National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

Aquatic Macroinvertebrate Bioassessment Programs Throughout the Eastern Rivers and Mountains Network Region: Commonalities Among Regulatory Authorities

Technical Report NPS/NER/NRTR—2008/001

ON THE COVER
Perlid stonefly nymph (top left), heptageniid mayfly nymph (top right), chironomid midge larvae (bottom left), and hydropsychid caddisfly larvae (bottom right).
Photographs by Caleb Tzilkowski.

Aquatic Macroinvertebrate Bioassessment Programs Throughout the Eastern Rivers and Mountains Network Region: Commonalities Among Regulatory Authorities

Technical Report NPS/NER/NRTR—2008/001

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U.S. Department of the Interior
National Park Service
Northeast Region
Philadelphia, Pennsylvania

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Abstract

The Eastern Rivers and Mountains Network (ERMN) selected benthic macroinvertebrates (BMI) as one of the 10 vital signs in the ERMN Inventory and Monitoring Program. To maximize benefits of the Program, data collected by the ERMN monitoring programs must be comparable to data collected by environmental protection agencies in New Jersey, New York, Pennsylvania, and West Virginia. This report summarizes and compares the BMI bioassessment and biomonitoring protocols used or advocated by state and federal agencies in the ERMN region. The report also includes access information for agency representatives, in addition to recommendations for the ERMN to develop a broadly applicable BMI sampling protocol that meets data quality criteria of agencies with jurisdiction in the ERMN region.

The Clean Water Act of 1972 (CWA) provides states, tribes, and territories the legal authority to use biological assessments and criteria in their water quality programs. States must have water quality standards that consist of designated uses (e.g., Aquatic Life Uses [ALUs]), criteria to protect those uses, and an antidegradation policy. Measures of BMI assemblages and other ALUs help protect intact stream communities from degradation and are used to establish restoration goals for impaired ecosystems. Because the EPA is the primary entity charged with achieving goals of the CWA, that agency has been a primary source for development of bioassessment methods. Most notably, the EPA produced and updated several volumes of Rapid Bioassessment Protocols (RBPs) for habitat, periphyton, BMI, and fish that all states within the ERMN region have used (to varying extents) to develop their BMI bioassessment and biomonitoring protocols.

All states in the ERMN region use some component of the RBPs for part(s) of their BMI monitoring programs, but the programs are much more dissimilar than alike. One major difference among state BMI biomonitoring programs throughout the ERMN region is the structure of the sampling design. Although all states in the region use some kind of tiered approach to determine sampling coverage and frequency, the designs differ considerably. For example, the New Jersey Department of Environmental Protection (NJDEP) has one program for BMI monitoring, and Pennsylvania and West Virginia agencies have three main categories; whereas, the New York State Department of Environmental Conservation (NYSDEC) has five subprograms (including tissue analysis) in its BMI monitoring program. In addition to differing at the broadest scale (i.e., program goals and sampling stratification), state BMI monitoring programs differ at all lower levels (e.g., sampling intensity, sampling gear, taxonomic resolution). The state program details are described extensively and compared in this report.

The design of a BMI monitoring program for the ERMN should be based on the national and network goals of the I&M program. The primary motivation for state BMI and water quality monitoring programs is to comply with standards set forth by their respective governments and, ultimately, by the CWA. This report includes general recommendations for the design of an ERMN BMI monitoring protocol that would meet data quality standards of state-level regulatory authorities with jurisdiction over water resources in the ERMN region. Although the BMI data collected in the ERMN could (and should) aid state agencies in complying with regulatory water quality standards, the ERMN may want more sensitivity from its BMI program, which would require more effort at most program levels (e.g., sampling frequency, taxonomic resolution).

Introduction

The conservation and protection of natural resources requires monitoring of temporal and spatial variability of ecosystem conditions, particularly with regard to human-induced stressors. The National Park Service (NPS) received a science mandate from Congress with the passing of the 1998 National Parks Omnibus Management Act and created the Inventory and Monitoring (I&M) Program. A primary role of the I&M Program is to collect, organize, and make available natural resource data and to contribute to the NPS's institutional knowledge by facilitating the transformation of data into information through analysis, synthesis, and modeling (NPS 2006a).

The Eastern Rivers and Mountains Network (ERMN) selected benthic macroinvertebrates (BMI) as one of the 10 vital signs in the ERMN I&M Program. Benthic macroinvertebrates are aquatic invertebrate animals larger than microscopic size (e.g., insects, crustaceans, worms, clams, and snails) that live on or in the streambed. In addition to their intrinsic value, BMI provide an important link from basal resources (e.g., algae, detritus) to larger vertebrates (e.g., fish, amphibians, birds). Given their ecological value and their use in water management programs, BMI are a frequently studied and monitored group of organisms. The purpose of this document is to provide information for development of a BMI monitoring protocol in ERMN streams.

Aquatic systems support consumptive and non-consumptive human uses and are vital components of the natural landscape. The 1948 Federal Water Pollution Control Act and its 1972 amendments in the Clean Water Act (CWA) recognized that the propagation of fish and other aquatic life was not only important inherently, but also for the value of water and fisheries resources to society (EPA 2002a). The CWA requires states, tribes, and territories to report the quality of their waters through a biennial report, commonly referred to as the "305(b) report." States and other jurisdictions often use biological condition of streams, (e.g., BMI) to evaluate water quality conditions and set Aquatic Life Uses (ALUs) as measurable criteria. Designated ALUs typically cover a broad range of biological conditions and can be organized in tiers, which allows allocation of resources to waterbodies in proportion to their need for protection (EPA 2002a).

Measures of the BMI assemblage and other ALUs help protect intact stream communities from degradation and can be used to establish restoration goals for impaired ecosystems (EPA 2002a). A variety of spatial scales, system types, and levels of biological organization (e.g., gene, individual, population, system) can be used to measure ecosystem change, but assemblages are effective and efficient indicators of alterations. Throughout time, BMI integrate multiple stressors from point-source and nonpoint-source pollution; consequently, biological assessments (hereafter bioassessments) and biological monitoring (hereafter biomonitoring) provide information regarding environmental perturbations that may not be revealed by water chemistry or toxicity tests.

The terms bioassessment and biomonitoring are often used interchangeably, but they have important distinctions. Biological assessments are evaluations of the condition of a water body using biological surveys and other direct measurements of the resident biota in surface waters (Barbour et al. 1995); conversely, biomonitoring consists of repeated biosurveys throughout time to assess the maintenance, improvement, or degradation of ecological integrity of a chosen area

(e.g., stream reach). Although other assemblages (e.g., periphyton, fish) are used as indicators of impairment, BMI are the most frequently used organisms for aquatic bioassessments because: (a) they are relatively easy to collect; (b) many taxa can be identified to the family level in the field (EPA 1999); and (c) several BMI life history traits make them particularly advantageous for assessing water quality (Table 1).

The NPS must effectively cooperate with other agencies and organizations to maximize I&M program benefits because multiple stakeholders have interests in, or jurisdiction over natural resources within or near NPS properties. Although BMI are the most commonly used biological indicators of stream integrity, there has historically been a lack of consistency among state and federal agencies for how BMI assemblages are used in biomonitoring programs and policy development. To create a BMI monitoring program for the ERMN that is comparable to or of greater predictive power than state and federal programs, components (e.g., sampling methods, sampling effort, data organization/analyses) of those programs must be known.

The purpose of this document is to provide information for development of a BMI monitoring protocol in ERMN streams. Included in this report are: (a) summaries (i.e., objectives, longevity, approach, methods, locations) of BMI bioassessment and biomonitoring protocols used by state (New Jersey, New York, Pennsylvania, West Virginia) and federal (EPA) agencies in the ERMN region; (b) comparisons among sampling, analytical, interpretative, and application (e.g., policy) methodologies of the programs; (c) access information for agency representatives and world wide web resources for relevant monitoring programs; and (d) recommendations to the ERMN regarding development of a broadly applicable BMI sampling protocol that meets data quality criteria of agencies with jurisdiction in the ERMN region.

Table 1. Advantageous traits of aquatic macroinvertebrates for water quality assessment

Trait	Advantage for water quality assessment*
Sedentary	Relatively limited migration of macroinvertebrates permits examination of spatial effects from environmental perturbations.
Ubiquitous	Macroinvertebrates are affected by stress in a variety of aquatic habitats. Small (1st and 2nd order) streams that may not support fish fauna usually support a diverse macroinvertebrate fauna.
Trophic level	Macroinvertebrates form the food base of at least a portion of the life cycle of most fishes and other aquatic vertebrates.
Speciose	Macroinvertebrate assemblages constitute a wide range of trophic levels, providing information regarding cumulative effects of perturbations.
Complex life cycle	Most macroinvertebrate taxa have a complex life cycle of one year or more and sensitive life stages respond quickly to stress.

*from Merritt and Cummins 1996 and EPA 1999.

The U.S. Environmental Protection Agency and the Clean Water Act

The EPA is the primary federal agency responsible for achieving the ultimate CWA goal, which is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Although much of the monitoring and policy efforts are conducted at lower governmental levels, the EPA provides technical guidance and support for states, tribes, and territories to implement water management programs.

In sections 303 and 304 of the CWA and its amendments, states and tribes are given legal authority to use biological assessments and criteria in their water quality programs. States must have water quality standards that consist of designated uses (e.g., ALUs), criteria to protect those uses, and an antidegradation policy. States are required to review these standards every three years, and, if necessary, alter them to achieve CWA goals. States must also have numeric criteria for pollutants that can interfere with attainment of designated uses if the pollutant concentrations/quantities in the waterbody exceed published EPA criteria. According to the CWA, if numeric criteria are not available, states adopt criteria based on biological assessment and monitoring methods consistent with information published by the EPA. Section 304(a)(8) of the CWA directs the EPA to develop and publish methods (e.g., bioassessment and biomonitoring protocols) for establishing and measuring water quality criteria for toxic pollutants on bases (e.g., biocriteria) other than pollutant-by-pollutant.

Biocriteria are derived from bioassessment data and are narrative descriptions and/or numeric values that set desired conditions for biological communities with designated ALUs. Biocriteria can be formally adopted into water quality standards and antidegradation policies and can thus provide regulatory mechanisms to assess and protect biological resources at risk from chemical, physical, or biological impacts. The EPA is responsible for many of the standards that states are expected to achieve as required by the CWA; consequently, the EPA has been a primary source for development of bioassessment methods and applications that states are expected to use to achieve and maintain water resource standards.

