependency, habitat specificity, and trophic level. In the metric scoring system, species that were more sensitive to habitat disturbance received high scores, whereas species unaffected or benefited by habitat disturbance received low scores. Undisturbed habitats, then, should contain a greater percentage of birds with high guild scores. Because their work seems most germane to EMAP bird assessments for streams, it is summarized in the following five paragraphs.

Trophic Level: Top carnivores receive the highest score because they are assumed to be most sensitive to habitat disturbance. Determination of trophic level is based on the species' overall diet when it is a resident in the sampling region. Most species become somewhat insectivorous for a short period when feeding young. These species would not be considered insectivorous if they revert back to another diet after nesting. The following list of trophic levels is ranked from highest score to lowest (Croonquist and Brooks, 1991):

- Carnivore, specialist = insectivorous (e.g., flycatchers)
- Carnivore, generalist = insects, small mammals (e.g., shrikes)
- Herbivore, specialist = fruits or nuts (e.g., acorn woodpecker)
- Herbivore, generalist = seed, nuts (e.g., finches)
- Omnivore = plants or animals (e.g., thrushes)

Foraging strategy: Where and how a species feeds should be based on that species' response to riparian degradation. Scores should reflect the level of riparian disturbance for specific impacts. For example, in the Northeast, a forested riparian zone is an undisturbed habitat and

should provide a high percentage of canopy/foliage gleaners. A logging impact would leave foraging habitat for ground or shrub gleaners. Conversely, livestock grazing within a riparian zone that maintains a canopy cover may impact the ground or shrub gleaners but not the canopy gleaners. Foraging guilds supplement the trophic guilds. If one foraging type is absent from an area where it is expected, this absence suggests a problem. For example, ground gleaners missing from a forest may suggest ground predators. The following foraging strategies are ranked from highest to lowest score for undisturbed riparian areas of the Northeast:

- Canopy gleaners
- Bark gleaners
- Shrub gleaners
- Air, flycatchers
- Ground gleaners

Habitat specificity: For the purpose of EMAP, we are interested in determining the ecological health of the stream system and surrounding riparian/upland landscape. With this in mind, habitat specificity is scored similarly to foraging strategy in that the scores are based on presence or absence of riparian degradation. Therefore, the highest scoring species should be those of the least disturbed habitats. These scores are based on a disturbance gradient:

- Undisturbed forest interior; forested and emergent wetlands
- Second growth, young seral stage; old fields; undisturbed lacustrine wetlands
- Undisturbed prairie grassland; partially disturbed lacustrine wetlands
- Pasture; agriculture; development

The use of multimetric indices in analysis will be complemented by the use of multivariate statistics, especially during the data exploration phase of analysis. A full range of analyses allows for cross checking of one method against the other. Methods vary in their sensitivity as well as in their ability to find ecologically relevant relationships at various scales. The analysis of data from the EMAP-SW 1991 pilot demonstrated the potential of an avian index of biotic integrity. Though the analyses varied in their ranking of moderately disturbed lakes, the guild analysis, species richness, and principal components analysis all identified the highly impacted sites.

HERPETOFAUNA (Panelists: Janalee Caldwell, Joe Freda, Mark Jennings, Sandy Thiele)

Introduction

Amphibians meet several criteria of a good response indicator (Vitt et al., 1991). In some areas, such as the forest streams of the Pacific Northwest, New England, and Appalachia, amphibians comprise the highest vertebrate biomass. Aquatic amphibians average 10 times the abundance and 4 times the biomass of salmonids in Pacific Northwest streams (Bury et al., 1991); they also represent the greatest biomass of vertebrate predators in the southern Appalachians (Hairston, 1987). In addition, they have become the focus of increasing concern because of a loss of biodiversity, with continuing reports of dramatic declines worldwide (Blaustein and Wake, 1990; Phillips, 1990). Known causes for amphibian decline include habitat destruction and predation from introduced species of fish and frogs. Other possible causes include increased ultraviolet radiation, pesticide poisoning, disease, and drought.

Amphibians, with their two-phase life history, serve as a link between aquatic and terrestrial environments. Due to their highly permeable skin, they are extremely sensitive to both airborne and waterborne contaminants. They are particularly stressed during the time of metamorphosis. The dependence on littoral areas by larvae of some species and on riparian areas by adults make amphibians vulnerable to shoreline habitat alteration in both lake and stream habitats.

Questions arise, however, when sampling procedures, indicator population variability, and information gain versus cost of survey are considered. Can amphibian sampling be tailored to an EMAP-style survey? The members of the herpetofauna indicator group kept these questions in mind while considering the suitability of amphibians as indicators of stream condition. The panel concluded that for certain regions of the country, and for headwater or intermittent systems, amphibians may provide information about ecosystem condition when other indicator information is poor or lacking.

Characteristics of assemblages that could serve as indicators

The panel concluded that amphibians and turtles were the candidates most likely to serve as indicators of condition. Herpetofauna activity varies regionally and within regions depending upon yearly temperature and precipitation fluctuations. Particular populations may vary significantly from year to year, which poses difficulties for sampling within a prescribed index

period (Jones, 1986; Pechmann et al., 1991). For these reasons, the group's attention turned to regions of the country and particular habitats that have amphibian species with relatively stable populations that are easily sampled. Aquatic turtles were chosen as possible indicators for sampling in larger streams and river systems. Appendix A lists major assemblages of interest in various regions of the country and ranks them according to 12 criteria. The following sections summarize these criteria.

Societal Value: HIGH. Amphibians compose the bulk of vertebrate biomass in the forests of the Pacific Northwest, Appalachia, and New England. They are attractive to children because they are visible and easily captured, their mating songs are an early sign of spring, and their territorial calls are a source of enjoyment on summer evenings. They are suffering serious declines, nationally and internationally, even in seemingly undisturbed wilderness areas.

Responsiveness: HIGH. Amphibians are especially sensitive during their larval life stage to riparian habitat, water quality, and introduced species problems. Amphibians, during all life stages, are very sensitive to both waterborne and airborne contaminants due to their highly permeable skin. Metamorphosis is a stressful time for amphibians, when they are particularly vulnerable to outside impacts. The dependence on littoral areas by larvae of some species and on riparian areas by adults puts amphibians at risk from shoreline habitat alteration. Amphibians have been used to show the effects of logging on old growth forests in the Pacific Northwest (Corn and Bury, 1989).

Ease of Sampling: LOW. Two-thirds of the sampling will be incidental to other types of sampling (fish and macrobenthos). The riparian searches could also be combined with some other sampling effort, such as birds. In addition, the index period is very flexible. Sampling will be most cost effective if it is conducted in conjunction with other indicator work. The index period of most amphibian assemblages is flexible enough to mesh with spring or summer surveys. During riparian searches, field staff would search appropriate habitats, turning logs and rocks, along a corridor parallel to the stream channel. Larvae and aquatic adult amphibians could also routinely be taken during macroinvertebrate sampling, as well as during electrofishing. Thus, amphibian indicator information could be gained through the incidental take of the fish and macroinvertebrate sampling; the riparian searches would be the only facet of field work that would require a significant addition of time and effort, about 6 work hours.

To minimize the amount of field expertise required for sampling, voucher specimens should be taken for later identification. For larvae, a 5% visual estimate will be sufficient; the larvae may be placed directly in formalin. Training will be required for field staff to correctly preserve adult specimens. Each animal must be humanely killed with chlorotone or MS-222, injected with formalin, and laid out in formalin in a tray before being placed in storage containers. Aquatic turtles should not be killed or preserved, but photographed for later identification and released.

Laboratory Ease: MODERATE. Identification of larvae and confirmation of adult voucher specimens is estimated to require less than 2 hours/site.

Measurement Stability: MODERATE. Identification error should be low since the individuals caught may be identified later by professional taxonomists; however, collection is done by searching, which involves moderate error. Targeting regions with stable populations for sampling reduces detection error due to lower population variability. If only collected along with fish and benthos, measurement error may be high, especially in estimating proportionate abundance and riparian species.

Index Period Stability: HIGH. Target populations are stable during the chosen index period. Adult populations living in riparian areas are active and observable from early spring through summer. Many taxa are long-lived and have low mobility, ensuring that year-to-year population variability will be low.

Among-Site/Among-Year Variability: MODERATE. The variability in observations between sites differing in vegetative cover and habitat condition is greater than the variability in year-to-year observations at a particular site. In target areas, populations of salamanders are stable from year to year.

Among-Site/Within-Site Variability: MODERATE. Variability among sites is also a function of the variability in habitat quality. Within-site variability is high at heterogeneous sites, but this is countered by composite sampling along a transect.

Available Database: LOW. Databases of limited spatial distribution are available that address the autecology of particular populations: salamanders of the Appalachians and the Pacific Northwest; turtles in the east, central and southern United States; frogs and toads, nationwide. However, there is a general lack of long-term census data (Pechmann et al., 1991). Much of the information

on population declines is anecdotal or indicative of sites where historical populations once occurred (Hayes and Jennings, 1986). This lack of baseline data on the sizes and natural fluctuations of herpetofauna populations complicate efforts to distinguish declines resulting from human activities (Pechmann et al., 1991).

Expected Taxa Richness: LOW. During a study conducted in montane forested areas of the Pacific Northwest, Bury and Corn (1991) caught a mean of 42.6 amphibians per 10-m section of 23 headwater streams in uncut forests. Nine species of amphibians occur in this area near small streams. However, three species dominated the sample: Pacific giant salamander, tailed frog, and Olympic salamander.

Macrohabitat Use: HIGH. Depending upon life stage, both aquatic and riparian habitats are used extensively: larvae of terrestrial species and aquatic species are found in both fast and slow water in-stream; terrestrial adults are found under logs, rocks, and leaf litter in riparian areas.

Guild Information: LOW. See "Possible assessment metrics and analyses," page 24.

Diagnostic Power: MODERATE. The diagnostic power of amphibians is high in target areas such as the mid-Appalachians or Pacific Northwest, where stable, easily observed populations of salamanders occur. It is also high in intermittent systems where in-stream data may be lacking. Diagnostic power is low in areas where populations fluctuate or depend upon favorable weather conditions.

Signal/Noise Ratio: HIGH for target populations mentioned in the foregoing paragraphs. Salamanders are long-lived, have low mobility, and are active in forested montane habitats throughout all but the coldest periods of the year. They are sensitive to disturbances in water quality and habitat structure. Hairston (1987) collected and compared long-term count information on plethodontid salamanders in the mountains of North Carolina and found their populations to be stable over a five-year period. Pond breeding species, on the other hand, are subject to higher fluctuations in numbers due to changing seasonal weather conditions (Hairston, 1987).

Information/Cost Ratio: MODERATE. The information/cost ratio will be particularly high in forested upland regions such as the Pacific Northwest and the Appalachians where salamander communities form the bulk of the vertebrate biomass in riparian and aquatic habitats. Data on

particular species habitat and feeding requirements is available. Adding amphibian sampling to fish and macroinvertebrate sampling will keep sampling costs low. However, in other areas of the country where knowledge of amphibian autecology is low, the information/cost ratio is low.

