



Protocol Implementation Plan for Benthic Macroinvertebrate Monitoring in the Mid-Atlantic Network

Natural Resource Report NPS/MIDN/NRR—2018 1740



ON THE COVER

Photograph of *Corydalis cornutus* on a cobble in the Appomattox River at Appomattox Court House National Historical Park.
Photograph courtesy of the National Park Service

Protocol Implementation Plan for Benthic Macroinvertebrate Monitoring in the Mid-Atlantic Network

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Abstract

This Protocol Implementation Plan (PIP) outlines the means by which monitoring data are collected, managed, and reported for the benthic macroinvertebrate (BMI) “Vital Sign” in the Mid-Atlantic Inventory and Monitoring Network (MIDN). MIDN has selected three state-published protocols to implement in order to meet the objectives of this PIP: (1) Pennsylvania Wadeable Riffle-Run Stream Macroinvertebrate Data Collection Protocol, (2) Virginia Stream Condition Index for Non-Coastal Streams, and (3) Virginia Coastal Plain Macroinvertebrate Index. Each protocol will be implemented at parks within the appropriate ecoregion to maximize comparability with reference and impaired conditions established by the Commonwealths of Pennsylvania and Virginia. Additionally this document describes deviations from the source protocols.

Acknowledgments

We would like to thank several park resource managers for their support in the implementation of this work and their thoughtful input throughout the development of this protocol implementation plan including Kristen Allen, Tim Blumenshine, Brian Eick, Gregg Kniepp, Dafna Reiner, Amy Ruhe and Timbo Sims. We would also like to acknowledge Jim Comiskey for his efforts in guiding this document, as well as Jeb Wofford for his contributions to the development of this work and Mark Johnson for his work in establishing proper data management. Additionally, we would like to express our gratitude to reviewers for their insights and feedback including Dustin Shull and Jason Hill. Lastly, we would like to thank J. Reese Voshell Jr. and Stephen Hiner who established the benthic macroinvertebrate monitoring programs at the Mid-Atlantic I&M Network and Shenandoah National Park. Their insights into the ecology of benthic macroinvertebrates and the methods used to sample these taxa have been invaluable in the development of these monitoring programs.

Introduction

In an effort to provide a broad understanding of baseline conditions as well as the status and trends of ecosystems within national parks, the Natural Resource Inventory and Monitoring Program (I&M) was established by congressional mandate in 1998 through the Natural Resource Challenge. This program was initiated, in part, to help National Park Service (NPS) managers gain a better understanding of the status and trends in natural resources they are charged with protecting and conserving now and into the future. The Mid-Atlantic Network (MIDN) serves 10 park service units spanning the Blue Ridge, Piedmont, and Coastal Plain of the mid-Atlantic region.

This protocol implementation plan (PIP) provides a description of the objectives and strategy for monitoring the benthic macroinvertebrate community (BMI) in wadeable streams (Strahler stream order 1st -5th) across the Piedmont and Coastal Plain parks associated with the MIDN. Additionally, a series of standard operating procedures (SOPs) provide detailed guidance to carry out the PIP. The MIDN parks monitored as part of this protocol include: Appomattox Court House National Historical Park (APCO), Booker T. Washington National Monument (BOWA), Eisenhower National Historic Site (EISE), Fredericksburg and Spotsylvania National Military Park (FRSP), Gettysburg National Military Park (GETT), Hopewell Furnace National Historic Site (HOFU), Petersburg National Battlefield (PETE), Richmond National Battlefield Park (RICH), and Valley Forge National Historical Park (VAFO; Figure 1). Benthic macroinvertebrate monitoring in the Blue Ridge ecoregion (Shenandoah National Park) is addressed in a separate protocol (Wofford et al. 2018) and therefore not included in this document.

A Science Advisory Committee (SAC) was created by the MIDN to guide the process of defining and selecting vital signs relevant to park resources that could be monitored effectively within logistical and budgetary constraints. A candidate list of vital signs was developed and prioritized through engagement with nearly 100 subject matter experts representing park managers, academia, non-governmental organizations, and other federal and state agencies from the mid-Atlantic region. The SAC recognized that streams are one of the most important and conspicuous natural resources found in national park units associated with the MIDN and that benthic macroinvertebrate communities are ideal for assessing stream condition. Of the 43 candidate vital signs, benthic macroinvertebrate monitoring was ranked third for ecological, management, and policy significance within the MIDN (Comiskey and Callahan 2008).

