Forest Ecosystem Monitoring in Saskatchewan and Alberta: Identification of Aquatic Elements and Sampling Protocols

Garry Scrimgeour
Sharon Kendall

Alberta Research Council, P.O. Bag 4000, Vegreville, AB T9C 1T4
E-mail: gscrimgeour@arc.ab.ca; sharonk@arc.ab.ca

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Disclaimer

The views, statements, and conclusions expressed in this report are those of the authors and should not be construed as conclusions or opinions of the ABMP. Development of the ABMP has continued during the time since this report was produced. Thus, the report may not accurately reflect current ideas.

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Introduction

Biological monitoring of stream ecosystems

Over the last decade, biological monitoring has emerged as an important component of adaptive management (Hughes et al. 1986, Browder 1988, Mundie and Simpson 1991, Abate 1992, Buikema and Voshell 1993, Rosenberg and Resh 1993, Grumbine 1994, Cash 1995, Grumbine 1997, Scrimgeour et al. 1998). Adaptive management includes:

- quantifying the outcomes of management options
- assisting with hypothesis development and testing
- providing early warning indicators of impending environmental degradation

Irrespective of its function, success is greatly enhanced when the program is developed in a rigorous fashion and the purpose of the program is explicitly stated. The sampling design, measured elements and sampling protocols should flow logically from the overall purpose. Following this process also clarifies and simplifies trade-offs between sampling frequency (i.e., how often sites are sampled through time) and intensity (i.e., how many sites are sampled). Even when these decisions are made, monitoring programs need to be viewed as being dynamic. Results from the program feedback into the design to optimize the spatial or temporal scales at which elements are measured or to determine whether some elements are added or removed through time.

Biological monitoring of stream ecosystems has historically focused on monitoring chemical concentrations within receiving waters combined with single species toxicity tests to predict relationships between contaminant concentrations and biological effects. Direct measurements of the effects on biological endpoints of effluents, abstractions, or changes in land use are relatively new (e.g., Cairns et al. 1992, Buikema and Voshell 1993, Dube et al. 1997). Currently, methods for monitoring stream ecosystems are typically designed to detect changes in density, biomass, or species richness of one or more stream elements combined with the collection of a suite of habitat or water quality parameters that are expected to explain changes in elements among sites or through time. While potential explanatory or diagnostic variables do not establish cause and effect, they can assist in the interpretation of changes in biological elements and the generation of testable hypotheses. For the purposes of this chapter, we define biological monitoring programs as those that attempt to detect changes in one or more biotic elements through time and among sites, irrespective of whether potential explanatory variables are measured concurrently when elements are quantified.

This chapter describes aquatic elements and sampling protocols that could be used to monitor forested stream ecosystems in Alberta and Saskatchewan and is divided into five major sections. In the first section the need to monitor stream ecosystems is placed within the broader context of resource management and technical terms used throughout the report are defined. The second section identifies the broad suite of potential elements that could be included within a stream monitoring program and the rationale used to refine these potential elements to a subset that have utility within a biological monitoring program. The third section describes protocols that could be use to monitor benthic algal, benthic macroinvertebrate, fish, and amphibian communities. The fourth and fifth sections discuss data management and pilot studies that would test and refine field techniques to quantify relationships between sampling effort and sample variance.

Definitions

To increase clarity, we define several terms that appear throughout this chapter. In presenting these definitions we acknowledge that these terms are not accepted universally and that controversy on definitions continues to exist, especially concerning ecosystem health and integrity (e.g., Scrimgeour and Wicklum 1996).

- Adaptive Management: the formal process of problem assessment, hypothesis development, implementation, execution, monitoring, evaluation, and feedback (Lee and Hanus 1998).
- Allochthonous matter: matter derived outside of a system.
- Autochthonous matter: matter derived from within a system.
- Bankfull height and width: the height and width of the stream channel at the discharge that maintains the active channel.
- Biodiversity: the variability among living organisms from all ecosystems, and ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Canadian Biodiversity Strategy Working Group 1995).
- Biomonitoring: the intermittent or continuous surveillance of biological or chemical attributes to detect ecosystem change, assess the effectiveness of policy or legislation, or within a regulatory context to determine the effectiveness of a management practice (see Hellawell 1991).
- Criterion: a valued attribute that is to be achieved or maintained through resource management.
- Epilithic algae: algal communities growing on stone surfaces
- Epipelic algae: algal communities growing on fine or organic sediments.
- Epiphytic algae: algal communities growing on macrophytes.
- Episammic algae: algae growing on moving sand.
- Epizooic algae: algae growing on animal surfaces.
- Drift: the downstream movement of invertebrates within the water column. Drift is typically categorized into catastrophic, behavioral or constant drift depending on the mechanism responsible for entry into the water column.
- Hyporheic macroinvertebrates: macroinvertebrates that live within the area below the bedrock of a stream where interstitial water moves by percolation.
- Indicator: a measure that quantifies an attribute of one or more criteria. Indicators can be viewed as elements that provide information on changes in elements other than themselves. For example, McGeoch (1998) separates indicators into the three categories of environmental indicators, ecological indicators and biodiversity indicators.
- Macrophyte: macroscopic aquatic vegetation including macroalgae, mosses, ferns and true angiosperms.
- Merovoltine: species that complete their life cycle in more than two years.
- Semivoltine: species that complete their life cycle in one two less.

- Stone surface organic layers: the film of material present on stone surfaces comprising algae, fungi, protozoans, bacteria, invertebrates and both terrestrially and aquatically derived organic and inorganic materials.
- Univoltine, bivoltine, trivoltine, multivoltine: species that complete their life cycle in one year or less.

Selection of stream elements

Goal and approach

Elements identified as being suitable to monitor forested streams were selected based on guiding principles and criteria identified by the AFBMP Steering and Technical Committees. Selected elements should display the following attributes:

- Cost-effective to monitor
- Responsive to expected changes in the forested land base
- Inclusive of multiple levels of biological organization
- Chosen without respect to whether they are known to be environmental, ecosystem or biodiversity indicators (sensu McGeogh 1998)

For the stream monitoring component, elements and protocols were selected with the following assumptions:

- Performed by a field crew of 2-3 people
- Conducted at a given site within 2-3 days
- Measured using recognized techniques
- Integrated with sampling of terrestrial elements if possible

The goal, approach and criteria for selection of elements identified for monitoring by the AFBMP Steering and Technical Committees profoundly influences the number and type of elements sampled within stream ecosystems.

Selection of potential elements and financial constraints

Diversity of potential stream elements

Stream ecosystems are diverse, comprising numerous categories of biotic and abiotic elements that potentially could be included within a biological monitoring program (Table 1). When each of these categories is further divided into species assemblages and habitat-specific communities, the potential elements that could be monitored number in the hundreds. Such high numbers require that elements be prioritized in order to choose only the most relevant elements to be monitored. Additional elements and diagnostic instream habitat and watershed attributes may be added or removed from the program as results and feedback from pilot studies or other sources become available.

Table 1. List of potential instream and watershed elements that could be monitored within forested ecosystems of Alberta and Saskatchewan.

<table>
<tr><th colspan="2">Stream elements</th></tr>
<tr><th>Instream elements</th><th>Watershed elements</th></tr>
<tr><td><u>Biotic</u>
1) Microbes (e.g., bacteria, fungal communities).
2) Algae (phytoplankton, epipelic, epilithic, epizooic, and episammic algal communities).
3) Macrophytes.
4) Macroinvertebrates (hyporheic, benthic, drift).
5) Amphibians.
6) Fish.

<u>Abiotic</u>
1) Stream morphology (e.g., sinuosity, slope).
2) Bankfull attributes (e.g., depth, width).
3) Substratum (size fractions, embeddness, nutrient levels, contaminants, particulate organic matter size fractions, woody debris).
4) Hydrology.
5) Stream elevation.
6) Water physiochemistry.
7) Light attenuation.
8) Crown closure.</td><td><u>Biotic</u>
1) Watershed and riparian vegetation.
2) Soil communities.
3) Animal communities.

<u>Abiotic</u>
1) Watershed attributes (e.g., location, elevation, order, size, slope, aspect).
2) Bedrock and soil chemistry.
3) Hydrology (flow regimes).
4) Degree of industrial development</td></tr>
</table>

From an evaluation of the broad suite of potential elements based on the criteria above, we recommend that monitoring of forested streams in Alberta and Saskatchewan focus initially on benthic algae, benthic macroinvertebrate, amphibian and fish communities. All four groups of biota are used to evaluate the environmental effects of industrial and agricultural effluents (Cairns and Dickson 1971, Buikema et al 1981, Cushman 1984, Behmer and Hawkins 1986, Browder 1988, Barbour et al. 1992, Lenat 1993) and changes in land use, including forestry (Newbold et al. 1980, Hawkins et al. 1982, Corn and Fogleman 1984, Campbell and Doeg 1989, Corn and Bury 1989, Carlson et al. 1990, Beechie and Sibley 1997, Cattaneo et al. 1997, Chetelat et al. 1999) and agriculture (Evensen et al. 1981, Berkman et al. 1986, Cooper 1987, Corkum 1996).

Many biotic elements in forested streams of Alberta's forested natural regions are found within the groups selected. However, a comprehensive description of how elements were evaluated and subsequently incorporated or rejected is not discussed. However, the exclusion of aquatic macrophytes and adult aquatic insects in the monitoring program warrants further discussion.

Rationale for excluding aquatic macrophytes and adult aquatic insects from the monitoring program

Aquatic Macrophytes

At present, we are not recommending that aquatic macrophytes be monitored, despite the fact that they display all of the criteria identified as relevant by the AFBMP. Their exclusion from this monitoring program is due to the current paucity of information on aquatic macrophytes within Alberta's forested natural regions. If this element is identified as a priority for monitoring by the AFBMP, a study plan should be developed to provide information on species distributions and how they change throughout the open-water period. Because of the large amount of basic research required to obtain this information, surveys of aquatic macrophytes were excluded from the recent pilot study.

Adult Aquatic Insects

Although adult aquatic insects are also informative within a stream monitoring program, we do not recommend implementing this element within the AFBMP. Adult aquatic insects are useful for describing the stream macroinvertebrate community and for augmenting species–level identifications of larval aquatic stages. While aquatic invertebrates can monitor contaminant loadings in aquatic systems (e.g., Kovats and Ciborowski 1989, Dukerschein et al. 1992, Scrimgeour et al 1998), their use as a monitoring element is restricted when sampling for only 2-3 days at a given site.

First, flight periods of adult Ephemeroptera, Plecoptera, Trichoptera, Lepidoptera and Diptera typically range from 4 - 8 weeks and differ greatly among species (Harper 1973, Madsen et al 1973, Svensen 1974, Madsen et al. 1977, Singh et al. 1984, Waringer 1986, Zwick 1990, Sode and Wiberg-Larsen 1993, Merritt and Cummins 1996, Petersen 1999). In addition, catch rates are strongly affected by meteorological conditions (e.g., Norrie 1969, Warringer 1991), typically reduced by cool temperatures and high wind. To overcome these problems, adults are trapped over extended periods (e.g., 2 weeks to 9 months) in the majority of previous studies (Madsen et al. 1973, Singh et al. 1984, Waringer 1986, Jones and Resh 1988, Zwick 1990, Kuusela and Huusko 1996 Sode and Wiberg-Larsen 1993, Collier and Smith 1998, Petersen et al. 1999). Thus, the 2-3 day window set to sample all aquatic elements at an individual site is not conducive to monitoring stream invertebrate communities using adult insects or to collect adults to assist with larval identifications.

Second, flight periods of many aquatic insects are restricted to either the spring or fall (See Merritt and Cunmmins 1996 for a review). Collections of adults during the spring can contain different species assemblages than those in the fall (e.g., Madsen et al. 1973, Waringer 1986, Sode and Wiberg-Larsen 1993, Giberson and Garnett 1996). Thus, variation in the phenology of adult insects requires that adults be sampled in both seasons, an approach that is inconsistent with monitoring stream invertebrate communities over a 2-3 day period.

Third, collections of adult invertebrates may not be representative of the entire stream benthic community because a proportion of aquatic invertebrates (e.g., oligochaetes) do not have an aerial adult stage and because of differences in catchability among groups. For example, adult Ephemeroptera require higher air temperatures than Plecoptera for mating because they mate in flight, while Plecoptera generally mate on the ground (Brittain 1990, Flecker and Allen 1988). Thus, based solely on flight activity, cool weather sampling may produce a bias in the relative abundance of Plecoptera compared with Ephemeroptera. Given these factors, we believe that the investment required for monitoring adult insects to describe the stream macroinvertebrate community or to assist with the identification of larvae is not warranted at the present time. Our reservations to include adult invertebrates within the AFBMP monitoring program arise because of a virtual lack of detailed information on phenologies of aquatic macroinvertebrates in forested streams of Alberta. In addition, existing information from other stream ecosystems suggests that their use could be problematic. Results from future research might minimize these potential problems, by examining changes to the scope of the field sampling window and by better defining flight periods of stream insects.

Recognition of a hierarchical approach

Elements that should be monitored within forested streams in Alberta and Saskatchewan can be viewed as a third level of a hierarchical decision-making tree. The first decision level identifies the types of stream that should be monitored and largely focuses on whether all (e.g. small, headwater 1st order streams to larger 7th order rivers) or a sub-set (e.g., 1st to 5th order) of lentic systems should be included in the program.

The second decision level addresses which habitat types are to be monitored. Stream ecosystems can be divided broadly into the three habitat types: 1) riffles (i.e., shallow, fast flowing water), 2) pools (i.e., deep, slower flowing reaches) and 3) runs (moderately shallow, slower flowing water). Depending on the purpose of the monitoring program, only certain habitats need be sampled. Indeed, monitoring all elements within each of these habitats would require such large amounts of resources that ultimately, the number of sites monitored would be reduced and/or the length of time between repeated sampling would be increased compared to monitoring a smaller set of elements. Sampling costs could be greatly reduced by sampling reach-specific habitats, rather than all habitats within each lentic system order. While sampling only shallow-water habitats could also substantially reduce costs, this is a strategic decision that should be made based on cost/benefit modeling. As a result, we describe techniques to monitor benthic algal, benthic macroinvertebrate and fish communities from shallow and deep-water habitats. These habitats are sufficiently broad to include the majority of streams within Alberta’s forested natural regions. We also include methods to sample benthic algae and macroinvertebrates from fine (e.g., silts and sands) and coarse substrata (cobbles and rocks) within the two habitat types.

The third decision level of this hierarchical approach focuses on the appropriate length of representative reaches that should be monitored (e.g, Rabeni et al. 1999). Selection of what constitutes a representative reach (e.g., 20 times mean bank width) and the number of reaches that are sampled profoundly affects the economics of monitoring. While most monitoring programs describe the length of the study reach and the number of reaches that are sampled, few studies provide a rationale for these decisions. In the absence of empirical studies, we provide only guidelines of what may constitute a representative reach and do not answer the question of how many reaches should be sampled. However, these challenges could be addressed by integrating pilot studies within the initial implementation stage of the AFBMP.

Review of selected elements and protocols

Benthic algae

Categorized as benthic algae, a diverse suite of species occurs within a complex matrix of fungi, bacteria, micro and macroinvertebrates, inorganic particles and organic matter on rocks, stones, sediments and plants. Definitions of benthic algae are numerous, often overly complicated and inappropriately used historically. For the purposes of this report, we define benthic (i.e., bottom-dwelling) algae as:

- epilithic algae - algal species growing on rock or stone surfaces
- epipelic algae - algal species growing on fine or organic sediments
- epiphytic algae - algal species growing on macrophytes

Diatoms are usually the most numerous taxa within benthic algal communities of streams.

While at the present time benthic algae are not always included within biological monitoring programs within forested streams, many studies show that they are strong indicators of water quality (e.g., Stockner and Shortreed 1978, Bothwell 1989, 1992, Lampkin and Sommerfeld 1982, Sumner and McIntire 1982, Blanck et al. 1984, Perrin et al. 1987, LaPerriere et al. 1989, Corkum 1990, Peterson and Stevenson 1990, Corkum 1996, Rosemond and Brawley 1996, Chetelat et al. 1999), display faunal changes along environmental gradients (Lamberti and Resh 1985, Chessman 1986, Coleman and Dahm 1990, Cattaneo et al. 1997, Rothfritz et al. 1997) and are indicative of longer-term environmental change (Dixitt et al. 1992, Dixitt et al. 1993, McCormick and Cairns 1994). Numerous studies have shown that benthic algal assemblages can be highly diverse including up to 150 species for a given habitat type (e.g., Leland et al. 1986). In addition, they have intuitive appeal to aquatic ecologists as indicators of water quality (Anderson and Rippey 1994, McCormick and Cairns 1994, Pan et al. 1996, Scrimgeour and Chambers 1997).

Number of Benthic Algal Species

At any one location, benthic algal communities in streams typically comprise 50 to 150 species (e.g., Hamilton and Duthie 1984, Chessman 1986, Rothfritz et al. 1997). These communities also differ greatly among habitat types depending upon water velocity, light attenuation and temperature gradients. The number of species comprising benthic algal communities in Alberta and Saskatchewan is currently not known, but there is no a-priori expectation that they should be any less diverse in these provinces than elsewhere.

Ecosystem Role

Benthic algal communities play important ecological roles in streams as critical components of primary production and by accounting for a substantial proportion of the biological diversity within streams.

Relationship to Land Use Change

Benthic algal community biomass and species composition have been shown to be highly responsive to changes in water chemistry (e.g., Archibald 1972, Evenson et al. 1981, Chessman 1986, Bothwell 1988, ter Braak and Dam 1989, Genter 1995, Cattaneo et al 1997, Scrimgeour and Chambers 1997, Quinn et al. 1997, Chetelat et al. 1999) including those arising from watershed disturbances (e.g., Corkum 1996, Quinn et al. 1997).

Potential Sampling Methods

Epilithic algal communities are typically described in terms of:

- numerical abundance (i.e., number of cells per unit area)
- species composition (i.e., relative abundance of individual species or families)
- biomass expressed (e.g., chlorophyll *a* [e.g., *u*g/cm^2], ash free dry mass [*u*g/cm^2], biovolumes [cell dimensions converted to volumes using geometric shapes of known volumes, followed by conversion of volumes to biomass assuming a specific density of 1 gcm^3] or pigment profiles from HPLC).

Benthic algal production (i.e., biomass produced per unit time) is rarely included in monitoring programs and for this reason is excluded from further discussion.

Sampling of epilithic algal communities is accomplished using a wide array of techniques (e.g., Austin et al. 1981, Aloi 1990, Cattaneo and Roberge 1991, Porter et al 1993) that are separated based on whether the benthic algal layer is removed from natural or artificial surfaces. Sampling of artificial substrata, such as tiles or glass slides, requires that substrata be incubated in a stream for typically two to six weeks to allow colonization and growth of the algal community. Revisiting sites after an appropriate length of time is not a viable sampling option under the current sampling scheme of AFBMP.

Shallow-water habitats

To sample algal communities from coarse substrata (e.g., cobbles and rocks) in shallow water habitats, substrata can be removed from the river bottom by hand and algal community samples processed at the stream margin. Following removal from the stream bottom, the epilithic mat is typically separated from known areas of a rock with either brushing syringe-samplers (Aloi 1990), or sharp-edged instruments (e.g., scalpel or a knife). An alternative is to scrub the epilithic community from the entire rock and then estimate biomass (e.g., chlorophyll a) or biovolume assuming that algal covered 60% of the rock surface (e.g., Chetelat et al. 1999).

Collection of epipelic (i.e., growing on sediments) and episammic (i.e., growing on or moving through sand) communities from shallow-water habitats can be accomplished using a hand held corer fitted with a liner that allows the entire sample to be removed intact and the uppermost layers to be analyzed. Commercial core samplers are available from a number of outlets. Combination core samplers (15 cm length core cylinder x 5 cm diameter) reduce equipment costs because they can be manually used to sample shallow areas or with extension tubes, to sample deeper areas. Replicate samples should be frozen for chlorophyll *a* analyses, preserved in a

Lugols solution for taxonomy or for biovolume estimates as described below. The entire sample can be shipped to a laboratory for analysis.

Deep–water habitats

Collection of natural substrata from deeper water habitats is more difficult and ordinarily requires the use of a boat to provide a platform for sampling. An Ekman dredge can be used to collect rocks or cobbles and processed as described for samples from shallow water habitats. Algal communities are not typically collected from deep-water depositional habitats where substrata are dominated by fine sands and silts (i.e., epipelic or episammic algae). However, these communities can be sampled using an Ekman dredge. When deployment and retrieval of the dredge mixes the sample, such that layers at the sediment-water interface cannot be separated from layers lower in the sediment profile, the sample can only be used to provide information on species presence and relative abundance. If the sample can be retrieved and placed into a pan without disturbing sample integrity, a portion of the sample can be removed using a template of known area and the sample processed to estimate cell density and biomasses. While organic substrata, fine sands, silts and gravels can be removed from the substratum using a core, air or water sampler (e.g., Walker 1955, Flannagan 1970, Gale 1971, Gillespie et al. 1985), a combination core sample capable of sampling shallow and deep water habitats is an effective option.

Sample processing

Samples removed from stone surfaces for chlorophyll *a* analysis must be stored in the dark, preferably frozen, prior to analyses. Samples for biovolumes and taxonomy should be preserved in either Lugols solution, a weak (5% to 40%) formalin solution or mixed with a combination of formalin, acetic acid and acetone.

Samples for dry mass or ash-free dry mass should be frozen. However, storage in the dark is not necessary since photodegradation of photosynthetic pigments is not a concern. Quantification of biomass as chlorophyll *a* is usually completed using a hot ethanol extraction. The differences between hot and cold ethanol extraction and acetone extraction are likely small compared with other sources of error. The majority of studies express algal biomass as biovolumes or chlorophyll *a* concentrations (e.g., *u*g/cm^2 or mg/m^2). Few studies express algal biomass solely as ash-free dry mass, except where remote study sites preclude the freezing of samples. The use of HPLC to quantify the entire spectral signature is becoming increasingly popular, requiring initial calibrations.

Replication

The number of replicate samples taken at a given location is also highly variable, generally ranging from four to ten. Few studies provide a rationale for sample numbers. However, such sampling information is required to quantify trade-offs between costs and sampling effort, and thus, sample variance should be considered in the design of the monitoring program. In addition, the variance of benthic algal communities throughout a season should be quantified.

Replicate samples from rock and cobble substrata are generally removed from 6 to 25 cm^2 areas. However, the average area is thought to be < 8 cm^2, and is delimited using some type core or template (Aloi 1990). In some cases, individual samples are split into two equal samples in the laboratory; one sample used for chlorophyll *a*, ash free dry mass or biovolume estimates (i.e., half-sample 1), the other sample used for species identification.

Logistical Constraints

Benthic algal communities from shallow water habitats poses minimal logistical constraints for sampling, except when large amounts of dry ice must be transported into remote locations to freeze algal samples.

Environmental Conditions

While algal samples can be collected under a range of weather conditions, high water discharges can cause serious safety risks. High water discharges may restrict sampling to shallow areas or prevent sampling for several days to weeks, depending upon patterns of precipitation and runoff.

Time Requirements

Trained staff can collect individual benthic algal samples from shallow water habitats quickly (e.g., 5 to 15 minutes per sample). Sampling of deep-water habitats requires 10 to 30 minutes per sample, depending on water depth, velocity and substratum type. The time required to launch and trailor a boat substantially increases the total time (i.e., 1-2 hours per site). For safety reasons sampling should be completed by at least two people.

Equipment Requirements, Portability and Costs

Sampling of shallow-water habitats requires waders, wading boots, safety flotation devices and a core sampler. Sampling of deep-water habitats requires a boat, related safety equipment, a boat trailer, a vehicle capable of safely towing the boat and either a core or an Ekman grab sampler. An Ekman grab ($700.00) costs about half of a commercially purchased liner-based corer sampler ($1500.00). However, both samplers are robust and should last for 20 years with regular maintenance.

Irrespective of habitat type, a relatively large (i.e., several hundred) number of pre-labeled sample jars (20 to 100 ml), a scraping tool, and sample preservative are needed. Two L Lugol's or formalin would be sufficient for several hundred samples, assuming that samples are collected in 20 to 100 ml vials. Mean water depth and velocity are typically estimated when benthic samples are collected. While water velocity meters using magnetic sensors and a wading rod are expensive ($10,000.00), they should last for at least 15 years with regular maintenance. Less expensive meters are available for $250.00 to $3000.00.