Applicability to temporary streams

HIGH. Salamanders, frogs, and toads form assemblages that would serve equally well for intermittent and ephemeral streams as for perennial streams. If fish are absent, salamanders and anurans may be even more abundant in intermittent streams than in perennial streams. Drying and ponding of stream channels may also cause amphibians to leave the riparian areas and concentrate in hiding places within the stream channel.

Length of stream segment sampled

HIGH. For riparian searches, the questions of optimum corridor length and width and the number of transects per stream segment should be answered during pilot efforts in various regions of the country. However, a reasonable corridor would be 10 m wide and 100 m long; several short transects could be chosen systematically, if a longer reach were sampled. Samples from various transects within a segment could be composited if habitats were recorded. The group also discussed the utility of sampling both sides of the stream bank. This would ensure that both the inside and outside bends in the stream channel and banks of different aspect would be sampled.

Field and lab expertise required

Field crew: LOW-MODERATE. Two persons could spend from one to four hours doing the riparian searches. Four hours would be the maximum time required for a transect in rough terrain. The macroinvertebrate and fish collections from the site should be checked to identify or preserve samples. Collecting jars, ziplock bags, and formalin are the only additional gear necessary for the amphibian work, since macroinvertebrate and fish crews will be taking amphibians as incidental catch. Where poisonous snakes reside, turning hooks and protective gloves are necessary.

Where turtles are used as indicators in larger streams and rivers, field crews would have to expend more time and energy to bait and set fyke traps every 25 m. Ideally, traps should be left overnight. If fish are sampled with the same gear, no additional effort is needed. Photographs would be required for species identifications.

Field training: LOW. One to two days of training are sufficient for basic identification skills and sampling methods if individuals are already schooled in biology.

Laboratory work: MODERATE. Voucher specimens would be sent to a recognized museum for final identification. The longevity of the museum and its natural history collections should be an important factor in choosing a repository. Normally a herpetologist requires about two hours to confirm identifications of voucher specimens. Large numbers of larvae, which are harder to identify, would result in occasional higher costs per site for identification.

Total Field and Lab Hours per Site: Field (2-8); lab (2). Total hours = 10.

Possible assessment metrics and analyses

- Total individuals
- % anomalies of total
- Relative abundances of individuals
- Relative abundances of larvae versus adults
- Species richness
- % introduced species
- % intolerant species
- % tolerant species
- Reproductive guilds
- Feeding guilds
- Habitat guilds

Work with herpetofauna guilds is in the developmental stages. The rationale for the use of the guild concept in environmental assessment can be found in a review article by Simberloff and Dayan (1991).

Data Analysis and Estimate of Condition: Nonparametric statistics are normally used to analyze herpetofauna data. It is likely that a combination of multivariate analyses as well as indices would be used to assess the assemblage. Something similar to the Index of Biotic Integrity (IBI), used for monitoring fish communities (Karr et al., 1986), could be developed for herpetofauna. The IBI uses metrics similar to those listed in Objective 9, but it works best in areas with complex fish communities. The situation for amphibian metrics may be analogous to using the IBI in areas

with few fish species. In these areas, metrics are modified or other metrics are developed. If there is only a single sensitive species, for example, the proportion of sensitive species can be changed to percent of individuals as sensitive species (Karr et al., 1986). Other measures for an area of low species richness would focus on age classes or reproductive success.

The panel assembled a list of taxa for the Pacific Northwest, assigning each species a number score according to its tolerance or intolerance to habitat changes. For example, the intolerants received a 5, the common species a 3, and the exotics a 1 (Table 2).

Sites could be scored using a simple metric such as this. For example, the absence of true frogs and toads from appropriate habitat, reflected in the site score, would indicate a problem. Such an index could easily be refined by the addition of other metrics, such as relative abundance measures, proportions of intolerants, exotics, and trophic groups.

Table 2. Tolerance Rankings of Pacific Northwest Amphibians Likely to be Encountered in an Extensive Stream Survey

Taxon	Occurrence/Trend	Ranking
Tailed frog	Old growth species	5
Olympic salamander	Old growth species	5
Pacific tree frog	Relatively common	3
Taricha	Common newt	3
Ensatina, Dicamptodon	Common salamanders	3
True frogs (*Ranas*)	Common, but declining	3
Toads (*Rufo*)	Once common, but declining	3
Bullfrog	Introduced, indicates change	1
African clawed frog	Exotic, lives in highly disturbed conditions	1

FISH (Panelists: Mark Bain, John Baker, Susan Cormier, Chris Faulkner, Frank McCormick, Thom Whittier, Roger Yeardley, Chris Yoder)

Introduction

Fish are the most purely aquatic of all vertebrate assemblages, they are of immense interest to the public (both fishermen and nonfishermen), and they are experiencing precipitous declines. Because many species are relatively long-lived and mobile, fish are useful indicators of multi-year and broad-scale environmental conditions. Fish assemblages contain species representing a variety of trophic levels (omnivores, herbivores, invertivores, planktivores, piscivores) and they tend to integrate changes in lower trophic levels, thereby reflecting overall ecosystem health. Because they are at the top of the aquatic food chain and consumed by humans, they are important subjects for assessing bioaccumulation of toxics. Designated aquatic life uses, which along with criteria form water quality standards, are frequently characterized in terms of fisheries (coldwater, coolwater, warmwater, sport, forage, rough), and fishability is a goal of the Federal Water Pollution Control Act.

Their importance to American society has led to the establishment of three professional associations (American Fisheries Society, American Society of Ichthyologists and Herpetologists, and Desert Fishes Council) and eight professional journals (*Canadian Journal of Fisheries and Aquatic Science*, *Copeia*, *Environmental Biology of Fishes*, *Fisheries*, *Fishery Bulletin*, *North American Journal of Fisheries Management*, *The Progressive Fish-Culturist*, and *Transactions of the American Fisheries Society*). Because of the great professional interest in fishes, their declines as a result of migration barriers, exploitation, toxics, habitat loss, and introduced species have been recorded and reported (Hughes and Noss, 1992; Miller et al., 1989; Nehlsen et al., 1991; Williams et al., 1989).

Characteristics of assemblages that could serve as indicators

Initial discussion focused on the usefulness of fish as an indicator of biological integrity in streams. The expertise of the participants was strongly skewed to central and eastern *warmwater* systems, which were considered easier to describe for various metrics and multivariate comparisons because of their overall taxonomic richness. In that context, the group expressed strong sentiment for emphasizing the importance of using obligate fluvial taxa (e.g., percids, cyprinids, catostomids, and some lepomines) in whatever description of biological integrity would be used.

The feeling was that the "fishable" species of public interest in warm waters were least sensitive to perturbations. Size classification was regarded as important in that it generally reflects population structure. As a rule, 25 mm was suggested as the lower cutoff for species-level description. The group viewed larval taxonomy as too difficult and the temporal variation in larval abundance as too uncertain to be practical for including larval fish in EMAP.

Ohio EPA's experience with biomarkers indicated that two people need 3–5 hours/site for field processing; additional lab time and expense is also required. Biomarkers are considered by some to be most appropriate as diagnostic indicators, although genetic diversity in species depauperate assemblages has proven to be a useful indicator of biological integrity (Nehlsen et al., 1991). Such an indicator would require collection of 100 individuals of a single species (Carl Schreck, Oregon State University). Goede's Fish Health Index takes 1–5 hours and requires 20 fish of the same species and size. The group concluded that most biomarkers would be more appropriate for more intensive studies than the initial EMAP stream surveys.

The participants made the following assumptions:

- The objectives of the sampling methods to be employed were directed at obtaining a representative sample of the assemblage, not an inventory of the populations within it.

- Within a site, there was a probability that 10% of the species were likely to be missed by electrofishing and seining methods.

- Measurement error would be minimized by preserving all specimens collected for museum or laboratory identification. This would not be permitted nationally for protected species and is unnecessary for easily identified and large fish. It is also unwise for large sport fish.

- Sampling error, measurement error, and site variance would be smoothed by agglomerative metrics or analyses by stream class. Certain multimetric techniques may not be applicable across all classes where some of the descriptive power may be lost. The IBI must be recalibrated for headwater, mid-sized, wadeable, and boatable systems in most regions. Multivariate analyses may have some subjectivity in the types of analyses and data chosen.

- Rare and transient species may be missed. This is a matter of concern because they may be sensitive to disturbances.

Fish assemblages were ranked as follows.

Societal Value: HIGH. Over 30 million fishing licenses per year are issued in the United States and over $27 billion was spent on sport fishing in 1985, creating over 800,000 jobs (Sport Fishing Institute, 1992). People are concerned about fish for food and recreation, and simply as visible indicators of the health of aquatic ecosystems. Fish kills remain a serious concern to the public and natural resource agencies.

Responsiveness: HIGH. Different measures of fish assemblages are sensitive to both short-term and chronic perturbations. The recovery of an assemblage may be fast, that is, the assemblage may be more resilient to disturbance than it is resistant. Thus, fish assemblages may be better indicators of long-term disturbance than of acute effects. Fishes are also sensitive to changes in habitat structure, flow, and channel modifications, as well as to chemical changes (Judy et al., 1984; Miller et al., 1989; Smith, 1971).

Sampling Ease: LOW. Sampling effort is largely a matter of stream size and habitat complexity. For wadeable streams, the goal is to collect 90% of the species and age classes present, which may require the use of seines and electrofishing in 100 to 1000 m of stream. This may take a minimum of two people 1-5 hrs (mode of 8 work hours); at least one crew member should have a degree in fishery biology and expertise in fish sampling (Plafkin et al., 1989).

Laboratory Ease: MODERATE. In streams with complex fish assemblages, or where field identification of small fishes and some species is problematic, laboratory identification is necessary. Also, for quality assurance, a set of voucher specimens is needed. Both require a trained and experienced ichthyologist and a suitably equipped laboratory. Laboratory processing, identifications, and cataloging require 4 hours per site for EMAP lakes (Karsten Hartel, Harvard Museum of Comparative Zoology).

Measurement Stability: MEDIUM. This is increased considerably by laboratory identification/confirmation of species and by selecting an index period when flows are relatively low and stable. Field staff must be carefully trained in methods and level of effort (distance/habitats sampled, thoroughness). Although absolute abundance errors can be high in fish sampling, EMAP will be estimating only proportionate abundance and species richness.

Index Period Stability: HIGH. The major sources of variability are climatic (severe drought, flood) or anthropogenic (spills). Using data from 1,335 sites sampled three times from 15 June to 15 October, Rankin and Yoder (1991) found coefficients of variation of < 10–12% in minimally disturbed and highly toxic streams, but values of 30–40% in polluted streams and in those with poor physical habitat. They considered high variability during an index period as indicative of disturbance.

Among-Site/Among-Year Variation: HIGH. Rankin and Yoder (1991) also reported IBI (index of biotic integrity) values of 12–60 among sites but only 48–58 and 12–24 at several sites sampled over three years in minimally disturbed and highly disturbed streams, respectively.

Among-Site/Within-Site Variation: HIGH. This evaluation is based on the relatively high variance among sites across the state of Ohio compared to that of sites 1–2 km apart along the same stream. If sites in the same stream but distant from each other are similar, then within-site variance should be relatively low. Preliminary pilot data from multiple sites in an ecoregion had coefficients of variation around 20% for species richness and evenness.