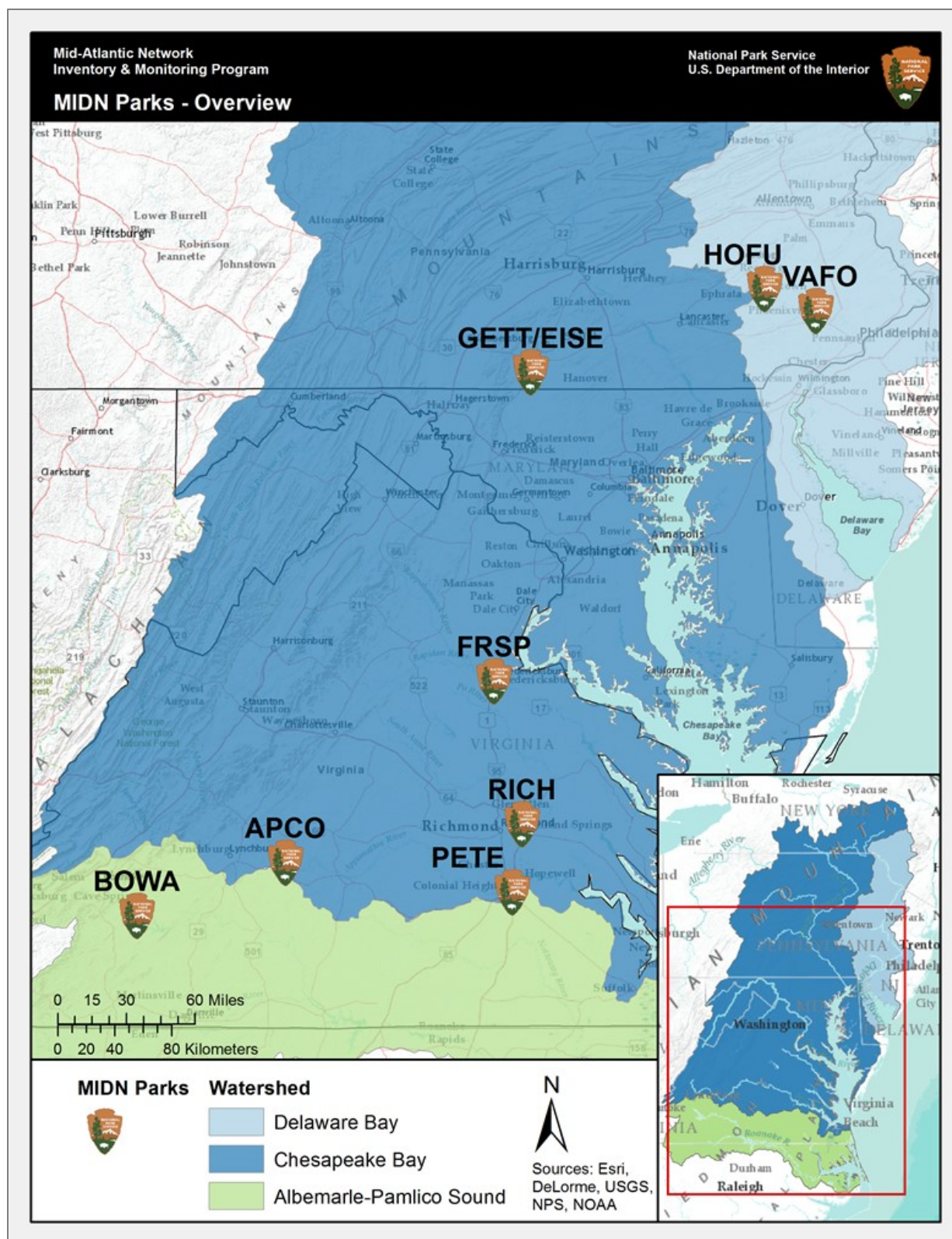


Figure 1. Map of parks monitored as part of the MIDN benthic macroinvertebrate monitoring protocol.

Benthic macroinvertebrates are aquatic invertebrates that are larger than microscopic size (can be seen with the unaided eye) and live on the bottom or on objects protruding from the bottom of streams and lakes. Because these animals are vital to the natural ecological function of streams, they are often used as indicators of ecological integrity. Freshwater benthic macroinvertebrates, including arthropods (insects, arachnids, and crustaceans), worms, clams, and snails, are instrumental to nutrient and carbon dynamics providing an important link in stream food webs. They are the most frequently used taxa in stream biomonitoring for many reasons (Voshell et al. 1997, Barbour et al. 1999, Carter et al. 2006) including:

1. Benthic macroinvertebrates are relatively easy to sample and do not require complicated collection devices.
2. Identification is relatively easy for professional taxonomist to the genus level.
3. Several life history traits make them uniquely advantageous for monitoring stream integrity. The duration of their life history is sufficiently long that they will likely be exposed to pollution and environmental stress, and the assemblage will not recover so quickly that the impairment will go undetected if monitoring is conducted annually. The most common life history is to produce one generation a year, and even among aquatic insects that become terrestrial adults, most spend approximately 10 months in aquatic life stages.
4. They occur in most types of freshwater habitats.
5. There are many benthic macroinvertebrate taxa, and among these taxa there is a wide range of sensitivity to all types of pollution and environmental stress.
6. Benthic macroinvertebrates have mostly sedentary habits so they are likely to be exposed to pollution or environmental stress. They are seldom able to respond to pollution by moving away from the source.
7. Pennsylvania and Virginia have developed regulatory thresholds for biomonitoring using benthic macroinvertebrates.

This PIP implements protocols developed by the Commonwealths of Pennsylvania (PADEP 2012, Shull and Lookenbill 2018) and Virginia (Burton and Gerritsen 2003, VADEQ 2008, Dail et al. 2013). Using these protocols allows the MIDN to leverage knowledge developed by state-based programs regarding benthic macroinvertebrates in the mid-Atlantic region. Adopting protocols developed specifically for the ecoregions where MIDN streams are located allows for direct comparability to other streams within those ecoregions as well as improves the precision and discriminatory power of these data (Dail et al. 2013). Additionally, using these methods will allow for data collected by the MIDN to be integrated into state based assessment procedures.