With the exception of transporting dry ice for field storage of samples and boat-related equipment, all supplies are portable and either inexpensive or moderately expensive. Laboratory costs to quantify algal biomass as chlorophyll *a* or biovolumes are relatively inexpensive (i.e., $25.00 to $45.00 per sample). Sample identification and enumeration generally range from

$75.00 to $150.00 per sample depending upon the level of taxonomy required and the number of samples. Large numbers of samples warrant a bulk-analysis discount of between 5% to 15%.

Recommended Protocols

Shallow water habitats containing coarse substrata should be sampled by manually removing substrata from the river bottom and scraping algal communities within a delimited area. Samples of fine substrata from shallow-water habitats should be taken using a hand-held core sampler. In deep-water habitats, fine substrata should be sampled using a core sampler, whereas coarse substrata should be sampled using an Ekman dredge.

Irrespective of sampler type, epilithic biomass should be quantified as either chlorophyll *a* or biovolume, identified to species or familial levels and enumerated. While pilot studies would quantify relationships between replication and variance, collection of 10 to 15 samples (stone samples, Ekman and core samples) from 4 to 10 cm^2 areas is likely to provide data sufficiently robust at relatively low costs. This procedure is likely to detect a 50% difference between two sample means. However, rare species will likely be underestimated. When possible, samples should be taken throughout the study reach (e.g., 100 to 200 m) to capture some of the inherent spatial variation in algal communities.

Related environmental variables

Environmental variables should be measured along with algae to assist in diagnosing changes in algal communities that are correlated with changes in the stream channel or the larger watershed. These include:

- Water chemistry and physical variables: pH, temperature, dissolved oxygen, conductivity, turbidity, and light attenuation profiles to quantify photosynthetically active radiation.
- Instream habitat variables including: substratum size fractions; water depth and velocity at individual benthic algal sampling locations; reach elevation and slope; instantaneous discharge (5 to 8 transects along the study reach); mean bankfull width and depth (based on 5 to 8 transects along the study reach); and stream bank attributes.
- Watershed variables including: area; mean slope; soil types; vegetation attributes (e.g., AVI-based attributes); number of beaver dams above and below the study site; and anthropogenic disturbance descriptors (e.g., number of stream crossings above study site, area and adjacency of roads, seismic, well sites, right-of –ways, cut blocks).

Other Considerations

Field staff will require a small amount of field training. Processing of algal samples for biovolume, chlorophyll *a* or taxonomy is not overly time consuming. However, large numbers of samples can cause delays of weeks to several months between the delivery of samples to a laboratory and receipt of data. We recommend that the AFBMP distribute requests for proposals (RFP) to several qualified consultants and identify the time frame for delivery of data in addition to sample processing costs in the RFP.

Quality Assurance

Field staff will require a small amount of training.

Overall Evaluation

Table 2. Overall evaluation of monitoring benthic algal communities within forested streams of Alberta and Saskatchewan.

Criterion	**Evaluation**
Distribution / spatial variability	
Variability within and between sites	Expected to be large
Statistical stratification	Likely to be required
Spatial scale sensitive to variability	Unlikely to be problematic
Temporal variability	
Within-day (diel) variability	Generally low under stable flow conditions assuming that relatively high numbers of replicate samples are collected (i.e., 5 to 10 samples)
Day-to-day variability	Low under stable flow conditions and assuming that relatively high numbers of replicate samples are collected (i.e., 5 to 10 samples)
Variability among the months of June, July and August	Expected to be moderate but currently not quantified
Magnitude of intrinsic between-year	Moderately high
Existing data on variability for power analysis	Available but little evidence that these types of analyses are completed as part of sampling designs
Sensitivity to human-caused environmental changes	
Response to forest harvesting and other silvicultural practices	Moderate to high
Response to linear disturbance	Unknown but expected to be relatively weak or not detectable
Response to fire suppression and control.	Expected to be high but generally unknown
Other biological considerations	
Risk status	Unknown but likely low
Trophic	Important
Home range size	Moderately sessile
Life span	Known to be short (hours to days) depending upon water temperature, nutrient and light levels

“Keystone” characteristics	Unknown
Dependence of particular species on natural disturbance processes	Unknown, but unlikely
Correlation with temporal trends in other biodiversity elements	Unknown
Logistics	
Quality of data obtainable within a relatively short period of time	Extremely high quality data for both algal biomass and species density estimates
Quality of data obtainable within a circumscribed area	High
Portability of required equipment	High
Ease with which required techniques can be learned by generalist biologists	Very easy
Degree to which data are unambiguously interpretable by non-specialists	Low
Expected amount of observer bias associated with measurement	Expected to be low following training
Suitability of existing data for retrospective summary and analysis	Moderately useful data sets are available
Expected environmental impact associated with monitoring this element	Low
Social significance	
Significance that society places on the element	Low to non-existent

Pilot Studies

Pilot studies need to be conducted, assuming that the priority to use benthic algae within biological monitoring programs continues to increase (See Section 5.1).

Benthic macroinvertebrates

Number of Benthic Macroinvertebrate Species

Benthic macroinvertebrate communities are relatively diverse, typically comprising 50 to 100 species at a given site (i.e., river reach). Benthic macroinvertebrates are highly responsive to changes in water chemistry, such as those arising from industrial and municipal effluents (Simpson 1980, Buikema et al. 1981, Lafont 1984, Bain et al. 1985, DePauw et al. 1986, Grubaugh et al. 1996, Wallace et al 1986, Barbour et al. 1992, Barbour et al. 1996, Hamalainen and Huttunen 1996, Hamalainen and Huttunen 1998) and watershed disturbances including forest harvesting (Newbold et al. 1980, Behmer and Hawkins 1986, Campbell and Doeg 1989, Ogbeibu and Victor 1989). Benthic macroinvertebrates are routinely included within lotic biological monitoring programs.

Ecosystem Role

Benthic macroinvertebrates play important ecological roles in streams by converting allochthonous and autothonous derived carbon into forms that can be utilized at higher trophic levels. As such they represent an important component of secondary production. As a highly speciose group, they can account for a moderate proportion of the biological diversity in streams.

Relationship to Land Use Change

Aquatic macroinvertebrates are indicators of water quality, responding strongly to changes in land use or other processes that alter water quantity or quality.

Potential Sampling Methods

Benthic macroinvertebrate sampling methods for biological monitoring programs can be broadly separated into rapid assessment approaches and more quantitative approaches (Corkum 1996, Abate 1992, Barbour et al. 1992, Brussock 1993, Resh et al. 1995, David et al. 1998). Some consider rapid assessment techniques to be screening or initial scoping exercises, but their utility as assessment tools is probably greater than generally admitted. Rapid assessment techniques often are not used within monitoring programs because they lack the resolution to detect even moderate changes through time or differences between or among sites.

Shallow-water habitats

Stream benthos from relatively shallow (< 0.6 m) areas of riffles, runs and pools with gravel-cobble-rock substrata are usually sampled with Hess, Neil, Surber or T-samplers (e.g., Cuffney et al. 1993, Merritt and Cummins 1996, Bailey 1998). While samplers differ in shape and construction, they essentially function in a similar fashion: an area of the substratum is delimited, macroinvertebrates are agitated from the delimited substratum and are collected in a mesh bag attached to the downstream side of the sampler. Hess, Neil, and T samplers circumscribe a round area of the substratum whereas the Surber sampler outlines a square area of the substratum. Hess samplers ($700.00) are used widely and can be readily purchased from a variety of scientific supply companies in Canada and the United States. Alternatively, smaller Hess-style and T samplers can be constructed using a standard T-shaped plumbing pipe. Although very inexpensive (<$100.00), they require additional maintenance compared to commercially manufactured products. Sampling of bedrock is generally accomplished by scraping known areas and collecting the removed sample in a D-shaped filter fitted with 250 *u*m mesh net.

Benthic macroinvertebrate communities from fine and coarse substrata can be effectively sampled with a Hess sampler (0.1 m^2 fitted with a 250 *u*m mesh net). Sampling should proceed in an upstream direction to reduce sample contamination.

Deep-water habitats

Deeper areas within stream and rivers are typically sampled using either an Ekman grab sampler or a core sampler. Sampling of these deeper habitats can be time consuming when boats are required to provide a sampling platform. Coarse substrata within deep habitat should be sampled with either a petite Ekman (length, width and height = 15 cm x 15 cm x 15 cm) or with a Ponar grab when substrata are highly compacted. Fine substrata could be sampled with either a core sampler, as described for algal sampling, or a petite Ekman grab sampler. While core samplers sample a small area (about 4 to 10 cm^2) and are advantageous because they allow for increased replication, they can only be used to sample fine substrata. In contrast, Ekman grabs enclose substantially larger areas (i.e. 230 cm^2) and can efficiently sample a wider range of substratum size fractions. Thus, if the use of standardized techniques through time is paramount and changes in substratum size fractions from coarse to fine substrata are expected, then sampling of deep-water habitats should be completed using an Ekman grab.

Sample processing

Once collected, samples should be placed into pre-labeled wide-mouth jars and preserved in 70% ethanol. While samples could be preserved in the better preservative formalin, it is a known carcinogen and should be avoided. Samples are typically processed in the laboratory where most consultants use a variety of techniques to separate macroinvertebrates from other materials (e.g., flotation techniques, application of dye to stain organics).

Replication

Hess and Ekman samplers generally delimit 0.1 and 0.023 m^2, respectively, and are fitted with 250 *u*m mesh net. As commonly practiced, the use of smaller Hess samplers' (e.g., 0.05 m^2) can be highly beneficial, but the sampler needs to be matched with substratum size fractions. The collection of greater numbers (e.g., 10 replicate samples) of small samples (e.g., 0.05 m^2) can greatly reduce sample variance compared with the collection of larger (e.g., 0.01 m^2) but fewer samples (e.g., 5 replicates) (e.g., Elliott 1977, Pringle 1984, Morin 1985). The majority of benthic monitoring programs collect 5 –10 samples from a given site depending upon monitoring objectives, availability of funding, and estimates of spatial variability in communities. Few studies describe how the number of replicate samples was determined and even fewer report statistical power, despite the almost universal acceptance of its importance in the design of monitoring and assessment programs.

Alternative techniques

Benthic macroinvertebrates are also present within the water column. Benthic macroinvertebrates drift downstream to locate food patches, to avoid benthic predators and due to passive dislodgment from the substratum (Allan and Russek 1985, Brittain and Eikeland 1988, Culp et al. 1994, Scrimgeour et al. 1997). Drift propensities and diel periodicities are species and body size specific and vary with the presence or absence of day-active benthivorous fish. As a result, the composition and abundance of drift varies greatly from that within the benthic community on the river bottom.

Logistical Constraints

Only minor logistical problems are posed by sampling benthic macroinvertebrate communities from small streams and riffle habitats from larger streams. However, sampling fast, deeper water habitats, such as pool and run habitats from large rivers, pose major difficulties that can only be overcome using boats. As discussed previously for algal sampling, boats can substantially increase sampling costs.

Environmental Conditions

Benthic macroinvertebrate samples can be collected under a range of weather conditions. High discharge levels, however, can impose serious safety concerns, restricting sampling to shallow areas or preventing sampling for several days or weeks, depending upon patterns of precipitation and runoff. Turbid waters impose similar challenges.

Time Requirements

Trained field staff can collect individual benthic macroinvertebrate samples from shallow-water habitats relatively quickly (i.e., 5 to 10 minutes per sample) depending upon stream type and substratum composition. In contrast, sampling of benthic macroinvertebrates from deep-water will likely take 10 to 15 minutes per sample with an additional amount of time required to launch and trailer the boat.

Equipment Requirements, Portability and Costs

Waders, wading boots, a safety flotation device and a Hess sampler are required for sampling shallow water habitats. For sampling of deep-water habitats, a boat, related safety equipment, a boat trailer, a vehicle capable of safely towing the boat and an Ekman grab ($700.00) are required.

Irrespective of habitat type, sampling will require a relatively large number of pre-labeled, wide mouthed jars (0.5 to 1 L; 20 to 50 per day), a benthic sampler with an attached mesh net, a spare mesh net and sample preservative. Assuming that 200 to 500 ml of 70% ethanol is used per sample, 8 liters/day will be required. Water depth and velocity are typically recorded when benthic samples are collected. For safety reasons, two people should conduct sampling together. With the exception of the boat, the vast majority of field equipment is inexpensive and moderately or highly portable.

Costs of processing benthic samples to produce density and biomass estimates are highly variable. Costs depend on whether samples are tracked using chain-of -custody protocols, on the cost of QA/QC procedures for both picking efficiency and taxonomy, on the level of taxonomic identification, on the sample volume and on whether sub-sampling techniques are used. Costs range from about $100.00 to $225.00 per sample with an average cost of $150.00 per sample.

Recommended Protocol

Sampling of benthic macroinvertebrates from shallow-water habitats should be conducted using a Hess-type sampler fitted with a 250 *u*m mesh net. Sampling should proceed upstream to reduce disturbance effects that could affect density estimates. Benthic macroinvertebrates in deep-water habitats should be sampled with an Ekman grab sampler. Ten samples taken with a 0.05 m^2 Hess-type sampler fitted with 250 um mesh net should provide sufficient community information for analysis. However, rare species will likely be underestimated. When possible, samples should be taken throughout the study reach (e.g., 100 to 200 m) to capture some of the inherent spatial variation in benthic communities. Samples should be preserved in 70% ethanol. Voucher specimens should be archived as part of laboratory processing procedures.

Related variables

Environmental variables should be measured during benthic macroinvertebrate sampling to assist in diagnosing benthic community changes that are related to changes in the stream channel or the larger watershed. Environmental variables to measure include:

- Water chemistry and physical variables: pH, temperature, dissolved oxygen, conductivity and turbidity.
- Instream habitat variables: substratum size fractions, water depth and velocity at individual benthic algal sampling locations, reach elevation and slope, instantaneous discharge (5 to 8 transects along the study reach), mean bankfull width and depth (based on 5 to 8 transects along the study reach) and stream bank attributes.
- Watershed variables: area, mean slope, soil types, vegetation attributes (e.g., AVI-based attributes), number of beaver dams above and below the study site, and anthropogenic disturbance descriptors (e.g., number of stream crossings above the study site, area and adjacency of roads, seismic, well sites, right-of –ways, and cut blocks).

Other Considerations

Processing of benthic samples can be time consuming depending upon the level of taxonomic identification. Delays of several months should be expected between sample collection and receipt of data. As for benthic algal samples, we recommend that the AFBMP distribute requests for proposals (RFP) to several qualified consultants. In addition to sample processing costs, the time frame for delivery of data should be identified within the proposal.

Quality Assurance

Field staff will require a small amount of training to become competent. Quality assurance and quality control protocols are important components of laboratory processing techniques and are routinely applied.

Overall Evaluation

Table 3. Overall evaluation of benthic macroinvertebrate community monitoring within forested streams of Alberta and Saskatchewan.

Criterion	**Evaluation**
Distribution / spatial variability	
Variability within and between sites	Expected to be moderate to high
Statistical stratification	Likely to be required
Spatial scale sensitive to variability	Unlikely to be problematic
Temporal variability	
Within-day (diel) variability	Low under stable flow conditions
Day-to-day variability	Low under stable flow conditions
Variability among the months of June, July and	Expected to be moderate to high

August	(currently not quantified)
Magnitude of intrinsic between-year	Moderate to high
Existing data on variability for power analysis	Available
Sensitivity to human-caused environmental changes	
Response to forest harvesting and other silvicultural practices	Highly responsive to watershed disturbances
Response to linear disturbance	Unknown but expected to be low and generally not detectable
Response to fire suppression and control.	Expected to be low to moderate over long time horizons but currently unknown
Other biological considerations	
Risk status	Low and poorly understood
Trophic	Important
Home range size	The majority of larvae are largely sessile but adults are known to travel up to several kilometers to search for mates.
Life span	Typically short ranging from 6 months to 1 year
"Keystone" characteristics	Unknown
Dependence of particular species on natural disturbance processes	Unknown but likely
Correlation with temporal trends in other biodiversity elements	Unknown but likely
Logistics	
Quality of data obtainable within a relatively short period of time	High quality data in terms of species-specific or functional group densities or biomasses based on: 1) spending ½ day at each site, 2) following the completion of pilot studies and 3) following staff training
Quality of data obtainable within a circumscribed area	High
Portability of required equipment	High
Ease with which required techniques can be learned by generalist biologists	Very easy
Degree to which data are unambiguously interpretable by non-specialists	Moderately high
Expected amount of observer bias associated with measurement	Moderately low following training
Suitability of existing data for retrospective	Extremely suitable

summary and analysis	
Expected environmental impact associated with monitoring this element	Low
Social significance	
Significance that society places on the element	Moderate when described as the prey base for fish

Pilot Studies

Pilot studies are required to better understand relationships between sample size area and variance estimates.

Fish communities

Fish Species

Fish communities of Alberta and Saskatchewan have relatively high species diversity with about 60 species (Scott and Crossman 1973, Nelson and Paetz 1992), including many that inhabit forested streams. Because many of these communities represent important recreational fisheries, they are deemed valuable socially.

A large body of scientific evidence shows that fish community structure is highly responsive to changes in water chemistry such as those that arising from industrial and municipal effluents (Berkman et al. 1986, Hawkes et al. 1986, Leonard and Orth 1986, Portt et al 1986, Berkman and Rabeni 1987, Hughes and Gammon 1987, Eaton and Scheller 1996, Frenzel and Swanson 1996, Mulholland et al. 1992) and watershed disturbances, including forest harvesting (Murphy and Hall 1981, Elliott 1986, Heifetz et al. 1986, Chapman 1988, Scrivener and Brownlee 1989).

Ecosystem Role

Fish are typically the top predators within stream ecosystems, affecting the abundance and distribution of other food-web components through trophic cascades.

Relationship to Land Use Change

Fish, especially salmonids, are known to be negatively influenced by increases in water temperature, suspended sediment loadings and habitat destruction that arise, for example, from forest harvesting or the establishment of roads.

Potential Sampling Methods

Fish communities can be monitored by electroshocking, netting, angling, visual searches, and tagging (Scott and Grossman 1973, Nielsen and Johnson 1983, Bain et al. 1985, Weddle and Kessler 1993). To a certain extent, all sampling techniques produce biased estimates of fish abundance because fish susceptibility can vary with species, age, and size class. Habitat type strongly influences susceptibility and variance estimates, especially in larger stream and rivers stretches where blocking nets can not be used to delimit the sampled reach. Sampling technique modifications are not necessary for fine versus coarse substrata texture.

Shallow-water habitats

While monitoring of fish communities is commonly accomplished by electro-shocking, the technique chosen depends on water depth and velocity. Electro-shocking of small (i.e., 1st and 3rd order streams) streams is generally completed using either a backpack or generator-powered shocker. Stream reaches of 100 to 300 m are shocked using a three-pass system (i.e., electroshocking the study reach three times). While underestimating densities, a one-pass system may none the less produce reliable estimates of community composition while requiring substantially less effort than the three-pass approach. Before implementation, the effects of sampling distance and number of passes should be evaluated during pilot studies. Irrespective of the number of passes, block nets are established minimally at the most upstream and downstream locations to delimit the sampled areas. Additional stop nets positioned along the study reach may improve catch rates by reducing the ability of fish to avoid the shocking field. For safety reasons, and to ensure that high proportions of shocked fish are captured, shocking crews should consist of three people.

Deep-water habitats

Electroshocking of deep-water habitats while wading within the stream channel is difficult, typically ineffective and unsafe where water depth exceeds 1 m. Monitoring of deeper regions should be accomplished using electroshock equipment mounted on a boat. While an effective method, daily rates for a three-person crew, including boat and equipment, generally range from $1200.00 to $2500.00.

Logistical Constraints

Assuming relatively good access, the logistical constraints of shocking small (i.e., 1st to 3rd order) forested streams are minor. Generally, the constraints are the ability of the field crew to negotiate through stream channels with high amounts of large woody debris or around large beaver dams.

Environmental Conditions

While electroshocking is a proven assessment and monitoring technique for fish, the improper use of shocking equipment poses serious safety concerns. Electroshocking with portable backpack equipment should be avoided during rainfall, when waders or rubber gloves no longer provide insulation from the electric field produced by the shocker. Most backpack shockers automatically shut off when moved from an upright position (e.g., when operator falls). None the less, personnel who wear the shocker or collect the shocked fish need to be well trained. Training includes how to operate the machine, to recognize the inherent safety concerns, and to avoid potentially unsafe practices. In addition, first aid and CPR training should be included. Improper use of electroshockers can result in serious injury or death. Similar concerns apply to boat-mounted shockers.

Time Requirements

Shocking of shallow-water habitats is relatively time consuming, depending upon the distance of streams to be surveyed, the number of passes through the stream reach, fish density, the abundance of instream and riparian woody debris and the experience level of the operators.

Completion of a 300 m reach, using a three pass approach, will typically require 3 to 6 hours, including the time required to delimit the stream reach and to process fish (e.g., fish identification, length and weight measurements).

Shocking of deep-water habitats requires additional time investments beyond that to launch and trailer the boat.

Equipment requirements, Portability and Costs

Electroshocking requires a moderate to a large amount of equipment, depending on whether shocking is completed using a backpack unit, generator, boat or raft. A Smith Root Model 12-B backpack electroshocker costs about $12,000.00. The price will vary depending on the amount of additional equipment purchased (e.g., batteries, electrodes, fish collection and blocking nets, gloves, shocker case). These costs are similar to those using a generator system ($10,000.00). They are substantially less than for a raft mounted system ($25,000.00) or for a boat designed for electroshocking ($85,000.00). Costs estimates also vary in concert with the strength of the Canadian dollar in relation to the American dollar.

Backpack and generator systems are moderately portable (length x width x height = 45cm x 25 x 1.25 m) and light (20-40 kg) compared to considerably larger and heavier systems mounted on rafts or boats.

Recommended Protocol

The preferred method for monitoring shallow-water fish communities is a backpack electroshocker, while the preferred method for deep-water habitats is a raft-mounted shocker. To evaluate the effects of shocking distance and effort (i.e., number of passes) on density and relative abundance estimates, we recommend that pilot studies be conducted using existing data sets.
Related variables should include basic stream attributes (e.g., instantaneous discharge, bankfull width and depth, substratum size fractions) and descriptions of habitat complexity including woody debris (Bilby and Likens 1980, Angermeier and Karr 1984, Bilby and Ward 1989, Culp et al. 1996).

Related variables

Environmental variables should be measured during algal sampling to assist in diagnosing changes in algal communities related to changes in the stream channel or the larger watershed. These include:

- Water chemistry and physical variables: pH, temperature, dissolved oxygen, conductivity, turbidity, and light attenuation profiles to quantify radiation required for photosynthetic activity.
- Instream habitat variables: substratum size fractions, reach elevation and slope, instantaneous discharge (5 to 8 transects along the study reach), mean bankfull width and depth (based on 5 to 8 transects along the study reach), and stream bank attributes and abundance of woody debris.

- Watershed variables: area, mean slope, soil types, vegetation attributes (e.g., AVI-based attributes), number of beaver dams above and below the study site, and anthropogenic disturbance descriptors (e.g., number of stream crossings above study site, area and adjacency of roads, seismic, well sites, right-of –ways, and cut blocks).

Other Considerations

Electroshocking is a potentially dangerous activity especially if operators are not aware of the risks or if they shock during unfavourable conditions. Electroshocking certification and First Aid (including CPR) courses should be a mandatory part of training.

Fish should be processed at the stream and then returned to habitats from which they were collected. Processing of fish does not require large amounts of time as long as large catches are sub-sampled.

Quality Assurance

Field staff will require substantial training to understand how electro-shockers work, how to produce reliable data, how to identify and process fish, and how to perform tasks safely (e.g., first aid and CPR).

Overall evaluation

Table 4. Overall evaluation of monitoring fish communities within forested streams of Alberta and Saskatchewan.

Criterion	**Evaluation**
Distribution / spatial variability	
Variability within and between sites	Expected to be moderate to high
Statistical stratification	Likely to be required
Spatial scale sensitive to variability	Unlikely to be problematic
Temporal variability	
Within-day (diel) variability	Low under stable flow conditions
Day-to-day variability	Low under stable flow conditions
Variability among the months of June, July and August	Expected to be low to moderately variable but rarely quantified
Magnitude of intrinsic between-year	Moderate to high
Existing data on variability for power analysis	Large amounts of information are available for some streams but generally lacking for streams within the boreal forest
Sensitivity to human-caused environmental changes	
Response to forest harvesting and other silvicultural practices	Moderate to high
Response to linear disturbance	Unknown
Response to fire suppression and control.	Expected to be moderate over long-time horizons but currently

	unknown
Other biological considerations	
Risk status	Variable but generally poorly understood for non-sport species
Trophic	Important but generally poorly documented in and Alberta and Saskatchewan
Home range size	Small (1 to 2 km) with the exception of spawning migrations
Life span	Highly variable among species but typically 5 to 10 years
“Keystone” characteristics	Likely but currently unknown
Dependence of particular species on natural disturbance processes	Unknown but likely weak
Correlation with temporal trends in other biodiversity elements	Unknown but likely to be weak
Logistics	
Quality of data obtainable within a relatively short period of time	High quality data for both presence/absence and density estimates based on spending 1 day at each site after completion of pilot studies and field training
Quality of data obtainable within a circumscribed area	Moderate to high
Portability of required equipment	Low to moderate
Ease with which required techniques can be learned by generalist biologists	Very easy
Degree to which data are unambiguously interpretable by non-specialists	Moderate to high
Expected amount of observer bias associated with measurement	Moderate low following training
Suitability of existing data for retrospective summary and analysis	Variable depending upon species but relatively suitable
Expected environmental impact associated with monitoring this element	Low to moderate following intensive training.
Social significance	
Significance that society places on the element	Highly relevant

<u>Pilot Studies</u>

Pilot studies are required.