Available Data: HIGH. There is a tremendous amount of autecological data in theses and the peer-reviewed literature, plus most states and major universities have long-standing ichthyological museums. Many of the data are on paper files or untranslatable and inflexible computer files; however, several major fish databases have been computerized (e.g., Massachusetts, Cornell, Pennsylvania, Ohio EPA, University of Michigan, Illinois Natural History Survey, Wsconsin Department of Natural Resources, Florida, Arkansas, Missouri, Nebraska, Kansas, Oklahoma, Colorado, Montana, Oregon State University). In addition, databases on fish assemblages exist from long-term (> 20 yrs) studies of major rivers (e.g., Mississippi, Missouri, Illinois, Wabash, Savannah, Colorado). Lastly, the American Fisheries Society publishes a list of common and scientific names of fishes every 10 years (e.g, Robins et al., 1991), ensuring that most taxonomic questions are resolved and all species collected on the continent are consistently named.

Taxonomic Richness: LOW-MEDIUM. The group's expertise was with warmwater, speciose assemblages. In most of the eastern United States, dominated by the Mississippi River fauna, stream fish assemblages in wadeable streams will be taxonomically rich, especially in regions with fluvial assemblages with predominantly sensitive taxa. Coldwater streams may gain species as they become warmer. High gradient, warmwater systems may behave like coldwater systems. The relationships (and taxonomy) of some of the Gulf Coastal and Tennessee/Cumberland

species are poorly understood. Regional museums will be useful in resolving taxonomic issues and regional scientists can offer better estimates of taxonomic richness. Generally, wadeable stream reaches in the United States support 0–40 fish species, with greatest richness in the Mississippi and Mobile drainages; most one-degree quadrats in the western United States support 10 or fewer fish species, whereas 40–70 species are typical of eastern quadrats (McAllister et al., 1985).

Macrohabitat Use: HIGH. Fish occupy nearly all macrohabitats in permanent and in many intermittent streams. Species autecology is described in a national atlas and numerous state fishes books (e.g., Becker, 1983; Cross and Collins, 1975; Miller and Robison, 1980; Minckley, 1973; Moyle, 1976; Pflieger, 1975; Scott and Crossman, 1973; Smith, 1979; Trautman, 1981; Wydoski and Whitney, 1979).

Guild Information: HIGH. Data are summarized in the books mentioned in the previous paragraph for trophic, sensitivity, habitat, and reproductive guilds. Matthews and Heins (1987) is an additional useful guide for the ecology of North American stream fishes; Karr et al. (1986) and Fausch et al. (1990) offer considerable insight into assemblage level assessments that make use of guilds.

Diagnostic Power: HIGH. Based on species- and assemblage-level knowledge of fishes and their responsiveness to the multitude of stressors affecting streams, fish should be highly diagnostic. However, it will be difficult to diagnose single stressors because of the expected high frequency of cumulative impacts.

Signal/Noise Ratio: HIGH. As long as measurement error is controlled, the fish assemblage will vary mostly as a result of flow fluctuations and anthropogenic disturbance. The data collected should closely represent the actual assemblage, and fish are sensitive to multiple stressors (water quality degradation, physical habitat degradation, flow regulation, migration barriers, harvest, stocking). No other assemblage is likely to produce a signal from all these stressors.

Information/Cost: HIGH. Information about the impacts of multiple stressors is high and the costs of obtaining data are moderate.

Applicability to temporary streams

LOW. Although temporary streams are unlikely to be wet during the summer low-flow period, some channels may contain enduring pools that have resident fish; if present at all, however, fish are probably transients in most intermittent and ephemeral streams. Tolerant species may replace headwater species, especially as streams dry. If fish are sampled in a spring index period when temporary streams are more likely to be wet, pioneer species of fish that reproduce in such habitats are apt to be present. Nonetheless, intermittent streams may be very important to some fishes; for instance, Erman and Hawthorne (1976) found that 39–47% of rainbow trout in a Sierra stream spawned in an intermittent tributary, whereas a total of only 10–15% spawned in several permanent tributaries.

Length of stream segment sampled

HIGH. 150–560 m, or 3 riffle-pool sequences, or 40 stream widths. NAWQA recommends shorter distances, but regional pilots are needed to determine appropriate lengths because of differences in stream morphology and species richness. Human-made structures such as low-flow dams would not change sampling regime or site and no alternate class sampling would be needed. If a site does not meet EMAP sampling criteria, it would not be sampled. The group recommended compositing samples from riffles, runs, and pools. However, it might be advisable to keep habitat splits and do the compositing after sampling, at least in pilots.

Field and lab expertise required

Field: HIGH. Two persons X 4 hr/site = 8 work hours.

Lab: MODERATE. One person X 4 hr/site = 4 work hours.

Field Training: LOW. One to two days.

Sampling Gear: HIGH (initially). Electrofishers, seines, dipnets.

Total Work Hours: 12/site.

At least one field person should be a trained and experienced fish biologist; the lab person should be a professional ichthyologist. Unless a systematic random sampling design is implemented, more field biologists will be needed in wide, shallow rivers with complex habitats.

Ohio EPA preferred to sample wadeable streams by electrofishing with bank or float generator gear. The group discussed other techniques, such as seining, also. The experience of Ohio EPA and others suggests that variance among crews is greatly reduced when electrofishing is used, along with prescribed sampling distance and time. The necessary power (weight) of the gear is important because of the possibility of a long walk to the site. The group concluded that light weight and high-power gear could be assembled to accommodate the EMAP design. Equipment described by Mark Bain was considered as an alternative to the Ohio EPA unit.

Possible assessment metrics and analyses

Metrics could be based on number or percent of species or individuals.

Assemblage Composition

- Ordination score (based on species or metrics)
- Species richness
- Family richness
- Index of Biotic Integrity

Trophic Guilds

- Omnivores
- Herbivores
- Invertivores
- Piscivores

Tolerance Guilds

- Intolerants
- Sensitives
- Tolerants

Habitat Guilds

- Benthics
- Water Column
- Headwater
- Riverine

Reproductive and Life History Characteristics

- Nonguarding lithophils
- Juveniles or Young of Year
- Adults
- Introduced
- Total Catch
- Anomalies
- Temporal Variance

MACROINVERTEBRATES (Panelists: Joseph Furnish, Marty Gurtz, Chuck Hawkins, Jim Lazorchak, Dave Lenat, Phil Lewis, Wayne Minshall, Bill Thoeny).

Introduction

Macroinvertebrates are important members of the food web, and their well-being is reflected in the well-being of the higher trophic groups such as fish. In addition, macroinvertebrates have a long history of use as a biomonitoring tool. Their value in bioassessments stimulated formation of the Midwest Benthological Society, which has since become the North American Benthological Society. Benthos comprise a heterogeneous assemblage of animal taxa that inhabit stream substrates.

Benthic invertebrates are frequently used as environmental indicators of biological integrity because (1) they are found in most aquatic habitats, (2) they are of a size that makes them easy to collect, (3) they are very sensitive to a wide range of stressors (agricultural, domestic, industrial, mining, etc.), (4) they have limited mobility and life cycles of a year or more, thus reflecting conditions during the recent past, including reactions to infrequently discharged pollutants, (5) they retain toxic substances for relatively long periods of time due to "biological magnification," and (6) most can be identified to genus or species using existing taxonomic keys. Few macroinvertebrate species are endangered, and getting a permit to sample would pose no difficulties.

Knowledge of changes in the assemblage structure (abundance and composition) and function of benthic macroinvertebrates helps to indicate water resource status and trends (Cummins and Klug, 1979; Plafkin et al., 1989). Different stressors produce different macrobenthic assemblage structure, function, or both (Armitage, 1978; Hart and Fuller, 1974; Hilsenhoff, 1977; Metcalfe, 1989; Resh and Unzicker, 1975).

Characteristics of assemblages that could serve as indicators

The major taxonomic groups of freshwater macroinvertebrates include the aquatic insects, annelids, mollusks, and crustaceans; all those collected while sampling streams will be identified.

Societal Value: LOW. Societal interest in macrobenthos is limited to those few persons aware of their importance as fish food.

Responsiveness to Stress: MODERATE. Taxa throughout North America show a wide range of tolerances. Many species are sensitive to both in-stream and riparian alterations. Benthos are highly responsive to changes in water quality, flow, and sedimentation, but show low to moderate sensitivity to many changes in habitat structure, and their reaction to introduced species is variable.

Sampling Ease: MODERATE. Quantitative sampling methods are available for all types of aquatic habitats. Plafkin et al. (1989) estimate 1–2 hours for two people, or 4 work hours.

Laboratory Ease: LOW. The group estimated that 2–3 composite samples would be taken from the site; each would require several hours to process.

Measurement Stability: MODERATE. This is a function of habitat heterogeneity, degree days, sampling design, and data analyses. Collecting the samples at the same time (based on degree days) and in the same habitat type each year would eliminate much of this variability. However, there is generally more difference among riffles than among samples from the same riffle; this indicates a need for composite sampling. A number of studies on stream assemblages have addressed the effects of physical microhabitat variability on the distribution of benthic macroinvertebrates (Cummins and Lauff, 1969; Haddock, 1977; Minshall and Minshall, 1977). The 1992 and 1993 pilots will further investigate aspects of measurement error to determine the necessary number of samples for both slow-water and fast-water composites.

Seasonality may be an even more significant factor than microhabitat variability because taxonomic and feeding guilds change naturally in composition throughout the year in response to emergence and reproductive cycles. These natural cycles may shift when influenced by pollution impacts. Preliminary analysis of data from the West Virginia RARE project indicates that varying the summer sampling period by two or three weeks from one year to the next may have a substantial effect on numbers of individuals and the taxa collected in the samples. There was, however, little difference in Hilsenhof Biotic Index (HBI) or Biological Integrity Index (BII) scores from one year to the next, even though different taxa were present.

Index Period Stability: MODERATE. The group suggested that streams could be sampled from low to high elevations and from south to north, to help minimize differences resulting from degree days. Panelists recommended sampling the same site on the first and last days of the index period to determine temporal variance and develop correction factors. Measuring degree days

also would facilitate calibrations between a cool, wet year and a warm, dry year. Sampling should not be scheduled when streams are dry or flooded, or soon after floods. If logistical difficulties hinder crews from sampling in such a manner or if temperatures and flows change rapidly in late spring, the index period stability is reduced.

Among-Site/Among-Year Variation: HIGH. North Carolina biologists found that similar riffles in the same stream yielded the same benthic assemblage from year to year. As long as similar habitats are sampled and no major disturbance occurs, among-year variation will be much less than the variation that occurs among different sites.

Among-Site/Within-Site Variation: MODERATE. For some metrics (taxa richness, number of individuals) this would be high, but for indices (such as EPT, HBI, and BII) it would be low for most sites. Compositing samples should smooth this variation.

Available Databases: MODERATE. Many small, short-term databases are available. Studies incorporating multi-year and multi-site designs include those of Utah State, Philadelphia Academy of Natural Sciences, and North Carolina Department of Environmental Management.