The PIP outlines the methods by which the MIDN will collect, manage, and report on the BMI community of park streams based on these state-published protocols. This document also describes deviations from the source protocols. These deviations are primarily related to logistical procedures and data management. Changes from the source protocols regarding the collection and processing of BMI data have been limited to ensure comparability to state standards and other streams within the

ecoregions. The naming and organization of other chapters, as well as the topics covered in NRR reports, are completely up to the author and official Peer Review Manager for that report.

Conceptual Framework for Monitoring

The MIDN produced large-scale conceptual models during the development of the vital signs monitoring plan through consultation and collaboration with a variety of stakeholders and subject matter experts (Comiskey and Callahan 2008). These models were then used to focus on specific ecological indicators, including benthic macroinvertebrates, which addressed park resources, management priorities, and threats (Table 1). There is a well-established relationship between the benthic macroinvertebrate community and the structure, function, and health of stream ecosystems (Vannote et al. 1980, Barbour et al. 1999). In addition, the MIDN is monitoring in-situ water quality parameters (Dammeyer and Weed 2017). By monitoring both the water quality and the biological aspects of these streams MIDN is able to better understand and interpret the ecological condition of these systems.

Table 1. Factors affecting the ecological integrity of streams within MIDN parks and potential measures for vital signs monitoring.

Category	Issue	Potential BMI Community Measures
Invasive Species	Introduction of exotic and invasive species.	Invasive species richness and density, proportion of sites with invasive species.
Historic and current land use within authorized park boundaries	Stream riparian buffers, agricultural land uses, atmospheric deposition.	Multimetric Indices, presence/absence of indicator taxa.
Historic and current upstream land use	Urban land use and % impervious cover, residential and commercial land conversion, impoundments, agricultural land use, extractive resource development.	Multimetric Indices, presence/absence of indicator taxa.
Stream habitat stability	Alteration of instream habitat by scouring and/or deposition of sediment.	Multimetric Indices, relative abundance, density, presence/absence.
Climate Change	Changing temperature and hydrologic (precipitation) regimes.	Taxa richness and community composition

Monitoring Objectives

The primary goal of this protocol is to monitor the status and trends of the benthic macroinvertebrate community in wadeable streams in order to inform management decisions within MIDN parks. The sampling design was developed in conjunction with the water quality monitoring protocol to provide a comprehensive assessment of the physical, chemical and biological attributes of park streams. Therefore, benthic macroinvertebrate sampling locations are collocated with water quality sites established in the MIDN water quality monitoring protocol (Dammeyer and Weed 2017).

Monitoring objectives include:

1. Determine the status of the ecological condition of selected wadeable streams (1st-5th order) through monitoring the benthic macroinvertebrate communities using state-based methods and provide these data to state-based regulatory agencies for assessment of adherence to Clean Water Act standards.
2. Determine long-term trends in the benthic macroinvertebrate communities in selected wadeable streams through the use of state-based multimetric indices.
3. Relate benthic macroinvertebrate community status and trends to habitat and water quality data to gain a broad understanding of ecological conditions in MIDN wadeable streams.

What is Being Measured and How

This PIP monitors the benthic macroinvertebrate communities in selected MIDN streams using procedures developed by the states where these streams are located. This allows for a direct assessment of the ecological condition using established, peer-reviewed metrics and for maximum comparability to reference and impaired conditions within the appropriate ecoregion. MIDN streams each fall into one of three ecoregions: (1) Virginia piedmont, (2) Virginia coastal plain, and (3) Pennsylvania piedmont. Each of these ecoregions has unique sampling methods and assessment procedures that were developed by the states: (1) Virginia Stream Condition Index (VASCI: Virginia piedmont; Burton and Gerritsen 2003, VADEQ 2008), (2) Virginia Coastal Plain Macroinvertebrate Index (VACPMI: Virginia Southeastern coastal plain; Dail et al. 2013), and (3) the Benthic Macroinvertebrate Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania (PAIBI: Pennsylvania piedmont; PADEP 2012, Shull and Lookenbill 2018).

In the Virginia piedmont, MIDN implements a single habitat (riffle) sampling methodology; samples materials are collected by disturbing a total of two square meters of riffle substrate and capturing dislodged organisms and materials in a 500-micron D-net. The disturbed area is distributed among riffles within a 100 meter reach of the stream via six 1/3 m² kicks or twelve 1/6 m² kicks. Within each reach the individual kicks are composited into a single sample container, labeled, and preserved using ethanol. All sample containers are retained by the MIDN until after the field season and then transferred to the contract laboratory where they are processed. Field sampling and laboratory methodologies are described in the quality assurance project plan for the VASCI (VADEQ 2008).

In the Virginia coastal plain, MIDN implements a multiple habitat sampling methodology; samples are collected within a 100 meter reach of the stream using a 500-micron D-net. The D-net is used to collect organisms and sample materials through a series (20) of one meter jabs distributed in productive, stable habitat (e.g., root mats, undercut banks, etc.). All sample containers are retained by the MIDN until after the field season and then transferred to the contract laboratory where they are processed. Field sampling and laboratory methodologies are described in the quality assurance project plan for the VACPMI (VADEQ 2008).

In the Pennsylvania piedmont, MIDN implements a single habitat (riffle) sampling methodology; samples are collected by disturbing a total of six square meters of riffle substrate and capturing dislodged organisms and materials in a 500-micron D-net. The disturbed area is distributed among riffles within a 100 meter reach of the stream via six one square meter kicks. At each site the individual kicks are composited into a single sample container, labeled, and preserved using ethanol. All sample containers are retained by the MIDN until after the field season and then transferred to the contract laboratory where they are processed. Field sampling and laboratory methodologies are described in the Water Quality Monitoring Protocols for Streams and Rivers (Shull and Lookenbill 2018).