Rapid Bioassessment Protocols for Benthic Macroinvertebrates

In the mid-1980s, EPA regional biologists and state agency representatives provided oversight for the development of bioassessment technical guidance. The result of those meetings was the first EPA Rapid Bioassessment Protocols (RBPs; Plafkin et al. 1989) that were revised and published 10 years later in a second edition (EPA 1999). The second RBPs have served as "…basic, cost-effective biological methods for states, tribes, and local agencies that: (a) have no established bioassessment procedures; (b) are looking for alternative methodologies; or (c) may need to supplement their existing programs (not supersede other bioassessment approaches that have already been successfully implemented)" (pg. 1-1, EPA 1999). The RBPs focused on three biological assemblages (i.e., periphyton, BMI, and fish), but they also provided information for habitat assessments and physiochemical parameters. Periphyton and fish are often used for bioassessments, but they are generally used in supplement to BMI in state biomonitoring programs. For example, 56 state or tribal monitoring programs in the United States use BMI; whereas, 41 and 20 entities use fish and periphyton, respectively (EPA 2002b). Plafkin et al.

(1989) presented a five-tiered framework for assessment methodology using fish and BMI. The first three tiers of assessments pertained to BMI:

> RBP I - order-level field taxonomy; no standardized level of sampling effort; requires much "best professional judgment;"
>
> RBP II - field or laboratory taxonomy, family-level; with standardized level of sampling effort; assessment decisions based on numerical data; and
>
> RBP III - laboratory taxonomy, genus/species-level; with standardized level of sampling effort; assessment decision based on numerical data.

Sampling Methods

The second RBPs (EPA 1999) outlined two BMI sampling procedures, one procedure that was geared towards a single, most productive habitat, and a multihabitat approach that was considered the most rigorous benthic RBP. According to the EPA (1999), the single habitat approach is considered to be valid because macroinvertebrate diversity and abundance are usually highest in cobble substrate habitats (i.e., riffles); however, in streams where cobble represents less than 30% of the sampled substrate in reference streams in the region, multihabitat approaches should be used. The following is an abbreviated summary of the field sampling procedures for the single habitat approach (EPA 1999, page 7-3):

1. Select a 100-m stream reach that is: (a) representative of selected stream characteristics, (b) 100 m upstream from any road or bridge crossing, and (c) without major tributaries discharging to the stream in the study area.

2. Complete physical/chemical field sheet with site description, weather conditions, land use, etc.

3. Draw a map of the sampling reach that illustrates in-stream attributes (e.g., habitats, flow, sampled area) and important features (e.g., plants, fields) on the bank and near the stream.

4. Begin sampling at the downstream end of the reach. Two or three areas throughout the reach are sampled and composited (minimally, a total of 2 m^2) using kicks (disruption of 1-m^2 area) and a 1-m kick net. If different gear is used (e.g., a D-frame or rectangular net), a composite is obtained from multiple kicks.

5. Multiple kicks from different locations in the reach are composited into a single sample, but after every kick, the collected material is rinsed with running stream water and large debris is rinsed individually and removed from the sample.

6. The sample is preserved in a container so that all of the material is submerged in 95% ethanol. Every sample receives a label that includes: sample identification code or lot number, date, stream name, sampling location, and collector name.

7. Record observations about the sample (e.g., qualitative estimates of BMI composition) as a cursory estimate of ecosystem integrity and to check sampling adequacy. Record any other pertinent site and sample information and complete field data sheet.

Stream types vary from cobble-bottomed high-gradient streams to low-gradient streams with fine particle substrates; consequently, the multihabitat sampling approach typically yields a more representative BMI collection than the single habitat approach. The multihabitat RBPs require BMI to be collected "… systematically from all available instream habitats by kicking the substrate or jabbing with a D-frame dip net for a total of 20 kicks or jabs" (EPA 1999, page 7-7). A *jab* consists of forcefully thrusting the net into a productive habitat for a linear distance of 0.5 m. The following is an abbreviated summary of the field sampling procedures for the EPA multihabitat approach.

1. Select a 100-m stream reach that is: (a) representative of the selected stream's characteristics, (b) 100 m upstream from any road or bridge crossing, and (c) without major tributaries discharging to the stream in the study area.

2. Complete a physical/chemical field sheet with site description, weather conditions, land use, etc.

3. Draw a map of the sampling reach that illustrates in-stream attributes (e.g., habitats, flow, sampled area) and important structures, plants, etc., on the bank and near the stream.

4. Sampling begins at the downstream end of the reach and proceeds upstream; 20 jabs or kicks are taken from the reach.

5. Different habitat types are sampled in proportion to their estimated abundance in the stream reach. For example, if snags comprise 50% of the habitat in a reach, and riffles comprise 20%, then 10 jabs should be taken in snag material and 4 jabs should be taken in riffle areas.

6. Jabs or kicks collected from multiple habitats are composited into a single sample. Collected material is rinsed with running stream water after every three jabs and large debris is rinsed individually and removed from the sample.

7. The sample is preserved in a container so that all of the material is submerged in 95% ethanol. Every sample receives a label that includes: sample identification code or lot number, date, stream name, sampling location, and collector name.

8. Observations regarding the sample (e.g., qualitative estimates of BMI composition) are recorded as a cursory estimate of ecosystem integrity and to check sampling adequacy.

<u>Laboratory Processing Methods</u>

Samples of BMI collected by either the single habitat or multihabitat methods are best processed in the laboratory under controlled conditions. There are bench sheets and equipment lists available in the RBPs that help standardize and expedite BMI sampling, but those are not summarized here.

Subsampling and Sorting: Fixed-count subsampling can miss rare BMI taxa, but the fixed-count method is the preferred technique for RBPs because it reduces sorting and identification effort and provides a more accurate estimate of time expenditure (Barbour and Gerritsen 1996). The following is a summary of the subsampling approach recommended for a 200-organism subsample (but it can be used for any subsample size):

1. Ensure that all samples in a lot (e.g., collection date, specific project) are accounted for and are in proper condition for processing.

2. Rinse the sample in a 500-µm mesh sieve and remove large debris (e.g., leaves, twigs) after it has been thoroughly rinsed. Allow samples to soak in sample contents and water for about 15 minutes to hydrate BMI (if the sample was preserved in alcohol).

3. After rinsing, spread the sample evenly across a pan marked with 6x6 cm grids.

4. With a random numbers table, select four numbers corresponding to squares within the pan. Remove all material (organisms and debris) from those squares and place the material into a shallow white pan with a small amount of water. If there appear to be 200 organisms + 20% (cumulative of 4 grids), then subsampling is complete. If there are far fewer or more than 200 organisms (+ 20%) in the subsample, additional subsampling is necessary and is described in the protocol.

5. Save the sorted residue and the 200 organism (+ 20%) subsample in separate containers and label them as such.

Macroinvertebrate Identification: According to the RBPs, taxonomy can be at any level, but should be done consistently among samples. Genus/species identifications provide more accurate information regarding ecological/environmental relationships and impairment; whereas, family-level identifications provide greater precision among samples and taxonomists, require less expertise to perform, and accelerate assessment results. The following is a summary of RBP identification protocols:

1. Most organisms are identified to the lowest practical level (usually genus or species) by a qualified taxonomist with a dissecting microscope. If midges are identified to genus or species, they are mounted on slides in an appropriate medium and identified using a compound microscope. Each taxon is counted and recorded in a bench notebook then transcribed to the laboratory bench sheet for subsequent reports.

2. Labels with taxa names and the taxonomist's initials are added to the vials; whereas, slides are initialed by the identifying taxonomist. A separate label may be added to slides to include the taxon (taxa) name(s) for use in a voucher or reference collection.

3. Record the identity, life stage, and number of organisms on the Laboratory Bench Sheet. Also record the taxonomist's initials and the Taxonomic Certainty Rating (TCR) as a measure of confidence.

4. For archiving samples, specimen vials are placed in jars with a small amount of denatured 70% ethanol and tightly capped. Ethanol in the jars should be periodically

replenished. The outside of the jar should be labeled indicating sample identifier, date, and preservative.

Metrics: During the 1980s and 1990s, benthic metrics were extensively developed and tested. The Invertebrate Community Index (DeShon 1995), RBPs (Shackleford 1988; Plafkin et al. 1989; Barbour et al. 1995; Smith and Voshell 1997), and the benthic Index of Biological Integrity (IBI; Kerans and Karr 1994) included metrics intended to evaluate elements and processes of BMI assemblages. Most metrics fall into at least one of the following categories: taxa richness, composition measures, tolerance/intolerance measures, feeding measures or trophic dynamics, or habit measures (Table 2).

Taxa Richness: Taxa richness measures reflect the diversity of BMI assemblages and are usually presented as the number of species, genera, families, or other groupings in a sample. Total taxa richness and a variety of subsets (e.g., mayfly taxa) are generally expected to decrease with increasing impairment.

Assemblage Composition: Composition measures are typically arranged among three groups: (a) identity = individual taxa and associated ecological patterns and environmental requirements; (b) key taxa = taxa that are of special interest or ecologically important and provide information regarding the condition of the targeted assemblage; or (c) relative abundance = the contribution of populations to the BMI assemblage.

Trophic Dynamics: Trophic metrics compare functional feeding groups and reflect the balance of feeding strategies (e.g., shredders, scrapers) in the BMI assemblage. Trophic dynamics describe the relative abundance of trophic groups (i.e., herbivores, carnivores, omnivores, and detritivores). These descriptors are important because a lack of stable trophic dynamics generally indicates stressed conditions.

Habit Measures: Habit is defined as the mode of BMI locomotion or existence. Some examples include: swimmers, clingers, climbers, and burrowers. These measures respond similarly to feeding measures because fewer types of habits are to be expected in more degraded stream conditions.

Environmental Protection Agency Bioassessment Summaries

In the late 1990s, the EPA made it a national priority for state and tribal water management programs to adopt biocriteria to protect aquatic life in waters where biological assessment methods were available (EPA 1998). According to the EPA (2002a), the Office of Water declared the following goals and objectives for the biocriteria program:

1. All states/tribes will use bioassessments/biocriteria to evaluate the health of aquatic life in all waterbodies.

2. Bioassessment data will be used by all states/tribes to better define aquatic life uses.

3. Numeric biocriteria will be adopted in all state/tribal water quality standards to protect aquatic life uses.

Table 2. Best candidate benthic macroinvertebrate metrics, their definitions, and expected responses to increasing perturbations.