Taxonomic Richness: HIGH. Although the taxonomy of some groups is poor, nearly all can be identified to genus and many can be taken to species. We can expect to collect 10–30 taxa in three Surber samples from most unpolluted streams in the Midwest. The number of taxa in a single riffle sample in the Appalachians ranges from 10 to 35, but 65-95 can be taken if more habitats are sampled (Plafkin et al. 1989). Nutrient-poor headwater streams typically support fewer taxa than larger, nutrient-rich streams.

Macrohabitat Use: HIGH. Any available substrate may provide suitable habitat for macroinvertebrates, including bottom sediments (mud, sand, silt, clay, gravel), submerged logs, debris, stones, vascular plants, filamentous algae, etc. They occur in fast and slow water, intermittent streams and large rivers, and off-channel waters.

Guild Information: MODERATE. The tolerance/niche requirements of many taxa are unknown, but our knowledge of them is increasing rapidly.

Diagnostic Power: HIGH. Assuming a sufficient plot scale sampling design and quality assurance in sampling, processing, identification, and data analysis, macrobenthos assemblages are very useful in diagnosing stressors.

Signal/Noise Ratio: MODERATE. As discussed above, macrobenthos demonstrate moderate responsiveness and measurement and index stabilities; therefore, their rating for signal/noise is estimated as moderate also.

Information/Cost Ratio: MODERATE. Up to 12 samples per reach were recommended for the 1992 pilot studies; these will be needed to assess the variability in assemblage structure between samples in similar habitats and in different habitats. Some 1992 samples will be analyzed separately and composited by computer to determine the appropriate number of 1993 pilot samples that should be composited in the field. Once that number is determined, a 100-300 organism subsample from composited Surber, grab, or kicknet samples will be used to characterize riffle, pool, snag, or all three habitats of the stream reach. That is, eventually only 2–3 composite samples per site will be processed in an estimated time of several hours each. Up to 4 field work hours may be needed to collect and field process the composite samples.

The ecology of most common macroinvertebrate taxa occurring in North America is fairly well documented in the literature, but the information must be assembled and integrated before being useful to EMAP biologists. Practically nothing is known about the life history or ecology of perhaps 10–20% of the taxa generally collected during stream surveys in the eastern United States.

Applicability to temporary streams

LOW. Intermittent and ephemeral streams would be sampled in the same way as the other streams, during flow periods. If they lack water they would not be sampled.

Length of stream segment sampled

HIGH. Riffles, runs, and pools should be sampled proportionately to their occurrence in a reach. The number of samples should be sufficient to produce index and metric variances <10% and <20%, respectively. We suspect that 3–12 samples from pools, snags, and runs/riffles might be adequate. Samples would be composited by habitat type and subsampled for identification.

Pilots should address the issues of quantitative versus qualitative sampling, number of habitats, number of samples per habitat, mesh size, and number of individuals counted. These issues should be determined by the number of samples needed to reach the point where variance flattens. Multiple habitats must be sampled to detect changes in macrohabitat. About 10% of the samples should be replicated as a QC activity.

Field and lab expertise required

MODERATE-HIGH. A two-person crew would require about 2 hours per reach for a total field time of 4 work hours. These estimates are based on Surber or grab sampling in first- to third-order streams in the Midwest. At least one person must be a professional biologist with training and experience (three years preferred) in benthic sampling methods.

The group recommended the Surber type sampler or D-frame net for fast water and an Eckman grab for sedimented pools in most wadeable streams. Artificial substrate samplers and drift net samples would require two trips to the sampling station and would take additional time. Most agreed that a suction type sampler is too cumbersome for routine sampling. A mesh size of 0.450 mm (No. 40) might improve precision.

The lab taxonomist must be capable of identifying aquatic macroinvertebrates to the genus or species level to detect the kind of changes at the level of precision demanded by EMAP. Taxonomic references and a high-quality dissecting scope are also necessary. Each sample will require approximately 1–3 hours for sorting and 2-7 hours for identification under normal conditions. Total lab time equals 3–10 hours/sample, or an average of 21 hours per site if 3 composite samples are taken, and 14 hours if 2 composites are taken.

Field: MODERATE. 4 hours.

Field Training: LOW. One day.

Lab: HIGH. (7 hours per composite sample) 14 to 21 hours per site.

Total Work Hours/Site: HIGH. 18 to 25 hours.

Possible assessment metrics and analyses

These include genus level HBI, BII, species richness, percent EPT, and percent dominance. The group felt that metrics based on assemblage similarity and assemblage loss would not be useful because the reference sites are likely to be distant and support different taxa. Panelists thought that multivariate analyses would be better in many ways than metrics, because they appear to be more efficient in showing the relationship between the macroinvertebrate assemblage and particular stressors. These techniques should be compared during pilot studies.

PERIPHYTON (Panelists: Loren Bahls, Donald Charles, Barry Rosen, R. Jan Stevenson, Gary Collins, Ben McFarland, Lythia Metzmeier)

Introduction

Periphyton are algae attached to substrates, and may include bacteria, microinvertebrates, and associated organic materials. Algae provide biomass for many primary consumers, such as macroinvertebrates and herbivorous fish. Periphyton are not the focus of public concern unless the accumulation of organisms is unsightly, produces taste and odor problems, or impedes water flow. In contrast to the lack of public concern about periphyton, they have been used extensively in the analysis of water quality for several decades (Kolkwitz and Marsson, 1908; Lange-Bertalot, 1979, Patrick, 1968; Stevenson and Lowe, 1986; Watanabe et al., 1988). Periphyton have proven useful for environmental assessments because they have rapid reproduction rates and short life cycles, thus they respond quickly to perturbation (Stevenson et al., 1991). They also are in direct contact with the water and are directly affected by water quality (Leclercq and Deplereux, 1987; Round, 1991). Periphyton are collected by sampling methods that are rapid and easily quantifiable and data can be standardized into indices (VanLandingham, 1976; Watanabe et al., 1990). Periphyton may also be sensitive to pollutants that other organisms tolerate relatively well (Mundie, 1991; Willemsen et. al., 1990), and they cannot avoid pollutants because they are immobile.

Periphyton assemblages reflect the water quality of a stream and to some extent, the riparian cover, which limits light. Several studies on streams have illustrated the usefulness of periphyton in detecting nutrient disturbance (Stevenson, 1984; Stevenson et al., 1991; VanLandingham, 1976), acidity (Mulholland et al., 1986; Planas et al., 1989), turbidity (Chessman, 1986), metal toxicity (Lampkin and Sommerfeld, 1982; Rushforth et al., 1981; Weitzel and Bates, 1981), urban storm water (Willemsen et al., 1990), and several other environmental disturbances. These studies indicate that periphyton respond to a great variety of pollutants and can be used to accurately diagnose the probable causes of degradation in a stream or river.

Periphyton are particularly relevant in the assessment of streams because they are often the base of the food web. In small streams that do not support fish, periphyton, along with macroinvertebrates, add some corroborating evidence to an assessment. The two state algalogists in our group, Lythia Metzmeier from Kentucky and Loren Bahls from Montana, selected periphyton and macroinvertebrates as the most cost-effective groups to use for assessment of stream condition.

The general consensus of the panel was that periphyton were potentially one of the best indicators of stream condition because they were directly affected by many disturbances in the catchment as well as instream chemical alterations. The available autecological information allow periphyton to be used as a diagnostic tool, and rapid growth make this group responsive to recent perturbations. In addition, simple field observations of macroalgae, such as bleaching of periphyton, can be the first signal that a recent disturbance has occurred.

Characteristics of assemblages that could serve as indicators

Estimates of Standing Crop

- Ash-free dry mass (AFDM)
- Chlorophyll-a
- Biovolume of cells
- Cell density
- Macroscopic assessment in field (moss, macrophytes, macroalgae)

Estimates of Species Composition

- Relative abundance and identification of diatoms, including indicator taxa and species richness

- Relative abundance and identification of soft-bodied algae (greens, blue-greens, chrysophytes, reds, etc.)

- Relative abundance, identification, and conditions of macrophytes

Measures of standing crop are general indicators of nutrient concentrations or toxicity; however, the group felt each measure has serious limitations for a program such as EMAP. Ash-free dry mass (AFDM) of periphyton samples includes microscopic heterotrophs and organic detritus as well as algae; thus, it is a poor measure of autotrophic standing crop. Chlorophyll-a was dismissed because of the adaptability of organisms to various physical and chemical conditions that would mask the signal from these organisms. For example, the same organism may have an order of magnitude more chlorophyll under low light and nutrient rich conditions than under high light and nutrient poor conditions (Rosen and Lowe, 1984). Other problems associated with

chlorophyll-a are high temporal variability and difficulty in interpreting trends. The panel considered biovolume too elaborate and expensive for routine monitoring. Also, different classes of algae have different sizes of cells and different proportions of internal structure occupied by vacuoles, which introduces variation to measurements of biovolume. Quantitative estimates of macrophyte standing crop (including vascular plants, macroalgae, mosses, liverworts, and ferns) require considerable field effort, plus they involve many of the measurement problems discussed for periphyton. Usually, more than one measure of standing crop is used as a ratio, such as AFDM:chlorophyll-a, but such ratios often only compound the problems of separate measures.

The panel, therefore, felt that species composition was preferable to standing crop for assessing and detecting changes in waterbody quality that would not be obtained with physico-chemical analysis or with other assemblages. Assessments of waterbody quality can be produced by interpreting species compositions with autecological information. Autecological information for as many as 3,000 algae (VanLandingham, 1976), particularly diatoms, has been recorded in the literature during the last century (Cleve, 1899; Hanna, 1933; Lowe, 1974; Patrick and Roberts, 1979; Rushforth et al., 1981; Stevenson et al., 1991). Periphyton data have been used to develop indices of pH, nutrient enrichment, salinity, organic enrichment, sedimentation, and toxic pollution (e.g., Descy, 1979; Sumita and Watanabe, 1983). The physiological characteristics of algae suggest that many other aspects of environmental quality could be determined through use of periphyton species composition and autecologies.

Species composition was also considered the most useful aspect of the periphyton for assessing biotic integrity of streams. The great richness and level of microhabitat specialization of algal species provide considerable material for quantitative analysis and metric and index development (Patrick, 1968).

Societal Value: LOW-MODERATE. Periphyton are rarely of public concern, although certain species tend to accumulate and are considered unsightly, produce taste and odor problems, impede water flow, or cause fish kills because of oxygen depletion when the algae die. In some waters, these effects can be of considerable concern to society, although the periphyton themselves are not highly regarded.

Stressor Responsiveness: HIGH. Periphyton are very sensitive to a number of stressors and the response is displayed by the loss of sensitive species and/or replacement or increase in tolerant species. Changes in species composition are due to differential species performance in different

environmental conditions. One of the main reasons periphyton are responsive to stressors and have good diagnostic capability is the large number of taxa in the assemblage that have known ranges and tolerances.

Periphyton response to natural macrohabitat changes can be distinguished from anthropogenic impacts. For example, clearcutting and logging roads in a catchment will increase diatom diversity and relative abundance of sediment-tolerant species, whereas streams without a canopy simply have many light dependent algae and fewer shade-tolerant forms.