Amphibians

Species in Group

The amphibian fauna of Alberta comprises only 10 species (Table 5). Two species (i.e., boreal chorus frog and the wood frog) are present throughout forested regions of Alberta whereas three species (i.e., western or boreal toad, spotted frog, Canadian toad) are patchily distributed within forested ecosystems. The remaining five amphibian species have relatively restricted distributions.

Ecosystem Role

In warmer clines, amphibian biomass can exceed that of all other vertebrates combined (deMaynadier and Hunter 1995). Amphibians play an important role in transferring carbon derived from aquatic ecosystems into terrestrial habitats. The role of amphibians within Alberta's cool forested ecosystems is unknown.

Relationship to Land Use Change

Amphibians are considered to be sensitive to changes in land use, such as those arising from forest harvesting. In reviewing 18 studies, deMaynadier and Hunter (1995) concluded that on average clear-cutting results in a 3.5-fold median decline in amphibian populations, although reductions were highly variable and the study database was biased in terms of forest types.

Table 5. Amphibian species of Alberta.

Distribution scores: "-" not commonly found in forested regions, "+" found in some forested regions, "++" widespread throughout forested regions. Data from Alberta Environmental Protection and Alberta Conservation Association (1997).

Common Name	**Scientific Name**	**Distribution**	**Score**
Long-toed Salamander	*Ambystoma macrodactylum*	Patchily distributed throughout alpine and sub-alpine regions southwestern Alberta	-
Tiger Salamander	*Ambystoma tigrinum*	Widely distributed throughout southeastern Alberta	-
Plains Spadefoot Toad	*Scaphiopus bombifrons*	Patchily distributed in southeastern Alberta	-
Western (Boreal) Toad	*Bufo boreas*	Widely distributed throughout western and central Alberta primarily in boreal forest and sub-alpine and alpine regions as far north as Lesser Slave Lake	+
Great Plains Toad	*Bufo cognatus*	Patchily distributed throughout southeastern Alberta	-
Canadian	*Bufo hemiophrys*	Very widely distributed throughout	+

Toad		the eastern half of Alberta within boreal forest and aspen parkland	
Boreal Chorus Frog	*Pseuacris triseriata*	Extremely widely distributed throughout Alberta with the exception of alpine regions	++
Northern Leopard Frog	*Rana pipiens*	Patchily distributed within southern Alberta	-
Spotted Frog	*Rana pretiosa*	Patchily distributed in southwestern foothills and mountains	+
Wood Frog	*Rana sylvatica*	Very widely distributed Alberta with the exception of southeastern Alberta	++

Potential Sampling Methods

A variety of sampling techniques can be used to monitor amphibian communities including visual encounter surveys, audio strip transects, quadrat sampling, transect sampling, track boards, patch sampling, drift fences (straight line and encircling breeding sites) and quantitative sampling of amphibian larvae (Heyer et al. 1994). Frogs and toads are usually monitored during the breeding season by noting their distinctive calls (e.g., audio strip transects), using visual encounter surveys methods or by capturing them within pitfall traps (deMaynadier and Hunter 1993, Heyer et al. 1994, Alberta Environmental Protection and Alberta Conservation Association 1997, Dr. C. Paszkowski, University of Alberta, personnel communication). In the majority of cases however, the cost effectiveness of sampling has not been analyzed. Preliminary studies are required to understand how sampling effort affects the detection or catch per unit effort.

There is a paucity of information on amphibian communities in forested regions of Alberta and Saskatchewan. The small amount of information that does exist has been collected near standing bodies of water rather than adjacent to stream ecosystems (Dr. C. Paszkowski, Department of Biological Sciences, University of Alberta, Edmonton, Alberta). The Alberta Amphibian Monitoring Program (Alberta Environmental Protection and Alberta Conservation Association 1997) suggests that frogs and toads can be detected by calling for at least one hour after dark and that lake and ponds can be examined closely following call surveys to locate adults, tadpoles and egg masses. Salamanders do not call and must be detected visually.

The presence of frogs can be determined relatively easily under optimal weather conditions, especially in early spring when vocalizations can be used to detect animals. In contrast, apparent absence of frogs and toads may arise either because animals are truly absent, because sampling effort was insufficient to detect low densities, or because animals were patchily distributed. As a result, repeated visits to a given site are required to confirm absence counts.

In contrast, the effectiveness of these sampling techniques to detect amphibians adjacent to running waters has been largely unknown. As a result, pilot field studies were completed to compare the effectiveness (e.g., catch per unit measures) of a number of monitoring techniques within forested stream ecosystems (see Chapter 11). Pilot field studies were also used to develop a field data sheet that includes habitat and other environmental variables.

Logistical Constraints

The effectiveness of different techniques to detect amphibians adjacent to forested streams waters has been poorly understood, thus pilot studies were conducted (see Chapter 11). Protocols used to monitor amphibians in other habitat types are very well understood and pose minor logistical challenges because the vast majority of sampling techniques are simple and require only minor capital outlay (Heyer et al. 1994).

Environmental Conditions

Detection of frogs and toads using audio transects and catches in pitfall traps are strongly affected by season and weather conditions of air temperature, relative humidity and wind speed (Heyer et al. 1994). Detection of amphibians using visual encounter surveys is also strongly affected by vegetation and habitat type.

Time Requirements

Several sampling techniques are relatively well understood:

- Pitfall traps require two to three hours to dig holes and to install an individual trap and drift fence. Traps are typically set for two or more nights. Daily inspections to remove and identify collected animals requires less than 1h per trap. Travel time between traps will be strongly affected by the proximity of traps to each other and the ease at which field staff are able to travel between traps.
- Visual encounter searches typically require 0.5 to three hours per transect depending upon the search area.
- Quadrat and patch sampling require one to six hours per sampling unit depending upon quadrat size and vegetation cover.
- Audio tape transects typically require less time than visual encounter searches (i.e., < two hours per transect), but detection of frogs and toads is strongly affected by weather conditions and season.

Equipment Requirements, Portability and Costs

Equipment required to monitor amphibians is highly dependent upon the sampling techniques adopted. However, equipment generally consists of shovels, field notebooks, tape measures, quadrats, field identification guide, tape recorders and audiotapes. Pitfall traps usually are made from a length of fine cloth (approximate length and height = 5 to 10 m x 1.0 m) and three to five sample collection jars (approximate diameter and height = 15 cm x 40 cm) that are buried in the ground.

The majority of field sampling equipment is lightweight (less than 5 kg for each site) and highly portable. With the exception of the use of data logger-based vocalization systems which cost about $150.00 per unit, initial costs for capital equipment to sample 50 to 100 sites are minimal ($5000.00 to $10,000.00); equipment can be used repeatedly.

Recommended Protocol

See Chapter 11 for amphibian protocol recommendations.

Other Considerations

Amphibians should be processed at the stream and returned to habitats from which they were collected. Processing of amphibians does not require large amounts of time as long as sub-sampling is used when processing large catches.

Quality Assurance

Field staff training is necessary in order to reduce observer bias, count variability, and to standardize sampling among and between sites. When monitoring is completed using audio strip transects, staff must be able to identify species-specific calls and to quantify relative abundances.

Overall Evaluation

Table 6. Overall evaluation of monitoring amphibian communities within forested streams of Alberta and Saskatchewan.

Criterion	**Evaluation**
Distribution / spatial variability	
Variability within and between sites	Expected to be large
Statistical stratification	Likely to be required
Spatial scale sensitive to variability	Unlikely to be problematic
Temporal variability	
Within-day (diel) variability	Moderately high
Day-to-day variability	High
Variability among the months of June, July and August	High but currently not quantified
Magnitude of intrinsic between-year	High
Existing data on variability for power analysis	Expected to be moderately high but currently unknown
Sensitivity to human-caused environmental changes	
Response to forest harvesting and other silvicultural practices	Contended to be moderate to high.
Response to linear disturbance	Unknown
Response to fire suppression and control.	Expected to be high but currently unknown
Other biological considerations	
Risk status	Variable and currently poorly understood

Trophic	Contended to be important but currently unknown.
Home range size	Likely to be small (< 10 ha) but currently unknown
Life span	Highly variable among species but generally poorly known. General estimates: frogs - 2 to 5 years, toads - 3 to 8 years, salamanders 5 to 12 years.
"Keystone" characteristics	Unknown
Dependence of particular species on natural disturbance processes	Unknown
Correlation with temporal trends in other biodiversity elements	Unknown
Logistics	
Quality of data obtainable within a relatively short period of time	High quality data from both presence/absence and catch per unit effort data based on spending ½ to 1day at each site after the completion of pilot studies.
Quality of data obtainable within a circumscribed area	High
Portability of required equipment	High
Ease with which required techniques can be learned by generalist biologists	Very easy
Degree to which data are unambiguously interpretable by non-specialists	Moderately high to high
Expected amount of observer bias associated with measurement	Moderately low following training
Suitability of existing data for retrospective summary and analysis	Moderately to highly unsuitable
Expected environmental impact associated with monitoring this element	Low
Social significance	
Significance that society places on the element	Highly relevant

Pilot Studies

Described in Chapter 11.

Recommended pilot studies and longer-term research

Our review of protocols that could be used to monitor four aquatic elements in forested streams ecosystems in Alberta and Saskatchewan show the need to analyze existing databases to better understand the relationships between sample effort and variance estimates for benthic algal, macroinvertebrate, amphibian and fish communities. We expect that short-term pilot studies will provide sufficient information so that these elements can be monitored within 1 to 2 years time.

Benthic algal communities

While we recommend the monitoring of algal communities within forested streams of Alberta and Saskatchewan, additional work is required to better understand trade-offs between sampling effort, biomass estimates, species counts and sample costs. Quantifying relationships between sample effort and variance estimates for a number protocols will require the analysis of existing databases. At present, a field-based pilot study is not required.

Benthic macroinvertebrates

While benthic macroinvertebrates are widely used within biological monitoring programs, the rationale for collecting 5 to 10 samples of about 0.1 m^2 rather than numerous other sampling options is usually not described. Sample effort, in terms of replication and sampled area, is a crucial consideration because sample effort dramatically affects project costs. It would be imprudent to implement a biological monitoring program where the relationships between sampling effort and variance estimates is not well understood.

We propose to evaluate the effect of sample replication on variance estimates of benthic macroinvertebrate density and where available, biomass. Our plan is to analyze two databases held by the authors and one currently held by the Government of Alberta.

Fish communities

Fish community descriptions from small, forested streams typically follow a protocol of three-pass electroshocking of 200 to 300 m of stream. This approach is adopted because it results in relatively low amounts of variance, at least for species density. Coefficients of variation are generally < 30%, provided that the number of fish captured on each successive shocking pass is < 75% of the number of fish captured on the previous pass and that the escapement fraction of the first pass is < 3%. The availability of new software greatly increases the ease at which density and variance estimates can be produced.

We recommend that a set of pilot studies be completed to better understand the relationships between sampling effort and variance estimates for streams present within 1) the mid-boreal mixedwood of northern Alberta and 2) the subalpine and montane foothills ecoregions of southwestern Alberta. We recommend that up to 3 streams in each ecoregion be electroshocked in order to describe the relationships between length of stream and number of passes electroshocked on the estimates of species richness, density and biomass.

Amphibians

Until recently, protocols to describe amphibian communities adjacent to forested stream ecosystems of Alberta and Saskatchewan have been untested. See Chapter 11 for a description of our amphibian pilot study.

References

Alberta Environmental Protection and Alberta Conservation Association. 1997. Alberta amphibian monitoring manual. Report published by Alberta Environmental Protection and the Alberta Conservation Association. 48 pp.

Abate, C. 1992. Environmental rapid-assessment programs have appeal and critics. *BioScience* 42: 486-489.

Allan, J. D. and E. Russek. 1985. The quantification of stream drift. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 210-215.

Aloi, J. E. 1990. A critical review of recent freshwater periphyton field methods. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 656-670.

Anderson, N. J. and B. Rippey. 1994. Monitoring lake recovery from point-source eutrophication: the use of diatom-inferred epilimnetic total phosphorus and sediment chemistry. *Freshwater Biology* 32: 625-639.

Angermeier, P. L. and J. R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113: 716-276.

Archibald, R. E. M. 1972. Diversity in some South African diatom associations and its relation to water quality. *Water Research* 6: 1229-1238.

Austin, A., S. Lund, and M. Pomerroy. 1981. Simple methods for sampling periphyton with observations on sampler design criteria. *Hydrobiologia* 85: 33-47.

Bailey, R. C., M. G. Kennedy, M. Z. Dervish, and R. M. Taylor. 1998. Biological assessment of freshwater ecosystems using a reference condition approach: comparing predicted and actual benthic invertebrate communities in Yukon streams. *Freshwater Biology* 39: 765-774.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985. A quantitative method for sampling riverine microhabitats by electroshocking. *North American Journal of Fisheries Management* 5: 489-503.

Barbour, M. T., J. L. Plafkin, B. P. Bradley, C. G. Graves, and R. W. Wisseman. 1992. Evaluation of EPA's rapid bioassessment benthic metrics: metric redundancy and variability among reference stream sites. *Environmental Toxicology and Chemistry* 11: 437-449.

Barbour, M. T., J. Gerritsen, G. E. Griffith, R. Frydenborg, E. McCarron, J. S. White, and M. L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of the North American Benthological Society* 15: 185-211.

Beechie, T. J. and T. H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. *Transactions of the*

American Fisheries Society 126: 217-229.

Behmer, D. J. and C. P. Hawkins. 1986. Effects of overhead canopy on macroinvertebrate production in a Utah stream. *Freshwater Biology* 16: 287-300.

Berkman, H. E. and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. *Environmental Biology of Fishes* 18: 285-94.

Berkman, H. E., C. F. Rabeni, and T. P. Boyle. 1986. Biomonitors of stream quality in agricultural areas: fish versus invertebrates. *Environmental Management* 10: 413-419.

Bilby, R. E. and J. W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. *Transactions of the American Fisheries Society* 118: 368-378.

Bilby, R. E. and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61: 1107-1113.

Blanck, H., G. Wallin, and S. A. Wangberg. 1984. Species-dependent variation in algal sensitivity to chemical compounds. *Ecotoxicology and Environmental Safety* 8: 339-351.

Bothwell, M. L. 1988. Growth rate responses of lotic periphytic diatom communities to experimental phosphorus enrichment: the influence of temperature and light. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 261-270.

Bothwell, M. L. 1989. Phosphorus-limited growth dynamics of lotic periphyton diatom communities: areal biomass and cellular growth rate responses. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1293-1301.

Bothwell, M. L. 1992. Eutrophication of rivers by nutrients in treated kraft pulp mill effluent. *Water Pollution Journal of Canada* 27: 447-472.

Brittain, J. E. and T. J. Eikeland. 1988. Invertebrate drift – a review. *Hydrobiologia* 166: 77-93.

Browder, J. A. 1988. Introduction: aquatic organisms as indicators of environmental pollution. *Water Resources Bulletin* 24: 927-229.

Brussock, P. 1993. Experimental design and control: keys to refining rapid bioassessment metrics. *Environmental Toxicology and Chemistry* 12: 1-4.

Buikema, A. L. and J. R. Voshell Jr. 1993. Toxicity studies using freshwater benthic macroinvertebrates. Pp.344-398 in Freshwater Biomonitoring and Benthic Macroinvertebrates, eds. D. M. Rosenberg and V. H. Resh. New York, U.S.A.: Chapman and Hall.

Buikema, A. L., E. F. Benfield, and B. R. Niederlehner. 1981. Effects of pollution on freshwater-invertebrates. *Journal of the Water Pollution Control Federation* 53: 1007-1014.

Cairns, J. Jr. and K. L. Dickson. 1971. A simple method for the biological assessment of the effects of water discharges on aquatic bottom-dwelling organisms. *Journal of the Water Pollution Control Federation* 41: 755-772.

Note: deleted this reference from text document.

Campbell, I. C. and T. J. Doeg. 1989. Impact of timber harvesting production on streams: a review. *Australian Journal of Marine and Freshwater Research* 40: 519-539.

Canadian Biodiversity Strategy Working Group. 1995. Canadian Biodiversity Strategy: Canada's response to the Convention on Biological Diversity. Environment Canada, Hull, Quebec. 80 pp.

Carlson, J. Y., C. W. Andrus, and H. A. Froehlich. 1990. Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1103-1111.

Cash, K. 1995. Assessing and monitoring aquatic ecosystem health: approaches using individual, population and community/ecosystem measurements. Northern River Basins Study Project Report 45, Northern River Basins Study, Edmonton, Alberta. 70 pp.

Cattaneo, A., T. Kerimian, M. Roberge, and J. Marty. 1997. Periphyton distribution and abundance on substrata of different size along a gradient of stream trophy. *Hydrobiologia* 354: 101-110.

Cattaneo, A., and G. Roberge. 1991. Efficiency of a brush sampler to measure periphyton in streams and lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1877-1881.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. *Transactions of the American Fisheries Society* 117: 1-20.

Chessman, B. C. 1986. Diatom flora of an Australian river system: spatial patterns and environmental relationships. *Freshwater Biology* 16: 805-819.

Chetelat, J., F. R. Pick, A. Morin, and P. B. Hamilton. 1999. Periphyton biomass and community composition in rivers of different nutrient status. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 560-569.

Clifford, H. F. 1972. Comparison of samples of stream benthos fauna collected during day and night. *Limnology and Oceanography* 17: 479-481.

Coleman, R. L. and C. N. Dahm. 1990. Stream geomorphology: effects of periphyton standing crop and primary production. *Journal of the North American Benthological Society* 9: 293-302.

Collier, K. J., B. J. Smith, and B. R. Baillie. 1997. Summer light-trap catches of adult trichoptera in hill-country catchments of contrasting land use, Waikato, New Zealand. *New Zealand*

Journal of Marine and Freshwater Research 31: 623-634.

Collier, K. J. and B. J. Smith. 1998. Dispersal of adult caddisflies (Trichoptera) into forests alongside three New Zealand streams. *Hydrobiologia* 361: 53-65.

Cooper, C. M. 1987. Benthos in Bear Creek, Mississippi: effects of habitat variation and agricultural sediments. *Journal of Freshwater Ecology* 4: 101-113.

Corkum, L. D. 1996 . Responses of chlorophyll-a, organic matter, and macroinvertebrates to nutrient additions in rivers flowing through agricultural and forested land. *Archives fur Hydrobiologie* 136: 391-411.

Corkum, L. D. 1989. Patterns of benthic invertebrate assemblages in rivers of northwestern North America. *Freshwater Biology* 21: 191-205.

Corkum, L. D. 1990. Intrabiome distributional patterns of lotic macroinvertebrate assemblages. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2147-2157.

Corn, P. S. and J. C. Fogleman. 1984. Extinction of montane populations of the Northern Leopard Frog in Colorado. *Journal of Herpetology* 18: 147-152.

Corn, P. S. and R. B. Bury. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. *Forest Ecology and Management* 29: 39-57.

Cuffney, T. F., M. E. Gurtz, and M. R. Meador. 1993. Methods for collecting benthic samples as part of the National Water-quality assessment program. United States Geological Survey Open-File report 93-406, Raleigh, North Carolina, U.S.A. 66 pp.

Culp, J. M., G. J. Scrimgeour, and C. Beers. 1994. The effect of sample duration on the quantification of stream drift. *Freshwater Biology* 31: 165-173.

Culp, J. M., G. J. Scrimgeour, and G. D. Townsend. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. *Transactions of the American Fisheries Society* 125: 472-479.

Cushman, R. M. 1984. Chironomid deformities as indicators of pollution from a synthetic, coal-derived oil. *Freshwater Biology* 14: 179-182.

David, S. M., K. M. Somers, R. J. Reid, R. J. Hall, and R. E. Girard. 1998. Sampling protocols for the rapid assessment of streams and lakes. Dorset Environmental Science Centre, Ontario Ministry of the Environment, Dorset, Ontario, Canada. 29 pp.

deMaynadier, P. G. and M. L. HunterJr.. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental reviews* 3: 230-261.

deMaynadier, P. G. and M. L. Hunter Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. *Conservation Biology* 12: 340-352.

De Pauw, N., D. Roels, and P. Fontoura. 1986. Use of artificial substrates for standardized sampling of macroinvertebrates in the assessment of water quality by the Belgian Biotic Index. *Hydrobiologia* 133: 237-258.

Dixit, S. S., B. F. Cumming, H. J. B. Birks, J. P. Smol, J. C. Kingston, A. J. Uutala, D. F. Charles, and K. E. Camburn. 1993. Diatom assemblages from Adirondack lakes (New York, U.S.A.) and the development of inference models for retrospective environmental assessment. *Journal of Palaeolimnology* 8: 27-47.

Dixit, S. S., J. P. Smol, J. C. Kingston, and D. F. Charles. 1992. Diatoms: powerful indicators of environmental change. *Environmental Science and Technology* 26: 23-33.

Dubé, M. G., J. M. Culp, and G. J. Scrimgeour. 1997. Nutrient limitation and herbivory: processes influenced by bleached draft pulp mill effluent. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 2584-2595.

Dukererschein, J. T., J. G. Wiener, R. G. Rhada, and M. T. Steingraeber. 1992. Cadmium and mercury in emergent mayflies (Hexagenia bilineata) from the Upper Mississippi River. *Archives of Environmental Contamination and Toxicology* 23: 109-116.

Eaton, J. G. and R. M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography* 41: 1109-1115.

Elliott, S. T. 1986. Reduction of a dolly varden population and macrobenthos after removal of logging debris. *Transactions of the American Fisheries Society* 115: 392-400.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Sci. Publ. No. 25. 2nd edition. Freshwater Biological Association, Ambleside, England. 160 pp.

Evenson, W. E., S. R. Rushforth, J. D. Brotherson, and N. Fungladda. 1981. The effects of selected physical and chemical factors on attached diatoms in the Uintah Basin of Utah, USA. *Hydrobiologia* 83: 325-330.

Flannagan, J. F. 1970. Efficiencies of various grabs and corers in sampling freshwater benthos. *Journal of the Fisheries Board of Canada* 27: 1691-1700.

Frenzel, S. A. and R. B. Swanson. 1996. Relations of fish community composition to environmental variables in streams of central Nebraska, U.S.A. *Environmental Management* 20: 689-705.

Gale, W. F. 1971. Shallow-water core sampler. *Progressive Fish Culturalist* 33: 238-239.

Genter, R. B. 1995. Benthic algal populations respond to aluminum, acid, and aluminum-acid mixtures in artificial streams. *Hydrobiologia* 306: 7-19.

Giberson, D. J. and H. L. Garnett. 1996. Species composition, distribution, and summer emergence phenology of stoneflies (Insecta: Plecoptera) from Catamaran Brook, New

Brunswick. *Canadian Journal of Zoology* 74: 1260-1267.

Gillespie, D. M., D. L. Stites, and A. C. Benke. 1985. An inexpensive core sampler for use in sandy substrata. *Freshwater Biology* 4:147.

Grubaugh, J. W., J. B. Wallace, and E. S. Houston. 1996. Longitudinal changes of macroinvertebrate communities along an Appalachian stream continuum. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 896-909.

Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8: 27-38.

Grumbine, R. E. 1997. Reflections on "What is ecosystem management"? *Conservation Biology* 11: 41-47.

Hämäläinen, H. and P. Huttunen. 1996. Inferring the minimum pH of streams from macroinvertebrates using weighted averaging regression and calibration. *Freshwater Biology* 36: 697-709.

Hämäläinen, H. and P. Huttunen. 1998. Macroinvertebrate-inferred stream-water acidity in north eastern Finland along a sulphur deposition gradient. *Water, Air, & Soil Pollution* 104: 223-236.