Category*	Metric	Definition	Expected response to increasing perturbation
Richness measures	Total #taxa	Measures the variety of the macroinvertebrate assemblage	Decrease
	#EPT taxa	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	Decrease
	#Ephemeroptera Taxa	Number of mayfly taxa	Decrease
	#Plecoptera Taxa	Number of stonefly taxa	Decrease
	#Trichoptera Taxa	Number of caddisfly taxa	Decrease
Composition measures	% EPT	Percent of the composite of mayfly, stonefly, and caddisfly larvae	Decrease
	% Ephemeroptera	Percent of mayfly nymphs	Decrease
Tolerance/Intolerance measures	#of Intolerant Taxa	Taxa richness of organisms considered to be sensitive to perturbation	Decrease
	% Tolerant Organisms	Percent of macrobenthos considered to be tolerant to various types of perturbation	Increase
	% Dominant Taxon	Measures the dominance of the single most abundant taxon. Can be calculated as dominant 2, 3, 4, or 5 taxa	Increase
Feeding measures	% Filterers	Percent of the macrobenthos that filter organic matter from either the water column or sediment	Variable
	% Grazers and Scrapers	Percent of the macrobenthos that scrape or graze upon periphyton	Decrease
Habit measures	Number of Clinger Taxa	Number of insect taxa that are considered clingers (i.e., having fixed retreats or adaptations for attachment to surfaces in flowing water)	Decrease
	% Clingers	Percent of clinger insects in the assemblage	Decrease

*from EPA (1999)

4. Biocriteria/bioassessments will be used in ongoing regulatory programs.

5. Biocriteria/bioassessments will be used to assess the effectiveness of water quality management efforts.

6. Bioassessment data and biocriteria will be used to better communicate the health of the Nation's waters.

Every two years, the EPA compiles and analyzes water quality information submitted by states, tribes, and territories, which is then summarized in the *National Water Quality Inventory Report to Congress* (i.e., the 305(b) report), which is the primary vehicle for reporting water quality conditions throughout the United States. Although the 305(b) report contains information regarding nationwide ALU attainment among states, the results do not always present information needed to assess biological or ecological condition of the Nation's water resources. In other words, ALU attainment may be determined and/or reported based solely on chemical parameters in comparison to chemical water quality criteria set for corresponding ALUs. Chemical water quality standards do not, by themselves, ensure ecological integrity; therefore, most states are attempting to integrate more biological information in their ALU attainment determinations (Yoder and Rankin 1995).

Although the EPA has provided motivation, support, and guidance for states to use bioassessments to help achieve CWA goals, there is considerable variability among states in terms of the extent and methods that BMI are incorporated into water resources assessment and monitoring. The following section summarizes the BMI bioassessment and biomonitoring protocols used by states where ERMN properties occur (i.e., New Jersey, New York, Pennsylvania, and West Virginia).

State Protocol Summaries

New Jersey

Primary Contact:

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The Bureau of Freshwater and Biological Monitoring, within the Water Monitoring and Standards (WM&S) division of the New Jersey Department of Environmental Protection (NJDEP) is responsible for monitoring New Jersey fresh, ground, and marine waters (NJDEP 2006). The mission of the WM&S is "…development and implementation of appropriate water monitoring programs using innovative approaches for the design, collection, measurement, storage, retrieval, assessment and dissemination of water quality data" (NJDEP 2006, page 1). The NJDEP uses data generated by the WM&S to:

- Evaluate water quality status and trends
- Classify waters, including shellfish water quality
- Assess and rank waterbody impairments
- Develop Total Maximum Daily Loads (TMDLs)
- Inform water quality-sensitive land use
- Identify pollution sources and impacts
- Design and implement watershed management initiatives
- Determine effectiveness of pollution control programs
- Respond to environmental emergencies

The NJDEP initiated the Ambient Biological Monitoring Network (AMNET) in 1992, which is currently in use, but the NJDEP has conducted biological monitoring in the state's waterbodies since the 1970s (NJDEP 2006). The main goal of AMNET is to maintain a network of stream biological monitoring sites that adequately represent benthic macroinvertebrate community health in New Jersey's major drainage basins (McGeorge et al. 2004). To achieve that goal, the following objectives were established: "(a) track status and trends in ambient benthic assemblage health, (b) establish background biological quality, (c) obtain biomonitoring data that can be correlated with specific land uses (urban/suburban, agricultural, and undeveloped), and (d) coordinate water chemistry and biological networks" (McGeorge et al. 2004, page 26). Biomonitoring is conducted by the Bureau of Freshwater and Biological Monitoring and is used

in conjunction with other monitoring methods (e.g., water chemistry, toxicity testing). Initially, there were 31 fixed BMI biomonitoring sampling locations throughout the state. The AMNET program now samples approximately 800 stream sites throughout New Jersey, with an average of 165 sites in each of five major drainage basins (upper and lower Delaware, Northeast, Raritan, and Atlantic). The spatial distribution of stations was intended to provide biological impact data on a long-term, basin-wide or state-wide scale, but the design does not allow assessment of any one point source of pollution (NJDEP 2006).

Sampling Design and Methods

Twenty-one Watershed Management Areas (WMAs) are delineated among New Jersey's five major drainage basins. Within each WMA, there are several smaller sub-basins, delineated by the United States Geological Survey (USGS) as scale-11 hydrologic units (HUC11). The AMNET program was designed to monitor all stations within a basin during a fiscal year (July 1 through June 30). A different basin is sampled each year, which results in each basin being sampled once every five years. According to New Jersey's 305(b) Water Quality Inventory report (NJDEP 2002), a five-year interval is the optimum period for long-term biomonitoring; moreover, the five-year rotational basis allows: 1) time for recovery from possible transient environmental impacts and 2) establishment of trends in water and habitat quality (NJDEP 2006).

Most sampling sites are located on second-order streams (i.e., that have only first-order streams as tributaries) or greater (with a greater hierarchy of tributaries) because first order streams are often intermittent or have very low flow (NJDEP 2006). All sites are in reasonably accessible and wadeable segments, proceeding downstream to the head-of-tide. AMNET sites are collocated with Ambient Surface Water Chemical Monitoring Network stations wherever possible. Sites are generally numbered from north to south and in approximate upstream to downstream order, from the mainstem of each major sub-basin to each adjacent tributary, and then to the next adjacent sub-basin.

The EPA RBPs are an integral part of AMNET monitoring methods. Based on review of NJ summary reports, it was apparent that biologists among NJ regions rely on EPA RBP II methods, but they have wide latitude in terms of sampling duration, habitat, and replication. Although NJDEP (and many others) suggest riffles as the preferred sampling habitat in streams, modified EPA RBP field methods are used in low-gradient, coastal NJ streams where riffle substrate is uncommon (NJDEP 2002). Samples are collected in a semi-quantitative fashion with either a kick net or Petite Ponar dredge. Samples are collected from leaf litter and stable substrate (e.g., fine sediment, gravel/rocks, woody debris, vegetation) but the number of jabs or kicks is not standardized. Qualitative observations of habitat, surrounding land use, potential pollution sources, and the presence of aquatic biota are recorded, but not used to calculate bioassessment ratings. Samples are sieved (#30 mesh) and preserved in 5-20% formalin.

Laboratory Processing Methods

Subsampling and Sorting: Subsamples of 100 individuals are removed from the larger sample based on EPA RBP methods using a light-colored pan with grids. Grids are randomly selected and organisms are removed until a 100-organism subsample is established.

Macroinvertebrate Identification: BMI are identified with standard taxonomic keys, using 7 to 30X stereozoom and 40 to 400X compound magnification (NJDEP 2003). As described below, scoring criteria for New Jersey rapid bioassessment metrics are modified from EPA RBP II and are based on family-level taxonomy (NJDEP 2003); thus, BMI are usually identified to genus or species.

Data Analysis: New Jersey streams are classified as non-impaired, moderately impaired, or severely impaired based upon the New Jersey Impairment Score (NJIS), which is a numerical score comprised of five metrics (Table 3). Attributes of the three impairment levels are:

"*Non-impaired*: benthic assemblage comparable to other undisturbed streams within the region; assemblage characterized by a maximum taxa richness, balanced taxa groups, and good representation of intolerant individuals.

Moderately Impaired: macroinvertebrate richness reduced, in particular EPT taxa; reduced assemblage balance and numbers of intolerant taxa.

Severely Impaired: benthic assemblage dramatically different from those in less impaired situations; macroinvertebrates dominated by a few taxa, but with many individuals; only tolerant individuals present" (NJDEP 2003, page 21).

The NJIS was developed by Kurtenbach (1990) and relies on the EPA RBP II protocols (Plafkin et al. 1989; Barbour et al. 1995). Four metrics (taxa richness, percent contribution of the dominant family, number of EPT families, percent EPT families) of the five used for the NJIS are described in the above EPA RBP section. The remaining metric (Modified Family Biotic

Table 3. Biological criteria (metrics) incorporated in the New Jersey Impairment Score, which is used for screening water quality in New Jersey freshwater streams (modified from NJDEP 2003).

	Metric Score		
Metric	6	3	0
Taxa richness (# of families)	>10	10-5	4-0
EPT Index (# of Ephemeroptera, Plecoptera, and Trichoptera families)	>5	5-3	2-0
Percent Dominance (% contribution of individuals in the dominant family to the total # of organisms in a sample)	<40	40-60	>60
% EPT (% of total individuals that are in Ephemeroptera, Plecoptera, and Trichoptera families)	>35	35-10	<10
Modified Family Level Biotic Index	<5	5-7	>7

Index [FBI]; Hilsenhoff 1987) is based on tolerance values (0-10) for BMI families. Tolerance values increase with decreasing water quality, and these values, in conjunction with BMI assemblage composition (relative abundance of families) are used to characterize the BMI assemblage with a score. Summation of scores for the five metrics yields a total NJIS score. Ranges for the total scores for the three impairment classifications are: non-impaired = 24–30, moderately impaired = 9–21, severely impaired = 0–6 (NJDEP 2003).

Reporting and Policy Applications

The NJDEP produces annual basin reports of results and also provides bioassessment results via the New Jersey Integrated Water Quality Monitoring and Assessment Report. Benthic macroinvertebrate bioassessments are used to support general aquatic life standards, but there are no numeric biocriteria in the New Jersey Water Quality Standards (NJAC 2006). Designated uses of New Jersey waters are classified among subcategories of fresh waters (FW), Pinelands waters (PL), coastal saline waters (SC), and saline waters of estuaries (SE) (NJAC 2006). Because BMI are considered to be "associated and established aquatic biota," they are used to evaluate NJ stream attainment of FW and PL designated uses (Table 4).

Table 4. New Jersey flowing water classifications and their designated uses.

Classification	Designated Use
Fresh waters 1 (FW1)	Set aside for posterity to represent the natural aquatic environment and its associated biota
	Primary and secondary contact recreation
	Maintenance, migration, and propagation of the natural and established aquatic biota
	Any other reasonable uses
Fresh waters 2 (FW2)	Maintenance, migration and propagation of the natural and established biota
	Primary and secondary contact recreation
	Industrial and agricultural water supply
	Public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation, and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection
	Any other reasonable uses
Pinelands waters (PL)	Cranberry bog water supply and other agricultural uses
	Maintenance, migration and propagation of the natural and established biota indigenous to this unique ecological system
	Public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation, and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection
	Primary and secondary contact recreation
	Any other reasonable uses

New York

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Biological monitoring in New York streams was initiated in May 1972 by the New York State Department of Environmental Conservation (NYDEC) in response to enactment of the CWA. The Stream Biomonitoring Unit (SBU), within the Bureau of Water Assessment and Management, Division of Water, collects and analyzes BMI assemblages to evaluate the biological condition of New York streams and rivers. The primary activities of the SBU are BMI assemblage assessment and BMI tissue analysis (Bode et al. 2002).