MIDN will implement two notable deviations from each of the state based methods for collecting and processing samples. First, MIDN will contract with a professional taxonomic laboratory whereas the states process samples and identify organisms with in-house staff. All taxonomists identifying MIDN

samples are required to hold Society of Freshwater Science certifications for general arthropods (genus level) and Ephemeroptera, Plecoptera, and Trichoptera (genus level; Eastern United States). Second, a fixed count subsample target of 300 organisms will be used across each of the protocols using the state-specified methods. Each protocol specifies the target fixed count subsample (VA: $110 \pm 20\%$; PA: $200 \pm 10\%$) lower than the MIDN target. MIDN will statistically subsample (rarefaction) to the appropriate state protocol target number of individuals. By employing a higher target count and statistically reducing the sample to the protocol target MIDN will accomplish three goals: (1) have a robust dataset that is resilient to changes in state based protocols over time (e.g., VA is currently in the process of moving to a 200 organism target), (2) have a larger subsample which is in line with other national monitoring programs (e.g., USGS National Water Quality Assessment Program), and (3) have a larger data set to help address emerging questions over time.

At each field site (across all ecoregions) additional data are collected to document riparian and stream conditions. As described in both the Virginia and Pennsylvania protocols (VADEQ 2008, Shull and Lookenbill 2018), stream habitat assessment data is captured using methods developed by EPA in the Rapid Bioassessment Protocol (Plafkin et al. 1989, Barbour et al. 1999). A standard set of water quality observations (dissolved oxygen, water temperature, specific conductance, and pH) are collected during the sampling event following the MIDN water quality monitoring protocol procedures (Dammeyer and Weed 2017). Benthic macroinvertebrate community data along with stream habitat and water quality data is used to achieve the monitoring objectives of this protocol (Table 2). MIDN makes two minor deviations from field procedures outlined in the state protocols: (1) MIDN uses one standard data collection form in the field in lieu of multiple field forms developed by the state programs and (2) photo points are collected at 5 transects (0, 25, 50, 75, 100 meters) across the sampling reach.

Table 2. Monitoring objectives and the sampling methods, data types, and analyses used to address these objectives.

Monitoring Objective	Field Methods	Data Collected	Analysis Tool
Ecological status of MIDN streams	Sample benthic macroinvertebrate community using state-based methodology (VADEQ 2008, Shull and Lookenbill 2018)	Benthic macroinvertebrates from appropriate habitat	Multimetric indices developed for ecoregions within states, comparison to known reference/impaired conditions
Long-term trends in the benthic macroinvertebrate communities	Sample benthic macroinvertebrate community using state-based methodology (VADEQ 2008, Shull and Lookenbill 2018)	Benthic macroinvertebrates from appropriate habitat	Trend detection in multimetric index scores over long time periods within individual streams

Table 2 (continued). Monitoring objectives and the sampling methods, data types, and analyses used to address these objectives.

Monitoring Objective	Field Methods	Data Collected	Analysis Tool
Relate benthic macroinvertebrate community status to physical habitat and water quality conditions	Sample benthic macroinvertebrate community using state-based methodology (VADEQ 2008, Shull and Lookenbill 2018), Habitat assessment data (VADEQ 2008, Shull and Lookenbill 2018), and water quality data (Dammeyer and Weed 2017)	Benthic macroinvertebrates from appropriate habitat, Stream habitat assessment scores, water quality data	Used to inform interpretation of stream ecological condition based on benthic macroinvertebrate community composition

Sampling Design and Monitoring Schedule

The sample design and site selection implemented through this PIP is directly based on the MIDN water quality monitoring protocol (Dammeyer and Weed 2017). Due to the landscape attributes associated with contributing watersheds as well as the distribution of wadeable streams within MIDN parks, a spatially targeted sampling design is used to select aquatic monitoring sites. The target population is restricted to wadeable streams (Strahler stream order ≤ 5) within or adjacent to MIDN parks. Although this targeted sampling design precludes statistical inference to unsampled areas, other designs (i.e., probability-based) were inappropriate due to park boundary and stream characteristics. Given the large-scale habitat heterogeneity and varied land cover within and surrounding MIDN parks, our goal in developing the protocol was to assess the status and trends at the stream-level not park-wide (i.e., all stream segments that occur within the park). The design is tailored to monitor the water resources identified as prioritized by MIDN park resource managers. These priorities range from concentrated sampling of the main water resource in the park (e.g., Appomattox River at APCO) to sampling across a series of disjunct stream reaches distributed across several park units (e.g., wadeable streams at FRSP, RICH or GETT). This approach provides robust data to address the monitoring objectives of the aquatic monitoring protocols and obtain detailed information on streams of significant value to the parks. In each network park, the stream reaches selected for benthic macroinvertebrate monitoring were identified from within a larger population of water quality monitoring sites. The BMI monitoring sites were chosen based and management prioritization by park managers and MIDN staff to target streams of significant interest (e.g., high quality or threatened streams). For additional background information on the aquatic resources of MIDN parks and detailed reach/site descriptions for each park see the MIDN water quality monitoring protocol (Dammeyer and Weed 2017).