The periphyton assemblage is mostly non-motile and cannot avoid a particular stress. A chronic stressor will affect the community composition and will be easily detected. The community will integrate the effects of a stress over time since the last scouring event and will do a fair job of indicating brief periods of stress (day-month time scale).

The algal component of periphyton encompasses the major primary producers in most stream systems and is often the base of the food web, making this group an inherently important component of biological integrity. Periphyton can also give an accurate estimate of the biological integrity of the system because several organisms are found only in clean water, whereas others are pollution tolerant. A list of the taxa present and their proportionate abundance can be analyzed using several indices to determine biotic integrity or diagnose specific stressors.

Ease of Quantitative Sampling: HIGH. Sampling time is estimated as 2 work hours for composite samples from slow, fast, and perhaps vegetation, habitats. The appropriate techniques can easily be described and incorporated into a sampling protocol (Cattaneo and Roberge, 1991). To incorporate macrophyton in a quantitative sampling regime, a field form is needed to record percent cover by the various components. Monitoring macrophyton would require additional training of field personnel.

Laboratory Ease: LOW. Three composite samples (one each from pools, riffles/runs, and vegetation) would require about 5–9 hours/sample to process, with an average of 5 hours.

Measurement Stability: MODERATE. The group considered measurement stability controllable if sampling protocols are followed. Because different assemblages occupy pools, riffles, and runs, and different types of substrates, the most accurate way to raise measurement stability would be to collect only one type of habitat or to composite by habitat. Runs would be best, and if

possible, with current velocities of 10–20 cm/sec. Riffles would be a close second choice and pools would be the least desirable, although probably adequate if sampled at the edges. In any collection, the current velocity should be recorded. However, single habitat sampling only characterizes that habitat, not the reach. A systematic random sample is preferred for EMAP reach characterization, which increases measurement error and noise. These can be smoothed by separate composites of riffle/run, pool, and vegetation habitats.

Index Period Stability: MODERATE. The periphyton community develops after scouring of stream substrata during freshets (Peterson and Stevenson, 1990). As temperature, nutrients, pH, and dissolved solids change seasonally, the periphyton will also change. The use of relative abundance and species autecologies would alleviate most index period stability issues. Although natural succession may occur during the index period, organisms will be replaced by ecologically similar organisms that provide equally useful indication of aquatic condition.

Among-Site/Among-Year Variation: HIGH. The periphyton assemblage may change up to 30% from year to year within the spring-summer index period (Patrick, 1968). Although this is a substantial change in species, the inferred change based on indices is much less variable. The collective experience of the group indicated that differences among sites would be much greater than the year-to-year variation at a site. Data exist from several years of studies that support these conclusions (Chessman, 1986; Evenson et al., 1981; Leclercq and Depiereux, 1987; McCormick and Stevenson, 1992).

Among-Site/Within-Site Variation: MODERATE. As microorganisms, periphyton are sensitive to microecological differences in current, substrate, light, and nutrients. However, composite sampling by major habitat types smooths this variation. The presence of most species is a function of water quality, with microhabitat differences varying relative abundances slightly.

Available Databases: HIGH. Periphyton have been used for over 50 years in monitoring streams and rivers, and several reports are available that describe the taxa in these assemblages. In addition, there are several databases that describe the known ranges of taxa along environmental gradients, including chemical and physical features and pollution tolerance levels. Analyses of variance components and historical assessments of streams and river quality are possible with the many samples that have been collected by diatomists and archived in museums during the last 90 years (e.g., Philadelphia Academy of Sciences, California Academy of Sciences).

Taxonomic Richness: HIGH. For diatoms alone, 50 taxa in a 500-organism count are commonly encountered in a sample counted for relative abundance. Additionally, 10–15 taxa present may be soft-body forms. Composite samples will increase this number of periphyton species. In all aquatic habitats, some periphyton will always be present and typically there is greater taxonomic richness in the periphyton than in the next higher trophic level.

Macrohabitats Occupied: HIGH. Periphyton exist in all macrohabits that have light, water, and inorganic nutrients available. To keep the information constant from site to site, it is important that samples from riffle/run and pool habitats not all be combined together; instead they should be kept as habitat-specific composites. Separate analysis of each habitat can triple lab and field time and it is recommended that a pilot examine composite sampling issues.

Guild Information and Diagnostic Power: HIGH. Algal microhabitat guilds are well understood, but algae guilds based on trophic level or reproduction are inappropriate. Separate indices are currently used that are sensitive to pH, flow rate, inorganic nutrients, organic enrichment, salinity, temperature, toxic organics, metals, and siltation. These indices use the assemblage information and existing autecological databases to diagnose these characteristics of the waterbody.

Using constrained ordination [canonical correspondence analysis (CCA)], the relationships between measured physical and chemical variables and the algal distribution can be determined (ter Braak and Prentice, 1988). In addition, CCA is used to produce more autecological information for future investigations and index development. The multivariate approach provides a powerful means of maximizing ecological information obtained from periphyton assemblages.

Signal/Noise Ratio: HIGH. There is considerable guild information, taxonomic richness, and diagnostic power in periphyton assemblages. Concerns about within-site variation are easily mitigated by composite sampling.

Information/Cost Ratio: HIGH. .The initial cost of collecting a single periphyton sample is low because little expertise is needed and only 5–10 minutes per station is required to take the sample. Laboratory analysis is more intensive and requires 1–3 hours per sample, depending on several factors. An average time would be 3 hours per sample, although repeat samples could take less time because the taxonomic expertise gained from one sample would facilitate identification in replicates from the same site. The time for collecting and processing three composites from each site is estimated as 8 hours. The information desired is identification of 500 organisms

in each composite to the level of species or variety, and quantitative counts, which have been emphasized by Palmer (1969), VanLandingham (1976), and several others. This is important for this assemblage, because species of the same genera may have very different requirements and tolerances. Several studies indicate that only the dominant species need to be identified, which would greatly lessen the burden of an exhaustive taxonomic study for each sample (Archibald, 1972; Schoeman, 1976; van Dam, 1982).

Identification to species allows the data to be manipulated in several existing indices and analysis using an autecological database. VanLandingham (1976) states that over 3,000 species have autecological information in the literature, which can be built into an autecological database appropriate for the periphyton in a region. The most detailed and current consensus on the tolerance of diatoms was compiled by Leclercq and Maquet (1987) and Descy and Coste (1990). Between 25 and 75 taxa may be encountered in a proportional count of 500 (relative abundance method), which provides a wealth of ecological information for the cost involved in producing it. Those taxa identified and examined for autecological information collectively describe and diagnose the condition of a stream. Certain species or groups of species are key indicators of condition, such as the 20 species of diatoms identified by Lange-Bertalot (1979) as the most pollution tolerant taxa world-wide. When a large percentage of the diatom flora is composed of certain of these species, we can, for example, say that the stream has a BOD_5 of > 22 mg O_2/L and the O_2 saturation deficit is > 90%.

Applicability to temporary streams

HIGH. None of the information already provided is different for periphyton in intermittent or ephemeral streams. Periphyton are always present when streams are wet and as some streams dry, the periphyton form dried crusts that can be analyzed from areas that are completely dry. The assemblage information is conserved because one major group, the diatoms, have silica cell walls that allow identification of dead cells.

Length of stream segment sampled

UNCERTAIN (HIGH). Although only a few rocks may support a representative assemblage, with hundreds of thousands of individuals, a pilot study is needed to adequately answer this question. This study could also include macrophyton. Spatial variability in population abundance, well known for periphyton (Jones, 1978; Pryfogle and Lowe, 1979), is caused partly by substrate, flow

(Stevenson, 1984), and light intensity, but the use of species composition and composite sampling from the same habitat may overcome this variability. During the pilot, each habitat should be subsampled to determine the within-habitat (i.e., riffle, run, or pool) variability and the number of samples needed to adequately describe stream condition. This information would be useful in determining if it is essential to sample each habitat and if sampling different habitats is comparable. During the index period, only pools might be available or some streams may lack runs, which would also make the information from this pilot study essential.

Field and lab expertise required

Field work hours: LOW. 1 person X 2 hr (periphyton); 1 person X 1 hr (macrophyton).

Field expertise: LOW. 1 hour training course (periphyton sampling); 2 day plant taxonomy and training course (macrophyton).

Sampling gear: LOW. Small knife, tooth brush, aluminum foil (for quantification of surface area), 3–4" PVC pipe with rubber seal, bottle brush, suction device, plastic petri dishes, small sheet of Plexiglas to slide under petri dish, small enamel tray to composite samples, 4 oz. plastic collection jars, and preservative (formalin, ethanol).

Laboratory expertise: HIGH. Master's degree with training in identification of diatoms to the species level and soft algae to the genus level. Ability to use a microscope, prepare slides, and enter data into a personal computer.

Work hours for identification: MODERATE. 2 hours/sample initially (routine identifications); 1 hour/sample (difficult species identifications/literature examined); 6-9 hours depending on the number of composites. This is an estimate, and most routine analysis, from counts to final metric or index, is usually completed in a 3-hour period. Initial time must be set aside to accumulate the appropriate references and simple laboratory preparation. Another aspect of quality assurance that is not time consuming but very important is photographic documentation of identifications. Visits to appropriate museums are also advisable, with periodic taxonomic workshops for laboratory personnel. Slide storage is easy and archival.

Total Field and Lab Hours/Site (assuming 2 composite samples, periphyton only): 8 hours. QA subsamples would increase costs.

Possible assessment metrics and analyses

Periphyton Metrics: A combination of several metrics, which use the relative abundance of the species in the assemblage, can be used to evaluate periphyton assemblage characteristics and water related changes. Several new approaches, including multivariate analysis, make periphyton a better indicator than techniques that are more than 5 or 10 years old. The following examples are presently used in evaluating the periphyton assemblages.

- PBI was developed by Lythia Metzmeier (Kentucky SOP, 1992) and is currently used in Kentucky water quality assessments. Metrics used to construct the Periphyton Bioassessment Index include taxa richness, Shannon-Weaver diversity, diatom taxonomic index, relative abundance of sensitive species, and percent community similarity. Scores for each metric range from 1 to 5 and these scores can then be translated into descriptive site bioassessments such as poor, fair, good, or excellent.

- The Pollution Tolerance Index, developed by Lange-Bertalot (1979), highlights organisms that are sensitive to toxic substances.

- An index developed by Palmer (1969) ranks several genera, including soft-bodied forms, by their tolerance to organic pollution.

- The Halobien Index was developed by Kolbe (1927) for salinity.

- Eutrophication indices were developed by Smith (1966) and modified by Lowe (1974) for discerning nutrient concentrations and humic contributions. The ratio of greens/blue-greens identified to genus is also used as an indicator of eutrophication.

- A Siltation Index that examines the proportion and richness of *Navicula* and *Nitzschia* is currently used in Montana (Bahls et al., 1992). Another index that is sensitive to siltation would add more epipelic diatoms to this index (a motile/nonmotile diatom ratio).

- An evenness metric based on the proportion of the assemblage represented by the dominant taxon (Bahls et al., 1992).

- Multivariate analyses, such as CCA and weighted averaging, are useful because they make use of the ecological information in assemblages.