Hamilton, P. B. and H. C. Duthie. 1984. Periphyton colonization of rock surfaces in a boreal forest stream studied by scanning electron microscopy and track autoradiography. *Journal of Phycology* 20: 525-532.

Hansmann, E. W. and H. K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology* 54: 194-199.

Harper, P. P. 1973. Life histories of Nemouridae and Leutridae in Southern Ontario. *Hydrobiologia* 41: 309-356.

Hawkes, C. L., D. L. Miller, and W. G. Layher. 1986. Fish ecoregions of Kansas: stream fish assemblage patterns and associated environmental correlates. *Environmental Biology of Fishes* 17: 267-279.

Hawkins, C. P., M. L. Murphy, and N. H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology* 63: 1840-1856.

Heifetz, J., M. L. Murphy, and K. V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management* 6: 52-68.

Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster. 1994. Measuring and monitoring biological diversity: standard methods for amphibians. (Eds). Smithsonian Institution Press: Washington, U.S.A.

Hughes, R. M. and J. R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Transactions of the American Fisheries Society 116*: 196-209.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: a method for assessing stream pollution. *Environmental Management* 10: 629-635.

Kovats, Z. E. and J. J. H. Ciborowski. 1989. Organic contaminants in adult aquatic insects of the St. Clair and Detroit rivers, Ontario, Canada. *Journal of Great Lakes research* 14: 148-156.

Kuusela, K. and A. Huusko. 1996. Pot-emergence migration of stoneflies (Plecoptera) into nearby forests. *Ecological Entomology* 21: 171-177.

Jones, T. S. and V. H. Resh. 1988. Movements of adult aquatic insects along a Montana (USA) springbrook. *Aquatic insects* 10: 99-104.

Lafont, M. 1984. Oligochaete communities as biological descriptors of pollution in the fine sediments of rivers. *Hydrobiologia* 115: 127-139.

Lamberti, G. A. and V. H. Resh. 1985. Distribution of benthic algae and macroinvertebrates along a thermal stream gradient. *Hydrobiologia* 128: 13-21.

Lampkin, A. J. III and M. R. Sommerfeld. 1982. Algal distribution in a small intermittent stream receiving acid mine-drainage. *Journal of Phycology* 18: 196-179.

LaPerriere, J. D., E. E. Van Nieuwenhuyse, and P. R. Anderson. 1989. Benthic algal biomass and productivity in high subarctic streams, Alaska. *Hydrobiologia* 172: 63-75.

Lee, P. and S. Hanus. 1998. Criteria and indicators for monitoring biodiversity in Alberta's forests. Report prepared for Alberta Environmental Protection, Alberta Environmental Protection Publication#T/422, Alberta Research Council, Vegreville, Alberta, Canada. 121 pp.

Leland, H. V., S. V. Fend, J. L. Carter, and A. D. Mahood. 1986. Composition and abundance of periphyton and aquatic insects in a Sierra Nevada, California, stream. *Great Basin Naturalist* 46: 595-611.

Lenat, D. R. 1993. Using mentum deformities of Chironomus larvae to evaluate the effects of toxicity and organic loading in streams. *Journal of the North American Benthological Society* 12: 265-279.

Leonard, P. M. and D. J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. *Transactions of the American Fisheries Society* 115: 401-414.

Madsen, B. L., J. Bengstsson, and I. Butz. 1973. Observations on upstream migration by imagines of some Plecoptera and Ephemeroptera. *Limnology and Oceanography* 18: 678-681.

Madsen, B. L., J. Bengstsson, and L. Butz. 1977. Upstream movement by some Ephemeroptera species. *Archives fur Hydrobiologia* 81:119-127.

McCormick, P. V. and J. Cairns. 1994. Algae as indicators of environmental change: a review. *Journal of Applied Phycology* 6: 509-526.

McGeoch, M. A. 1998. The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* 73: 181-201.

Merritt, R. W. and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. 3rd edition. Kendall/Hunt Publishing, Duduque, Iowa, USA.

Morin, A. 1985. Variability of density estimates and the optimization of sampling programs for stream benthos. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1530-1534.

Mulholland, P. J., J. W. Elwood, and A. V. Palumbo. 1986. Effect of stream acidification on periphyton composition, chlorophyll, and productivity. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1846-1858.

Mundie, J. H. and K. S. Simpson. 1991. Responses of stream periphyton and benthic insects to increases in dissolved inorganic phosphorus in a mesocosm. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2061-2072.

Murphy, M. L. and J. D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 137-145.

Nelson, J. S. and M. J. Paetz. 1992. The fishes of Alberta. 2nd edition. The University of Calgary Press, Calgary, Alberta, Canada.

Nielsen, L. A. and D. Johnson. 1983. Fisheries techniques. American Fisheries Society: Bethesda, Maryland, U.S.A.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1076-1085.

Norrie, P. H. 1969. The flight activity of Ephemeroptera and Trichoptera in a Waitakere stream. Unpublished M.Sc thesis, University of Auckland, New Zealand. 218 pp.

Ogbeibu, A. E. and R. Victor. 1989. The effects of road and bridge construction on the bank-root macrobenthic invertebrates of a southern Nigerian stream. *Environmental Pollution* 56: 85-100.

Pan, Y. D., R. J. Stevenson, B. H. Hill, A. T. Herlihy, and G. B. Collins. 1996. Using diatoms as indicators of ecological conditions in lotic systems - a regional assessment. *Journal of the North American Benthological Society* 15: 481-495.

Perrin, C. J., M. L. Bothwell, and P. A. Slaney . 1987. Experimental enrichment of a coastal stream in British Columbia: Effects of organic and inorganic additions on autotrophic periphyton production. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 1247-1256.

Peterson, C. G. and R. J. Stevenson. 1990. Post-spate development of epilithic algal communities in different current environments. *Canadian Journal of Botany* 68: 2092-2102.

Petersen, I., J. H. Winterbottom, S. Orton, N. Friberg, A. G. Hildrew, D. C. Spiers, and W. S. C. Gurney . 1999. Emergence and lateral dispersal of adult Plecoptera and Trichoptera from Broadstone Stream, U.K. *Freshwater Biology* 42: 401-416.

Porter, S. D., T. F. Cuffney, M. E. Gurtz, and M. R. Meador. 1993. Methods for collecting algal samples as part of the National water-quality assessment program. US Geological Survey Open File Report 93-409. 39 pp.

Portt, C. B., E. K. Balon, and D. L. G. Noakes. 1986. Biomass and production of fishes in natural and channelized streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1926-1934.

Pringle, J. D. 1984. Efficiency estimates for various quadrat sizes used in benthic *sampling. Canadian Journal of Fisheries and Aquatic Sciences* 41: 1485-1489.

Quinn, J. M., A. B. Copper, R. J. Davies-Colley, J. C. Rutherford, and R. B. Williamson. 1997. Land use effects on habitat, water quality and benthic macroinvertebrates in Waikato, New Zealand, hill country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579-597.

Rabeni, C. F., N. Wang, and R. J. Sarver. 1999. Evaluating adequacy of the representative stream reach used in invertebrate monitoring programs. *Journal of the North American Benthological Society* 18: 284-291.

Rosenberg, D. M. and V. H. Resh. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Eds. New York, U.S.A.: Chapman and Hall.

Resh, V. H., R. H. Norris, and M. T. Barbour. 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology* 20: 108-21.

Rothfritz, H., I. Juttner, A. M. Suren, and S. J. Omerod. 1997. Epiphytic and epilithic diatom communities along environmental gradients in the Nepalese Himalaya - implications for the assessment of biodiversity and water quality. *Archives fur Hydrobiologie* 138: 465-482.

Round, F. E. 1991. Diatoms in river water-monitoring studies. *Journal of Applied Phycology* 3: 129-145.

Scott, W. G. and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184. 966 pp.

Scrimgeour, G. J. and P. A. Chambers. 1997. Development and application of a nutrient-diffusing bioassay for large rivers. *Freshwater Biology* 38: 221-231.

Scrimgeour, G. J. and D. Wicklum. 1996. Aquatic ecosystem health and integrity: problems and potential solutions. *Journal of the North American Benthological Society* 15: 254-261.

Scrimgeour, G. J., K. J. Cash, and J. M. Culp. 1997. Size-dependent flight initiation by a lotic mayfly in response to a predatory fish. *Freshwater Biology* 37: 91-98.

Scrimgeour, G. J., D. Wicklum, and S. D. Pruss. 1998. Selection of an aquatic indicator to monitor organic contaminants in trophically simple food webs. *Archives of Environmental Contamination and Toxicology* 35: 565-572.

Scrivener, J. C. and M. J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (Oncorhynchus keta) and coho salmon (O. kisutch) in Carnation Creek, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 681-96.

Simpson, K. W. 1980. Abnormalities in the tracheal gills of aquatic insects collected from streams receiving chlorinated crude oil wastes. *Freshwater Biology* 10: 581-593.

Singh, M. P., S. M. Smith, and A. D. Harrison. 1984. Emergence patterns of the stoneflies (Plecoptera) from a wooded stream iin Southern Ontario. *Aquatic insects* 6: 233-243.

Sode, A. and P. Wiberg-Larsen. 1993. Dispersal of adult Trichoptera at a Danish forest brook. *Freshwater Biology* 30: 439-446.

Stevenson, R. J. 1984. Epilithic and epipelic diatoms in the Sandusky River, with emphasis on species diversity and water pollution. *Hydrobiologia* 114: 161-174.

Svensson, B. W. 1974. Population movements of adult Trichoptera at a South Swedish stream. *Oikos* 25: 157-175.

terBraak, C. J. F. and H. van Dam. 1989. Inferring pH from diatoms: a comparison of old and new calibration methods. *Hydrobiologia* 178: 209-223.

Walker, C. R. 1955. A core sampler for obtaining samples of bottom muds. *Progressive Fish Culturalist* 17:140.

Wallace, J. B., D. S. Vogel, and T. F. Cuffney. 1986. Recovery of a headwater stream from an insecticide-induced community disturbance. *Journal of the North American Benthological Society* 5: 115-126.

Waringer, J. A. 1986. The abundance and distribution of caddisflies (Insecta: Trichoptera) caught by emergence traps in the 'Ritrodat' research area of the Lunzer Seebach (Lower Austria) from 1980 to 1982. *Freshwater Biology* 16: 49-59.

Waringer, J. A. 1991. Phenology and the influence of meteorological parameters on the catching success of light-trapping for Trichoptera. *Freshwater Biology* 25: 307-319.

Weddle, G. K. and R. K. Kessler. 1993. A square-meter electrofishing sampler for benthic riffle fishes. *Journal of the North American Benthological Society* 12: 291-301.

Zwick, P. 1990. Emergence, maturation and upstream oviposition flights of Plecoptera from the Breitenbach, with notes on the adult phase as a possible control of stream insect populations. *Hydrobiologia* 194: 207-223.

Appendix: Identification of Aquatic Elements and Sampling Protocols: Annotated Bibliography

This appendix was initially prepared for the Prince Albert Model Forest Association and the Alberta Forest Biodiversity Monitoring Program Steering Committee (AFBMP). An annotated bibliography of published materials is presented that relates to the development and use of biological indicators, as well as the concepts underlying their use. The annotated bibliography is broadly limited to: 1) stream ecosystems within forested landscapes; and 2) indicators, monitoring practices and conceptual frameworks.

Materials referenced within the annotated bibliography have been divided into those pertaining to: 1) indicators and criteria; 2) assessments and monitoring; and 3) conceptual issues.

The later section, while highly relevant to stream ecosystems, addresses a broader issue of the role of indicators for monitoring and resource management. There is considerable debate among scientists, regulators and land base managers regarding what constitutes an indicator species, group or assemblage and the function of indicators in biological monitoring. The diversity of conceptual issues and opinions expressed within many of the documents is a reflection of this fact. While diversity of viewpoints is problematic to some, argument should be viewed as a part of the process by which new paradigms are evaluated. Put differently, the debate is part of the problem solving process.

Introduction

Framework

The Canadian Forest Industry is experiencing a period of transition regarding the concept of sustainability. The definition of sustainability and the mechanisms through which to attain it are being critically evaluated. Much of the discussion is based on the notion that sustainability includes economic, social and biological attributes. This focus is fundamentally different from the traditional view, in which sustainability largely reflects economic considerations. The traditional viewpoint focuses on forest attributes primarily related to fiber and wood resources, and their flow to the market place, as did the management practices that were derived from it. Social, cultural and biological impacts of other forest attributes were considered to a lesser degree.

The current fluctuation within the forest sector also results from the debate on whether natural disturbance-based models of forestry can, or should, be used for developing a management strategy to ensure biological sustainability of forested ecosystems. These models assume that harvesting will be biologically sustainable when operating practices are similar to natural disturbance regimes, as defined by the particular magnitude, intensity and frequency of disturbance (e.g., Payette 1992, Hunter 1993, Bergeron and Charron 1994, Johnson and Miyanishi 1995 and references therein). Testing this assumption requires a detailed understanding of the appropriate spatial and temporal scales at which natural disturbances operate, the biophysical features that they produce, and how these compare with forest harvesting.

During the development of biologically sustainable forestry practices, it is essential to determine which aquatic elements are tightly related to the overall objective of maintaining sustainable ecosystems (i.e., criteria) and how to measure these elements in an economically efficient and statistically rigorous manner. This report represents the first step in that process by providing an annotated bibliography of studies describing stream elements and how they are measured.

Definitions

To improve clarity, several terms are defined that appear consistently within this report including those that appear as part of the bibliography. In presenting these definitions we acknowledge that these terms are not accepted universally and that controversy concerning definitions, including conceptual frameworks exists (e.g., Scrimgeour and Wicklum 1996).

- Adaptive Management

The formal process of problem assessment, hypothesis development, implementation, execution, monitoring, evaluation, and feedback (Lee and Hanus 1998).

- Bankfull Height and Width

The height and width of the stream channel at the discharge that maintains the active channel.

- Benthos

Benthic invertebrates living on the substratum.

- Biodiversity

The variability among living organisms from all ecosystems, and ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Canadian Biodiversity Strategy Working Group 1995).

- Biomonitoring

The intermittent or continuous surveillance carried out to detect ecosystem change, assess the effectiveness of policy or legislation, or within a regulatory context to determine the effectiveness of a management practice (Hellawell 1991).

- Criteria

A valued attribute that is to be achieved or maintained through resource management.

- Epilithic Algae

Algal communities (epilithon) growing on rock or stone surfaces (Wetzel 1983).

- Epipelic algae

Algal communities growing on fine or organic sediments.

- Epiphytic algae

Algal communities growing on macrophytes.

- Indicator

A measure that quantifies an attribute of one or more criteria. Indicators can be viewed as elements that provide information on changes in other elements. For example, McGeoch (1998) separates indicators into the three categories of environmental indicators, ecological indicators and biodiversity indicators.

- Macrophyte

Macroscopic aquatic vegetation including macroalgae, mosses, ferns and true angiosperms.

- Stone Surface Organic Layers

The film of material present on stone surfaces comprised of algae, fungi, protozoans, bacteria and terrestrial and aquatic-derived organic and inorganic materials.

Literature Cited

Bergeron Y., and D. Charron. 1994. Postfire stand dynamics in a southern boreal forest (Québec): a dendrological approach. *Ecoscience* 1: 173-184.

Canadian Biodiversity Strategy Working Group. 1995. Canadian Biodiversity Strategy: Canada's response to the convention on biological diversity. Environment Canada. Environment Canada, Hull, Quebec.

Hellawell, J. H. 1991. Development of a rationale for monitoring. Pp. 1-14 in Monitoring for Conservation Biology, ed. F. B. Goldsmith. London: Chapman and Hall.

Hunter, M. L. Jr. 1993. Natural fire regimes as spatial models for managing boreal forests. *Biological Conservation* 65: 115-120.

Johnson, E. A, and K. Miyanishi. 1995. The need for consideration of fire behavior and effects in prescribed burning. *Restoration Ecology* 4: 271-278.

Lee P., and S. Hanus. 1998. Criteria and indicators for monitoring biodiversity in Alberta's forests. Part I: Review of Legislation, Policies, External Agreements, and Programs. Alberta Environmental Protection Publication # T/422.

Payette, S. 1992. Fire as a controlling process in the North American boreal forest. Pp. 144-169 in A Systems Analysis of the Global Boreal Forest, eds. H. Shugart, R. Leemans, and G. B. Bonan, Cambridge: Cambridge University Press.

Scrimgeour, G. J, and D. Wicklum. 1996. Aquatic ecosystem health and integrity: problems and potential solutions. *Journal of the North American Benthological Society* 15: 254-261.

Wetzel, R. G. 1983. Limnology. 2nd Edition. Saunders College Publishing. U.S.A.

Annotated Bibliography Methods

Approach

An intensive literature search was joined with the senior author's extensive bibliographical database to produce the annotated bibliography of articles on stream elements within forested landscapes and related monitoring protocols. Thus, the two data sources were combined to provide an intensive review of recent materials (1995-1998) and a large, qualitative review of relevant older material (1990-1998).

Intensive Search

An intensive search of relevant literature from 1995 to November 1998 was conducted by CD-ROM exploration of Current Contents databases: 1) Life Sciences and 2) Agriculture, Biology and Environmental Sciences. This literature survey examined materials published in 58 journals (Table 10.1). The objective of the search was to identify a large number (several thousand) of potentially relevant records. Subsequently, a more manageable number would be selected through a review and screening process. Three general key words (forest, stream, and monitoring) were used to create the initial list of article references.

As expected, the search produced about 3,000 potentially relevant articles, which were screened to produce a sub-set of records. The sub-set was sufficiently large to describe elements and protocols while reducing redundancy among records. During the screening process, all article hits were reviewed and grouped for relevance, ensuring that the sub-set of records:

- Reflected research throughout Europe, North America, New Zealand and Australia, where the majority of work on stream indicators and monitoring is being carried out.
- Covered a broad suite of potential elements.
- Comprised a large number of methodologies for measurement of elements.
- Identified documents that addressed the larger challenges and issues related to ecosystem management, monitoring and aquatic ecosystems.

Table 10.1 List of journals searched within the Current Contents Life Sciences and Agriculture, Biology and Environmental Sciences CD-ROM databases

1.1.1.1.Journals	
American Naturalist	Fisheries
American Scientist	Forest Ecology Management
Annual Review of Ecology and Systematics	Forest Science
Annual Review of Entomology	Freshwater Biology
Aquatic Insects	Hydrobiologia
Archiv fur Hydrobiologie	Hydrological Processes
Australian Journal of Ecology	Journal of Applied Ecology
Australian Journal of Marine and Freshwater Research	Journal of Applied Phycology
Biological Conservation	Journal of Environmental Quality
Biological Journal of the Linnean Society	Journal of Forestry
BioScience	Journal of Great Lakes Research
Bulletin of Environmental Contamination and Toxicology	Journal of Herpetology
Canadian Entomologist	Journal of Phycology
Canadian Field-Naturalist	Journal of the North American Benthological Society
Canadian Journal Fisheries and Aquatic Sciences	Limnology and Oceanography
Canadian Journal of Botany	Nature
Canadian Journal of Zoology	New Phycologist
Conservation Biology	New Zealand Journal of Marine and Freshwater Research
Copeia	Oecologia
Ecological Applications	Oikos
	Regulated Rivers: Research and Management

Ecological Modelling	Science
Ecological Monographs	Transactions of the American Fisheries Society
Ecology	Water Research
Environmental Biology of Fishes	Water Resources Bulletin
Environmental Conservation	Water Resources Research
Environmental Management	Water Science and Technology
Environmental Monitoring and Assessment	Water, Air, and Soil Pollution
Environmental Pollution	Wetlands
Environmental Science and Technology	

The Existing Database

Records identified during the intensive search were combined with those within the extensive existing database held by GJS. The later database contains about 3,000 records with the following topics:

- stream, lake, and wetland habitats
- water quality
- benthic algae
- aquatic macrophytes
- benthic macroinvertebrates
- fishes
- parasites
- biological monitoring
- indicators and their measurement
- environmental effects of forestry and other industrial sectors
- experimental design and analysis

These records were published predominantly between 1986 and 1997 and appeared in approximately 70 journals (Table 10.2) or were produced as published or unpublished reports within Canada, the United States or Europe.

Records within the extensive database were screened in a manner similar to the intensive data, ensuring that records complemented those already identified.

Table 10.2 **List of journals comprising an extensive bibliographical database held by the senior author**

Journals	
American Midland Naturalist	Journal of Applied Ecology
American Naturalist	Journal of Applied Phycology
American Scientist	Journal of Aquatic Ecosystem Health
Annual Review of Ecology and Systematics	Journal of Freshwater Ecology
Annual Review of Entomology	Journal of Great Lakes Research
Aquatic Biology	Journal of Herpetology
Aquatic Insects	Journal of Phycology
Archiv fur Hydrobiologie	Journal of the North American Benthological Society
Australian Journal of Ecology	Journal of the Water Pollution Control Federation
Australian Journal of Marine and Freshwater Research	Limnology and Oceanography
Biological Conservation	Nature
Biological Journal of the Linnaean Society	New Zealand Journal of Marine and Freshwater Research
BioScience	North American Journal of Fisheries Management
Bulletin of Environmental Contamination and Toxicology	Oecologia
Bulletin of the North American Benthological Society	Oikos
Canadian Entomologist	Quarterly Review of Biology
Canadian Field-Naturalist	Regulated Rivers: Research and Management
Canadian Journal Fisheries and Aquatic Sciences	Rivers
Canadian Journal of Zoology	Science

Conservation Biology	The Environmental Professional
Copeia	Transactions of the American Fisheries Society
Ecological Applications	Transactions of the North American Fisheries Society
Ecological Monographs	Water Pollution Control
Ecology	Water Pollution Research Journal of Canada
Environmental Biology of Fishes	Water Research
Environmental Conservation	Water Resources Bulletin
Environmental Management	Water Resources Research
Environmental Monitoring and Assessment	Water Science and Technology
Evolution	Water Science Technology
Fisheries	Water, Air, and Soil Pollution
Forest Ecology Management	Wetland Ecology Management
Forest Science	Wetland Journal
Freshwater Biology	Wetlands
Freshwater Invertebrate Biology	
Holarctic Ecology	
Hydrobiologia	
Journal of Animal Ecology	

Annotated Bibliography of Stream Elements and Protocols

Indicators and Criteria

Agami, M., M. Litav, and Y. Waisel. 1976. The effects of various components of water pollution on the behavior of some aquatic macrophytes of the coastal rivers of Israel. *Aquatic Botany* 2: 203-213.

Aloi, J. E. 1990. A critical review of recent freshwater periphyton field methods. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 656-670.

Angermeier, P. L. and J. R. Karr. 1986. Applying an index of biotic integrity based on stream-fish communities: considerations in sampling and interpretation. *North American Journal of Fisheries Management* 6: 418-429.

Angermeier, P. L. and I. J. Schlosser. 1987. Assessing biotic integrity of the fish community in a small Illinois stream. *North American Journal of Fisheries Management* 7: 331-338.

Archibald, R. E. M. 1972. Diversity in some South African diatom associations and its relation to water quality. *Water Research* 6: 1229-1238.

Armitage, P. D., D. Moss, J. F. Wright, and M. T. Furse. 1983. The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research* 17: 333-347.

Austin, M. P. and I-M. Noy. 1971. The problem of non-linearity in ordination: experiments with two-gradient models. *Ecology* 59: 763-773.

Barbour, C. D. and J. H. Brown. 1974. Fish species diversity in lakes. *American Naturalist* 108: 473-488.

Barbour, M. T., J. L. Plafkin, B. P. Bradley, C. G. Graves, and R. W. Wisseman. 1992. Evaluation of EPA's rapid bioassessment benthic metrics: metric redundancy and variability among reference stream sites. *Environmental Toxicology and Chemistry* 11: 437-449.

Barbour, M. T., J. Gerritsen, G. E. Griffith, R. Frydenborg, E. McCarron, J. S. White, and M. L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of the North America Benthological Society* 15: 185-211.

Bascombe, A. D., J. B. Ellis, D. M. Revitt, and R. B. E. Shutes. 1990. The development of ecotoxicological criteria in urban catchments. *Water Science and Technology* 22: 173-179.

Battarbee, R. W., R. J. Flower, A. C. Stevenson, V. J. Jones, R. Hariman, and P. G. Appleby. 1988. Diatom and chemical evidence for reversibility of acidification of Scottish lochs. *Nature* 332: 530-532.

Baumann, R. W. 1979. Nearctic stonefly genera as indicators of ecological parameters (Plecoptera: Insects). *Great Basin Naturalist* 39: 241-244.

Bayne, B. L. 1989. Measuring the biological effects of pollution: the mussel watch approach. *Water Science and Technology* 21: 1089-1100.