Benthic macroinvertebrate sampling occurs annually and is restricted to the index periods identified in the state-based protocols. In Virginia the spring index period begins March 1st and extends through May 31st; the Pennsylvania index period is from November 1st through May 31st (VADEQ 2008, Shull and Lookenbill 2018). MIDN sampling is conducted in late winter/early spring across all ecoregions to reduce variability related to seasonal differences present in benthic macroinvertebrate communities. Exact timing of sampling in any given year is determined by weather conditions, hydrologic patterns, and logistical constraints. When possible sampling will occur between March 1st—May 31st. However, when logistical constraints preclude this period samples may be collected outside of this date range so long as samples are collected within the index periods established by the states. A power analysis was conducted on pilot data collected during the development of this protocol. Power to detect a small (20%) to large (50%) decline in stream condition (lower multimetric scores over time) was evaluated over three sampling periods (4, 8 and 12 years) on a site-by-site basis. This analysis indicates the probability of detecting declines in stream condition is high at most sites especially in our most pristine streams (Appendix A).

Data Management, Analysis and Reporting

Data captured as part of the monitoring process fall into one of four categories: (1) habitat assessment data, (2) in-situ water quality data, (3), photo documentation, and (4) taxonomic data. The first two categories are captured on paper data sheets at field sites and, along with the photo documentation, are used to provide context to the interpretation of the taxonomic data. The taxonomic data is returned to the MIDN after the samples have been processed by the contract laboratory. In lieu of using separate state developed databases, MIDN taxonomic data is maintained in a single database developed and maintained by the NPS. Data collected as part of this protocol is processed and certified through a series actions completed by MIDN staff and the contract laboratory (Table 3). After all data have been certified, MIDN will produce data summary reports for each park on an annual basis. These reports will be presented as concise products and will use a combination of tables and visual graphics to report on the state based metrics along with limited text to provide context. In lieu of annual reports as static documents, web based outreach through data visualizers and delivery portals may be implemented. Trend reports will be completed at approximately five to ten year intervals and will present a more thorough interpretation of stream conditions based on the benthic macroinvertebrate community. Trend reports may include a series of other metrics which can be reported from these data to “drill down” into the data and provide context to state based metrics.

Table 3. Data processing and finalization procedures.

Data Quality Level	Unprocessed	Processing Level 1 (Entered \Validated)	Processing Level 2 (Analysis)
Raw	Field data is captured on paper data sheets, photos are stored on MIDN equipment, and biological samples are collected/preserved.	Field data entered into Access database and field data sheets scanned. Photos copied onto MIDN server. Biological samples transferred to contract laboratory.	NA
Provisional	Taxonomic data transferred from contractor in electronic format (e.g., .csv).	Taxonomic data imported into Access database. QA/QC procedures for taxonomic data import and field data entry completed.	NA
Pre-certified and Certified	Paper field data sheets, field data sheet scans, photos, and provisional taxonomic data archived locally.	All QA/QC procedures completed and laboratory and field data finalized.	Calculate multimetric indices and habitat assessment scores based on state protocols.

Processing and Workflow

1. Benthic macroinvertebrate samples are collected and preserved and field data are captured (metadata, photos, habitat assessment, and water quality) at sampling locations annually during the index period.

2. Benthic macroinvertebrate samples are held at MIDN office until transfer to contract laboratory and field data are entered into the Access database annually following the spring sampling period.
3. Taxonomic data are returned to MIDN along with associated quality control data from the contract laboratory and imported into the Access database annually.
4. QA/QC procedures are completed for all data entered into the Access database and data are finalized annually.
5. Multimetric indices and stream habitat scores are calculated for each sampling location and these data are reported to parks annually.

Budget

The estimated annual cost for the MIDN benthic macroinvertebrate monitoring protocol is presented in Table 4. Startup costs (approximately \$1000) include acquiring sampling nets and other equipment (totes, bags, etc.) that will require periodic replacement.

Table 4. Estimated annual operational cost associated with the implementation the benthic macroinvertebrate monitoring protocol.

Category	Detail	Cost
Personnel	MIDN Ecologist (0.40 FTE GS-12)	\$36,140
	MIDN Technician (0.20 FTE GS-07)	\$10,187
	MIDN Data Manager (0.05 FTE GS-11)	\$3,769
	MIDN Biologist/Science Writer (0.05 FTE GS-11)	\$3,769
	Subtotal	\$53,865
Contracts & Supplies	Taxonomic Contract	\$4,025
	Ethanol	\$200
	Field Supplies and Equipment	\$250
	Subtotal	\$4,475
Travel	Virginia Parks	\$1,000
	Pennsylvania Parks	\$1,000
	Subtotal	\$2,000
Total Annual Cost	—	\$60,340

Safety

The MIDN considers the occupational health and safety of their employees, cooperators, and volunteers to be of utmost importance, and is committed to ensuring that all receive adequate training on NPS safety procedures, incident reporting, and emergency response prior to field work. Emergency procedures and contacts, incident reporting, field preparations, safe field procedures, vehicle safety, and workers' compensation procedures are outlined in the Aquatic Safety Procedures SOP (Mid-Atlantic Network 2017).

Standard Operating Procedures and Deviations from Source Protocols

The MIDN implements this protocol primarily through the adoption of SOPs from protocols developed by the Commonwealths of Pennsylvania and Virginia. Additional SOP's that cover procedures not addressed in the state-based protocols are maintained by the MIDN (e.g., Data Management, Decontamination of Equipment, etc.). A full list of SOPs associated with this protocol along with citations is presented in Table 5.