Unless otherwise noted, the following summary of BMI monitoring in New York streams was condensed from the Quality Assurance Work Plan (Bode et al. 2002) developed for the SBU. It should be noted that, based on review of the available literature, BMI biomonitoring conducted by the five-person SBU is the most consistent, thorough, and scientifically defensible BMI program among state programs in the ERMN region.

Sampling Design and Methods

The three main categories that the SBU uses to study BMI are trend monitoring, waterbody assessments, and site assessments. Sampling sites are chosen with targeted-, fixed station-, and probabilistic- (by stream order) sampling designs, but trend monitoring is done primarily with a rotating basin strategy (EPA 2002b).

Two rounds of baseline BMI surveys, from 1972–1977 and 1978–1983, were conducted throughout New York; subsequently, trend monitoring began on the Rotating Intensive Basin Studies (RIBS) network which is currently in use (Bode et al. 2002). The RIBS devotes three-year periods to each of the 17 major New York drainage basins—year one includes planning, reconnaissance, and biological monitoring; the second year is devoted to chemical/intensive monitoring; and, the third year is used to develop evaluations and assessments. Typically, BMI assemblages are assessed in 150–200 streams each year which results in sampling all major drainage basins during a five-year period. Waterbody assessments and site assessments are typically conducted at the request of a NYSDEC regional office and include sampling several sites along the length of a stream reach. These assessments can be very intensive and are typically used to: (a) collect baseline data for streams of unknown quality; (b) isolate/identify pollution sources; (c) document severity of a perceived problem; and/or (d) document possible improvement after remediation of pollution.

Sampling sites are selected to be representative of stream conditions and comparable to upstream and downstream areas. Representativeness is achieved by sampling in the mainstream (opposed to peripheral areas); whereas, comparability is achieved by selecting sites with similar physical characteristics (i.e., dominant substrate, stream current, and percent canopy cover).

The SBU collects information regarding the following parameters at each sampling site:

1. Site location: river or stream, station number, site description relative to landmark (e.g., bridge, town), latitude and longitude, access.

2. Collection date and time, collectors.

3. Site physical condition: width, depth, stream velocity, substrate type, embeddedness, canopy cover.

4. Water chemical condition: temperature, conductivity, dissolved oxygen, pH.

5. Biological parameters: major BMI groups present, aquatic vegetation.

6. Sample type: multiplate, kick sample, tissue collection, photograph.

7. Field assessment of water quality: based on BMI assemblage, aquatic vegetation, chemical parameters, and other impact indicators.

In wadeable streams, the SBU generally uses multiplate sampling devices (multiplates), or kick sampling; whereas, Ponar sediment sampling is conducted in rivers and lakes. Each sampling strategy has advantages and disadvantages, and device selection is based on professional judgment of the biologists.

Multiplate Sampling: Multiplate samplers, often called Hester and Dendy samplers, are artificial substrate samplers typically used in flowing waters that are too deep for kick sampling. Multiplates are constructed of square hardboard plates that are held together with a bolt or turnbuckle. A spacer between each plate results in a comb-like sampler that provides standardized sampling substrate and area to compare BMI assemblages among sites or streams. Multiplates have various designs, but the design used by the SBU consists of three 15-cm^2 hardboard plates.

Stream velocity is considered the primary factor that influences multiplate comparability among sites; consequently, if samplers are placed in similar currents among sites, water quality is expected to be the factor that will most influence the sampled BMI assemblage. Samplers are usually placed in the main current, preferably in a pool or run, rather than a riffle. Two sampling units are placed at each site during routine monitoring to increase the chances of recovering at least one sample in case of vandalism, washout, or mishandling during retrieval. Multiplate installation depends on site condition, but multiplates are usually installed or suspended 1 m below the water surface and held in place with steel cables and/or bricks. After five weeks of submersion, multiplates are removed, placed in water in plastic buckets, and disassembled. Sampler contents are rinsed through a U.S. #30 standard sieve (0.59 mm mesh) and preserved in 95% ethyl alcohol.

In the laboratory, only one sample from each site/date is processed for routine monitoring; the other sample is retained for possible future use. The sample is rinsed and sieved with a US #40 standard sieve and is then subsampled in a tray with a divider that splits the sample into quarters. BMI are identified to genus or species, quarter by quarter, until 250 individuals are identified.

Most taxa are identified with a dissecting stereo-microscope; whereas, Chironomidae and oligochaetes are slide-mounted and identified with a compound microscope. Representative organisms are stored separately in a reference collection.

Kick Sampling: The SBU recognized that kick sampling provides a semi-quantitative sample of the BMI assemblage and lends itself to rapid assessments, but it is limited to wadeable streams. The SBU samples riffles (depth <1 m, stream velocity >0.4 m/sec), preferably between July-September. Spring sampling is typically avoided because of the abundance of naidid worms. An effort is made to have sampling dates consistent among years. Sites are chosen with safe and convenient access and comparable stream velocity, substrate type, and canopy cover to upstream and downstream sites.

The SBU kick sampling method employs a rectangular aquatic net (9×18 in, 0.8×0.9 mm mesh), positioned 0.5 m downstream from a biologist who disturbs substrate by foot. Sampling is conducted for five minutes while the biologist moves diagonally along a 5 m transect across the stream. Net contents are emptied into a pan, BMI taxa (typically, orders) are recorded, and the sample is then rinsed through a US #30 standard sieve and transferred to a quart jar. Samples are preserved in the field with 95% ethyl alcohol.

In the laboratory, kick samples are drained through a US #60 standard sieve and emptied into an enamel pan. A subsample is randomly removed from the pan with a spatula and rinsed with tap water in a sieve, and placed into a 90 mm Petri dish. The subsample is viewed under a dissecting scope and all BMI larger then 1.5 mm are removed until 100 organisms are removed. As they are removed from the sample, BMI are sorted and counted by major taxonomic groups and placed in one dram vials filled with 70% ethyl alcohol. Organisms are identified following the same procedures as for multiplate sampling with the exception that Chironomidae and Oligochaeta are identified intact.

Ponar Sampling: The Ponar grab sampler and Petite Ponar grab sampler provide quantitative samples of soft sediments in rivers and lakes. The samplers are designed to be dropped, usually from a boat, to the bottom of a river or lake. River and lake substrates that Ponar samplers can sample include gravel, sand, silt, and clay. The weight of the sampler penetrates the river or lake bottom and a gravity-activated closing mechanism then encloses a portion of the sediment. The standard Ponar sampler and Petite Ponar sampler that the SBU use enclose surface areas of 0.052 m^2 and 0.023 m^2, respectively. Sampling is conducted from May–October, usually from a boat. The sampler is lowered to within 1 m of the sediment and then allowed to freefall so that the sampler penetrates and collects the sediment. The sampler is retrieved and its contents are then sieved with a U. S. Standard #30 sieve in a bucket, transferred to a quart jar, and preserved with 95% ethyl alcohol.

In the laboratory, kick samples are drained through a U.S. #40 standard sieve and emptied into an enamel pan. Subsampling and BMI identification follow the same protocol as for multiplate sampling.

Biological Impairment Criteria Sampling: Biological impairment criteria sampling is used for enforcement or compliance monitoring and is detailed in the Biological Impairment Criteria document (Bode et al. 1990). This method allows determination of significant water quality

impairment based on comparisons of BMI assemblages at two sites, one upstream and one downstream of a suspected pollution source. Habitat parameters at upstream and downstream sites are measured to determine the appropriate sampling method (i.e., multiplate or kick sampling) and BMI sampling is then conducted at sites upstream and downstream of the potential pollution source. Four replicates are collected if kick samples are used, and if multiplates are used, three 5-week exposures are conducted.

Multiplate and kick samples are analyzed on site. The entire sample is placed in a large enamel pan with water and examined for BMI without magnification. Kick samples are sorted for 100 individuals and a percentage similarity calculation (Bode et al. 1990) is used to estimate similarity among the three kick sample replicates at each site. If similarity is low (<50) for any replicate pair, 100 organisms are re-subsampled from the replicate with the lowest average similarity. If similarity continues to be low for replicate pairings, re-sampling is necessary. Five metrics (Hilsenhoff Biotic Index, EPT richness, Species richness, Species dominance, and Percent Model Affinity) are calculated for kick samples; whereas, all but Percent Model Affinity are calculated for multiplate samples. The average metric values of the three replicates at each site are used to determine impairment. If criteria (available in Bode et al. 1990) are violated for one or more of the metrics, the site is characterized as impaired. For example, if the Biotic index (which increases as impairment increases) is +1.5 at the downstream site relative to the upstream site, provisional impairment is indicated.

Nonpoint Source Sampling: Measuring impacts of nonpoint source discharges on water quality can be difficult because nonpoint sources often have diffuse effects and upstream control sites in agricultural areas are typically unavailable. Bode et al. (1995) determined that modification of biological impairment criteria used by the SBU can effectively document nonpoint source impacts in wadeable riffles. Nonpoint source sampling follows a similar protocol to biological impairment criteria sampling, but only kick samples in riffles with rock/gravel/sand substrates are collected. Other modifications include: 1) preliminary, non-replicated kick samples that are intended to identify potential nonpoint impacts and 2) use of Impact Source Determination to determine probable causes. A full description of the method is given in Bode et al. (2002).

On-site Screening: The on-site screening procedure is intended to allow coverage of more sites by quickly determining whether water quality at a stream/site is unimpaired. The traveling kick sampling method (described above) is used for the on-site screening procedure and BMI are examined in an enamel pan without magnification. To determine that a site is not impaired, the following criteria must be met:

1. Mayflies must be numerous; at least three species represented.

2. Stoneflies must be present.

3. Caddisflies must be present but less abundant than mayflies.

4. Beetles must be present.

5. Aquatic worms must be absent or sparse.

If any one of these criteria is not met, the sample is preserved and examined in the laboratory. If all criteria are met, BMI are returned to the stream. The procedure is intended only to determine severe impairment, and if the on-site determination is questionable, the sample is processed in the laboratory.

Data Management and Analysis

All BMI data are recorded on separate laboratory data sheets for each site/date collection. Data are entered into an Excel spreadsheet with a master template that includes all potential species. The list is reduced by eliminating taxa that are not in the sample. One file can contain species lists for multiple sampling sites.

The Excel file for a sampling location or group of locations is imported into FoxPro for analysis and incorporation into the SBU data management system. The SBU typically calculates seven metrics (taxa richness, EPT richness, Hilsenhoff Biotic Index, Percent Model Affinity, species diversity, five most abundant species, and percent contribution of 10 major groups). Water quality assessments are based on the Biological Assessment Profile, which is a scaled ranking of the metrics that transforms values to a common scale (0–10). Severely impacted sites receive low scores; whereas, non-impacted sites have values approaching 10. Impact Source Determination values are also calculated which help identify pollution types (e.g., toxics, siltation).