Bechtel, T. J. and B. J. Copeland. 1970. Fish species diversity indices as indicators of pollution in Galveston Bay, Texas. *Contributions in Marine Science* 15: 103-132.

Beitinger, T. L. 1990. Behavioral reactions for the assessment of stress in fishes. *Journal of Great Lakes Research* 16: 495-528.

Bella, D. A, R. Jacobs, and H. Li. 1994. Ecological indicators of global climate change: a research framework. *Environmental Management* 18: 489-500.

Berkman, H. E., C. F. Rabeni, and T. P. Boyle. 1986. Biomonitors of stream quality in agricultural areas: fish versus invertebrates. *Environmental Management* 10: 413-419.

Bick, H. 1963. A review of Central European methods for the biological estimation of water pollution levels. *Bulletin of the World Health Organization* 29: 401-413.

Binns, N. A. and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. *Transactions of the American Fisheries Society* 108: 215-228.

Blanck, H., G. Wallin, and S. A. Wangberg. 1984. Species-dependent variation in algal sensitivity to chemical compounds. *Ecotoxicology and Environmental Safety* 8: 339-351.

Bloom, S. A. 1981. Similarity indices in community studies: potential pitfalls. *Marine Ecology Progress Series* 5: 125-138.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. *Journal of Wildlife Management* 18: 229-239.

Boyle, T. P., G. M. Smillie, J. C. Anderson, and D. P. Beeson. 1990. A sensitivity analysis of nine diversity and seven similarity indices. *Journal of the Water Pollution Control Federation* 62: 749-762.

Bramblett, R. G. and K. D. Fausch. 1991. Variable fish communities and the index of biotic integrity in a western great plains river. *Transactions of the American Fisheries Society* 120: 752-769.

Brinkhurst, R. O., P. M. Chapman, and M. A. Farrell. 1983. A comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress. *Internationale Revue Der Gesamten Hydrobiologie* 68: 683-699.

Brinkhurst, R. O., K. E. Chua, and E. Batoosingh. 1969. Modifications in sampling procedures as applied to studies on the bacteria and tubificid oligochaetes inhabiting aquatic sediments. *Journal of the Fisheries Research Board of Canada* 26: 2581-2593.

Brock, D. A. 1977. Comparison of community similarity indices. *Journal of the Water Pollution Control Federation* 49: 2488-2494.

Browder, J. A. 1988. Introduction: aquatic organisms as indicators of environmental pollution. *Water Resources Bulletin* 24: 927-929.

Burton, T. M. and J. W. Allan. 1986. Influence of pH, aluminum, and organic matter on stream invertebrates. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1285-1289.

Cain, D. J., S. N. Luoma, J. L. Carter, and S. V. Fend. 1992. Aquatic insects as bioindicators of trace element contamination in cobble-bottom rivers and streams. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 2141-2154.

Cairns, J. Jr. 1974. Indicator species vs the concept of community structure as an index of pollution. *Water Resources Bulletin* 10: 338-3347.

Cairns, J. Jr. 1983. Are single species toxicity tests alone adequate for estimating environmental hazard? *Hydrobiologie* 100: 47-57.

Cairns, J. Jr., D. W. Albaugh, F. Bussey, and M. D. Chaney. 1968. The sequential comparison index-a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. *Journal of the Water Pollution Control Federation* 40: 1607-1613.

Caton, L. W. 1991. Improved subsampling methods for the EPA 'rapid bioassessment' benthic protocols. *Bulletin of the North American Benthological Society* 8: 317-319.

Chadwick, J. W. and S. P. Canton. 1984. Inadequacy of diversity indices in discerning metal mine drainage effects on stream invertebrate community. *Water, Air, and Soil Pollution* 22: 217-223.

Chapman, P. M. 1986. Sediment quality criteria from the sediment quality triad: An example. *Environmental Toxicology and Chemistry* 5: 957-964.

Chapman, P. M. and R. O. Brinkhurst. 1984. Lethal and sublethal tolerances of aquatic oligochaetes with reference to their use as a biotic index of pollution. *Hydrobiologie* 115: 139-144.

Chessman, B. C. 1986. Diatom flora of an Australian river system: spatial patterns and environmental relationships. *Freshwater Biology* 16: 805-819.

Chessman, B. C. and P. K. Mcevoy. 1998. Towards diagnostic biotic indices for river macroinvertebrates. *Hydrobiologia* 364: 169-182.

Chutter, F. M. 1972. An empirical biotic index of the quality of water in South African streams and rivers. *Water Research* 6: 19-30.

Chutter, F. M. 1972. A reappraisal of Needham and Usinger's data on the variability of a stream fauna when sampled with a Surber sampler. *Limnology and Oceanography* 17: 138-141.

Clark, T. E. and M. J. Samways. 1996. Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *Journal of Applied Ecology* 33: 1001-1012.

Clarke, A. H. 1979. Gastropods as indicators of tropic lake stages. *Nautilus* 94: 138-142.

Clements, W. H. and P. M. Kiffney. 1995. The influence of elevation on benthic community responses to heavy metals in rocky mountain streams. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 1966-1977.

Coler, R. A., M. S. Coler, and P. T. Kostecki. 1988. Tubificid behavior as a stress indicator. *Water Research* 22: 263-267.

Collier, K. J. 1995. Environmental factors affecting the taxonomic composition of aquatic macroinvertebrate communities in lowland waterways of Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29: 453-465.

Cooper, C. M. and J. W. Burris. 1984. Bryozoans-possible indicators of environmental quality in Bear Creek, Mississippi. *Journal of Environmental Quality* 13: 101-113.

Corkum, L. D. 1990. Intrabiome distributional patterns of lotic macroinvertebrate assemblages. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2147-2157.

Corn, P. S. and J. C. Fogleman. 1984. Extinction of montane populations of the Northern Leopard Frog in Colorado. *Journal of Herpetology* 18: 147-152.

Corn, P. S. and R. B. Bury. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. *Forest Ecology and Management* 29: 39-57.

Cosser, P. R. 1988. Macroinvertebrate community structure and chemistry of an organically polluted creek in southeast Queensland. *Australian Journal of Marine and Freshwater Research* 39: 671-683.

Couch, J. A. 1982. Aquatic animals as indicators of environmental exposures. *Journal of Environmental Science and Health* 17: 473-476.

Croonquist, M. J. and R. P. Brooks RP. 1991. Use of an avian and mammalian guilds as indicators of cumulative impacts in riparian-wetland areas. *Environmental Management* 1: 701-714.

Crumby, W. D., M. A. Webb, F. J. Bulow, and H. J. Cathey. 1990. Changes in the biotic integrity of a river in north-central Tennessee. *Transactions of the American Fisheries Society* 119: 885-893.

Crunkilton, R. L. and R. M. Duchrow. 1991. Use of stream order and biological indices to assess water quality in the Osage and Black River basins in Missouri. H*ydrobiologia* 224: 155-156.

Cushman, R. M. 1984. Chironomid deformities as indicators of pollution from synthetic, coal-derived oil. *Freshwater Biology* 14: 179-182.

De Pauw, N., D. Roels, and A. P. Fontoura. 1986. Use of artificial substrates for standardized sampling of macroinvertebrates in the assessment of water quality by the Belgian Biotic Index. *Hydrobiologia* 133: 237-258.

Descy, J. P. 1979. A new approach to water quality estimation using diatoms. *Nova Hedwigia* 64: 305-323.

Dixit, S. S., J. P. Smol, J. C. Kingston and D. F. Charles. 1992. Diatoms: powerful indicators of environmental change. *Environmental Science and Technology* 26: 23-33.

Dixit, S. S., B. F. Cumming, H. J. B. Birks, J. P. Smol, J. C. Kingston, A. J. Uutala, D. F. Charles, and K. E. Camburn. 1993. Diatom assemblages from Adirondack lakes (New York, U.S.A.) and the development of inference models for retrospective environmental assessment. *Journal of Palaeolimnology* 8: 27-47.

Donald, D. B. 1980. Deformities in Capniidae (Plecoptera) from the Bow River, Alberta. *Canadian Journal of Zoology* 58: 682-686.

Evenson, W. E., S. R. Rushforth, J. D. Brotherson, and N. Fungladda. 1981. The effects of selected physical and chemical factors on attached diatoms in the Uintah Basin of Utah, U.S.A. *Hydrobiologia* 83: 325-330.

Faith, D. P. and R. H. Norris. 1989. Correlation of environmental variables with patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* 50: 77-98.

Fausch, D. O., J. R. Karr, and P. R. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. *Transactions of the American Fisheries Society* 113: 39-55.

Flannagan, J. F., W. L. Lockhart, D. G. Cobb, and D. Metner. 1978. Stonefly (Plecoptera) head cholinesterase as an indicator of exposure to fenitrothion. *Manitoba Entomologist* 12: 42-48.

Fore, L. S., J. R. Karr, and L. L. Conquest. 1993. Statistical properties of an index of biotic integrity used to evaluate water resources. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 1077-1087.

France, R. 1992. Use of sequential sampling of amphipod abundance to classify the biotic integrity of acid-sensitive lakes. *Environmental Management* 16: 157-166.

Freda, J. and W. A. Dunson. 1986. Effects of low pH and other chemical variables on the local distribution of amphibians. *Copeia* 1986: 454-466.

Genter, R. B. 1995. Benthic algal populations respond to aluminum, acid, and aluminum-acid mixtures in artificial streams. *Hydrobiologia* 306: 7-19.

Gerritsen, J. 1995. Additive biological indices for resource management. *Journal of the North American Benthological Society* 14: 451-457.

Grassle, J. F. and W. Smith. 1976. A similarity measure sensitive of the contribution of rare species and its use in investigation of variation in marine benthic communities. *Oecologia* 25: 13-22.

Gray, J. S. 1989. Effects of environmental stress on species rich assemblages. *Biological Journal of the Linnean Society* 37: 19-32.

Guhl, W. 1997. Aquatic ecosystem characterizations by biotic indices. *Internationale Revue Der Gesamten Hydrobiologie* 72: 431-455.

Hamalainen, H. and P. Huttunen. 1996. Inferring the minimum pH of streams from macroinvertebrates using weighted averaging regression and calibration. *Freshwater Biology* 36: 697-709.

Hamilton, A. L. and O. A. Saether. 1971. The occurrence of characteristic deformities in the chironomid larvae of several Canadian lakes. *Canadian Entomologist* 103: 363-368.

Hawkes C. L., D. L. Miller, and W. G. Layher. 1986. Fish ecoregions of Kansas: stream fish assemblage patterns and associated environmental correlates. *Environmental Biology of Fishes* 17: 267-279.

Hawkins, C. P., M. L. Murphy, N. H. Anderson, and M. A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 1173-1185.

Hellawell, J. M. 1984. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science Publishers, London and New York.

Hermann, J. and K. G. Andersson. 1986. Aluminum impact on respiration of lotic mayflies at low pH. *Water, Air, and Soil Pollution* 30: 703-709.

Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. *Great Lakes Entomologist* 20: 31-39.

Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7: 65-68.

Hofmann, W. 1988. The significance of chironomid analysis (Insecta: Diptera) for paleolimnological research. *Palaeogeography, Palaeoclimatology, Palaeoecology* 62: 501-509.

Howmiller, R. P. and M. A. Scott. 1977. An environmental index based on relative abundance of oligochaete species. *Journal of the Water Pollution Control Federation* 49: 809-8015.

Hoyer, M. V. and D. E. Canfield Jr. 1991. A phosphorus-fish standing crop relationship for streams? *Lake and Reservoir Management* 71: 25-32.

Hruby, T. 1987. Using similarity measures in benthic impact assessments. *Environmental Monitoring and Assessment* 8: 163-80.

Hughes, B. D. 1978. The influence of factors other than pollution on the value of Shannon's diversity index for benthic macroinvertebrates in streams. *Water Research* 12: 359-364.

Hughes, R. M. and R. F. Noss. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. *American Fisheries Society* 17: 11-19.

Jackson, D. A., H. H. Harvey, and K. M. Somers. 1990. Ratios in aquatic sciences: statistical shortcomings with mean depth and the morphoedaphic index. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1788-1795.

Jeglum, J. K. 1971. Plant indicators of pH and water level in peatlands at Candle Lake, Saskatchewan. *Canadian Journal of Botany* 49: 1661-1676.

Jenkins, R. M. 1982. The morphoedaphic index and reservoir fish production. *Transactions of the American Fisheries Society* 111: 133-140.

Johannsson, O. E. and C. K. Minns. 1987. Examination of association indices and formulation of a composite seasonal dissimilarity index. *Hydrobiologia* 150: 109-121.

Johnson, R. K. and T. Wiederholm. 1989. Classification and ordination of profundal macroinvertebrate communities in nutrient poor, oligo-mesohumic lakes in relation to environmental data. *Freshwater Biology* 21: 375-386.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21-27.

Karr, J. R., R. C. Heidinger, and E. H. Helmer. 1985. Sensitivity of the index of biotic integrity to changes in chlorine and ammonia levels from wastewater treatment facilities. *Journal of the Water Pollution Control Federation* 57: 912-915.

Kerans, B. L. and J. R. Karr. 1994. Development and testing of a benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. *Ecological Applications* 4: 768-785.

Kiffney, P. M. and W. H. Clements. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a rocky mountain stream in experimental microcosms. *Journal of the North American Benthological Society* 13: 511-523.

Kimura, D. K. 1988. Analyzing relative abundance indices with log-linear models. *North American Journal of Fisheries Management* 8: 175-180.

Krause-Dellin, D. and C. Steinberg. 1986. Cladoceran remains as indicators of lake acidification. *Hydrobiologia* 143: 129-134.

Kremen, C. 1992. Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological Applications* 2: 203-217.

Lafont, M. 1984. Oligochaete communities as biological descriptors of pollution in the fine sediments of rivers. *Hydrobiologia* 115: 127-129.

Lange-Bertalot, H. 1979. Pollution tolerance as a criterion for water quality estimation. *Nova Hedwigia* 64: 285-304.

Lapoint, T. W., S. M. Melacon, and M. K. Morris. 1984. Relationships among observed metal concentrations, criteria and benthic community structural responses in 15 streams. *Journal of the Water Pollution Control Federation* 56: 1030-1038.

Leland, H. V., S. V. Fend, T. L. Dudley, and J. L. Carter.. 1989. Effects of copper on species composition of benthic insects in a Sierra Nevada, California, stream. *Freshwater Biology* 21: 163-179.

Lenat, D. R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society 7*: 222-233.

Lenat, D. R. 1993. A botic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water quality rating. *Journal of the North American Benthological Society* 12: 279-290.

Lenat, D. R. 1993. Using mentum deformities of Chironomus larvae to evaluate the effects of toxicity and organic loading in streams. *Journal of the North American Benthological Society* 12: 265-269.

Leonard, P. M. and D. J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. *Transactions of the American Fisheries Society* 115: 401-414.

Long, E. R. and P. M. Chapman. 1985. A sediment quality triad: measures of sediment contamination, toxicity and infaunal composition in Puget Sound. *Marine Pollution Bulletin* 16: 405-415.

Lyons, J., S. Navarroperez, P. A. Cochran, E. Santana, and M. Guzmanarroyo. 1995. Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in west-central Mexico. *Conservation Biology* 9: 569-584.

Mahoney, D. and D. C. Erman. 1984. An index of stored fine sediment in gravel bedded streams. *Water Resources Bulletin* 20: 343-348.

Marcus, M. D. 1980. Periphytic community response to chronic nutrient enrichment by a reservoir discharge. *Ecology* 61: 387-399.

Marcus, M. D. and L. L. McDonald. 1992. Evaluating the statistical bases for relating receiving water impacts to effluent and ambient toxicities. *Environmental Toxicology and Chemistry* 11: 1389-1402.

McCormick, P. V. and J. Cairns. 1994. Algae as indicators of environmental change: a review. *Journal of Applied Phycology* 6: 509-526.

McDonald, D. G. and J. G. Robinson. 1993. Physiological responses of lake trout to stress: effects of water hardness and genotype. *American Fisheries Society* 12: 1146-1155.

Merilainen, J., P. Huttunen, and K. Pirttiala. 1982. The effect of land use on the diatom communities in lakes. *Hydrobiologia* 86: 99-103.

Metcalfe, J. L. 1989. Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. *Environmental Pollution* 60: 101-139.

Metcalfe, J. L., M. E. Fox, and J. H. Carey. 1988. Freshwater leeches (Hirudinea) as a screening tool for detecting organic contaminants in the environment. *Environmental Monitoring and Assessment* 11: 147-169.

Michener, M. C. 1983. Wetland site index for summarizing botanical studies. *Wetlands* 3: 180-191.

Miller, D. L., Leonard, P. M., R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniel, K. D. Fausch, G. A. Fitzhugh, J. R. Gammon, D. B. Halliwell, P. L. Angermeier, and D. J. Orth. 1988. Regional applications of an Index of Biotic Integrity for use in water resource management. *Fisheries* 13: 12-20.

Moss, D., M. T. Furse, J. F. Wright, and P. D. Armitage. 1987. The predication of the macroinvertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. *Freshwater Biology* 17: 41-52.

Murphy, P. M. 1978. The temporal variability in biotic indices. *Environmental Pollution* 17: 227-236.

Myers, T. J. and S. Swanson. 1991. Aquatic habitat condition index, stream type, and livestock bank damage in northern Nevada. *Water Resources Bulletin* 27: 667-677.

Myslinski, E. and W. Ginsburg. 1977. Macroinvertebrates as indicators of pollution. *Journal of the American Water Works Association* 69: 538-544.

Narf, R. P., E. L. Lange, and R. C. Wildman. 1984. Statistical procedures for applying Hilsenhoffs biotic index. *Journal of Freshwater Ecology* 2: 441-448.

Nehring, R. B. 1976. Aquatic insects as biological monitors of heavy metal pollution. *Bulletin of Environmental Contamination and Toxicology* 15: 147-154.

Nehring, R. B., R. Nisson, and G. Minasian. 1979. Reliability of aquatic insects versus water samples as measures of aquatic lead pollution. *Bulletin of Environmental Contamination and Toxicology* 22: 103-108.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4: 355-364.

Novak, M. A. and R. W. Bode. 1992. Percent model affinity, a new measure of macroinvertebrate community composition. *Journal of the North American Benthological Society* 11: 80-85.

Oberdorff, T. and R. M. Hughes. 1992. Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. *Hydrobiologia* 228: 117-130.

Ormerod, S. J. and R.W. Edwards. 1987. The ordination and classification of macroinvertebrate assemblages in the catchment of the River Wye in relation to environmental factors. *Freshwater Biology* 17: 533-546.

Osborne, L. L., R. W. Davies, and K. J. Linton. 1980. Use of hierarchical diversity indices in lotic community analysis. *Journal of Applied Ecology* 17: 567-580.

Packer, P. E. 1967. Criteria for designing and locating logging roads to control sediment. *Forest Science* 13: 2-18.

Palmer, C. M. 1969. A composite rating of algae tolerating organic pollution. *Journal of Phycology* 5: 78-82.

Palmer, M. W. 1993. Putting things in even better order: The advantages of canonical correspondence analysis. *Ecology* 74: 2215-2230.

Pan, Y. D., R. J. Stevenson, B. H. Hill, A. T. Herlihy, and G.B. Collins. 1996. Using diatoms as indicators of ecological conditions in lotic systems - a regional assessment. *Journal of the North American Benthological Society* 15: 481-495.

Phillips, D. J. H. and D. A. Segar. 1986. Use of bio-indicators in monitoring conservative contaminants: program design imperatives. *Marine Pollution Bulletin* 17: 10-17.

Pontasch, K. W. and M. A. Brusven. 1988. Diversity and community comparison indices: assessing macroinvertebrate recovery following a gasoline spill. *Water Research* 22: 619-626.

Potyondy, J. and T. Hardy. 1994. Use of pebble counts to evaluate fine sediment increase in stream channels. *Water Resources Bulletin* 30: 509-520.

Reynoldson, T. B., S. P. Thompson, and J. L. Bamsey. 1991. A sediment bioassay using the tubificid oligochaete worm Tubifex. *Environmental Toxicology and Chemistry* 10: 1061-1072.

Reynoldson, T. B. and M. A. Zarull. 1989. The biological assessment of contaminated sediments-the Detroit River example. *Hydrobiologia* 188/189: 463-476.

Rossaro, B. and A. Pietrangelo. 1993. Macroinvertebrate distribution in streams: a comparison of CA ordination with biotic indices. *Hydrobiologia* 26: 109-118.

Rothfritz, H., I. Juttner, A. M. Suren, and S. J. Ormerod. 1997. Epiphytic and epilithic diatom communities along environmental gradients in the Nepalese Himalaya - implications for the assessment of biodiversity and water quality. *Archiv Fur Hydrobiologie* 138: 465-482.

Round, F. E. 1991. Diatoms in river water-monitoring studies. *Journal of Applied Phycology* 3: 129-145.

Routledge, R. D. 1979. Diversity indices: Which ones are admissible? *Journal of Theoretical Biology* 76: 503-515.

Ryder, R. A. 1982. The morphoedaphic index-use, abuse, and fundamental concepts. *Transactions of the American Fisheries Society* 111: 154-164.

Ryder, R. A., S. R. Kerr, K. H. Loftus, and H. A. Regier. 1974. The morphoedaphic index, a fish yield estimator-review and evaluation. *Journal of the Fisheries Research Board of Canada* 28: 663-688.

Saether, O. A. 1979. Chironomid communities as water quality indicators. *Holarctic Ecology* 2: 65-74.

Scrimgeour, G. J. and P. A. Chambers. 1997. Development and application of a nutrient-diffusing bioassay for large rivers. *Freshwater Biology* 38: 221-231.

Seddon, B. 1972. Aquatic macrophytes as limnological indicators. *Freshwater Biology* 2: 107-130.

Simpson, K. W. 1980. Abnormalities in the tracheal gills of aquatic insects collected from streams receiving chlorinated crude oil wastes. *Freshwater Biology* 10: 581-583.

Slooff, W. 1983. Benthic macroinvertebrates and water quality assessment: Some toxicological considerations. *Aquatic Toxicology* 4: 73-82.

Spencer, C., A. I. Robertson, and A. Curtis. 1998. Development and testing of a rapid appraisal wetland condition index in south-eastern Australia. *Journal of Environmental Management* 54: 143-159.

Steedman, R. J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 492-501.

Steedman, R. J. 1991. Occurrence and environmental correlates of black spot disease in stream fishes near Toronto, Ontario. *Transactions of the American Fisheries Society* 120: 494-499.

Steinhart, C. E., L. J. Schierow, and W. C. Sonzogni. 1982. An environmental quality index for the Great Lakes. *Water Resources Bulletin* 18: 1025-1031.

Stevenson, R. J. 1984. Epilithic and epileptic diatoms in the Sandusky River, with emphasis on species diversity and water pollution. *Hydrobiologia* 114: 161-174.

TerBraak, C. J. F. and H. van Dam. 1989. Inferring pH from diatoms: a comparison of old and new calibration methods. *Hydrobiologia* 178: 209-223.

United States Environmental Protection Agency. 1994. Biological criteria: Technical guidance for streams and small rivers. US Environmental Protection Agency Office of Science and Technology EPA/822/B-94/001.

VanHorne, B. 1983. Density as a misleading indicator of habitat quality. *Journal of Wildlife Management* 47: 893-901.

Wade, I. R., S. J. Ormerod, and A. S. Gee. 1989. Classification and ordination of macroinvertebrate assemblages to predict stream acidity in upland Wales. *Hydrobiologia* 171: 59-78.

Warner, B. G. and B. J. Hann. 1987. Aquatic invertebrates as paleoclimatic indicators? *Quaternary Research* 28: 427-430.

Warwick, W. F. 1985. Morphological abnormalities in Chironomidae (Diptera) larvae as measures of toxic stress in freshwater ecosystems: indexing antennal deformities in *Cheirognomies Meigen*. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1881-914.

Washington, H. G. 1984. Diversity, biotic and similarity indices. *Water Resources Research* 18: 653-694.

Waterhouse, J. C. and M. P. Farrell. 1985. Identifying pollution related changes in chironomid communities as a function of taxonomic rank. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 406-413.

Weatherley, N. S. and S. J Ormerod. 1987. The impact of acidification on macroinvertebrate assemblages in Welsh streams: Towards an empirical model. *Environmental Pollution* 46: 223-240.

Welch, E. B., J. M. Jacoby, R. R. Horner, and M. R. Seeley. 1998. Nuisance biomass levels of periphytic algae in streams. *Hydrobiologia* 157: 161-168.

Wesche, T. A., D. W. Reiser, V. R. Hasfurther, W. A. Hubert, and Q. D. Skinner. 1989. New technique for measuring fine sediment in streams. *North American Journal of Fisheries Management* 9: 234-238.