Table 5. Standard Operating Procedures (SOPs) required.

Standard Operating Procedure/Topic	Citation	Adopted from Existing Protocol or New	Deviations from Source SOP	IRMA Holding*
Aquatic Safety Procedures	Mid-Atlantic Network SOP 1.0, (2017a)	Adopted	None	2238906
Site Establishment	Mid-Atlantic Network SOP 1.1, (2017b)	Adopted	None	2238935
Field Season Preparation and Close-Out Activities	Mid-Atlantic Network SOP 1.1, (2018a)	New	N/A	2254852
Collection of Benthic Macroinvertebrates in the Virginia Coastal Plain	VADEQ (2008)	Adopted	None	N/A
Collection of Benthic Macroinvertebrates in the Virginia Piedmont	VADEQ (2008)	Adopted	None	N/A
Collection of Benthic Macroinvertebrates in Pennsylvania Piedmont	Shull and Lookenbill (2018)	Adopted	None	N/A
Site Visit Procedures and Collection of Field Data	Mid-Atlantic Network SOP 1.2, (2018b)	New	N/A	2254851
Decontamination of Equipment	Mid-Atlantic Network SOP 1.11, (2017c)	Adopted	None	2238945
Taxonomic Laboratory Methods: Virginia Coastal Plain	VADEQ (2008)	Adopted	ID to genus; sub-sample to 300 individuals	N/A
Taxonomic Laboratory Methods: Virginia Piedmont	VADEQ (2008)	Adopted	ID to genus; sub-sample to 300 individuals	N/A
Taxonomic Laboratory Methods: Pennsylvania Piedmont	Shull and Lookenbill (2018)	Adopted	Sub-sample to 300 individuals	N/A
Field and Laboratory Data Management and QA/QC Procedures	Mid-Atlantic Network SOP 2.1, (2018c)	New	N/A	2254853

*IRMA – Integrated Resource Management Applications Data Store (<https://irma.nps.gov/DataStore>)

Table 5 (continued). Standard Operating Procedures (SOPs) required.

Standard Operating Procedure/Topic	Citation	Adopted from Existing Protocol or New	Deviations from Source SOP	IRMA Holding*
Benthic Macroinvertebrate Metric Calculations: VA Coastal Plain	VADEQ (2008)	Adopted	Taxonomic data electronically subsampled to appropriate number of organisms for metric calculation	N/A
Benthic Macroinvertebrate Metric Calculations: VA Piedmont	Dail et al. (2013)	Adopted	Taxonomic data electronically subsampled to appropriate number of organisms for metric calculation	N/A
Benthic Macroinvertebrate Metric Calculations: Pennsylvania Piedmont	PADEP (2012)	Adopted	Taxonomic data electronically subsampled to appropriate number of organisms for metric calculation	N/A

*IRMA – Integrated Resource Management Applications Data Store (<https://irma.nps.gov/DataStore>)

Literature Cited

- Barbour, M. T. and J. Gerritsen. 1996. Subsampling of Benthic Samples: A Defense of the Fixed-Count Method. *Journal of the North American Benthological Society* 15(3):386-391.
- Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish. Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water, Washington, DC.
- Burton, J. and J. Gerritsen. 2003. A stream condition index for Virginia non-coastal streams. Page 163, Owings Mills, MD.
- Carter, J. L., V. H. Resh, M. J. Hannaford, and M. J. Myers. 2006. Macroinvertebrates as biotic indicators of environmental quality. Pages 805-833 in F. R. Hauer and G. A. Lamberti, editors. *Methods in stream ecology*. Academic Press/Elsevier, Boston, MA.
- Champely, S. 2017. pwr: Basic Functions for Power Analysis. R package version 1.2-1. Available at: <https://CRAN.R-project.org/package=pwr>. Accessed 3 Dec 2017.
- Comiskey, J. A. and K. K. Callahan. 2008. Mid-Atlantic Network vital signs monitoring plan. Natural Resource Report NPS/MIDN/NRR—2008/071. National Park Service, Fort Collins, Colorado.
- Dail, M. R., J. R. Hill, and R. D. Miller. 2013. The Virginia Coastal Plain Macroinvertebrate Index. VDEQ Technical Bulletin WQA/2013-002. Virginia Department of Environmental Quality, Richmond, VA.
- Dammeyer, N. T. and A. S. Weed. 2017. Water Quality Monitoring Protocol for the Mid-Atlantic Network. 2017/1388. National Park Service, Fort Collins, CO.
- Mid-Atlantic Network. 2017a. Mid-Atlantic Network Water Quality Monitoring Protocol SOP 1.0 - Aquatic Safety Procedures. National Park Service, Fredericksburg, VA.
- Mid-Atlantic Network. 2017b. Mid-Atlantic Network Water Quality Monitoring Protocol SOP 1.1 – Site Establishment and Documentation. National Park Service, Fredericksburg, VA.
- Mid-Atlantic Network. 2017c. Mid-Atlantic Network Water Quality Monitoring Protocol SOP 1.11 - Decontamination of Field Gear and Sampling Equipment. National Park Service, Fredericksburg, VA.
- Mid-Atlantic Network. 2018a. Mid-Atlantic Network Benthic Macroinvertebrate Monitoring, SOP 1.1 - Field Season Preparation and Close-out Activities. National Park Service, Fredericksburg, VA.