Macrophyton Metrics: Percent cover of: flowering macrophytes (to family), macroalgae (to division and/or genus), mosses and liverworts (to division/genus, only 10 genera are common), ferns (to genus, 4 genera common), horsetails (1 genus, *Equisetum*), quillwort (1 genus, *Isoetes*). Metrics have not been developed for this group; however, certain species are known to cause persistent problems such as clogging of waterways, and some taxonomic information may be useful in the future.

METABOLISM (Panelists: Tom Bott, Cliff Dahm, Steve Golladay, Alan Herlihy, Brian Hill, Bob Sinsabaugh)

Introduction

Ecosystems are complex, self-regulating, functional units, often described by rates and processes, such as energy flow or material cycling, which are mediated by the trophic structure of the ecosystem. Such processes integrate the functioning of the entire community and are important components of two major concepts in stream ecology: the river continuum (Vannote et al., 1980) and resource spiraling (Newbold et al., 1981). Heterotrophic microorganisms (bacteria and fungi) are responsible for oxygen sags in streams and for much of the decomposition of organic matter (leaves, twigs, fruit, algae, macrophytes) naturally deposited in them (Hynes, 1970; Petersen and Cummins, 1974).

Process indicators are those metrics that measure energy flow and material transformation within the ecosystem. Some commonly used process measures of stream ecosystems include: benthic community metabolism (both primary productivity and respiration), microbial community activity, and nutrient spiralling. These measures are addressed in the following sections.

Characteristics of attributes that could serve as indicators

After grappling with numerous potential metabolic indicators, including primary production, community respiration, microbial enzyme activity, and nutrient uptake rates, the metabolism group settled on sediment (benthic) respiration as the attribute most likely to succeed. The other candidate indicators were abandoned, given the one-time sampling constraint, for the following reasons:

Primary production: Too variable for a one-time analysis, though there is a substantial database for comparisons.

Microbial enzymes: Interpretation is too subjective, too site specific, and too variable.

Nutrient Uptake: Too site specific; too hard to understand complex interactions within hyporheic zone.

The group selected benthic respiration as the only indicator that could be used, with some sampling constraints, on a one-time sampling basis (Bott and Kaplan, 1985; Hedin, 1990; Smith et al., 1985). The sampling constraints include sampling respiration only on fine-grained sediments, and reporting respiration on a "per gram organic carbon" basis. These constraints preclude the use of chambers, and compel the use of BOD-bottles or smaller equipment for sampling. The proposed sampling system involves 50-mL centrifuge tubes and measurement of changes in dissolved oxygen (see methods section).

After selecting benthic respiration as the indicator of choice, the group re-evaluated the indicator in light of its responsiveness to perturbations and possible metrics that could be derived from this information. Panelists felt that benthic respiration was perturbation responsive; that is, it would show positive or negative deflections in response to specific stressors, with some uncertainty arising from the fact that microbial communities are highly adaptive (Anderson et al., 1981; Barkay and Pritchard, 1988). Acclimation to stressed conditions could mask responses to stressors. However, this also could be an advantage, because it allows measurement of "pre-adaptation" to major classes of pollutants (Bott and Rogenmusen, 1978; Freeman et al., 1990, also see "Substrate-Influenced Respiration," Table 3).

Respiration relative to the amount of organic carbon available would yield an estimate of organic carbon turnover, a metric that could be compared across sites and regions, and one that might be adjusted to temperature using known or derived Q_{10} relationships. The proposed method is designed for headwater to mid-order streams, whose metabolism is primarily sediment-based. The group maintained that the method could easily be adapted for larger rivers exhibiting respiration that is more water-column based.

Despite the patchiness of substrate and organic matter distributions, panelists felt that pools would yield consistently similar sediments from site to site and region to region. Pool sampling also minimizes the problem of comparing perennial, intermittent, and ephemeral streams, if enduring pools remain in temporary streams.

The attributes recommended were:

- Sediment respiration (initial minus final sediment dissolved oxygen after 2 hours incubation).
- Sediment organic matter (ash-free dry mass)

- Microbial density counts (cells/g AFDM)
- Substrate-influenced respiration (intial minus final dissolved oxygen of sediments spiked by major classes of pollutants and then incubated 2 hours).

Table 3. Microbial Metric Ratings by Criteria

CRITERIA	Water BOD	Sediment Resp.	Sediment OM	Substrate-influenced Resp.	Mean
Societal value	L	L	L	L	L
Responsiveness	M	M	L	H	M
Sampling ease	H	H	H	H	H
Laboratory ease	M	M	M	M	M
Measurement stability	H	M	M	M/H	M
Index period stability	M	M	M	M	M
Among-site/Among-year variability	M	H	H	H	H
Among-site/Within-site variability	M	H	H	H	H
Available databases	H	M	H	L	M
Taxonomic richness	L	L	L	L	L
Macrohabitats	H	L	L	L	L
Guild information [pollutant response guilds]	M	M	M	M	M
Diagnostic power	M	M	L	M	M
Signal/Noise ratio	M	M	M	H	M
Info/Cost	M	M	M	M	M

Societal Value: LOW. There is very little concern with stream metabolism, unless the system becomes anerobic and foul smelling.

Responsiveness: MODERATE. Bacteria are responsive to toxics, but less so to physical habitat alteration, flow, and species introductions and exploitation.

Sampling Ease: MODERATE. About 4 work hours are needed to assemble and disassemble the incubation apparatus and collect sediments for laboratory analyses.

Laboratory Ease: MODERATE. We estimate 6 work hours will be needed, to be accomplished by an entry-level microbiologist.

Measurement Stability: MODERATE. Measurement stability is increased by compositing sediment samples from multiple stations at a reach. Like most assemblages, scouring events will disupt bacteria, but they reestablish once the organic sediments are redeposited.

Index Period Stability: MODERATE. Periods of high temperature (summer) and organic deposition (autumn, late summer) will increase variance, but the major destabilizing factor during the proposed spring index period is flooding.

Among-Site/Among-Year Variation: HIGH. Microbes vary considerably among sites with differing organic and toxic loads, but they are relatively insensitive to inter-annual climatic changes.

Among-Site/Within-Site Variation: HIGH. Although there are substantial differences in microbe populations within a site, composite samples from depositional habitats will smooth within-site variation. This allows discrimination of among-site differences.

Available Databases: MODERATE. Several long-term databases exist as a result of intensive site-specific studies by academicians, however the number of sites studied is relatively small.

Expected Taxonomic Richness per Reach: LOW. Richness is not a concern for this assemblage.

Macrohabitat Use: LOW. Although microbes occupy all habitats, our focus is only on those in depositional, organic-rich areas (i.e., fine sediments in pools).

Guild Information: MODERATE. Pollution response guilds have been identified for pesticides, metals, petroleum, and sewage. However, less is known about tolerance, habitat structure, and feeding guilds.

Diagnostic Power: MODERATE. Microbes are differentially sensitive to different pollutants and organic loads, which can be evaluated via substrate-influenced respiration.

Signal/Noise Ratio: MODERATE. Although a pollutant signal may be strong, the signal for other more common stressors may be quite noisy. Also, Ford (1989) and Schindler (1987) found that process-level signals of stress were generally noisier than structure-level signals.

Information/Cost Ratio: MODERATE. The estimated cost of this candidate indicator is the lowest of those examined; however, it is only moderately responsive and stable, incorporates little taxonomic and macrohabitat information, and is often relatively noisy.

Applicability to temporary streams

LOW. Because of the emphasis on pool sampling, the methods are equally useable in perennial, intermittent, and ephemeral streams; however, if residual pools are lacking, this assemblage is inapplicable to temporary streams.

Length of stream segment sampled

HIGH. If pools are small, multiple pools should be sampled and composited. In large pool-dominated reaches, multiple samples within the pool should suffice. A pilot study is needed to determine the number of small pools that should be sampled per reach, the number of samples that should be taken from a pool when the reach is dominated by a single large pool, and the distance apart the samples should be. The stream length sampled should be the same as the rest of the biota to be consistent.

Field and lab expertise required

Field: MODERATE. Two persons are needed for 2 hours each to assemble and disassemble the respiration apparatus and collect sediment samples. The apparatus must remain in place for 2 hours, but does not require attention during this time.

Laboratory: MODERATE. Two persons are also needed for 3 hours each in the laboratory to count microbes, conduct BOD analyses, determine sediment organic mass, and measure sediment-influenced respiration.

Total Field and Lab Labor Hours: MODERATE. 10.

Gear: Field work: sterile centrifuge tubes, pipettes/pipetteman, DO meter and probe, hand vacuum pump, bucket, 1 mm sieve, SIR supplements, thermometer. Lab work: vacuum pump, nucleopore filters (Irgalan black), fluorescein diacetate, UV-fluorescence microscope with 1000X objective, muffle furnace.

Possible assessment metrics and analyses

- Organic matter turnover rate (mg/day)
- Microbial density (cells/g AFDM)
- Substrate-influenced respiration rate (change in mg/day)

PHYSICAL HABITAT (Panelists: R.L. Beschta, P.R. Kaufmann, L. Poff, E. Rankin, and K. Stein)

Introduction

Habitat in streams can be considered to include all the elements of the abiotic and biotic environment that influence and provide sustenance to organisms within the stream. Karr et al. (1983, 1986) have identified habitat structure, flow regime, energy source, chemical variables, and biotic factors as the five principal factors that influence the biotic integrity or ecological health of aquatic ecosystems. Several authors and agencies have described physical habitat evaluation procedures or provided review and guidance on setting up programs to measure physical habitat in streams and streamside riparian zones (e.g., Platts et al., 1983; Plafkin et al., 1989; Rankin, 1989; MacDonald et al., 1991). In the context of physical habitat for EMAP's proposed national monitoring program for streams, we focus on habitat structure and flow regime. We also consider energy sources (light, canopy, woody debris) and some biotic factors (riparian vegetation influences, aquatic macrophytes, and attached algae) as part of the physical habitat.

Our consensus was that we could assess physical habitat during any season. In general, we identified this time as a low-flow season after leaf-out and not closely following major flood events. For most of the country, this is the summer season, although some regional differences are likely and should be examined. For example, late summer (August) might be appropriate for snowmelt systems in the Rocky Mountains, but spring might be more appropriate in parts of the arid Southwest.

Characteristics of attributes that could serve as indicators

Stream Classification Level: Stream physical habitat varies naturally, as do biological characteristics; expectations differ even in the absence of anthropogenic disturbance. We recommended a hierarchical classification, in which ecoregion is the highest level, for grouping streams according to similar climate, topography, elevation, vegetation, temperature, hydrology, and aquatic geochemistry. Ecoregion boundaries may need to be adjusted for zoogeographical reasons, but that is mainly a biologically driven concern. Stream size is the second level of hierarchical classification, and general gradient is the lowest level. Admittedly, there is some overlap or correlation among these stream attributes. Additional classification by valley landform might be necessary if constrained and unconstrained reaches are not separated by the other three variables. Only stream size would constitute statistical sampling strata. The purpose of stream size stratification

would be to balance sampling effort relatively evenly across the range of stream sizes, rather than in strict proportion to the length or number of stream segments of each size.