Whitton, B. A. and M. G. Kelly. 1995. Use of algae and other plants for monitoring rivers a review. *Australian Journal of Ecology* 20: 45-56.

Wiederholm, T. 1980. Use of benthos in lake monitoring. *Journal of the Water Pollution Control Federation* 52: 537-547.

Wilhm, J. L. and T. C. Dorris. 1968. Biological parameters for water quality criteria. *BioScience* 18: 477-481.

Wright, J. F., D. Moss, P. D. Armitage, and M. T. Furse. 1984. A preliminary classification of running-water sites in Great Britain based on macroinvertebrate species and the prediction of community type using environmental data. *Freshwater Biology* 14: 221-256.

Yoder, C. O. and E. T. Rankin. 1998. The role of biological indicators in a state water quality management process. *Environmental Monitoring & Assessment* 51: 61-88.

Assessments and Monitoring

Abate, C. 1992. Environmental rapid-assessment programs have appeal and critics. *BioScience* 42: 486-489.

Adams, J. N. and R. L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Science* 37: 1514-1521.

Adams, M. S., K. D. Ham, and J. J. Beauchamp. 1994. Application of canonical variate analysis in the evaluation and presentation of multivariate biological response data. *Environmental Toxicology and Chemistry* 13: 1673-1683.

Allan, J. D. 1982. The effects of reduction in trout density on the invertebrate community of a mountain stream. *Ecology* 63: 1444-1455.

Allan, J. D. and E. Russek. 1985. The quantification of stream drift. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 210-215.

Allard, M. and G. Moreau. 1987. Effects of experimental acidification on a lotic macroinvertebrate community. *Hydrobiologia* 144: 37-49.

Alley, W. M. 1988. Using exogenous variables in testing for monotonic trends in hydrologic time series. *Water Resources Research* 24: 1955-1961.

Anderson, B. and D. F. Potts. 1987. Suspended sediment and turbidity following road construction and logging in western Montana. *Water Resources Bulletin* 23: 681-690.

Andrus, C. W., B. A. Long, and H. A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 2080-2086.

Angermeier, P. L. and I. J. Schlosser. 1989. Species-area relationships for stream fishes. *Ecology* 75: 1450-1462.

Angermeier, P. L. and J. R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113: 716-726.

Armitage, P. D., R. J. M. Gunn, M. T. Furse, J. F. Wright, and D. Moss. 1987. The use of prediction to assess macroinvertebrate response to river regulations. *Hydrobiologia* 144: 25-32.

Armour, C. L., D. A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16: 7-11.

Atkinson, S. 1985. Habitat-based methods for biological affect assessment. *The Environmental Professional* 7: 265-282.

Aubertin, G. M. and J. H. Patric. 1974. Water quality after clearcutting a small watershed in West Virginia. *Journal of Environmental Quality* 3: 243-249.

Austin, A., S. Lund, and M. Pomerroy. 1981. Simple methods for sampling periphyton with observations on sampler design criteria. *Hydrobiologia* 85: 33-47.

Bain, M. B. 1993. Assessing impacts of introduced aquatic species: grass carp in large systems. *Environmental Management* 17: 211-224.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985. Quantifying stream substrate for habitat analysis studies. *North American Journal of Fisheries Management* 5: 499-500.

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69: 382-392.

Baker, J. P., J. Van Sickle, C. J. Gagen, D. R. Dewalle, W. E. Sharpe, R. F. Carline, B. P. Baldigo, P. S. Murdoch, D. W. Bath, W. A. Kretser, , H. A. Simonin, and P. J. Wigington. 1996. Episodic acidification of small streams in the northeastern United States - effects on fish populations. *Ecological Applications* 6: 422-437.

Baker, J. P., W. J. Hicks, J. Gallagher, and S. W. Christensen. 1993. Fish population losses from Adirondack lakes: the role of surface water acidity and acidification. *Water Resources Research* 29: 861-874.

Balloch, D., C. E. Davies, and F. H. Jones. 1976. Biological assessment of water quality in three British Rivers: the North Es (Scotland), the Ivel (England) and the Taf (Wales). Water *Pollution Control* 75: 92-114.

Barko, J. W. and R. M. Smart. 1983. Effects of organic matter additions to sediment on the growth of aquatic plants. *Ecology* 71: 161-175.

Barling, R. D. and I. D. Moore. 1994. Role of buffer strips in management of waterway pollution: A review. *Environmental Management* 18: 543-558.

Barbour, M. T., J. Gerritsen, and B. D. Snyder. 1997. Revision to rapid bioassessment protocols for use in streams and rivers. EPA 841-D-97-002, Office of Water, United States Environmental Protection Agency, Washington, DC.

Bartholow, J. M. 1996. Sensitivity of a salmon population model to alternative formulations and initial conditions. *Ecological Modeling* 88: 215-226.

Baskerville, G. 1985. Adaptive management wood availability and habitat availability. *Forestry Chronicle* 2: 171-175.

Beals, E. W. 1973. Ordination: mathematical elegance and ecological naivete. *Ecology* 61: 23-36.

Beaty, K. G. 1994. Sediment transport in a small stream following two successive forest fires. *Canadian Journal of Fisheries & Aquatic Sciences* 51: 2723-2733.

Bedford, B. L. and E. M. Preston. 1988. Cumulative effects on landscape systems of wetlands: scientific status, prospects, and regulatory perspectives. *Environmental Management* 12: 561-771.

Beechie, T. J. and T. H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. *Transactions of the American Fisheries Society* 126: 217-229.

Behmer, D. J. and C. P. Hawkins. 1986. Effects of overhead canopy on macroinvertebrate production in a Utah stream. *Freshwater Biology* 16: 287-300.

Belford, D. A. and W.R. Gould. 1989. An evaluation of trout passage through six highway culverts in Montana. *North American Journal of Fisheries Management* 9: 437-445.

Belt, G., J. O'Laughlin, and T. Merrill. 1992. Design of forest riparian buffer strips for the protection of water quality: Analysis of scientific literature. Idaho Forest, Wildlife and Range Policy Analysis Group 8.

Bencala, K. E. 1993. A perspective on stream-catchment connections. *Journal of the North American Benthological Society* 12: 44-47.

Benke, A. C., R. L. III Henry, D. M. Gillespie, and R. J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. *Fisheries* 10: 8-12.

Benner, R. 1985. Effects of pH and plant source on lignocellulose biodegradation rates in two wetland ecosystems, the Okefenokee Swamp and a Georgia salt marsh. *Limnology and Oceanography* 30: 489-499.

Berkman, H. E. and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. *Environmental Biology of Fishes* 18: 285-294.

Beschta, R. L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. *Water Resources Research* 14: 1011-1016.

Beschta, R. L. and R. L. Taylor. 1988. Stream temperature increases and land use in a forested Oregon watershed. *Water Resources Bulletin* 24: 19-25.

Beschta, R. L. and W. L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. *Journal of the Fisheries Research Board of Canada* 36: 204-210.

Bilby, R. 1977. Effects of a spate on the macrophyte vegetation of a stream pool. *Hydrobiologia* 56: 109-112.

Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. *Journal of Forestry* 82: 609-613.

Bilby, R. E. and J. W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. *Transactions of the American Fisheries Society* 118: 368-378.

Bilby, R. E. and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61: 1107-1013.

Bodini, A. and G. Fiavelli. 1992. Multicriteria analysis as a tool to investigate compatibility between conservation and development on Salina Island, Awolian Archipelago, Italy. *Environmental Management* 16: 633-652.

Bormann, F. H., G. E. Likens, D. W. Fisher, and R. S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. *Science* 159: 882-884.

Bormann, F. H., G. E. Likens, and J. S. Eaton. 1969. Biotic regulation of particulate and solution losses from a forest ecosystem. *BioScience* 19: 600-610.

Bormann, F. H., G. E. Likens, T. G. Siccama, R. S. Pierce, and J. S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. *Ecological Monographs* 44: 255-277.

Boyle, J. R., J. E. Warila, R. L. Beschta, M. Reiter, C. C. Chambers, W. P. Gibson, V. Gregory, J. Grizzel, J. C. Haga, J. L. Li, W. C. McComb, T. W. Parzybok, and G. Taylor. 1997. Cumulative effects of forestry practices - an example framework for evaluation from Oregon, U.S.A. *Biomass & Bioenergy* 13: 223-245.

Brussock, P. 1993. Experimental design and control: keys to refining rapid bioassessment metrics. *Environmental Toxicology and Chemistry* 12: 1-4.

Brussock, P. P., A. V. Brown, and J. C. Dixon. 1985. Channel form and stream ecosystem models. *Water Resources Bulletin* 21: 859-866.

Bryant, M. D. 1995. Pulsed monitoring for watershed and stream restoration. *Fisheries* 201: 6-13.

Buikema, A. L., E. F. Benfield, and B. R. Niederlehner. 1981. Effects of pollution on freshwater-invertebrates. *Journal of the Water Pollution Control Federation* 53: 1007-1014.

Burd, B. J., A. Nemec, and R. O. Brinkhurst. 1990. The development and application of analytical methods in benthic marine infaunal studies. *Advances in Marine Biology* 26: 169-247.

Burgess, S. A. and J. R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations, and mink activity. *Journal of Wildlife Management* 44: 871-880.

Burmaster, D., C. Menzie, and J. Freshman. 1991. Assessment of methods for estimating aquatic hazards at Superfund-type sites: a cautionary tale. *Environmental Toxicology and Chemistry* 10: 827-842.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* 72: 1-202.

Burns, C. D. 1991. Cumulative effects of small modifications to habitat. *Fisheries* 16: 12-17.

Burton, T. M. and G. E. Likens. 1973. The effect of strip-cutting on stream temperatures in the Hubbard Brook Experimental Forest, New Hampshire. *BioScience* 23: 433-435.

Cairns, J. Jr. and K. L. Dickson. 1971. A simple method for the biological assessment of the effects of water discharges on aquatic bottom-dwelling organisms. *Journal of the Water Pollution Control Federation* 41: 755-772.

Cairns, J. Jr. and P. V. McCormick. 1992. Developing an ecosystem-based capability for ecological risk assessments. *The Environmental Professional* 14: 186-196.

Camarg, J. A. and N. J. Voelz. 1998. Biotic and abiotic changes along the recovery gradient of two impounded rivers with different impoundment use. *Environmental Monitoring & Assessment* 50: 143-158.

Campbell, J. M. and W. J. Clark. 1983. Effects of microhabitat heterogeneity on the spatial dispersion of small plant-associated invertebrates. *Freshwater Invertebrate Biology* 2: 180-185.

Campbell, P. G. C. and P. M. Stokes. 1985. Acidification and toxicity of metals to aquatic biota. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 2034-2049.

Canton, S. P. and J. W. Chadwick. 1988. Variability in benthic invertebrate density estimates from stream samples. *Journal of Freshwater Ecology* 4: 291-297.

Carlson, J. Y., C. W. Andrus, and H. A. Froehlich. 1990. Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1103-1111.

Casey, D., P. N. Nemetz, and D. H. Uyeno. 1983. Sampling frequency for water quality monitoring: measures of effectiveness. *Water Resources Research* 19: 1107-1110.

Casselman, J. and J. Gunn. 1992. Dynamics in year-class strength, growth and calcified structure size of native lake trout (*Salvelinus namaycush*) exposed to moderate acidification and whole-lake neutralization. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 102-113.

Cattaneo, A., T. Kerimian, M. Roberge, and J. Marty. 1997. Periphyton distribution and abundance on substrata of different size along a gradient of stream trophy. *Hydrobiogia* 354: 101-110.

Cattaneo, A. and G. Roberge. 1991. Efficiency of a brush sampler to measure periphyton in streams and lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1877-1881.

Chadwick, J. W. and S. P. Canton. 1983. Comparison of multiplate and surber samplers in a Colorado mountain stream. *Journal of Freshwater Ecology* 2: 287-292.

Chandler, J. R. 1970. A biological approach to water quality management. *Water Pollution Control* 69: 791-792.

Charvet, S., A. Kosmala, and B. Statzner. 1998. Biomonitoring through biological traits of benthic macroinvertebrates - perspectives for a general tool in stream management. *Archiv Fur Hydrobiologie* 142: 415-432.

Cherry, D. S., R. K. Guthrie, E. M. Davis, and R. S. Harvey. 1984. Coal ash basin effects (particulates, metals, acidic pH) upon aquatic biota: an eight-year evaluation. *Water Resources Bulletin* 20: 535-544.

Chutter, F. M. and R. G. Noble. 1966. The reliability of a method of sampling stream invertebrates. *Archiv Fur Hydrobiologie* 62: 95-103.

Claret, C. 1998. A method based on artificial substrates to monitor hyporheic biofilm development. *International Review of Hydrobiology* 83: 135-143.

Clark, M. J. R. and P. H. Whitfield. 1993. A practical model integrating quality assurance into environmental monitoring. *Water Resources Bulletin* 29: 119-130.

Clements, W. H., D. S. Cherry, and J. Cairns Jr. 1988. Impact of heavy metals on insect communities in streams: a comparison of observational and experimental results. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 2017-2025.

Clements, W. H., D. S. Cherry, and J. Cairns Jr. 1989. The influence of copper exposure on predator-prey interactions in aquatic insect communities. *Freshwater Biology* 21: 483-488.

Clifford, H. F. and R. J. Casey. 1992. Differences between operators in collecting quantitative samples of stream macroinvertebrates. *Journal of Freshwater Ecology* 7: 271-276.

Coleman, R. L. and C. N. Dahm. 1990. Stream geomorphology: effects of periphyton standing crop and primary production. *Journal of the North American Benthological Society* 9: 293-302.

Collier, K. J., B. J. Smith, and B. R. Baillie. 1997. Summer light-trap catches of adult Trichoptera in hill-country catchments of contrasting land use, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31: 623-634.

Collier, K. J., R. J. Wilcock, and A. S. Meredith. 1998. Influence of substrate type and physico-chemical conditions on macroinvertebrate faunas and biotic indices of some lowland Waikato, New Zealand, streams. *New Zealand Journal of Marine and Freshwater Research* 32: 1-19.

Cooper, C. M. 1987. Benthos in Bear Creek, Mississippi: effects of habitat variation and agricultural sediments. *Journal of Freshwater Ecology* 4: 101-113.

Cope, W. G. and D. L. Waller. 1995. Evaluation of freshwater mussel relocation as a conservation and management strategy. *Regulated Rivers-Research & Management* 11: 147-155.

Corkhum, L. D. and J. J. H. Ciborowski. 1988. Use of alternative classification in studying broad-scale distributional patterns of lotic invertebrates. *Journal of the North American Benthological Society* 7: 167-179.

Corkum, L. D. 1989. Patterns of benthic invertebrate assemblages in rivers of northwestern North America. *Freshwater Biology* 21: 191-205.

Corkum, L. D. 1996. Responses of chlorophyll-a, organic matter, and macroinvertebrates to nutrient additions in rivers flowing through agricultural and forested land. *Archiv Fur Hydrobiologie* 136: 391-411.

Courtemanch, D. L. and S. P. Davies. 1987. A coefficient of community loss to assess detrimental change in aquatic communities. *Water Research* 21: 217-222.

Cranston, P. S. 1990. Biomonitoring and invertebrate taxonomy. *Environmental Monitoring and Assessment* 14: 265-273.

Corpsman, J. S., R. L. Chiseler, and J. Cairns Jr. 1974. The use of cluster analysis in the assessment of spills of hazardous materials. *American Midland Naturalist* 92: 94-114.

Culp, J. M. and R. W. Davies. 1980. Reciprocal averaging and polar ordination as techniques for analyzing lotic macroinvertebrate communities. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1358-1364.

Culp, J. M., G. J. Scrimgeour, and G. D. Townsend. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. *Transactions of the American Fisheries Society* 125: 472-479.

Culp, J. M., G. J. Scrimgeour, and C. Beers. 1994. The effect of sample duration on the quantification of stream drift. *Freshwater Biology* 31: 165-173.

Culp, J. M., F. J. Wrona, and R. W. Davies. 1986. Response of stream benthos and drift to fine sediment deposition versus transport. *Canadian Journal of Zoology* 64: 1345-1351.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. *American Midland Naturalist* 67: 477-504.

Cunjak, R. A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1970-1981.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. *North American Journal of Fisheries Management* 5: 330-339.

Cushman, R. M. and J. C. Goyert. 1984. Effects of a synthetic crude oil on pond benthic insects. *Environmental Pollution* (Series A) 33: 163-186.

Dance, K. W. and H. B. N. Hynes. 1980. Some effects of agricultural land use on stream insect communities. *Environmental Pollution* (Series A) 22: 19-28.

Daneke, G. A. 1982. The future of environmental protection and reflection on the difference between planning and regulating. *Public Administration Review* 42: 227-233.

Davic, R. D. and J. E. DeShon. 1989. The Ohio Lake Condition Index: a new multiparameter approach to lake classification. *Lake and Reservoir Management* 5: 1-8.

Day, R. W. and G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs* 59: 433-463.

Death, R. G. 1995. Spatial patterns in benthic invertebrate community structure: products of habitat stability or are they habitat specific? *Freshwater Biology* 33: 455-467.

DeBano, L. F. and B. H. Heede. 1987. Enhancement of riparian ecosystems with channel structures. *Water Resources Bulletin* 23: 463-470.

DeMarch, B. G. E. 1976. Spatial and temporal patterns in macrobenthic stream diversity. *Journal of the Fisheries Research Board of Canada* 33: 1261-1270.

Demaynadier, P. G. and M. L. Hunter Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. *Conservation Biology* 12: 340-352.

DeNicola, D. M., K. D. Hoagland, and S. C. Roemer. 1992. Influences of canopy cover on spectral irradiance and periphyton assemblages in a prairie stream. *Journal of the North American Benthological Society* 11: 391-404.

DePauw, N. and G. Vanhooren. 1983. Method for biological quality assessment of watercourses in Belgium. *Hydrobiologia* 100: 153-168.

Detenbeck, N., P. DeVore, G. Niemi, and A. Lima. 1992. Recovery of temperate-stream fish communities from disturbance: a review of case studies and synthesis of theory. *Environmental Management* 16: 33-53.

Detra, R. L. and W. J. Collins. 1991. The relationship of parathion concentration, exposure time, cholinesterase inhibition and symptoms of toxicity in midge larvae (Chironomidae: Diptera). *Environmental Toxicology and Chemistry* 10: 1089-1095.

Dewey, S. L. 1986. Effects of the herbicide atrazine on aquatic insect community structure and emergence. *Ecology* 67: 148-162.

Dickman, M., C. Prescott, and K. L. E. Kaiser. 1983. Variations in the aquatic vegetation of the Wellan River (Ontario, Canada) above and below an industrial waste discharge. *Journal of Great Lakes Research* 9: 317-325.

Downing, J. A. 1979. Aggregation, transformation, and the design of benthos sampling programs. *Journal of the Fisheries Research Board of Canada* 36: 1454-1463.

Downing, J. A. 1986. A regression technique for the estimation of epiphytic invertebrate populations. *Freshwater Biology* 16: 161-173.

Downing, J. A. 1989. Precision of the mean and the design of benthos sampling programs: caution revised. *Marine Biology* 103: 231-234.

Downing, J. A and M. R. Anderson. 1985. Estimating the standing biomass of aquatic macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1860-1869.

Downing, J. A. and H. Cyr. 1985. Quantitative estimation of epiphytic invertebrate populations. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1570-1579.

Drake, C. M. and J. M. Elliott. 1983. A new quantitative air-lift sampler for collecting macroinvertebrates on stony bottoms in deep rivers. *Freshwater Biology* 13: 545-559.

Dromgoole, F. I. and J. M. A. Brown. 1976. Quantitative grab sampler for dense beds of aquatic macrophytes. *New Zealand Journal of Marine and Freshwater Research* 10: 109-118.

Dudley, T. L., S. D. Cooper, and N. Hemphill. 1986. Effects of macroalgae on a stream invertebrate community. *Journal of the North American Benthological Society* 5: 93-106.

Duinker, P. N. 1989. Ecological effects monitoring in environmental impact assessment: what can it accomplish? *Environmental Management* 13: 797-805.

Dyer, D. P. 1978. An analysis of species dissimilarity using multiple environmental variables. *Ecology* 59: 117-125.

Eaton, L. E. and D. R. Lenat. 1991. Comparison of a rapid bioassessment method with North Carolina's qualitative macroinvertebrate collection method. *Journal of the North American Benthological Society 1*0: 335-338.

Edwards, D. 1969. Some effects of siltation upon aquatic macrophyte vegetation in rivers. *Hydrobiologia* 34: 29-37.

Eidt, D. C. 1981. Recovery of aquatic arthropod populations in a woodland stream after depletion by fenitrothion treatment. *The Canadian Entomologist* 113: 303-313.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic macroinvertebrates. Freshwater Biological Association Scientific Publication, 2nd Edition.

Elliott, S. T. 1986. Reduction of a dolly varden population and macrobenthos after removal of logging debris. *Transactions of the American Fisheries Society* 115: 392-400.

Fager, E. W. 1972. Diversity: a sampling study. *American Naturalist* 106: 293-310.

Faith, D. P. 1990. Benthic macroinvertebrates in biological surveillance: Monte Carlo significance tests on functional groups' responses to environmental gradients. *Environmental Monitoring and Assessment* 14: 247-264.

Faith, D. P, P. R. Minchin, and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69: 57-68.

Fausch, K. D. 1988. Tests of competition between native and introduced salmonids in streams: what have we learned? *Canadian Journal of Fisheries and Aquatic Sciences* 45: 2238-2246.

Feller, M. C. and J. P. Kimmins. 1984. Effects of clearcutting and slash burning on streamwater chemistry and watershed nutrient budgets in southwestern British Columbia. *Water Resources Research* 20: 29-40.

Ferraro, S. P. and F. A. Cole. 1990. Taxonomic level and sample size sufficient for assessing pollution impacts on the southern California Bight macrobenthos. *Marine Ecology-Progress Series* 67: 251-262.

Ferraro, S. P. and F. A. Cole. 1992. Taxonomic level sufficient for assessing a moderate impact on macrobenthic communities in Puget Sound, Washington, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1184-1188.

Fisher, R. A., A. S. Corbet, and C. B Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology* 12: 42-58.

Freeman, B. J., H. S. Greening, and J. D. Oliver. 1984. Comparison and three methods for sampling fishes and macroinvertebrates in a vegetated freshwater wetland. *Journal of Freshwater Ecology* 2: 603-609.

Furse, M. T., D. Moss, J. F. Wright, and P. D. Armitage. 1984. The influence of seasonal and taxonomic factors on the ordination and classification of running-water sites in Great Britain and on the prediction of their macro-invertebrate communities. *Freshwater Biology* 14: 257-280.

Garie, H. L. and A. McIntosh. 1986. Distribution of benthic macroinvertebrates in a stream exposed to urban runoff. *Water Resources Bulletin* 22: 447-455.

Gauch, H. G. Jr and R. H. Whittaker. 1972. Comparison of ordination techniques. *Ecology* 53: 868-875.

Geist, D. R. and D. D. Dauble. 1998. Redd site selection and spawning habitat use by fall chinook salmon: The importance of geomorphic features in large rivers. *Environmental Management* 22: 655-669.

Gerrodette, T. 1987. A power analysis for detecting trends. *Ecology* 68: 1364-1372.

Ghosh, M. and J. P. Gaur. 1994. Algal periphyton of an unshaded stream in relation to in situ nutrient enrichment and current velocity. *Aquatic Botany* 47: 185-189.

Gillespie, D. M. and C, J, D. Brown. 1966. A quantitative sampler for macroinvertebrates associated with aquatic macrophytes. *Limnology and Oceanography* 11: 404-406.

Gislason, J. C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. *North American Journal of Fish Management* 5: 39-46.

Golladay, S. W. and J. R. Webster. 1988. Effects of clearcut logging on wood breakdown in Appalachian Mountain streams. *The American Midland Naturalist* 119: 143-155.

Gore, J. A. 1980. Ordinational analysis of benthic communities upstream and downstream of a prairie storage reservoir. *Hydrobiologia* 69: 33-44.

Gore, J. A. and R. Judy. 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. *Canadian Journal Fisheries and Aquatic Sciences* 38: 1363-1370.

Gorman, O. T. 1986. Assemblage organization of stream fishes: the effect of rivers on adventitious streams. *American Naturalist* 128: 611-616.

Gorman, O. T. and J. R. Karr. 1978. Habitat structure and stream fish communities. *Ecology* 59: 507-515.

Gower, J. C. 1967. A comparison of some methods of cluster analysis. *Biometrics* 23: 623-637.

Green, R. H. and G. L. Vascotto. 1978. A method for the analysis of environmental factors controlling patterns of species composition in aquatic communities. *Water Research* 12: 583-590.