Reporting and Policy Applications

Bode et al. (2002, page 5) characterized the primary uses of BMI data in New York as:

1. Trend monitoring – All data is compiled in a dataset that is used for trend monitoring. The initial trend monitoring report was issued in 1993 and subsequent reports are conducted at 10-year intervals to evaluate long-term changes in BMI assemblages.

2. RIBS water quality assessments – Biological data are used in combination with chemical data to make water quality assessments at RIBS sites.

3. Priority Water List – Data are used to supplement documentation of water quality problems cited on the Priority Water List.

4. 303(d) listing – Waterbodies with moderately or severely impacted classification may be included in the 303(d) list.

5. 305(b) reports – Data are used to provide water quality assessments for 305(b) reports.

6. Nonpoint source discharges – BMI data that are indicative of nonpoint discharges are forwarded to personnel within the department who are concerned with nonpoint source issues.

7. Permitting – Biological Assessment Reports may determine if an existing discharge permit is protective of resident fauna. If the discharge is determined to impair the fauna, the permit may be recommended for review.

8. Compliance and enforcement – Data that indicate significant biological impacts on aquatic life may be used as supporting documentation during violation procedures.

9. Contaminant tracking – Tissue analysis results that indicate a likely source of contaminant may be used by the Division of Fish, Wildlife, and Marine Resources or the Division of Environmental Remediation.

10. Regional uses – Many assessments are used by Regional Department of Environmental Conservation offices to assess effects of dischargers, to determine the need for additional testing, and/or document improvements.

The SBU documents BMI biomonitoring progress by preparing monthly reports, water quality assessment reports, and water quality trend reports that include: study background, site descriptions, results and conclusions, species lists for all sites in a survey, discussion of biological results, comparison to previous studies, raw data, summaries of field and laboratory data, and literature cited.

Pennsylvania

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The Pennsylvania Department of Environmental Protection (PADEP) has used bioassessments since water quality monitoring began in the Commonwealth during the late 1960s (EPA 2002b); however, PADEP has conducted intensive biomonitoring for less than 20 years. PADEP currently uses BMI for bioassessment and biomonitoring of Pennsylvania's surface waters under three main categories – The Statewide Surface Water Assessment Program (SSWAP), the Surface Water Quality Monitoring Network (WQN), and the Antidegradation Program.

Sampling Design and Methods

State-wide Surface Waters Assessment Program: The SSWAP (originally called the Unassessed Waters Program) was conducted from 1997–2006 to provide baseline data regarding instream habitat and BMI assemblage composition for all 83,000 miles of Pennsylvania streams (EPA 2002b, PADEP 2006a). According to the PADEP (2004a), 76,114 stream miles (91.5% of all Pennsylvania streams) in 102 watersheds had been assessed eight years into the SSWAP program. Specifically, the SSWAP was designed to: (a) conduct stream assessments as quickly and effectively as possible; (b) complete a state-wide assessment of all streams within 10 years; (c) document point-source and nonpoint-source impairments state-wide; (d) identify causes and sources of impairments; (e) provide supporting data for 305(b) and 303(d) reporting requirements; and (f) document findings in a manner that is useful for TMDL development (PADEP 2006a). Now that the SSWAP is completed, the PADEP intends to use more "detailed methods" to evaluate various aquatic life uses with "multiple biological benchmarks" using both targeted and probabilistically selected sites. According to PADEP (2006a), the new methods and a discussion of their deployment will appear in future Assessment Methodology documents.

The PADEP used their existing 104 State Water Plan (SWP) watershed management delineations to organize the SSWAP sampling strategy as follows:

- Target Population: All wadeable flowing waters in Pennsylvania.
- Division 1: SWP watersheds.
- Division 2: Assessment watersheds.
- Division 3: Assessment subwatersheds.
- Division 4: Assessment units - assemblages of assessment subwatersheds and stream reaches of similar stream order and land use characteristics.

- Division 5: Assessment site - Location where habitat and BMI indicator data are collected to assess the ability of waters in a particular assessment unit, or waterbody, to support its intended aquatic life use.

After reviewing existing information regarding Pennsylvania's watersheds (e.g., land uses, known point source discharges), biologists conducted field reconnaissance to determine and verify land-use patterns, point source discharge locations, stream habitat types, flow conditions, accessibility, and other conditions to determine sampling station placement (PADEP 2004a). Assessment sites in the SSWAP were located, to the extent possible, on tributaries, on mainstems, and at point source discharges. Tributaries were sampled "…at the mouth of at least one representative stream for every combination of stream order, land use, and general benthic macroinvertebrate assemblage identified during the field reconnaissance" (PADEP 2006b, page 7). Mainstems were sampled at their headwaters upstream of the first tributary stream, at the mouth, and at intermediate locations to bracket groups of tributary streams. Point source discharges were included in the SSWAP by sampling (a) immediately upstream of the discharge, (b) in the potential impact zone of all identified point source discharges, and (c) downstream of the recovery zone, if present.

In Pennsylvania, the great majority of streams "… were assessed using the same biological standard and field technique regardless of the aquatic life use designation" (PADEP 2006a, page 3). At all sites and on the same day of BMI collections, biologists conducted a stream habitat evaluation (PADEP 2006a) that was modified from EPA RBP habitat assessment protocols.

Wadeable Flowing Waters - Freestone Streams: My interpretation of the sometimes contradictory BMI sampling methodology used in most Pennsylvania streams for the SSWAP protocol (PADEP 2006b):

1. At least two kick screen samples are collected from the "best available" riffle habitat at each assessment site; however, the next paragraph in the protocol (PADEP 2006b, page 9) says to "Collect a minimum of four screens at each site."

    a. The kick screen is designed to be used by two people and is constructed with a 1×1 m piece of net (800–900 µm mesh) fastened to two dowel handles (~1.3 m long).

    b. Facing upstream, one person places the net in the stream with the bottom edge of the net firmly against the streambed; the other person vigorously kicks a 1×1 m area of substrate immediately upstream of the net to a depth of 10 cm.

    c. The amount of effort (expressed as area) expended should be approximately equivalent while collecting each sample to make valid comparisons.

2. The biologists have the option to collect additional kick screens or use a D-frame net if conditions warrant. Possible situations when that could occur include gross disparity between initial screen samples or if the stream is too shallow or narrow to effectively sample with a screen. An odd suggestion in the protocol is that collections "…in additional habitats to generate a more complete taxa list can be conducted at the

discretion of the investigator" (PADEP 2006b, page 9). Biologists have different opinions and perceptions; consequently, their sampling "discretion" would likely affect assessment of BMI assemblages and possibly yield mischaracterizations of water quality.

3. After each kick screen sample is collected, it is examined in the field and BMI are identified to family. Some taxa (e.g., Oligochaeta, Turbellaria) are identified to order. Initial data analysis is limited to riffle data for standardization. Relative abundance of each recognizable family is recorded on a standard field sheet. Categories include: rare (0–3), present (3–10), common (11–24), abundant (25–99), and very abundant (100+). The biologist may elect to enumerate target taxa.

4. Taxa abundance in kick screen samples is compared and the highest relative abundance among samples for each taxon is recorded.

5. Given these relative abundance measures, BMI assemblages are assessed based on 13 macroinvertebrate criteria (Table 5).

Assessment summaries are prepared for each site based on BMI collections and habitat evaluations. The station/stream segment is classified as not impaired, impaired due to biology, impaired due to habitat, or impaired due to both based on the biologist's field assessment findings. If the stream reach is determined to be impaired, subsequent observations are made in the field to identify causes and sources of impairments.

Wadeable Flowing Waters - Limestone Streams: Limestone streams, as defined by PADEP (2006b), meet the following criteria: spring-fed, <20 mi^2 drainage, high alkalinity (>150 mg/l), and constant year-round temperature. Although limestone streams are less common than freestone streams in Pennsylvania, they are well known to the public because of their productive fisheries; moreover, they are especially vulnerable to impairment because they often occur in intensively farmed valleys and make ideal locations for fish hatcheries (PADEP 2006b). According to the PADEP (2006b), the SSWAP protocol does not work in limestone streams because even unimpaired limestone streams support comparatively few BMI taxa in relative abundance because of their productivity.

Table 5. Benthic macroinvertebrate assemblage criteria used by the Pennsylvania Department of Environmental Protection to assess wadeable streams in the State-wide Surface Waters Assessment Program. Criteria are scored in checkboxes as yes or no, and from these responses, biologists make an "in-the-field" impairment assessment.

Criteria	Description
Abundance obviously low	A subjective assessment of the abundance of organisms collected on the kick screen
Seven or fewer families	Self-explanatory
Three or fewer mayfly individuals	Excluding Baetidae, Caenidae, and Siphlonuridae
Stoneflies present	Self-explanatory
Mayflies and caddisflies are collectively abundant	Excluding Baetidae, Caenidae, Siphlonuridae, Hydropsychidae, and Polycentropodidae
EPT families	July thru September: at least four EPT families with Hilsenhoff pollution tolerance value of 4 or less. November thru May: at least six EPT families with Hilsenhoff pollution tolerance value of 4 or less.
Four or more families with a Hilsenhoff of 3 or less	Self explanatory
Six or more families with a Hilsenhoff of 4 or less	Self explanatory
Dominant family with a Hilsenhoff of 4 or less	Mutually exclusive with #10
Dominant family with a Hilsenhoff greater than 5	Mutually exclusive with #9
Seven or more families with a Hilsenhoff greater than 6	Self explanatory
Sample dominated by families with a mean Hilsenhoff of 5 or less	Mutually exclusive with #13
Sample dominated by families with a mean Hilsenhoff of 5 or less	Mutually exclusive with #12

The Limestone Stream sampling method specifies use of a D-frame kick net (800–900 µm mesh) from January through May to collect BMI from two, 1×1 m areas in riffle/run habitats. One of the samples is collected from an area with fast current in the riffle and the other sample is collected in the same riffle but in slower current. "If there are no riffles in the sample area, a run or the best rock substrate available is sampled" (PADEP 2006c). The samples are composited into one jar and preserved in 95% ethyl alcohol.

A modified EPA RBP subsampling procedure is used to obtain a subsample of 300+20% organisms. The method requires rinsing the subsample with a standard U.S. #35 sieve and then placing the subsample in a pan with 28 grids. Four squares are selected at random with a grid-cutter and organisms are removed and identified. This process is repeated until 300+20% organisms have been removed and identified. Most BMI are identified to genus, but other groups are identified to family (e.g., Chironomidae) or order (e.g., Turbellaria). Impairment of BMI assemblages is determined by comparing standardized metrics (total taxa, EPT taxa, %

tolerant, % intolerant, Hilsenhoff Biotic Index, Shannon Diversity) to thresholds defined for impairment.