- Mid-Atlantic Network. 2018b. Mid-Atlantic Network Benthic Macroinvertebrate Monitoring, SOP 1.2 - Site Visit Procedures and Collection of Field Data. National Park Service, Fredericksburg, VA.
- Mid-Atlantic Network. 2018c. Mid-Atlantic Network Benthic Macroinvertebrate Monitoring, SOP 2.1 - Management of MIDN Benthic Macroinvertebrate Field and Lab Data. National Park Service, Fredericksburg, VA.
- PADEP. 2012. A Benthic Macroinvertebrate Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania. Pennsylvania Department of Environmental Protection, Harrisburg, PA.
- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. EPA 440-4-89-001.
- Shull, D. R., and J. Lookenbill (editors). 2018. Water Quality Monitoring Protocols for Streams and Rivers. Pennsylvania Department of Environmental Protection, Harrisburg, Pennsylvania.
- Sovell, L. A. and B. Vondracek. 1999. Evaluation of the Fixed-Count Method for Rapid Bioassessment Protocol III with Benthic Macroinvertebrate Metrics. *Journal of the North American Benthological Society* 18(3):420-426.
- VADEQ. 2008. Biological Monitoring Program Quality Assurance Project Plan for Wadeable Streams and Rivers. VADEQ Biological Monitoring Program, Richmond, VA.
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130-137.
- Vinson, M. R. and C. P. Hawkins. 1996. Effects of Sampling Area and Subsampling Procedure on Comparisons of Taxa Richness among Streams. *Journal of the North American Benthological Society* 15(3):392-399.
- Voshell, J. R., Jr., S. Smith, K. Evans, and M. Hudy. 1997. Effective and Scientifically Sound Bioassessment: opinions and Corroboration from Academe. *Human and Ecological Risk Assessment* 3:941-954.
- Wofford J. E. B., E. D. Demarest, J. R. Voshell. 2018. Shenandoah National Park benthic macroinvertebrate monitoring protocol: Version 3.0. Natural Resource Report NPS/SHEN/NRR—2018/1621. National Park Service, Fort Collins, Colorado.

Appendix A. Power Analysis

Approach

This protocol was designed to evaluate the status and long term trends in the community structure and diversity of benthic macroinvertebrates within MIDN streams. Power analyses were conducted to evaluate how well the protocol could detect specified levels of change in state based multimetric indices (MMI's) at the site level. These methods and metrics were chosen for analysis because they provide a robust indication of the health of stream ecosystems. These data can be used to elucidate the source of issues affecting stream health (e.g., nutrient enrichment, habitat degradation, thermal regime change, etc.). The MMI's were calculated using data from MIDN streams during a pilot study period (2009 – 2014; spring sampling index period [March 1st – May 31st]) to illustrate the power of the sampling design to meet the objectives of this protocol. The methods used to collect and process organisms during the pilot study period varied from the methods in the state based protocols used to develop the MMI's. During the pilot study a much smaller total area was sampled within streams compared to state based methods and no subsampling occurred during laboratory processing. These differences in methodologies might prevent direct comparisons to state based thresholds (e.g., MMI score < 60 indicates impaired status). However, these pilot data do provide valuable insight into benthic macroinvertebrate community composition in MIDN streams and an assessment of variation found within these streams using standardized methodologies. Power of the sampling design to detect changes in metric scores was assessed on a site by site basis.

Decreases in diversity and shifts in the composition of benthic macroinvertebrate communities away from intolerant taxa over time are an indication of deteriorating stream integrity. The power of our sampling design was evaluated to detect small (20%) and large (50%) decreases, over three different sampling periods (4, 8, and 12 years), of the appropriate state based multimetric index. Power calculations were based on the estimated mean and variance of each metric from sites monitored for at least three years. The estimated variance of each metric was assumed to be constant over time. The `power.t.test` function in the 'pwr' package in R (Champely 2017) was used to calculate power to detect the specified level of change at each site with the alpha level set to 0.10. Power calculations were based on a paired design to account for the non-independence in each metric estimated within the same stream over time.

Results

There was notable variation in macroinvertebrate community composition among sites and within some sites between sampling events (Table A-1). Consequently, the power to detect changes over each time period for each index demonstrated similar variation among sites (Figs. A-1–A-3). The sampling design implemented through this protocol has strong power to detect large changes across all ecoregions in the state multimetric indices (Table A-2). On average, our sampling protocol has an 80% probability of detecting a 50% decrease in the state MMI after only 4 years across all sites; average power to detect a similar amount of change increases to 96% after 8 years (Table A-1). Power to detect smaller (20%) changes is more variable among ecoregions ranging from a low over 4 years in the coastal plain (31%) to a high in the Virginia Piedmont after 12 years (82%). Please note that the above averages are summary statistics of the power to detect change at individual sites across

each ecoregion and is intended to provide a general idea of the power of this protocol, not inference across ecoregions or to unsampled areas. Power to detect small changes (20%) over the shortest time period (4 years) at individual sites ranged from a low (17%) at PETE_10 to a high at APCO_02 (99%). Power to detect large changes (50%) at individual streams was strong across all time periods and all streams ranging from 86% to 100% over 8 years (Figs. A-1- A-3).

Table A-1. Mean ($\pm$ sd) multimetric scores for each stream included in the power analyses.