Gregg, W. and F. Rose. 1982. The effects of aquatic macrophytes on the stream microenvironment. *Aquatic Biology* 14: 309-324.

Gregg, W. W. and F. L. Rose. 1985. Influences of aquatic macrophytes on invertebrate community structure, guild structure, and microdistribution in streams. *Hydrobiologia* 128: 45-56.

Griffith, M. B. and S. A. Perry. 1993. Colonization and processing of leaf litter by macroinvertebrate shredders in streams of contrasting pH. *Freshwater Biology* 30: 93-103.

Griffith, M. B., and S. A. Perry. 1994. Fungal biomass and leaf litter processing in streams of different water chemistry. *Hydrobiologia* 294: 51-61.

Grimm, N. B. and S. G. Fisher. 1989. Stability of periphyton and macroinvertebrates to disturbance by flash floods in a desert stream. *Journal of the North American Benthological Society* 8: 293-307.

Grossman, G. D., J. F. Dowd, and M. Crawford. 1990. Assemblage stability in stream fishes: a review. *Environmental Management* 14: 661-671.

Grubaugh, J. W., J. B. Wallace, and E. S. Houston. 1996. Longitudinal changes of macroinvertebrate communities along an Appalachian stream continuum. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 896-909.

Gurtz, M. E. and J. B. Wallace. 1984. Substrate-mediated response of stream invertebrates to disturbance. *Ecology* 65: 1156-569.

Hamalainen, H. and P. Huttunen. 1998. Macroinvertebrate-inferred stream-water acidity in north eastern Finland along a sulphur deposition gradient. *Water, Air, & Soil Pollution* 104: 223-236.

Hankin, D. G. and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 834-843.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1575-1591.

Hannaford, M. J. and V. H. Resh. 1995. Variability in macroinvertebrate rapid-bioassessment surveys and habitat assessments in a northern California stream. *Journal of the North American Benthological Society* 14: 430-439.

Hansmann, E. W. and H. K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology* 54: 194-199.

Hart, D. D. 1992. Community organization in streams: the importance of species interactions, physical factors, and change. *Oecologia* 91: 220-228.

Hartman, G. F., J. C. Scrivener, and M. J. Miles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. *Canadian Journal of Fisheries and Aquatic Science* 53: 237-251.

Haslam, S. M. 1982. A proposed method for monitoring river pollution using macrophytes. *Environmental Technical Letter* 3: 19-34.

Hauer, F. R. and N. L. Poff. 1986. Leaf litter decomposition across broad thermal gradients in southeastern coastal plain streams and swamps. *Journal of Freshwater Ecology* 3: 545-549.

Hawkins, C. P., M. L. Murphy, and N. H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology* 63: 1840-1856.

Heede, B. H. 1987. Overland flow and sediment delivery five years after timber harvest in a mixed conifer forest, Arizona, U.S.A. *Journal of Hydrology* 91: 205-216.

Heifetz, J., M. L. Murphy, and K. V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management* 6: 52-58.

Herman, D., N. K. Kaushik, and K. R. Solomon. 1986. Impact of atrazine on periphyton in freshwater enclosures and some ecological consequences. *Canadian Journal of Fisheries and Aquatic Sciences 44*: 1917-1925.

Herricks, E. E. and J. Cairns Jr. 1982. Biological monitoring Part III-Receiving system methodology based on community structure. *Water Research*16 : 141-153.

Hershey, A. E. and A. L. Hiltner. 1988. Effect of a caddisfly on black fly density: Interspecific interactions limit black flies in an arctic river. *Journal of American Benthological Society* 7: 188-196.

Hewlett, J. D. and J. C. Fortson. 1982. Stream temperature under and inadequate buffer strip in the southeast Piedmont. *Water Resources Bulletin* 18: 983-988.

Hilderbrand, R. H., D. A. Lemly, A. C. Dolloff, and K. L. Harpster. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 931-939.

Hildrew, A. G., C. R. Townsend, J. Francis, and K. Finch. 1984. Cellulolytic decomposition in streams of contrasting pH and its relationship with invertebrate community structure. *Freshwater Biology* 14: 323-328.

Hill, K. R. 1986. Classification of Iowa lakes and their fish standing stock. *Lake and Reservoir Management* 2: 105-109.

Hill, W. R. and B. C. Harvey. 1990. Periphyton responses to higher trophic levels and light in a shaded stream. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2307-2314.

Hilsenhoff, W. L. 1988. Seasonal correction factors for the Biotic Index. *Great Lakes Entomologist* 21: 9-13.

Hipel, K. W. 1988. Nonparametric approaches to environmental impact assessment. *Water Resources Bulletin* 24: 487-492.

Hirsch, R. M., J. R. Slack, and R. A. Smith. 1982. Techniques of trend analysis for monthly water quality data. *Water Resources Research* 18: 107-1021.

Hoenig, J., W. Warren, and M. Stocker. 1994. Bayesian and related approaches to fitting surplus production models. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 1823-1831.

Hogg, I. D. and R. H. Norris. 1991. Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river. *Australian Journal of Marine and Freshwater Research* 42: 507-518.

Hope, D., M. F. Billett, R. Milne, and T. A. W. Brown. 1997. Exports of organic carbon in British rivers. *Hydrological Processes* 11: 325-344.

Hubert, W. A. and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plans streams: a test of habitat suitability index models. *North American Journal of Fisheries Management* 9: 332-340.

Hughes, J. P. and S. P. Millard. 1988. A tau-like test for trend in the presence of multiple censoring points. *Water Resources Bulletin* 24: 521-531.

Hughes, R. M. and J. R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Transactions of the American Fisheries Society* 116: 196-209.

Hughes, R. M. and D. P. Larsen. 1988. Ecoregions: an approach for surface water protection. *Journal of the Water Pollution Control Federation* 60: 486-493.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: a method for assessing stream pollution. *Environmental Management* 10: 629-635.

Hughes, R. M., E. Rexstad, and C. E. Bond. 1987. The relationship of aquatic ecoregions, river basins, and physiographic provinces to the ichthyogeographic regions of Oregon. *Copeia* 1987: 423-432.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54: 187-211.

Hussey, M. R., Q. D. Skinner, and J. C. Adams. 1986. Changes in bacterial populations in Wyoming mountain streams after 10 years. *Journal of Range Management* 39: 369-370.

Hynes, H. B. N. and U. R. Yadav. 1985. Three decades of post-impoundment data on the littoral fauna of Lyn Tegid, North Wales. *Archiv Fur Hydrobiologie* 104: 39-48.

Irvine, J. R. 1985. Effects of successive flow perturbations on stream invertebrates. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1922-1927.

Jackson, D. A. and H. H. Harvey. 1989. Biogeographical associations in fish assemblages: local vs. regional processes. *Ecology* 70: 1472-14784.

Jackson, J. K. and V. H. Resh. 1988. Sequential decision plans in monitoring benthic macroinvertebrates: cost savings, classification accuracy, and development of plans. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 280-286.

--------1989. Sequential decision plans, benthic macroinvertebrates, and biological monitoring programs. *Environmental Management* 13: 455-468.

Jennings, M. J., L. S. Fore, and J. R. Karr. 1995. Biological monitoring of fish assemblages in Tennessee Valley reservoirs. *Regulated Rivers-Research and Management* 11: 263-274.

Jensen, S. 1979. Classification of lakes in southern Sweden on the basis of their macrophyte composition by means of multivariate analysis. *Vegetatio* 39: 129-146.

Johnson, S. W., J. Heifetz, and K. V. Koski. 1986. Effects of logging on the abundance and seasonal distribution of juvenile steelhead in some southeastern Alaska streams. *North American Journal of Fisheries Management* 6: 532-537.

Johnson, W. C. 1992. Dams and riparian forests, case study from the Missouri River. *Rivers* 3: 229-242.

Jones, R. C. and C. C. Clark. 1987. Impact of watershed urbanization on stream insect communities. *Water Resources Bulletin* 23: 1047-1055.

Jowett, I. and M. Duncan. 1990. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research* 24: 305-317.

Kaesler, R. L. and E. E. Herricks. 1979. Hierarchical diversity of communities of aquatic insects and fishes. *Water Resources Bulletin* 1: 1117-1125.

Karr, James R. 1987. Biological monitoring and environmental assessment: a conceptual framework. *Environmental Management* 11: 249-256.

Karr, James R., Louis A. Toth, and Daniel R. Dudley. 1985. Fish communities of midwestern rivers: A history of degradation. *BioScience* 35: 90-95.

Kennedy, A. J. and W. A. Ross. 1992. An approach to integrate impact scoping with environmental impact assessment. *Environmental Management* 16: 475-484.

Kerans, B. L., J. R. Karr, and S. A. Ahlstedt. 1992. Aquatic invertebrate assemblages: spatial and temporal differences among sampling protocols. *Journal of the North American Benthological Society* 11: 377-390.

Korte, V. L. and D. W. Blinn. 1983. Diatom colonization on artificial substrata in pool and riffle zones studied by light and scanning electron microscopy. *Journal of Phycology* 19: 332-341.

Kreis, R. D. and W. C. Johnson. 1968. The response of macrobenthos to irrigation return water. *Journal of the Water Pollution Control Federation* 40: 1614-1621.

Kushlan, J. A. 1974. Quantitative sampling of fish populations in shallow freshwater environments. *Transactions of the North American Fisheries Society* 103: 348-352.

Lamberti, G. A. and V. H. Resh. 1979. Substrate relationship, spatial distribution patterns, and sampling variability in a stream caddisfly population. *Environmental Entomology* 8: 561-567.

--------1985. Distribution of benthic algae and macroinvertebrates along a thermal stream gradient. *Hydrobiologia* 128: 13-21.

Lamberti, G. A., Gregory, S. V., Ashkenas, L. A.,Wildman, R. C. and K. M. S. Moore.1991. Stream ecosystem recovery following a catastrophic debris flow. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 196-208.

Lampkin, A. J. III and M. R. Sommerfeld. 1982. Algal distribution in a small intermittent stream receiving acid mine-drainage. *Journal of Phycology* 18: 196-199.

Lancaster, J., M. Real, S. Juggins, D. T. Monteith, R. J. Flower, and W. R. C. Beaumon. 1996. Monitoring temporal changes in the biology of acid waters. *Freshwater Biology* 36: 179-201.

Lawrence, B. G., R. D. Fuller, and C. T. Driscoll. 1987. Release of aluminum following whole-tree harvesting at the Hubbard Brook Experimental Forest, New Hampshire. *Journal of Environmental Quality* 16: 383-390.

Layher, W. G. and O. E. Maughan. 1985. Relations between habitat variables and channel catfish populations in prairie streams. *Transactions of the American Fisheries Society* 114: 771-781.

Leland, H. V., J. L. Carter, and S. V. Fend. 1986. Use of detrended correspondence analysis to evaluate factors controlling spatial distribution of benthic insects. *Hydrobiologia* 131: 113-123.

Lenat, D. R. 1983. Chironomid taxa richness: natural variation and use in pollution assessment. *Freshwater Invertebrate Biology* 2: 192-197.

Lewis, C. A., N. P. Lester, A. D. Bradshaw, J. E. Fitzgibbon, K. Fuller, L. Håkanson, and C. Richards. 1996. Considerations of scale in habitat conservation and restoration. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 440-445.

Liess, M. and R. Schulz. 1996. Chronic effects of short-term contamination with the pyrethroid insecticide fenvalerate on the caddisfly limnephilus lunatus. *Hydrobiologia* 324: 99-106.

Likens, G. E., F. H. Bormann, R. S. Pierce, and W. A. Reiners. 1978. Recovery of a deforested ecosystem. *Science* 199: 492-496.

Limburg, K. E. and R. E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban gradient? *Ecology* 71: 1238-1245.

Loeb, S. L. and A. Spacie. 1994. Biological monitoring of aquatic systems. Lewis Publications, Boca Raton, Florida.

Luey, J. B. and I. R. Adelman. 1980. Downstream natural areas as refuges for fish in drainage development watersheds. *Transactions of the American Fisheries Society* 109: 332-335.

Lynch, J. A., G. B. Rishell, and E. S. Corbett. 1984. Thermal alteration of streams draining clearcut watersheds: Quantification and biological implications. *Hydrobiologia* 111: 161-169.

Lyons, J. 1989. Correspondence between the distribution of fish assemblages in Wisconsin streams and Omernik's ecoregions. *American Midland Naturalist* 12: 122-163.

Mäki-Petäys, A., T. Muotka, A. Huusko, P. Tikkanen, and P. Kreivi. 1997. Seasonal changes in habitat use and preference by juvenile brown trout, Salmo trutta, in a northern boreal river. *Canadian Journal of Fisheries and Aquatic Science* 54: 520-530.

Maciorowski, A. F. 1988. Populations and communities: linking toxicology and ecology in a new synthesis. *Environmental Toxicology and Chemistry* 7: 677-678.

Marchant, R. 1988. Vertical distribution of benthic invertebrates in the bed of the Thomson River, Victoria. *Australian Journal of Marine and Freshwater Research* 39: 775-784.

---------1989. Changes in the benthic invertebrate communities of the Thomson River, southeastern Australia, after dam construction. *Regulated Rivers: Research and Management* 4: 71-89.

Marchant, R., P. Mitchell, and R. Norris. 1984. Distribution of benthic invertebrates along a disturbed section of the La Trobe River, Victoria: an analysis based on numerical classification. *Australian Journal of Marine and Freshwater Research* 35: 355-374.

Martin, D. J., L. J. Wasserman, and V. H. Dale. 1986. Influence of riparian vegetation on posteruption survival of coho salmon fingerlings on the west-side streams of Mount St. Helens, Washington. *North American Journal of Fisheries Management* 6: 1-8.

Matthews, W. J. and H. W. Robison. 1988. The distribution of the fishes of Arkansas: a multivariate approach. *Copeia* 1988: 358-373.

Matthews, W. J. and E. G. Zimmerman. 1990. Potential effects of global warming on native fishes of the southern Great Plains and the Southwest. *Fisheries* 15: 26-31.

Mattson, M. D., P. J. Godfrey, M. F. Walker, P. A. Kerr, and O. T. Zajicek. 1997. Evidence of recovery from acidification in Massachusetts streams. *Water, Air, & Soil Pollution* 96: 211-232.

Mayack, D. T. and J. S. Waterhouse. 1983. The effects of low concentrations of particulates from paper mill effluent on the macroinvertebrate community of a fast-flowing stream. *Hydrobiologia* 107: 271-282.

McClurkin, D. C., P. D. Duffy, and N. S. Nelson. 1987. Changes in forest floor and water quality following thinning and clearcuts of 20-year-old pine. *Journal of Environmental Quality* 16: 237-241.

McElravy, E. P., G. A. Lamberti, and V. H. Resh. 1989. Year-to-year variation in the aquatic macroinvertebrate fauna of a northern California stream. *Journal of the North American Benthological Society* 8: 51-63.

McHenry, M. L., E. Shott, R. H. Conrad, and G. B. Grette. 1998. Changes in the quantity and characteristics of large woody debris in streams of the Olympic Peninsula, Washington, USA (1982-1993). *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1395-1407.

Meffe, G. K. and A. L. Sheldon. 1988. The influence of habitat structure on fish assemblage composition in southeastern blackwater streams. *American Midland Naturalist* 120: 225-240.

---------1990. Post-defaunation recovery of fish assemblages in southeastern blackwater streams. *Ecology* 71: 657-667.

Menzel, R. G. 1991. Long-term field research on water and environmental quality. *Agronomy Journal* 83: 44-49.

Messer, J. J., R. A.Linthurst, and W. S. Overton. 1991. An EPA program for monitoring ecological status and trends. *Environmental Monitoring and Assessment* 17: 67-78.

Millard, S. P. and D. P. Lettenmaier. 1986. Optimal design of biological sampling programs using the analysis of variance. *Estuarine, Coastal, and Shelf Sciences* 22: 637-656.

Millard, S. P., J. R. Yearsley, and D. P. Lettenmaier. 1985. Space-time correlation and its effects on methods for detecting aquatic ecological change. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1391-1400.

Minchin, P.R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. *Vegetatio* 69: 89-108.

Minns, C. K. 1989. Factors affecting fish species richness in Ontario lakes. *Transactions of the American Fisheries Society* 118: 533-545.

Moore, J. N., S. N. Luoma, and D. Peters. 1991. Downstream effects of mine effluent on an intermontane riparian system. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 222-232.

Morgan, M. D. 1987. Impact of nutrient enrichment and alkalinization on periphyton communities in the New Jersey pine barrens. *Hydrobiologia* 144: 233-241.

Morgan, M. D. and K. R. Phillip. 1986. The effect of agricultural and residential development on aquatic macrophytes in the New Jersey Pine Barrens. *Biological Conservation* 35: 143-158.

Morin, A. 1985. Variability of density estimates and the optimization of sampling programs for stream benthos. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1530-1534.

Mulholland, P. J., J. W. Elwood, and A. V. Palumbo. 1986. Effect of stream acidification on periphyton composition, chlorophyll, and productivity. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1846-1858.

Mullholland, P. J., C. T. Driscoll, J. W. Elwood, M. P. Osgood, A. V. Palumbo, A. D. Rosemond, M. E. Smith, and C. Schofield. 1992. Relationships between stream acidity and bacteria, macroinvertebrates, and fish: a comparison of north temperate and south temperate mountain streams, U.S.A. *Hydrobiologia* 23: 7-24.

Mundie, J. H. and K. S. Simpson. 1991. Responses of stream periphyton and benthic insects to increases in dissolved inorganic phosphorus in a mesocosm. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2061-72.

Murphy, M. L., J. Heifetz, S. W. Johnson, K. V. Koski, and J. F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1521-1533.

Murphy, M. L. and J. D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 137-145.

Murphy, M. L. and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. *North American Journal of Fisheries Management* 9: 427-436.

Naiman, R. J. H. Decamps and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3: 209-212.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1076-1085.

Niederlehner, B.R. and J. Cairns Jr. 1994. Consistency and sensitivity of community level endpoints in microcosm tests. *Journal of Aquatic Ecosystem Health* 3: 93-99.

Noel, D. S., C. W. Martin, and C. A. Federer. 1986. Effects of forest clearcutting in New England on stream macroinvertebrates and periphyton. *Environmental Management* 10: 661-670.

Norris, R. H. 1986. Mine waste pollution of the Molonglo River, New South Wales and the Australian Capital Territory: effectiveness of remedial works at Captains Flat mining area. *Australian Journal of Marine and Freshwater Research* 37: 147-157.

Norris, R. H., P. S. Lake, and R. Swain. 1982. Ecological effects of mine effluents on the South Esk River, northeastern Tasmania III-Benthic macroinvertebrates. *Australian Journal of Marine and Freshwater Research* 33: 789-809.

Odum, E. P., J. T. Finn, and E. H. Franz. 1979. Perturbation theory and the subsidy-stress gradient. *BioScience* 29: 349-352.

Ogbeibu, A. E. and R. Victor. 1989. The effects of road and bridge construction on the bank-root macrobenthic invertebrates of a southern Nigerian stream. *Environmental Pollution* 56: 85-100.

Ormerod, S. J. 1987. The influences of habitat and seasonal sampling regimes on the ordination and classification of macroinvertebrate assemblages in the catchment of the River Wye, Wales. *Hydrobiologia* 150: 143-151.

Ormerod, S. J., P. Boole, C. P. McCahon, N. S. Weatherley, D. Pascoe, and R. W. Edwards. 1987. Short-term experimental acidification of a Welsh stream: comparing the biological effects of hydrogen ions and aluminum. *Freshwater Biology* 17: 341-356.

Osborne, L. L. and R. W. Davies. 1987. The effects of a chlorinated discharge and a thermal outfall on the structure and composition of the aquatic macroinvertebrate communities in the Sheep River, Alberta, Canada. *Water Research* 21: 913-921.

Owe, M. 1985. Long-term streamflow observations in relation to basin development. *Journal of Hydrology* 78: 243-260.

Parkinson, E. A., J. Berkowitz, and C. J. Bull. 1988. Sample size requirements for detecting changes in some fisheries statistics from small trout lakes. *North American Journal of Fisheries Management* 8: 181-190.

Parsons, M. and R. H. Norris. 1996. The effect of habitat-specific sampling on biological assessment of water quality using a predictive model. *Freshwater Biology* 36: 419-434.

Patrick, R. 1968. The structure of diatom communities in similar ecological conditions. *American Naturalist*: 173-183.

Perrin, C. J., M. L. Bothwell, and P. A. Slaney. 1987. Experimental enrichment of a coastal stream in British Columbia: Effects of organic and inorganic additions on autotrophic periphyton production. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 1247-1256.

Peterson, C. G. and R. J. Stevenson. 1990. Post-spate development of epilithic algal communities in different current environments. *Canadian Journal of Botany* 68: 2092-2102.

Peterson, M. J., G. R. Southworth, and W. D. Crumby.1996. Monitoring mercury in fish in a stream system receiving multiple industrial inputs. *Environmental Monitoring & Assessment* 40: 91-105.

Phillips, G. L., D. Eminson, and B. Moss B. 1978. A mechanism to account for macrophyte decline in progressively eutrophicated freshwaters. *Aquatic Botany* 4: 103-126.

Portt, C. B., E. K. Balon, and D. L. G. Noakes. 1986. Biomass and production of fishes in natural and channelized streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1926-1934.

Powers, R. F. and V. C. L. Keith. 1991. Long-term ecological research in temperate and boreal forest ecosystems. *Journal of Agronomy* 83: 11-24.

Pratt, J. M., R. A. Color, and P. J. Godfrey. 1981. Ecological effects of urban stormwater runoff on benthic macroinvertebrates inhabiting the Green River, Massachusetts. *Hydrobiologia* 83: 29-42.

Quinn, J. M. and C. W. Hickey. 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand Journal of Marine and Freshwater Research* 24: 387-409.

Raven, P. H. and E. O. Wilson. 1992. A fifty-year plan for biodiversity surveys. *Science* 25: 1099-1100.

Regier, H. A. and J. D. Meisner. 1990. Anticipated effects of climate change on freshwater fishes and their habitat. *Fisheries* 15: 10-15.

Reice, S. R. 1991. Effects of detritus loading and fish predation on leafpack breakdown and benthic macroinvertebrates in a woodland stream. *Journal of the North American Benthological Society* 10: 42-56.

Reid, L. M. and T. Dunne. 1984. Sediment production from forest road surfaces. *Water Resources Research* 20: 1753-1761.

Resh, V. H. 1979. Sampling variability and life history features: basic consideration in the design of aquatic insect studies. *Journal of the Fisheries Research Board of Canada* 36: 290-311.

Resh, V. H., R. H. Norris, and M. T. Barbour. 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology* 20: 108-121.

Resh, V. H., R. H. Norris, and M. T Barbour. 1995. Design and implementation of rapid assessment approaches using benthic macroinvertebrates. *Australian Journal of Ecology* 20: 108-121.

Resh, V. H. and D. M. Rosenberg. 1989. Spatial-temporal variability and the study of aquatic insects. *Canadian Entomologist* 121: 941-963.

Richards, C. and G. Host. 1994. Examining land use influences on stream habitats and macroinvertebrates: A GIS approach. *Water Resources Bulletin* 30: 729-738.

Roberts, D. A., R. Singer, and C. W. Boylen. 1985. The submerged macrophyte communities of Adirondack Lakes of varying degrees of acidity. *Aquatic Botany* 21: 219-35.

Robinson, C. L. K. and W. M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 81-89.

Rosenberg, D. M., H. V. Danks, and D. M. Lehmkuhl. 1986. Importance of insects in environmental impact assessment. *Environmental Management* 10: 773-783.

Rosenberg, D. M., V. H. Resh, S. S. Balling, M. A. Barnby, J. N. Collin, D. V. Durbin, T. S. Flynn, D. D. Hart, G. A. Lamberti, E. P. McElravy, J. R. Wood, T. E. Blank, B. M. Schultz, D. L. Marrin, and D. G. Price. 1981. Recent trends in environmental impact assessment. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 591-624.

Rothrock, J. A., P. K. Barten, and G. L. Ingman. 1998. Land use and aquatic biointegrity in the Blackfoot River watershed, Montana. *Journal of the American Water Resources Association* 34: 565-581.

Rott, E., H. C. Duthie, and E. Pipp. 1998. Monitoring orgainic pollution and eutrophication in the Grand River, Ontario, by means of diatoms. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1443-1453.

Schindler, D. W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. *Science* 184: 897-889.

---------1988. Effects of acid rain on freshwater ecosystems. *Science* 238: 149-158.