Non-wadeable Flowing Waters: "Biological sampling in large non-wadeable flowing waters is a cost and labor intensive endeavor" (PADEP 2006a, page 4); consequently, PADEP is tracking the development of monitoring protocols being developed by interstate commissions on the Ohio, Susquehanna, Delaware, and Potomac Rivers. "Until a method is finalized, DEP will assist in field collections when possible and will review large river assessment results and include them in the Integrated List when appropriate" (PADEP 2006a, page 4).

Surface Water Quality Monitoring Network: BMI samples are collocated with water chemistry samples and collected three times annually (spring, summer, fall) at 26 fixed Water Quality Network (WQN) stations and once a year (summer) at an additional 123 WQN stations (EPA 2002b). Some of these fixed sites are considered reference sites; whereas, others are standard sites. Reference sites are chosen based on stream classification in the antidegradation program and other criteria that include land use and habitat (primarily forested, no water quality criteria violations, minimal siltation). Habitat evaluations are conducted each time a BMI sample is collected. These BMI samples are evaluated with modified EPA RBP methods to monitor long-term trends in water quality on major streams in the Commonwealth (PADEP 2004b).

The semi-quantitative WQN sampling protocol is as follows:

- A D-frame net (500 µm mesh) is used to collect one sample at standard stations and three samples at reference stations. Each sample consists of two kicking efforts that disturb a total of 0.6 m^2 (one in a shallow riffle habitat and the other from a deeper run habitat). The two kicking efforts are composited into one sample and a field inspection is done to ensure that 100 organisms are collected. The entire sample is then preserved and taken to the laboratory.

- Subsampling follows the same protocol as for the Wadeable Limestone Stream protocol except that only 200+20% organisms are identified to genus or lowest practical taxonomic level.

- Taxa are counted and recorded on a standard form and submitted to the Division of Water Quality Standards for entry into the WQN Biological Database.

Reporting and Policy Applications

The four Pennsylvania ALU designations are fishery-based (i.e., cold water fishes, warm water fishes, migratory fishes, and trout stocking); however, BMI are included in the Pennsylvania Code (PA Code 2003) as a proxy measure of aquatic communities that meet those uses. In the Code, numeric water quality criteria are set to protect designated uses, but biological criteria can be used to afford waterbodies the highest levels of protection as High Quality (HQ) or Exceptional Value (EV) (PA Code 2003).

Section 93.4b(a)(2)(i) of the Code states that a water body can qualify as HQ if it:

> "…supports a high quality aquatic community based upon information gathered using peer-reviewed biological assessment procedures that consider physical habitat, benthic macroinvertebrates or fishes based on *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish*, Plafkin et al., (EPA/444/4-89-001), as updated and amended. The surface water is compared to a reference stream or watershed, and an integrated benthic macroinvertebrate score of at least 83% shall be attained by the referenced stream or watershed … The surface water supports a high quality aquatic community based upon information gathered using other widely accepted and published peer-reviewed biological assessment procedures that the Department may approve to determine the condition of the aquatic community of a surface water."

To designate waterbodies as HQ or EV, assessments can be initiated by the PADEP or by petition from the public (person or persons) to the PADEP (PA Code 2003). To assess candidate streams, BMI assemblages, physical habitat, and fish assemblages are studied, but the only numeric criterion in the Code is in regard to BMI condition relative to a reference site (i.e., score $\geq$83% of reference). Reference site selection is done on a regional basis and is based on land use, stream classification in the antidegradation program, and habitat (PADEP 2006a). Reference streams are often chosen based on professional judgment of PADEP biologists and are usually forested, without water quality criteria violations, and with excellent habitat and minimal siltation (PADEP 2006a). Metrics used to compare candidate streams to reference streams include: taxa richness, modified Ephemeroptera, Plecoptera, and Trichoptera Richness, modified Hillsenhoff Biotic Index, percent dominant taxa, and percent modified mayflies (PADEP 2006a).

Delaware River Basin Commission

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The Delaware River flows through Delaware, New Jersey, New York, and Pennsylvania; consequently, the governors of those four states and a federal representative serve as Delaware River Basin Commission (DRBC) chairs. The DRBC manages water resources in the Delaware River Watershed under several programs, including: water quality protection, water supply allocation, regulatory review (permitting), water conservation initiatives, watershed planning, drought management, flood loss reduction, and recreation (DRBC 2006). Because two ERMN parks (i.e., Upper Delaware Scenic and Recreational River and Delaware Water Gap National Recreation Area) were established based on use of Delaware River resources, the ERMN BMI Monitoring Program will cooperate extensively with the DRBC.

The DRBC, in cooperation with the NPS, maintains the Scenic Rivers Monitoring Program (SRMP) which focuses on water quality monitoring in the 200-mile long non-tidal Delaware River corridor. Although the SRMP has been in existence since the early 1980s, "…the DRBC has never used biological criteria for 305(b) assessments or determinations of impairment, other than reports arising from fish-tissue toxics analysis and inference of aquatic life use attainment based upon water chemistry" (EPA 2002b, page 3-231).

The Delaware River Biomonitoring Program (DRBP) is responsible for biomonitoring and biocriteria development for the non-tidal portion of the Delaware River and includes habitat, benthic macroinvertebrate, and periphyton components. According to the EPA (2002b), objectives of the DRBP include:

1. Protection of high quality aquatic life uses of the Delaware River, from Hancock, New York to Trenton, New Jersey.

2. Development of anti-degradation biological criteria based upon existing water quality.

3. Definition of longitudinal changes in benthic community structure along the Delaware River corridor, to support decisions to maintain or improve water quality where necessary.

Based on the most recent available literature (i.e., DRBC 2007), the DRBC has rarely used BMI, although they have been considered part of DRBC monitoring program. According to the EPA, (2002b) BMI biocriteria were developed for DRBC's Special Protection Waters rules issued in 1990, but the criteria were determined to be based on inconsistent and non-representative methods; thus, were not used as envisioned during development of the DRBC's anti-degradation policies.

According to the DRBC (2007), plans for the DRBC monitoring program in the main stem of the Delaware River include:

1. Development of a reference baseline of the existing BMI community throughout the 200-mile, non-tidal portion of the river (2001–2006).

2. Once baseline is established, test to determine which metrics are the best at detecting 'measurable' change. Incorporate these metrics into biological criteria that can be used to establish numerical values for "existing water quality" and to establish anti-degradation reference values.

When the DRBC biomonitoring quality assurance plan (DRBC 2007) was printed, reconnaissance had been completed, three years of macroinvertebrate samples were collected, their processing was initiated, and creation of the biocriteria framework was underway

Sampling Design and Methods

Field Methods

Much of the following summary was condensed from the DRBC biomonitoring quality assurance project plan (DRBC 2007).

The DRBC annually collects BMI at 25 stations along the main stem, non-tidal Delaware River and its East and West Branches using a modified EPA RBP format (DRBC 2007). Sampling sites are distributed longitudinally, as evenly as the geology and hydrology allow, along the river course at approximately eight-mile intervals throughout the 200 river miles (DRBC 2007). All samples are collected during the August–September critical low flow index period.

Site selection focuses on the midstream or margin gravel-cobble riffle microhabitat, which has been specified as the richest targeted habitat of the Delaware River. According to the DRBC (2007), the exact location of the sample is chosen based on visual inspection by the principle investigator who looks for the ideal depth, substrate, and flow characteristics required for BMI colonization and representation of the entire riffle to be sampled. Unfortunately, no values or descriptions for those characteristics are provided in the Macroinvertebrates Standard Operating Procedure of the DRBC (2007) document.

Samples are collected using a Big River Frame Net (BFN) with a substrate frame. The BFN is 3 ft W × 2 ft H with a tapered mesh (595 µm) top and canvas bottom; whereas, the substrate frame measures 2 ft × 2.1 ft W × 4 in H and delineates a 4 ft^2 sampling area that provides for semi-quantitative analysis. Samples are collected using a modified version of the Traveling Kick Method described by EPA (1999). Three sampling locations are established along an imaginary line or arc. Sampling begins at the downstream-most location. One person secures the net downstream of the sampling area while the second person agitates the substrate within the sampling frame by foot. After disturbing the substrate by foot, the area within the frame is inspected and any areas that were not sampled are disrupted by hand. The amount of embeddedness is characterized and recorded in addition to the difficulty of particle disturbance (easy, medium, hard). The area inside the frame is scanned for live mussels, which are

identified, counted, photographed, and returned to the river. The same process is repeated in the upstream direction at the remaining two sampling locations.

The entire net contents are then rinsed into a large, water-filled container and any BMI clinging to the net are picked off using forceps. Contents of the large container are condensed by pouring it through a 500 µm sieve and are then transferred to a sample container that is labeled both inside and out.

Laboratory Methods

Samples are checked immediately upon return to DRBC, split if material fills any jar more than halfway, and their information is recorded on a sample log. The DRBC uses a 500 individual subsample that is removed from the sample using a gridded pan (grid characteristics are not provided in DRBC 2007). Organisms are removed from randomly selected grids until the 500 organism subsample is reached. The DRBC uses the genus or "lowest achievable taxon" level of taxonomic resolution. Three samples (10% of total) are sent to U.S. EPA Region 3 Laboratory for quality control analysis following DRBC identification.

The DRBC biomonitoring quality assurance project plan states that "At this time, a long list of macroinvertebrate and periphyton community metrics are being reviewed and compared as appropriate for Delaware River bioassessment. A committee of regional experts including U.S. EPA ORD staff, are assisting DRBC in selection of metrics and biotic index techniques for biocriteria and river assessment" (DRBC 2007).

Reporting and Policy Applications

As stated previously, the DRBC has rarely used BMI for reporting and policy applications, although that will likely change in the near future as their methods are developed and refined.

West Virginia

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The West Virginia Department of Environmental Protection (WVDEP) regulates the use, protection, and monitoring of West Virginia's natural resources. Within the WVDEP, the Watershed Branch of the Division of Water and Waste Management is responsible for surface water quality monitoring and watershed assessment. WVDEP has used BMI for water quality monitoring since the 1960s, but intensive biomonitoring was not a part of the program until the late 1990s.

The Watershed Assessment Program (WAP) was initiated in 1996 to "…systematically measure the water quality and biological health of the state's rivers and streams" (EPA 2002b, page 3-193). According to WVDEP (2005), data obtained through the monitoring program are intended to support the following goals:

- Provide pertinent information to establish, review, and revise water quality standards
- Determine water quality standard attainment
- Provide estimates regarding the condition/use support of all state waters
- Identify impaired waters [i.e., 303(d) List]
- Identify causes and sources of impairments [303(d) List and 305(b) Report]
- Support implementation of new water management programs and modification of existing programs
- Evaluate program effectiveness.