All three of the classification characteristics (ecoregion, size, and gradient) would be used in analyzing and interpreting physical habitat measurements. Reference site and historical data would probably be required to define expected habitat condition in the absence of disturbance, and diagnostic analyses would be necessary to separate natural and anthropogenic disturbances. Physical effects of natural and anthropogenic disturbances may be quite similar, and natural and anthropogenic disturbances may interact to obscure the true causes of physical habitat changes.

At the classification level, only general quantification of stream size and gradient are desired, and the information should probably be derived from maps. Stream segment size might best be classified in terms of topographic basin size, mean annual discharge, or stream order. There would certainly be climatic, hydrologic and geologic differences that would make stream size comparison by any one parameter difficult across different ecoregional settings (Hughes and Omernik, 1983). At the classification level, stream segment gradient obtained from 1:24,000 scale (or 1:100,000) would be adequate.

Stream Habitat Monitoring Level: Based on our experience, judgment, and reading of the literature, we identified seven stream physical habitat attributes that are biologically relevant and that are typically changed by humans:

1. Channel/Riparian interaction
2. Stream size
3. Channel gradient
4. Habitat complexity and cover (including woody debris)
5. Channel substrate (including aquatic macrophytes)
6. Riparian vegetation
7. Anthropogenic alterations

Notice that stream size and channel gradient are also considered as stream classification variables. The monitoring level consists of more specific measurements made in the field. For example, the change in size attributes, such as width or discharge relative to other streams within a catchment size class, may be a response to anthropogenic perturbations. Local reach gradient and its spatial variability may differ substantially from that measured from a map used to roughly

classify streams. The following paragraphs provide brief discussions of the seven general physical habitat attributes and the approaches that might be used to index them.

Channel/Riparian Interaction: Anthropogenic activities, including grazing, farming, flood control, and urbanization, can result in the separation of streams from their flood plains and riparian zones. The secondary effects on channel structure, riparian vegetation, and ephemeral aquatic habitats can markedly affect the biotic integrity of stream ecosystems. Expectations for the potential magnitude and extent of interaction of streams with the terrestrial environment differ for streams according to the degree of valley constraint (see discussion of stream classification variables). Possible metrics that might comprise an index of channel/riparian interaction are:

- Channel sinuosity (obtained from remote imagery or high resolution maps).
- Channel incision (semi-quantitative measure of bank height of active channel).
- Channel morphometric complexity (index from calculation of spatial variability in channel width and depth profile data).

Stream Size: Some aspects of stream size may be affected by anthropogenic activities and may alter the quantity and quality of aquatic habitat. We recommend that the following stream size variables be measured:

- Depth (mean, median, and spatial variability from long profile of approximately 100 systematic depth measurements at intervals of 0.5 channel-widths along reach).

- Width (mean, median, and spatial variability from long profile of approximately 100 sequential wetted channel width measurements at intervals of 0.5 channel-widths along reach).

- Discharge (field measurement of baseflow using current meter at one channel cross-section; office calculation of estimated mean annual flow obtained from generalized runoff data).

Channel Gradient: Channel gradient is a very important determinant of the potential energy that can be converted into water velocity (Leopold et al., 1964). At a given gradient, water velocity in a stream is determined by the discharge, channel cross-section area and shape, and channel hydraulic roughness (Chow, 1959). It would be determined by field measurements over a whole reach or 5 to 10 subcomponents of each study reach.

Habitat Complexity and Cover: Several stream characteristics do not fit neatly into classic hydrological measurements, but are extremely important to the quality of the overall physical habitat for aquatic life. Probable metrics include:

- Habitat type and distribution. Classification, coarse measurement (width and maximum depth), and schematic mapping of study reaches into channel-unit scale habitat types. In higher gradient streams, the approach would be much like that of Bisson et al. (1981), including three fast water types (cascades, rapids, riffles), glides, pools identified by their likely formative agents, marginal backwaters, and off-channel backwaters and sloughs.

- Large woody debris. Count, estimated diameter and length, and position along study reach. We define "large woody debris" as pieces larger than 10 cm in diameter and longer than 0.5 m, but we include smaller pieces found in massive aggregations.

- Residual pools, channel complexity, hydraulic roughness. Estimates of residual pool (Lisle, 1982, 1987) frequency and size distribution, and reach-scale indices of slackwater volume, channel morphometric complexity, and hydraulic roughness can be quantitatively estimated from simple and rapid systematic profiles of width and depth along stream reaches (Kaufmann, 1986; O'Neill and Abrahams, 1984; Robison and Beschta, 1990; Stack, 1989). Indices of morphometric and hydraulic complexity may be correlated with nutrient retentivity and may also be indicators of high-flow velocity cover in a stream reach (Kaufmann, 1986, 1987). Residual pool depths and volumes give an indication of habitat space during extremely low flows (Lisle, 1987).

- In-channel cover. Abundance (spatial frequency) of various types of cover that could provide fish concealment and macrobenthos substrate (undercut banks, overhanging vegetation, aquatic macrophytes, large woody debris, boulders).

- Shading. The group recommended canopy densiometer (or possibly solar pathfinder) measurements of percent shading cover at 10 stations. Notice that riparian vegetation structure surveys at the same locations provide information on size and whether cover is broadleaf or coniferous.

Channel Substrate, Including Aquatic Macrophytes: Substrate is often cited as a major control on the species composition of macroinvertebrate, periphyton, and fish assemblages. Changes in

substrate composition are often indicative of catchment and streamside disturbances that mobilize sediment. The size of substrate also gives some indication of the magnitude of channel-forming peak flows. We have included aquatic macrovegetation because of its role as a substrate, but perhaps more importantly, because its presence may be a useful indication of water velocities and trophic status.

- Areal cover. The panelists recommended rough schematic mapping of dominant substrate size class. It could be done during the habitat classification pass up the stream reach).

- Size distribution. Systematic transects should be made to quantify substrate embeddedness and the distribution of particle sizes. We did not settle on a method; there are several, and some are quite rapid.

- Aquatic macrophytes and algae. At 10 channel/riparian habitat evaluation stations, determine presence/absence of aquatic macrophytes (including moss), filamentous algal mats or streamers, or slick rock substrates.

Riparian Vegetation: The importance of riparian vegetation to channel structure, cover, shading, nutrient inputs, large woody debris, and wildlife corridors, and as a buffer against anthropogenic perturbations is well recognized. We recommend that riparian vegetation structure be measured on study reaches. Measures at 10 systematically located stations along reaches might be adequate. Measures should include the areal cover in three layers of vegetation (canopy, mid-layer, and ground cover), should distinguish coniferous from deciduous vegetation, and should identify whether vegetation is woody, herbaceous, or grass.

Anthropogenic Alterations: Anthropogenic alterations, structures, and other evidence of human activities in the stream channel and its riparian zone may in themselves serve as habitat quality indicators, and may also serve as diagnostic indicators of anthropogenic stress.

- Channel disturbances. Note the abundance or extent of channel revetment, straightening, tiling, ditching, snagging, channelization, bridges, culverts, trash (car bodies, grocery carts, pavement blocks, etc.).

- Near-channel disturbances. Note the frequency or extent of buildings, roads, croplands, livestock, logging, mining, landfills, effluent pipes, etc., in the near-channel riparian zone.

Societal Value: MODERATE. Habitat structure is generally the first stream quality perceived, and is subsequently hard to ignore. People appear to have very strong preferences with regard to stream habitat. However, the degree to which society's stream habitat preferences support biotic integrity appears to be highly dependent on the geographic setting. The preferred habitat quality for open canopy, high-elevation, mountain meadow streams, for example, seems to approximate the "pristine" condition. When the pristine condition includes extremely dense vegetation, or the "natural" channel condition includes elements that interfere with comfort, fishing, or boating, humans are inclined to "clean up" the stream and its banks. Growing ecological sophistication may lead many people to value stream habitat structure that is typical of natural stream environments. These habitat structural qualities may be valued for their own sake, but also because they support the type, abundance, and diversity of organisms that are found in pristine stream environments.

Responsiveness: MODERATE, depends upon the stressor. For example, habitat structure would be unresponsive to chemical inputs and exotic species, but responsive to riparian grazing or "earth moving" associated with urbanization. Changes in habitat structure may be direct, as in the case of channelization and bank revetment.

Sampling Ease: LOW. The physical habitat measurements described typically require 5–8 work hours, but the time depends on the size and complexity of the stream, and whether the work is done by one or two people. One person requires 4 to 6 hours; two persons 2.5 to 6 hours.

Laboratory Ease: HIGH. No material samples are brought out of the field. The only laboratory requirements are data entry, verification, and analysis.

Measurement Stability: MODERATE, overall, but varies from low to high. When taken over sufficient stream length (e.g., 40 channel widths), quantitative measurements like width, depth, and residual pool size distributions are quite robust. The more subjective visual estimates, like riparian vegetation cover and habitat typing, are more variable among observers.

Index Period Stability: HIGH. Except for discharge and habitat type classification (perceived differently as flows change), physical habitat attributes are relatively stable over the time frame of a summer index period. The quantitative channel measures, such as multiple width and depth measurements, also vary with flow, but robust, flow-independent residual pool calculations can be based upon such measurements.

Among-Site Versus Among-Year Variation: MODERATE. In a homogeneous region with similar degrees of anthropogenic habitat alteration, habitat structural variations at single sites may vary moderately in relation to those among sites in the region. As physical habitat differences among sites increase in a region, the between-year differences at single sites become comparatively less important.

Among-Site Versus Within-Site Variation: MODERATE. Within-site variation can be reduced by explicitly specifying an unbiased physical habitat sampling design on each stream reach, and by insuring that the reaches are of adequate length to allow the measurements to incorporate sufficient variability. Just as with among-year variation, the importance of within-site variation in relation to among-site differences depends upon the natural heterogeneity of the region and the range of anthropogenic alteration of habitat structure encountered.

Available Databases: MODERATE. There is a large amount of physical habitat classification and sediment size data. Some very good data sets exist for examining the utility of systematic, quantitative channel structure measurements in several dozen streams.

Applicability to Temporary Streams: HIGH. Except perhaps for traditional physical habitat typing, virtually all the channel and riparian habitat structural measures can be applied to intermittent and ephemeral streams. Understandably, attributes like water depth and discharge may have values of zero, but this itself is valuable information. Measurement of the presence of water and riparian vegetation in large numbers of channels of sufficient length (e.g., 40 channel widths) may serve as sensitive indicators of climatic change.

Diagnostic Power: HIGH. Physical habitat information directly serves a diagnostic role for biotic indicators. Natural differences in physical habitat must be used to define biotic expectations in the absence of human disturbances. Similarly, examination of trends or differences in physical habitat is essential to discriminating between chemical, thermal, biotic, and other possible causes of changes in biotic integrity.

Signal/Noise Ratio: MODERATE. As an overall suite of measures, habitat structure incorporates a tremendous amount of natural variability and there are many variables. Consequently, physical habitat classification effectively reduces noise in biological indicators. Many types of physical habitat response to anthropogenic alteration are massive and obvious (e.g., direct channel alteration and riparian vegetation removal). However, many are difficult to separate from natural varia-

tion (e.g., substrate size), many physical habitat measures are imprecise and somewhat subjective, and data interpretation is also imprecise. Therefore, we estimate that overall signal/noise ratio is moderate.