Schindler, D. W., K. G. Beaty, E. J. Fee, D. R. Cruikshank, E. R. DeBruyn, D. L. Findlay, G. A. Linsey, J. A. Shearer, M. P. Stainton, and M. A. Turner. 1990. Effects of climatic warming on lakes of the central boreal forest. *Science* 250: 967-970.

Schlosser, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs* 52: 395-414.

Schwenneker, B. W. and R. A. Hellenthal. 1984. Sampling consideration in using stream insects for monitoring water quality. *Environmental Entomology* 13: 741-750.

Scrimgeour, G. J., R. J. Davidson, and J. M. Davidson. 1988. Recovery of benthic macroinvertebrate and epilithic communities following a large flood, in an unstable, braided, New Zealand river. *New Zealand Journal of Marine and Freshwater Research* 22: 337-344.

Scrimgeour, G. J. and M. J. Winterbourn. 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand river. *Hydrobiologia* 171: 33-44.

Scrimgeour, G. J., W. M. Tonn, C. A. Paszkowski, and P. M. K. Aku. 2000. Evaluating the effects of forest harvesting on littoral benthic communities within a natural disturbance-based management model. *Forest Ecology and Management* 126: 77-86.

Scrimgeour, G. J., W. M. Tonn, C. A. Paszkowski, and C. M. Goater. 2001. Benthic macroinvertebrate biomass and wildfires: evidence for enrichment of boreal subarctic lakes. *Freshwater Biology* 46: 367-378.

Scrivener, J. C. and B. C. Andersen. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (Oncorhynchus kisutch) in Carnation Creek, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1097-1105.

Scrivener, J. C. and M. J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (Oncorhynchus keta) and coho salmon (O. kisutch) in Carnation Creek, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 681-696.

Seager, J. and R. G. Abrahams. 1990. The impact of storm sewage discharges in the ecology of a small urban river. *Water Science Technology* 22: 163-171.

Sebastien, R. J., R. A. Brust, and D. M. Rosenberg. 1989. Impact of methoxychlor on selected nontarget organisms in a riffle of the Souris River, Manitoba. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1047-1061.

Sheath, R. G., M. L. Vis, J. A. Hambrook, and K. M. Cole. 1996. Tundra stream macroalgae of North America: composition, distribution and physiological adaptations. *Hydrobiologia* 336: 67-82.

Sheldon, A. L. 1984. Cost and precision in a stream sampling program. *Hydrobiologia* 111: 147-152.

---------1985. Perlid stoneflies (*Plecoptera*) in an Appalachian drainage: a multivariate approach to mapping stream communities. *American Midland Naturalist* 113: 334-342.

Sheldon, S. P. 1986. The effects of short-term disturbance on a freshwater macrophyte community. *Journal of Freshwater Ecology* 3: 309-317.

Shigehisa, H. and H. Shiraishi. 1998. Biomonitoring with shrimp to detect seasonal change in river water toxicity. *Environmental Toxicology and Chemistry* 17: 687-694.

Shortreed, K. S. and J. G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in British Columbia: effects of environmental changes caused by logging. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 1887-1895.

Smith, W. and J. F. Grassle. 1977. Sampling properties of a family of diversity measures. *Biometrics* 33: 283-292.

Specht, W. L., D. S. Cherry, R. A. Lechleitner, and J. Cairns Jr. 1984. Structural, functional, and recovery responses of stream invertebrates to fly ash effluent. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 884-896.

Spence, J. A. and H. B. N. Hynes. 1971. Differences in benthos upstream and downstream of an impoundment. *Journal of the Fisheries Research Board of Canada* 28: 35-43.

Stevenson, R. J. 1990. Benthic algal community dynamics in a stream during and after a spate. *Journal of the North American Benthological Society* 9: 277-288.

Stevenson, R. J. and S. Hashim. 1986. Variation in diatom community structure among habitats in sandy streams. *Journal of Phycology* 25: 678-686.

Storey, G. 1991. Surber and kick sampling: a comparison for the assessment of macroinvertebrate community structure in streams of southwestern Australia. *Hydrobiologia* 21: 111-121.

TerBraak, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167-1179.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in Eastern Washington. *Journal of Environmental Quality* 7: 580-588.

Tonn, W. M. 1990. Climate change and fish communities: a conceptual framework. *Transactions of the American Fisheries Society* 119: 337-352.

Tramer, E. J. and P. M. Rogers. 1973. Diversity and longitudinal zonation in fish populations of two streams entering a metropolitan area. *American Midland Naturalist* 90: 366-374.

Vezina, A. F. 1988. Sampling variance and the design of quantitative surveys of the marine benthos. *Marine Biology* 97: 151-155.

Voelz, N. J. and J. V. Ward. 1991. Biotic responses along the recovery of a regulated stream. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2477-2490.

Walker, I. R. and R. W. Mathewes. 1987. Chironomids, lake trophic status, and climate. *Quaternary Research* 28: 431-437.

Wallace, J. B., J. W. Grubaugh, and M. R. Whiles. 1996. Biotic indices and stream ecosystem processes - results from an experimental study. *Ecological Applications* 6: 140-151.

Wallace, J. B., G. J. Lugthart, T. F. Cuffney, and G. A. Schurr. 1989. The impact of repeated insecticidal treatments on drift and benthos of a headwater stream. *Hydrobiologia* 179: 135-147.

Wallace, J. B., D. S. Vogel, and T. F. Cuffney. 1986. Recovery of a headwater stream from an insecticide-induced community disturbance. *Journal of the North American Benthological Society* 5: 115-126.

Walters, C. J., J. S. Collie and T. Webb. 1988. Experimental designs for estimating transient responses to management disturbances. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 530-538.

Watters, G. T. 1992. Unionids, fishes, and the species-area curve. *Journal of Biogeography* 19: 481-490.

Weatherley, N. S. and S. J. Ormerod. 1987. The impact of acidification on macroinvertebrate assemblages in Welsh streams: Towards an empirical model. *Environmental Pollution* 46: 223-240.

Weisberg, S. B., A. J. Janicki, J. Gerritsen, and H. T. Wilson. 1990. Enhancement of benthic macroinvertebrates by minimum flow from a hydroelectric dam. *Regulated Rivers: Research and Management* 5: 265-277.

Weston, D. P. 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. *Marine Ecology Progress Series* 61: 233-244.

Whiting, E. R. and H. F. Clifford. 1983. Invertebrates and urban runoff in a small northern stream, Edmonton, Alberta, Canada. *Hydrobiologia* 102: 73-80.

Whitlow, J. R. and K. J. Gregory. 1989. Changes in urban stream channels in Zimbabwe. Regulated Rivers: *Research and Management* 4: 27-42.

Whittier, T. R., R. M. Hughes, and D. P. Larsen. 1988. The correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 1264-1278.

Wichert, G. 1994. Fish as Indicators of Ecological Sustainability: Historical Sequences in Toronto Area Streams. *Water Pollution Journal of Canada* 29: 599-617.

Wiegleb, G. 1981. Application of multiple discriminant analysis on the analysis of the correlation between macrophyte vegetation and water quality in running waters of central Europe. *Hydrobiologia* 79: 91-100.

Wiens, A. P. and D. M. Rosenberg. 1984. Effect of impoundment and river diversion on profundal macrobenthos of Southern Indian Lake, Manitoba. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 638-648.

Wilson, R. S. and J. D. McGill. 1977. A new method of monitoring water quality in a stream receiving sewage effluent, using chironomid pupal exuviae. *Water Research* 11: 959-962.

Witzel, L. D. and H. R. MacCrimmon. 1983. Redd-site selection by brook trout and brown trout in southwestern Ontario streams. *Transactions of the American Fisheries Society* 112: 760-771.

Wright, R. F. 1976. The impact of forest fire on the nutrient influxes to small lakes in Northeastern Minnesota. *Ecology* 57: 649-663.

Young, M. K. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. *Canadian Journal of Forest Research* 24: 1933-1938.

Conceptual Issues

Abubakar, M. M. and W. B. Lord. 1992. Persistent conflicts over timber management production and watershed management: a problem analysis. *Water Resources Bulletin* 28: 845-852.

Albert, R. C. 1995. Development of a nondegradation policy for high quality waters. *Water Resources Bulletin* 31: 59-66.

Allan, J. D. and A. S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43: 32-43.

Angermeier, P. L. and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives protecting biotic resources. *BioScience* 10: 690-697.

Angermeier, P. L. and R. J. Neves. 1991. Assessing stream values: perspectives of aquatic resource professionals. *North American Journal of Fisheries Management* 11: 1-10.

Austen, D. J., P. B. Bayley, and B. W. Menzel. 1994. Importance of the guild concept to fisheries research and management. *Fisheries* 19: 12-20.

Bailey, R. G. 1991. Design of ecological networks for monitoring global change. *Environmental Conservation* 18: 173-175.

Bender, E. A., T. J. Case, and M. E. Gilpin. 1984. Perturbation experiments in community ecology: theory and practice. *Ecology* 65: 1-13.

Benke, A. C. 1990. A perspective on America's vanishing streams. *Journal of the North American Benthological Society* 9: 77-88.

Birtwell, I. K., C. D. Levings, J. S. MacDonald, and I. H. Rogers. 1988. A review of fish habitat issues in the Fraser River system. *Water Pollution Research Journal of Canada* 23: 1-30.

Blockstein, D. E. 1992. An aquatic perspective on US biodiversity policy. *Fisheries* 17: 26-30.

Brown, M. and J. J. Dinsmore. 1988. Habitat islands and the equilibrium theory of island biogeography: testing some predictions. *Oecologia* 75: 426-429.

Cairns, J. Jr. 1989. Restoring damaged ecosystems: is predisturbance condition an option? *The Environmental Professional* 11: 152-9.

Cairns, J. Jr, P. V. McCormick, and B. R. Niederlehner. 1993. A proposed framework for developing indicators of ecosystem health. *Hydrobiologia* 263: 1-44.

Cairns, J. and J. R. Pratt. 1986. On the relation between structural and functional analyses of ecosystems. *Environmental Toxicology and Chemistry* 5: 785-786.

Cairns, M. A. and R. T. Lackey. 1992. Biodiversity and management of natural resources: the issues. *Fisheries* 17: 6-10.

Calow, P. 1992. Can ecosystems be healthy? Critical consideration of concepts. *Journal of Aquatic Ecosystem Health* 1: 1-5.

Campbell, I. C. and T. J. Doeg. 1989. Impact of timber harvesting production on streams: a review. *Australian Journal of Marine and Freshwater Research* 40: 519-539.

Caro, T. M. and M. K. Laurenson. 1994. Ecological and genetic factors in conservation: A cautionary tale. *Science* 26: 485-86.

Carpenter, S. E. and J. E. Chaney. 1983. Scale of spatial pattern: four methods compared. *Vegetatio* 53: 153-160.

Carpenter, S. R., T. M. Frost, D. Heisey, and T. K. Kratz. 1989. Randomized intervention analysis and the interpretation of whole-ecosystem experiments. *Ecology* 70: 1142-1152.

Chapman, P. M. 1992. Ecosystem health synthesis: Can we get there from here? *Journal of Aquatic Ecosystem Health* 1: 69-79.

Costanza, R., S. Funtowicz, and J. Ravetz. 1992. Assessing and communicating data quality in policy-relevant research. *Environmental Management* 16: 121-131.

Courtemanch, D. L. 1994. Bridging the old and new science of biological monitoring. *Journal of the North American Benthological Society* 13: 117-121.

Cuff , W. and N. Coleman. 1979. Optimal survey design: lessons from a stratified random sample of macrobenthos. *Journal of the Fisheries Research Board of Canada* 36: 351-361.

Culotta, E. 1994. Is marine biodiversity at risk? *Science* 26: 918-920.

DeMaynadier, P. G. and M. L. Hunter Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental Reviews* 3: 230-261.

Dewberry, T. C. and C. M. Pringle. 1994. Lotic science and conservation: moving toward common ground. *Journal of the North American Benthological Society* 13: 399-404.

Eaton, J. G. and R. M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology & Oceanography* 41: 1109-1115.

Eberhardt, L. L. and J. M. Thomas. 1991. Designing environmental field studies. *Ecological Monographs* 21: 53-73.

Ebersole, J. L., W. J. Liss, and C. A. Frissell CA. 1997. Restoration of stream habitats in the western united states - restoration as re-expression of habitat capacity. *Environmental Management* 21: 1-14.

Ehrlich, P. and E. Wilson. 1991. Biodiversity studies: Science and policy. *Science* 25: 758-762.

Ellis, J. C. and R. F. Lacey. 1980. Sampling: defining the task and planning the scheme. *Water Pollution Control* 79: 452-467.

Ferguson, B. K. 1994. The concept of landscape health. *Journal of Environmental Management* 40: 129-137.

Firehock, K. and J. West. 1995. A brief history of volunteer biological water monitoring using macroinvertebrates. *Journal of the North American Benthological Society* 14: 197-202.

Frissell, C. A. and D. Bayles. 1996. Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. *Water Resource Bulletin* 32: 229-240.

Gilmore, D. W. 1997. Ecosystem management - A needs driven, resource-use philosophy. *The Forestry Chronicle* 73: 560-564.

Goodman, D. 1975. The theory of diversity-stability relationships in ecology. *Quarterly Review of Biology* 50: 237-266.

Gosselink, J. G., G. P. Shaffer, L. C. Lee, D. M. Burdick, D. L. Childers, N. C. Leibowitz, S. C. Hamilton, R. Boumans, D. Cushman, S. Fields, M. Koch, and J. M. Visser. 1990. Landscape conservation in a forested wetland watershed: can we manage cumulative impacts? *BioScience* 40: 588-600.

Gosz, J. R. 1992. Gradient analysis of ecological change in time and space: implications for forest management. *Ecological Applications* 2: 248-261.

Graul, W. D. and G. C. Miller. 1984. Strengthening ecosystem management approaches. *Wildlife Society Bulletin* 12: 282-289.

Green, R. H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. New York: John Wiley and Sons, Inc.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* 41: 540-551.

Grumbine, R. E. 1994. What is Ecosystem Management? *Conservation Biology* 8: 27-38.

---------1997. Reflections on "What is Ecosystem Management"? *Conservation Biology* 11: 41-47.

Hansen, A. J., S. L. Garman, B. Marks, and D. L. Urban. 1993. An approach for managing vertebrate diversity across multiple-use landscapes. *Ecological Applications* 3: 481-496.

Hansen, A. J., T. A. Spies, F. J. Swanson, and J. L. Ohmann. 1991. Conserving biodiversity in managed forests. *Bioscience* 41: 382-392.

Harper, D., M. Ebrahimnezhad, and F. C. C. Cot. 1998. Artificial riffles in river rehabilitation: setting the goals and measuring the successes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 5-16.

Harris, H. J., M. S. Milligan, and G. A. Fewless. 1983. Diversity: quantification and ecological evaluation in freshwater marshes. *Biological Conservation* 27: 99-110.

Hart, D. D. 1994. Building a stronger partnership between ecological research and biological monitoring. *Journal of the North American Benthological Society* 13: 110-116.

Hartig, J. H. and M. A. Zarull. 1992. Towards defining aquatic ecosystem health for the Great Lakes. *Journal of Aquatic Ecosystem Health* 1: 97-107.

Hartman, G. F., J. C. Scrivener, and T. E. McMahon. 1987. Saying that logging is either "good" or "bad" for fish doesn't tell you how to manage the system. *The Forestry Chronicle*: 159-64.

Harvey, B. C. and T. E. Lisle. 1998 Aug. Effects of suction dredging on streams - a review and an evaluation strategy. *Fisheries* 23: 8-17.

Havens, K. 1992. Scale and structure in natural food webs. *Science* 25: 1107-1144.

Hawkins, C. P. 1986. Pseudo-understanding of pseudoreplication: a cautionary note. *Bulletin of the Ecological Society of America* 67: 184-185.

Helliwell, D. R. 1983. The conservation value of areas of different size: Worchestershire Ponds. *Environmental Management* 16: 179-183.

Herricks, E. E. 1984. Aspects of monitoring in river basin management. *Water Science and Technology* 16: 259-274.

Herricks, E. E. and D. J. Schaeffer. 1985. Can we optimize biomonitoring? *Environmental Management* 9: 487-492.

Hornbeck, J. W. and W. T. Swank. 1992. Watershed ecosystem analysis as a basis for multiple-use management of eastern forests. *Ecological Applications* 2: 238-247.

Hughes, R. M., T. R. Whittier, C. M. Rohm, and D. P. Larsen. 1990. A regional framework for establishing recovery criteria. *Environmental Management* 14: 673-683.

Humphrey, C. L., D. P. Faith, and P. L. Dostine. 1995. Baseline requirements for assessment of mining impact using biological monitoring. *Australian Journal of Ecology* 20: 150-166.

Hurlbert, S. H. 1971. The nonconcept of species diversity: a critique and alternative parameters. *Ecology* 52: 577-586.

Isom, B. G. 1991. Biomonitoring. *Journal of the Water Pollution Control Federation* 63: 746-749.

Jackson, J. B. B. 1994. Community unity? *Science* 26: 1412-1413.

James, F. C. and C. E. McCulloch CE. 1990. Multivariate analysis in ecology and systematics: panacea or Pandora's box? *Annual Review of Ecology and Systematics* 21: 129-166.

Jassby, A. D. and T. M. Powell. 1990. Detecting changes in ecological time series. *Ecology* 71: 2044-2052.

Karr, J. R. 1990. Biological integrity and the goal of environmental legislation: lessons for conservation biology. *Conservation Biology* 4: 244-250.

Karr, J. R. 1993. Defining and assessing ecological integrity beyond water quality. Environmental Toxicology and Chemistry 12: 1521-1531.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5: 55-68.

Kimball, K. D. and S. A. Levin. 1985. Limitation of laboratory bioassays: the need for ecosystem-level testing. *BioScience* 35: 165-171.

Knight, D. H. and L. L. Wallace. 1989. The Yellowstone fires: issues in landscape ecology. *BioScience* 391: 700-706.

Kondolf, G. M. and E. R. Micheli. 1995. Evaluating stream restoration projects. *Environmental Management* 19: 1-15.

Kruess, A. and T. Tscharntke. 1994. Habitat fragmentation species loss, and biological control. *Science* 26: 1581-1584.

La Point, T. W. and J. A. Perry. 1989. Use of experimental ecosystems in regulatory decision making. *Environmental Management* 13: 539-544.

Landres, P. B., J. Verner, and J. W. Thomas. 1988. Ecological uses of vertebrate indicator species: a critique. *Conservation Biology* 2: 316-328.

Levin, S. A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943-1967.

Likens, G. E. and F. H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. *BioScience* 24: 447-456.

Loftis, J. C., G. B. McBride, and J. C. Ellis. 1991. Considerations of scale in water quality monitoring and data analysis. *Water Resources Bulletin* 27: 255-264.

Lorenz, C. M., G. M. Vandijk, A. G. M. Vanhattum, and W. P. Cofino. 1997. Concepts in river ecology - implications for indicator development. *Regulated Rivers-Research & Management* 13: 501-16.

Lynch, J. A., E. D. Corbett, and R. Hoopes. 1977. Implications of forest management practices on the aquatic environment. *Fisheries* 2: 16-22.

Malley, D. F. and K. H. Mills. 1992. Whole-lake experimentation as a tool to assess ecosystem health, responses to stress, and recovery: the Experimental Lakes Area experience. *Journal of Aquatic Ecosystem Health* 1: 159-174.

Mann, C. and M. Plummer. 1993. The high cost of biodiversity. *Science* 26: 1868-1871.

Mann, C. C. 1991. Extinction: are ecologists crying wolf? *Science* 25: 736-738.

Mazumder, A. 1994. Patterns of algae biomass in dominant odd-vs even-link lake ecosystems. *Ecology* 75: 1141-1149.

McBride, B. B., J. C. Loftis, and N. C. Adkins. 1993. What do significance tests really tell us about the environment? *Environmental Management* 17: 423-432.

Meyer, J. L. 1997. Stream health - incorporating the human dimension to advance stream ecology. *Journal of the North American Benthological Society* 16: 439-447.

Naiman, R. J. and H. Decamps. 1997. The ecology of interfaces. *Annual Review of Ecology and Systematics* 28: 621-658.

Niemi, G. J., G. J. Niemi, P. DeVore, N. Detenbec, D. Taylor, A. Lima, J. Pastor, J. D. Yount, and R. J. Naiman. 1990. Overview of case studies on recovery of aquatic ecosystems from disturbance. *Environmental Management* 14: 571-588.

Norris, R. H. 1995. Biological monitoring: the dilemma of data analysis. *Journal of the North American Benthological Society* 14: 440-450.

Odum, E. P. 1985. Trends expected in stressed ecosystems. *BioScience* 35: 419-422.

Peterman, R. M. 1990. The importance of reporting statistical power: the forest decline and acidic deposition example. *Ecology* 71: 2024-2027.

---------1990. Statistical power analysis can improve fisheries research and management. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2-15.

Pimm, S. L. and J. L. Gittleman JL. 1992. Biological diversity: Where is it? *Science* 25: 940.

Pulliam, H. R. 1988. Sources, sinks, and population regulation. *American Naturalist* 132: 652-661.

Rapport, D. J. 1992. Evaluating ecosystem health. Journal of Aquatic Ecosystem Health 1: 15-24.

Rapport, D. J, H. A. Regier, and T. C. Hutchinson. 1985. Ecosystem behavior under stress. *American Naturalist* 125: 617-640.

Reynoldson, T. B. and J. L. Metcalfe-Smith. 1992. An overview of the assessment of aquatic ecosystem health using benthic invertebrates. *Journal of Aquatic Ecosystem Health* 1: 295-308.

Reynoldson, T. B., R. H. Norris, V. H. Resh, K. E. Day, and D. M. Rosenberg. 1997. The reference condition - a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. *Journal of the North American Benthological Society* 16: 833-852.

Robinson, G. R., R. D. Holt, M. S. Gaines, S. P. Hamburg, M. L. Johnson, H. S. Fitch, and E. A. Martinko. 1992. Diverse and contrasting effects of habitat fragmentation. *Science* 25: 524-526.

Ross, S. T. 1991. Mechanisms structuring stream fish assemblages: Are there lessons from introduced species? *Environmental Biology of Fishes* 30: 359-368.

Sawhill, J., P. Raven, B. Babbit, J. Bird, and T. Lovejoy. 1994. Understanding biodiversity. *Nature Conservancy* 44: 1-38.

Schaeffer, D. J., E. E. Herricks, and H. W. Kerster. 1988. Ecosystem health: I measuring ecosystem health. *Environmental Management* 12: 445-455.

Schindler, D. W. 1987. Detecting ecosystem responses to anthropogenic stress. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 6-25.

Schneider, S. H. 1994. Detecting climatic change signals: Are there any 'fingerprints'? *Science* 26: 341-347.

Schoener, T. 1983. Rate of species turnover decreases from lower to high organisms: a review of the data. *Oikos* 41: 372-377.

Schuster, E. G. and H. R. Zuuring. 1986. Quantifying the unquantifiable: or, have you stopped abusing measurement scale? *Journal of Forestry* 1986: 25-30.

Scrimgeour, G. J. and D. Wicklum. 1996. Aquatic ecosystem health and integrity: problems and potential solutions. *Journal of the North American Benthological Society* 15: 254-261.

Smith, C. L. 1994. Connecting cultural and biological diversity in restoring northwest salmon. *Fisheries* 19: 20-26.

Southwood, T. R. E. 1977. Habitat, the templatet for ecological strategies? *Journal of Animal Ecology* 46: 337-365.

Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg CW. 1992. Assessing effects of unreplicated perturbations: no simple solutions. *Ecology* 73: 1396-1404.

Stewart-Oaten, A., W. W. Murdoch, and K. R. Parker. 1986. Environmental impact assessment: 'pseudoreplication' in time? *Ecology* 67: 929-940.

Suter, G. W. II. 1993. A critique of ecosystem health concepts and indexes. E*nvironmental Toxicology and Chemistry* 12: 1533-1639.

Swanson, F. J. and R. E. Sparks. 1990. Long-term ecological research and the invisible place. *BioScience* 40: 502-508.

Tecle, A. 1992. Selecting a multicriterion decision making technique for watershed resources management. *Water Resources Bulletin* 28: 129-140.

Vermeij, G. J. 1991. When biotas meet: understanding biotic interchange. *Science* 25: 1099-1104.

Vinson, M. R. and C. P. Hawkins. 1998. Biodiversity of stream insects: variation at local, basin, and regional scales. *Annual Review of Entomology* 43: 271-293.

Walters, C. J. and C. S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71: 2060-2068.

Ward, R. C., J. C. Loftis, and G. B. McBride. 1986. The 'data-rich but information-poor' syndrome in water quality monitoring. *Environmental Management* 10: 291-297.