State and federal water quality agencies signed a resolution of mutual intent in 1997 to form a partnership for statewide watershed management in West Virginia. Goals of the partnership were to: (a) improve public awareness, understanding, and involvement; (b) improve program efficiency; (c) improve program effectiveness and cost effectiveness; and (d) improve information/data management (WVDEP 2005). That partnership helped motivate the first five-year cycle (1997–2001) of BMI sampling in WV, which included sampling 30–35 sites throughout each of the major watersheds in the state. All sites within watersheds were sampled in a single year; however, the sampling design was changed in 2002 (EPA 2002b) and is described in the following section.

Sampling Design and Methods

The Watershed Branch (WB) monitors the condition of WV streams and rivers under a tiered approach. The group collects data from:

- Stratified, probabilistically chosen sites
- Targeted sites within watersheds on a rotating basin schedule
- Long-term monitoring stations (The Ambient Water Quality Monitoring Network, AWQM)
- Priority sites (e.g., sites chosen to further define stream impairment in support of TMDL development).

The probabilistic and targeted sampling programs use BMI as core indicators, whereas BMI are used in supplement to chemical parameters for the priority (i.e., pre-TMDL) sampling efforts. BMI assemblages are not sampled for the AWQM.

The WB collects BMI from 2.0 m of substrate with a rectangular kicknet (0.5×0.5 m, 8 kicks of 0.25 m^2) or a D-frame kicknet (0.3×0.33 m, 18 kicks of 0.109 m^2) using a modified version of EPA's RBP II. Rectangular nets are used in streams with "adequate riffle/run habitat;" whereas, D-frame kick nets are used in streams that are too small to accommodate rectangular nets. In streams with low flows that prohibit the use of nets, field crews use a procedure termed "hand picking" to pick and wash stream substrate in a bucket of water to sample 2 m^2 of substrate. Although field crews attempt to sample a consistent area of substrate (WVDEP 2005), there is apparently no protocol to ensure consistency of hand picking.

Probabilistic Sampling: West Virginia's probabilistic sampling program is stratified to provide consistency in data collection and information regarding status and long-term trends of water quality at the watershed and state scales (WVDEP 2005). There are 750 probabilistically-determined sites distributed among 25 watersheds and watershed groups (i.e., some small watersheds are grouped) throughout WV that are sampled during a five-year period. Six sites are sampled in each of the 25 watersheds each year, which results in 30 sites being sampled in each watershed at the end of a five-year cycle. The second cycle was completed during 2006 and it is anticipated that fish surveys will be included in the 2007–2011 sampling framework.

Targeted Sampling: Targeted sampling has been conducted in WV since 1996 (WVDEP 2005). Streams are sampled based on a five-year rotating basin design and sites are chosen to meet various needs including:

- Impaired stream assessment
- Reference stream assessment
- Spatial trends (multiple sites on streams exceeding 15 miles in length)
- Areas of concern to the public, agency programs, or other stakeholders

- Previously unassessed streams
- Refinement of impairment

A committee annually selects which sites to sample after resources have been allocated to the other three monitoring categories. After determining how many sites can be sampled in the remaining sampling season, "…resources are then allocated to the candidate watersheds (those slated for assessment in a particular year of 5-year rotation) according to total stream miles" (WVDEP 2005, page 15). Although it is not the goal of the program to collect data from every named stream in WV (WVDEP 2005), targeted sites are added in areas that are previously unassessed, with likely problems, or where previous assessments were ambiguous.

At targeted sites, one-time evaluations are conducted for riparian and instream habitat, selected water quality parameters, and BMI and periphyton assemblages (WVDEP 2005). The WVDEP (2005) recognized that lack of resampling at targeted sites was a shortfall of the program; therefore, they are developing a list of representative sites that will be revisited every year.

Ambient Water Quality Monitoring Network: The AWQM addresses the current status and trends of water quality in West Virginia's largest streams; whereas, the other watershed assessment activities assess the condition of the state's wadeable streams (WVDEP 2005). The AWQM began in the 1960s, but has undergone considerable changes since. Sampling stations (n = 25) are located at large river mouths throughout the state and in other areas chosen to isolate impacts from major industrial complexes and other potential impairment sources. Artificial BMI substrates (Hester-Dendy samplers) were used for several years at AWQM sites, but their use was discontinued in 1996. According to WVDEP (2005), BMI assemblages will be assessed at sites where artificial substrate samplers can be used effectively; however, that document did not provide details on when sampling will begin or how frequently it will be conducted.

Pre-TMDL Development Sampling: Pre-TMDL sampling is conducted following the five-year rotating basin design that is used for targeted sampling. The intent of this program is to collect sufficient data for TMDL modelers to develop stream restoration plans. Sampling BMI is considered supplementary for pre-TMDL sampling; thus, BMI are solely studied in streams listed as having aquatic life impairments on the 303(d) list. Although WVDEP (2005) stated that "…this method captures data under a broad variety of weather conditions and flow regimes," sampling seasons and methods were not specified.

Laboratory Processing Methods

For the first two years of the program (1996, 1997), sub-samples of 100 BMI were identified to the family level by WVDEP personnel (Gerritsen et al. 2000). From 1998 to the present, WVDEP has contracted Marshall University (Department of Biological Sciences) to subsample samples (200 organisms) by using methods outlined in the EPA RBPs (EPA 1999). According to WVDEP (1998), the subsampled organisms are returned to WVDEP biologists who identify them to the family level.

Data Management and Analysis: All targeted, probabilistic, and TMDL monitoring data is managed in a Microsoft Access database that was developed based largely on Tetra Tech's

EDAS (Ecological Data Application System). WAPBase houses all water quality, habitat, watershed, and BMI data in both raw and calculated metrics. Ambient Program data are stored in EPA's STORET database but will soon be migrated into WAPASE (WVDEP 2005). A Microsoft program-based, centralized database (Environmental Quality Information System, EQuIS) is under development for use by all of WVDEP.

Metrics: For stream assessments, WVDEP relies primarily on the use of reference conditions and the West Virginia Stream Condition Index (WVSCI) which is a family-level multimetric index developed specifically for use in West Virginia (Gerritsen et al. 2000). According to Gerritsen et al. (2000), a single region and index are suitable for statewide and rotating basin bioassessments/biomonitoring in West Virginia; consequently, the WVSCI has one scale that incorporates six BMI metrics: total taxa, EPT taxa, % EPT, % Chironomidae, % dominant two taxa, and HBI. Each of these metrics is standardized on a 0–100 (poorest–best) scale. Scores from 146 reference streams were analyzed and used to set an impairment threshold of 68.0 (Gerritsen et al. 2000); subsequently, WVDEP personnel calculated a precision estimate of 7.4 based on analysis of duplicate data. Given those results, WVDEP subtracted 7.4 from the impairment threshold to establish a "gray zone" (60.6–68) (WVDEP 2005). If a surveyed site has a WVSCI score in the "gray zone," a single kick sample is considered insufficient for classifying it as impaired; however, if a site has a score below 60.6, WVDEP is confident that the site should be considered impaired based on the BMI sample (WVDEP 2005).

Reporting and Policy Applications

The West Virginia Code (2006) prohibits the presence of wastes in West Virginia waters that adversely affect the chemical, physical, hydrological, and biological character of aquatic ecosystems; consequently, West Virginia streams can be listed as impaired based on chemical, physical, hydrological, and biological criteria. For reporting to the EPA, surface waters are evaluated in terms of the extent to which they support designated uses. As in most other states, WVDEP maintains narrative water quality based on numeric measurements (e.g., pH, dissolved oxygen), but also has established biological impairment criteria.

Streams are listed as biologically impaired based on BMI via the WVSCI. Streams with low WVSCI scores (i.e., <60.6) are listed on the 303(d) list as having an unknown cause of impairment and, by default, are listed for their entire length (WVDEP 2005). Streams identified as being in need of TMDL development are revisited to determine the impaired stream section(s) and cause(s) of impairment. If the stressor identification process demonstrates that the impairment is not caused by a pollutant, then a TMDL is not developed.

Conclusions and Recommendations

The design of a BMI monitoring program for the ERMN should be based on the national and network goals of the I&M program. According to the NPS (2006a), the national goals of the program are to:

- Inventory the natural resources and park ecosystems under National Park Service stewardship to determine their nature and status.
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.
- Establish natural resource inventory and monitoring as a standard practice throughout the national park system that transcends traditional program, activity, and funding boundaries.
- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.
- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

These goals are valuable as broad guiding statements, but development of a BMI monitoring protocol will require network-level decisions regarding the desired sensitivity of the BMI program (i.e., what magnitude of change or human-induced impairment must be detected). These decisions will strongly influence all aspects of the protocol design. The primary motivation for state BMI and water quality monitoring programs is to comply with standards set forth by their respective governments and ultimately by the Clean Water Act; consequently, their programs are generally designed to detect impairment of designated ALUs. As an example, BMI are used in Pennsylvania to discern among streams designated as trout stocking, coldwater, warmwater, and migratory fishes. These are somewhat broad categories and condition of BMI communities can vary widely within each of those designations. Although the BMI data collected in the ERMN could (and should) aid state agencies in complying with regulatory water quality standards, the ERMN may want more sensitivity from its BMI program, which would require more effort at most program levels (e.g., sampling frequency, taxonomic resolution). With that in mind, this section summarizes state BMI monitoring programs and provides general recommendations for how the ERMN could design a “highest common denominator” program that is comparable to all state programs in the region.

Data regarding BMI and other Vital Signs will be used primarily at the park level, but parks are encouraged to use or modify standard protocols and partner with existing programs wherever possible to allow comparability and synthesis of data at multiple scales (NPS 2006b). Although agencies use BMI and other biological assemblages for assessment and monitoring of surface waters throughout the ERMN region, there is considerable variation among the protocols (Table 6) and how data are used (Table 7).

Table 6. Methodological summaries of stream biomonitoring programs used by New Jersey, New York, Pennsylvania, and West Virginia to assess water quality in streams.