Information/Cost: MODERATE. From data collection to analysis, habitat structure information is relatively inexpensive. Depending upon the physical/biological setting and the type of anthropogenic stresses, however, the information content of various types of physical habitat measurements may vary considerably. Some will be critically important in defining biological expectations or diagnosing probable causes of impairment; others may seem to be superfluous. The information value may materialize if larger regional differences or anthopogenic stresses are encountered.

Work hours: MODERATE. See Sampling Ease, page 61. No laboratory costs other than data entry, verification, and analysis.

Applicability to temporary streams

HIGH. For the most part, we felt that all the measures listed for perennial streams would be appropriate for intermittent and ephemeral streams. It is still important to make such measurements on dry and near-dry channels in order to characterize available habitat structure and quantify changes over time that might result from such influences as climate change and irrigation withdrawal.

Length of stream segment sampled

HIGH. We caution that the segment design, in contrast to a basin design, is not optimal for discerning differences that occur along the stream size continuum. In addition, the segment design is not optimal for diagnosing probable causes of impairment if biotic condition is largely controlled by off-site influences not detectable on maps, such as upstream or downstream refugia that seed the study reach or dams that restrict flows or migrations.

The group believed that sample units of 30 to 50 times the average wetted channel width should be adequate for characterizing fluvial features at the scale of macrohabitat (habitat features with dimensions at least the magnitude of the channel width). We are aware of several fish assemblage studies from Oregon, Washington, Ohio, Wisconsin, and Maryland that tend to confirm this, as do some analyses of channel morphology from wetter parts of Oregon and Alaska. However,

we felt that the regional generality of this conclusion was somewhat of a guess, particularly in arid settings where refugia might be very important. We felt that it would be wise to confirm the "30 to 50 channel widths" assumption with additional literature search and analysis of data sets that in several cases already exist.

Field and lab expertise required

LOW-MODERATE. Two field persons would be required for field work. The most efficient mix would be one person with fluvial geomorphic and fish habitat experience and another with riparian vegetation experience. Except for the channel/riparian interaction indicators, the measurements could be simple and direct, so that field samplers would not have to be as highly qualified as hydrologists or fluvial geomorphologists. For example, we felt that because many fish biologists and ecologists routinely make similar measurements, they would be able to make the prescribed physical habitat measurements if given training and well-defined protocols.

Based upon our own field experiences, we estimated that the field work would at first require one person for about 7 to 8 work hours, or two people working for 4 to 5 hours. After streamlining techniques and gaining experience, one person could probably collect the data in 4–6 hours and two people would need 3–4 hours. Some of the habitat typing, substrate measurements, and riparian vegetation assessments might be counted as part of setting up the sampling schemes for fish and macroinvertebrates in the reach, or during collection of habitat data for riparian birds. According to the separate field activities, the breakdown would be as in Table 4.

Possible assessment metrics and analyses (see "Characteristics of attributes that could serve as indicators," page 59)

We did not include the following categories of information as physical habitat monitoring variables under Objective 5, but panelists felt these related physical/chemical variables are necessary for interpretation and diagnosis in EMAP-SW.

- Water chemistry and temperature

- Flow regime. Flow regime attributes would have to be estimated primarily in the office or laboratory from other information sources in combination with field information gathered under separate headings. They include the following:

Table 4. Field Work Breakdown for Physical Habitat Monitoring

2 p	1 hr	Width-Depth profiles at a resolution of about 2 measurements per channel-width of stream length. Residual pool measurements, local gradient (reach scale).
2 p	0.5 hr	Channel cross section measurement.
1 p	0.5 hr	Stream discharge at cross section.
1 p	1-2 hr	Classify and map major habitat types, measure substrate size and embeddedness, count and estimate size of large woody debris.
(1 p)	(1 hr)	Optional quantitative estimation of in-channel cover, shading, channel disturbances, aquatic macrovegetation, plus qualitative habitat evaluation (probably at 10 stations along study reach).
1 p	1 hr	Riparian vegetation structure and human disturbance evaluation using systematic sampling method (probably at 10 stations along study reach).
TOTAL: 7 to 8 work hours (1 to 2 people, 4 to 5 hours elapsed) Ultimately about 6 work hours (2 people, 3 hours)		

- Hydrologic flashiness. Ratio of peak flows to low flows; might be estimated from literature, landscape information from basin, and substrate and channel morphology data collected on site.

- Lowest flows. Estimated from literature and generalized regional runoff information.

- Seasonal flow pattern. Estimated from generalized regional runoff information.

- Flow alterations. Upstream and downstream dams and diversions.

- Biological barriers and corridors. Information concerning the connectedness to other waterbodies, hydraulic and chemical barriers, falls, lakes, temperature and shoalwater barriers.

- Catchment land use/land cover. Include up-slope areas and the riparian corridor; obtain from remote sensing and county databases.

- Riparian floral and faunal composition and ecological integrity. Though not absolutely necessary in a streamlined aquatic monitoring program, given the riparian measurements we recommended, we felt that EMAP should consider riparian corridors as a separate resource class. We felt that sample units for these riparian areas would best be located adjacent to the EMAP stream and river sample segments. We might most effectively define the riparian corridor as the "valley bottom", the part of the landscape that is reworked by the channel, the zone of bedload transport and deposition over time scales of centuries. This part of the valley often has groundwater exchange with the river, important hyporheic processes, and vegetation influenced by flooding and channel meandering. As a minimum, four general attributes of valley bottoms should be assessed:

  - Channel-valley interaction, indexed by sinuosity, flood frequency (evidence in vegetation), and channel incision.

  - Vegetation structure and composition.

  - Wildlife (amphibians, birds, possibly mammals).

  - Anthropogenic activities (human and livestock population density, land use, land cover, road density, irrigation, channelization, canals, etc.).

SUMMARY

Table 5 on the next page summarizes the results of the assemblage- or attribute-specific work groups. Based on the independent assessments of the individual groups and review by EMAP indicator leads, plus minimal editing, we rank the assemblages in order as follows, by total criteria score: periphyton, fish, birds, amphibians, macrobenthos, and bacteria. Based on the most critical criteria, the rankings are: fish, amphibians/periphyton, birds, and macrobenthos/bacteria. These estimates are of course preliminary and subjective; they must await pilot studies for more accurate estimates of several criteria. In addition, further review of the ratings may result in their modification, especially when the six assemblages are compared in the field. It is also possible that other criteria for selecting indicators will be proposed, which could easily result in considerably different selections. However, this workshop and the ratings that resulted from it portray a process by which EMAP-Surface Waters can attempt to make relatively objective selections of assemblages that appear most appropriate for monitoring and assessment.

Table 5. Summary of Assemblage and Physical Habitat Ratings by Criteria[a]

Criterion	Bird	Amphibian	Fish	Macrobenthos	Periphyton	Bacteria	Habitat
Societal value[b]	●	●	●	•	•	•	O
Responsiveness[b]	O	●	●	O	●	O	O
Sampling ease (hrs)	• (8)	• (6)	• (8)	O (4)	● (2)	O (4)	• (8)
Laboratory ease (hrs)	● (3)[c]	● (2)	O (4)	• (14)	O (6)	O (6)	● (0)
Measurement stability	●	O	O	O	O	O	O
Index period stability	O	●	●	O	●	O	●
Among-site versus among-year variation[b]	●	O	●	●	●	●	O
Among-site versus within-site variation	●	O	●	O	O	●	O
Available databases	●	•	●	O	●	O	O
Applicability to temporary streams	●	●	•	•	●	•	●
Taxonomic richness	O (35)	• (6)	• (20)	● (80)	● (120)	• (6)	NA[d]
Macrohabitat use	O	●	●	●	●	•	NA[d]
Guild information	●	•	●	O	●	O	NA[d]
Diagnostic power	O	O	●	●	●	O	●
Signal/noise ratio[b]	O	●	●	O	O	O	O
Information/Cost[b]	O	O	●	O	O	O	O
Work hours	11	8	12	18	8	10	8
Total score	62	54	64	50	70	44	NA[d]
Total critical criteria score	19	21	25	15	21	15	NA[d]

[a] • = low (1); O = moderate (3); ● = high (5).

[b] Most critical criteria

[c] Intensive field training

[d] NA = not applicable

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APPENDIX A

ASSEMBLAGE- AND REGION-SPECIFIC EVALUATIONS OF AMPHIBIAN AND REPTILE INDICATOR SELECTION CRITERIA

ASSEMBLAGE: Anurans - frogs and toads
REGION: X = East and Central, W = West

	High	Medium	Low	Comments
Responsiveness	X-W			
Biointegrity	X-W			
Ease of sampling	X	W		
Measurement stability		W	X	
Signal/noise ratio			X-W	1.
Information/cost ratio	W		X	
Available databases	X-W			
Sampling methods	X	W		2.
Taxonomic richness		X	W	3.
Macrohabitats				4.
Guild information	X	W		
Diagnostic power	W		X	5.
Among-site/Among-year variation			X-W	
Index period stability	X-W			

Comments:

1. Mobile, not dependent on streams.
2. Sampling methods could be improved.
3. Breed primarily in ponds, found in backwaters of streams.
4. First- to third-order streams east; first- to fifth-order streams west.
5. West - best diagnostic group of taxa we discussed; however, quickly disappearing from former ranges.

APPENDIX A (Continued)

ASSEMBLAGE: Turtles
REGION: X - Central, East, South; W - West

	High	Medium	Low	Comments
Responsiveness		X-W		1.
Biointegrity	X-W			
Ease of sampling		X-W		2.
Measurement stability	W	X		3.
Signal/noise ratio	X-W			
Information/cost ratio		X-W		
Available databases	X	W		
Sampling methods	X-W			
Taxonomic richness	X		W	
Macrohabitats				4.
Guild information				5.
Diagnostic power		X-W		
Index period stability	X-W			
Among-site/Among-year variation	X-W			

Comments:

1. Responsive to tissue contamination; some species more responsive than others.

2. Turtle traps, 24-hour sets, low tech, easy training.

3. Identification could be difficult, catch and photograph. ID easier in west.

4. East - third order and above; west - second order and above.

5. Not available.

APPENDIX A (Continued)

ASSEMBLAGE: Salamanders
REGION: X - Eastern mountains, C - Eastern Coastal, W - Pacific Northwest

	High	Medium	Low	Comments
Responsiveness	X-C-W			1.
Biointegrity	X-C-W			2.
Ease of sampling	X-C-W			
Measurement stability	W	X-C		3.
Signal/noise ratio	W	X-C		
Information/cost ratio	X-W		C	
Available databases	X-W	C		4
Sampling methods	X-C-W			
Taxonomic richness	X	W	C	
Macrohabitats				5.
Guild information	X-W		C	6.
Diagnostic power	X-W		C	
Index period stability	X-C-W			
Among-site/Among-year variation	X-C-W			

Comments:

1. Responsive to physical habitat change, fish predation, acidity.
2. High population density, easily located.
3. Year-to-year stability in number of taxa, individual numbers variable.
4. Available literature on old growth studies.
5. First- to third-order streams, riparian areas, splash zones, waterfalls.
6. Jaeger - work on feeding guilds; Hairston - habitat and feeding guilds.