		State			
		New Jersey	New York	Pennsylvania	West Virginia
Assemblages	Benthos	100–500 samples/yr, multiple seasons and sites, broad coverage for watershed level	100–500 samples/yr, single season, multiple sites, watershed level	100–500 samples/yr, multiple seasons and sites, broad coverage for watershed level	>500 samples/yr, single season, multiple sites, watershed level
	Fish	<100 samples/yr, single season, multiple sites, broad coverage	<100 samples/yr, single season, multiple sites, not at watershed level	<100 samples/yr, single season, multiple sites, not at watershed level	<100 samples/yr, single observation, limited sampling
	Periphyton	-	<100 samples/yr, single season, multiple sites, not at watershed level	-	-
	Phytoplankton	-	-	<100 samples/yr, single season, multiple sites, not at watershed level	-
Benthic sampling	Sampling gear	Rectangular kick net (9×18 in), >800 micron mesh	Multiplate, Ponar grab sampler, dipnet (>800 micron mesh)	Multiplate, D-frame and kick net (1 m), >800 micron mesh	D-frame and dipnet (500–600 micron mesh), collected by hand
	Habitat selection	Riffle/run (cobble) and multihabitat	Pool/glide, riffle/run (cobble)	Riffle/run (cobble)	Riffle/run (cobble)
	Subsampling size	100	100	100	200
	Taxonomy	family	species	genus	Family, genus
Quality assurance program elements		Standard operating procedures, quality assurance, periodic training for biologists, taxonomic proficiency checks, specimen archival	Standard operating procedures, quality assurance, periodic training for biologists, sorting and taxonomic proficiency checks, specimen archival	Standard operating procedures, quality assurance plan, periodic training for biologists, taxonomic proficiency checks, specimen archival	Standard operating procedures, quality assurance plan, periodic training for biologists, sorting and taxonomic proficiency checks, specimen archival

Table 7. Bioassessment and biocriteria uses for making management decisions regarding aquatic resource restoration in New Jersey, New York, Pennsylvania, and West Virginia.

	New Jersey	New York	Pennsylvania	West Virginia
Aquatic resource assessment		X	X	X
Cause and effect determinations	X	X	X	X
Permitted discharges			X	X
Monitoring	X	X	X	X
Watershed based management	X	X	X	X

Most states use bioassessments and biomonitoring primarily for reporting to the EPA via 305(b) reports and 303(d) lists. The 305(b) reports are statewide assessments of surface waters; whereas, 303(d) lists consider only impaired waters. Aquatic Life Use designations that are included in reports to the EPA and in other state policies also vary in their definitions and how they are determined (Table 8). Carter and Resh (2001) surveyed all U.S. state agencies and determined that differences among BMI monitoring programs were so widespread that calibration among programs would be exceptionally challenging. Despite the numerous differences among state BMI assessment and monitoring programs in the ERMN region, developing a comparable BMI monitoring protocol for the ERMN that meets state and federal standards is feasible because there are only four key programs to consider.

Although New Jersey, Pennsylvania, and West Virginia have used BMI sparingly since the 1960s or 1970s for assessments, comprehensive programs in those states were not initiated until the mid- to late-1990s. Conversely, the New York Stream Biomonitoring Unit (SBU) has used BMI for stream assessments and monitoring since 1972, which is likely part of the reason why the New York protocol is more refined than programs in the other three states. Given the comprehensive quality of the BMI protocol used by the SBU, the ERMN could meet the standards of the other three states by modeling much of its BMI monitoring program after the one used in New York.

National Park Service Networks were formed to link parks that share similar geographic and natural resource characteristics; however, ERMN parks harbor different biological communities and are distant from each other in four states. Nonetheless, if the NPS intends to monitor and compare trends at the network level, the BMI monitoring protocol should be the same, or at least comparable, among parks and networks. Different habitat types and BMI occur among different ERMN parks, but a common suite of sampling, processing, and identification methods could be developed and tailored to each park. Metrics and reporting could be identified regionally (e.g., by state), or on a park-specific basis, but the most important consideration is that BMI communities are sampled, processed, and identified consistently so that (a) data are analogous among parks and (b) network level assessments can be made. The following section provides recommendations for major components of an ERMN BMI program that would meet the requirements of state BMI assessment programs in the region.

Table 8. Aquatic Life Use (ALU) designations and their use for policy and management decisions in New Jersey, New York, Pennsylvania, and West Virginia.

	New Jersey	New York	Pennsylvania	West Virginia
Designations in State Water Quality Standards (WQS)	Three: Trout production, trout maintenance, and non-trout	One: Fish propagation and survival	Four: Coldwater fishes, Warmwater fishes, migratory fishes, trout stocking	Two: Warmwater and coldwater
Narrative Biocriteria in WQS	none[1]	none[2]	none[3]	none[4]
Numeric Biocriteria in WQS	none	none	none	none

[1] NJ – See EPA Rapid Bioassessment Protocols (impairment scoring criteria) for procedures used to support general aquatic life standards.
[2] NY – Reference sites are used by NYSDEC as merely site-specific "control" sites for rating the water quality near a suspected source of impairment. This is done by collecting water samples at the source of impairment and upstream of the source, and the biological impairment criteria are applied for rating purposes. For example, if more than eight species are lost between the two samples, then the impairment criteria have been exceeded and the stream section would be considered significantly impaired. Thus the biological impairment criteria define how much change is allowed from upstream to downstream.
[3] PA – Antidegradation protocols used to support general aquatic life standard are under development, not statutory-found in Chapter 93 of Statutory Code.
[4] NJ – "Internal program procedures are used to support general aquatic life standard."

Recommended Macroinvertebrate Monitoring Program for Eastern Rivers and Mountains Network Streams

Sampling Design and Methods

Most states, including those where ERMN parks exist, use tiered BMI sampling designs with rotational, fixed, and targeted strategies. Rotational sites are used primarily for statewide, long-term monitoring and are typically chosen with a stratified scheme based on watershed groupings or drainage basins. A rotational design maximizes precision and accuracy by intensively studying a fewer number of regions (e.g., parks) each year, as opposed to monitoring the same number of sites throughout the whole study area (e.g., ERMN). By doing so, a more statistically valid assessment of a smaller area (e.g., watershed) is made every several years as opposed to a relatively powerless, inefficient assessment of a larger area (e.g., state) each year. The ERMN could use a similar design and stratify sites by park to ensure that BMI communities throughout parks or portions of parks (e.g., watersheds) are assessed once during each chosen time interval (e.g., five years).

Fixed sites, preferably collocated with water quality monitoring sites, could be located at stream confluences and/or at locations with exceptional ecological or recreational value. Fixed sites are typically sampled more frequently (e.g., annually) than rotational sites to detect potential upstream stressors. A common practice is to use a subset of fixed sites as reference sites, which

are demonstrated (or judged by a biologist) to be in relatively pristine condition (Table 9). Many states, including NJ, PA, and WV, use reference sites as benchmarks at a watershed or greater scale. The NY SBU defines reference sites somewhat differently, in that they only use reference sites upstream of a perceived impairment source to evaluate the effects of that source on downstream BMI condition (Table 10).

Targeted sites usually receive lower priority than rotational and fixed sites and are sampled based on available time and resources once the other sampling efforts are allotted. Targeted site selection could be based on questions, concerns, or needs of park staff in consultation with the ecologist(s) who conduct(s) the sampling. Examples of targeted efforts include: 1) additional sampling to validate questionable assessments; 2) assessment of previously unstudied waters; 3) quantifying effects of upstream potential impairments (e.g., change in land use); and 4) quantifying effectiveness of management activities (e.g., streambank stabilization).

The New York SBU uses primarily multiplate samplers to sample wadeable streams and Ponar dredges to sample rivers. All other states in the ERMN region use Ponar dredges for river sampling, but they typically use nets in wadeable streams. There are a variety of gears to collect BMI, but most (64.5%) state programs throughout the U.S. use nets; 8.9% use multiplates (Carter and Resh 2001). Each sampling gear has advantages and disadvantages that must be balanced with sampling resources and program objectives.

A major advantage of multiplate samplers is that they standardize habitat type and sampling effort (i.e., plate area); consequently, comparisons among sites and sampling dates (e.g., years) have greater precision than sampling natural habitats because they are influenced more by water quality than habitat variability and sampling effort. Simultaneously, the unnatural character of multiplates can be a disadvantage because, in most situations, they underestimate BMI taxa richness because they provide relatively homogeneous habitat (i.e., plates) with minimal habitat variability. Nets minimize sampling trips to one per site per sampling event (compared to two for multiplates) and they also allow for sampling of most natural habitats. Primary disadvantages of sampling with nets are: 1) standardization of sampling effort is more difficult; and 2) habitat(s) chosen to be sampled can have major effects on assessment results.

If a BMI inventory is needed, sampling the natural habitat is necessary; conversely, if BMI are used only as long-term measures of water quality, then it is more important to have consistency among samples, even if only a subset of the community is sampled (i.e., those taxa that colonize multiplate samplers). Logistical limitation of multiplates is that they require a minimum of two trips to each site (i.e., deployment and collection) and are subject to being lost from vandalism and floods, which results in lost data.

Sample Processing and Identification

As suggested by the EPA (Barbour and Gerritsen 1996), fixed count subsampling provides an accurate estimate of time expenditure despite the fact that it can cause rare taxa to be missed. The West Virginia BMI monitoring program uses a subsample target size of 200 organisms and family-level taxonomy; whereas, the other three states in the ERMN region use a target of 100

Table 9. Criteria used for determining reference sites used by New Jersey, New York, Pennsylvania, and West Virginia state monitoring programs to assess water quality in streams.

State	Criteria
New Jersey	EPA's RBP visual habitat assessment protocol. Reference sites are those sites at the upper end of the habitat scale with slight anthropogenic disturbance. Biological criteria include a benthic macroinvertebrate assemblage comparable to other relatively undisturbed streams within the region. The assemblage is characterized by maximum taxa richness, balanced taxa groups, and good representation of pollution intolerant taxa.
New York	For application of biological impairment criteria, reference sites are control sites located upstream of a suspected source of impairment.
Pennsylvania	Based on stream classification in the antidegradation program, land use, and habitat: primarily forested, no water quality criteria violations, excellent habitat, and minimal siltation.
West Virginia	1) D.O. >5.0 mg/L; 2) pH between 6.0 and 9.0; 3) conductivity <500 µS/cm; 4) fecal coliform <800 colony/100 ml; 5) no violations of state water quality standards; 6) no obvious sources of nonpoint pollution; 7) epifaunal substrate/available cover score >10; 8) channel alteration score >10; 11) undisturbed vegetation zone width score>5; 12) total habitat score ≥130; 13) evaluation of anthropogenic activities and disturbances; and 14) non known point source discharges upstream and within view of assessment site (completed after 1–13 are met).

Table 10. Characteristics of reference sites used by New Jersey, New York, Pennsylvania, and West Virginia state monitoring programs to assess water quality in streams.

	State			
	New Jersey	New York	Pennsylvania	West Virginia
Number of reference sites	43	NA	~100	~105
Reference site determinations				
site-specific		X		
paired watersheds			X	
regional (aggregate of sites)	X		X	X
professional judgment	X			X
Characterization of reference sites within a regional context				
least disturbed sites	X			
other: minimally disturbed			X	X
Stream stratification within regional reference conditions				
ecoregions (or some aggregate)	X			
jurisdictional (i.e., statewide)				X
other:			X	
Additional information				
reference sites linked to ALU			X	
some sites represent acceptable human-induced conditions	X			X

organisms and usually genus or species-level taxonomy (EPA 2002b). By using a subsample target size of 200 organisms and genus-level taxonomic resolution, the ERMN could meet the standards of the state programs. If the ERMN requires more sensitivity then additional laboratory effort will be necessary (e.g., greater subsample size, species level resolution).

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