Ecoregion	Site	N	Mean ($\pm$ sd)
VA Coastal Plain (VA CPMI)	PETE_03	6	31 $\pm$ 12
	PETE_10	6	34 $\pm$ 13
	RICH_02	6	8 $\pm$ 3
	RICH_04	6	66 $\pm$ 8
VA Piedmont (VA SCI)	APCO_02	6	65 $\pm$ 4
	BOWA_02	6	53 $\pm$ 19
	BOWA_04	6	61 $\pm$ 7
	FRSP_01	6	25 $\pm$ 2
	FRSP_08	6	29 $\pm$ 10
	FRSP_13	6	53 $\pm$ 6
	FRSP_17	6	47 $\pm$ 8
PA Piedmont (PA IBI)	GETT_01	6	30 $\pm$ 6
	GETT_06	6	25 $\pm$ 2
	GETT_07	5	48 $\pm$ 3
	HOFU_01	6	44 $\pm$ 14
	HOFU_02	4	51 $\pm$ 13

Table A-2. Summary of power analyses (mean probability $\pm$ sd) to detect a 20% and 50% decrease in state based multimetrics indices at individual sampling locations after 4, 8, and 12 years across all MIDN sites and grouped by ecoregion.

Ecoregion	Number of Sites	Metric	4 years		8 years		12 years	
			-20%	-50%	-20%	-50%	-20%	-50%
All Streams	16	VA CPMI, VA SCI, PA IBI	0.50 $\pm$ 0.32	0.80 $\pm$ 0.21	0.67 $\pm$ 0.32	0.96 $\pm$ 0.05	0.74 $\pm$ 0.27	0.99 $\pm$ 0.02
VA Coastal Plain	4	VA CPMI	0.31 $\pm$ 0.24	0.66 $\pm$ 0.23	0.48 $\pm$ 0.33	0.92 $\pm$ 0.07	0.56 $\pm$ 0.29	0.98 $\pm$ 0.02
VA Piedmont	7	VA SCI	0.58 $\pm$ 0.31	0.87 $\pm$ 0.20	0.77 $\pm$ 0.31	0.98 $\pm$ 0.04	0.82 $\pm$ 0.27	0.99 $\pm$ 0.01
PA Piedmont	5	PA IBI	0.53 $\pm$ 0.38	0.83 $\pm$ 0.19	0.68 $\pm$ 0.31	0.98 $\pm$ 0.03	0.75 $\pm$ 0.26	0.99 $\pm$ 0.01

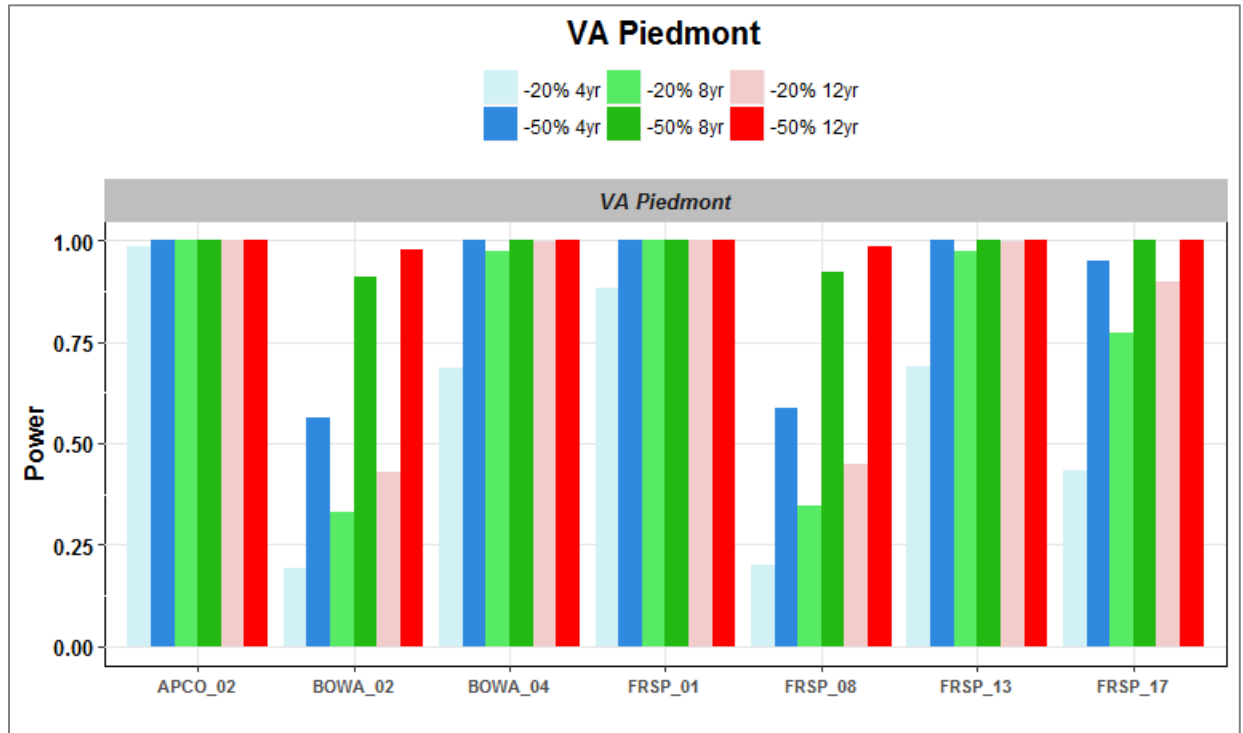


Figure A-1. Power to detect a 20% and 50% decrease in the VASCI after 4, 8, and 12 years of sampling on a site by site basis in the Virginia Piedmont ecoregion.

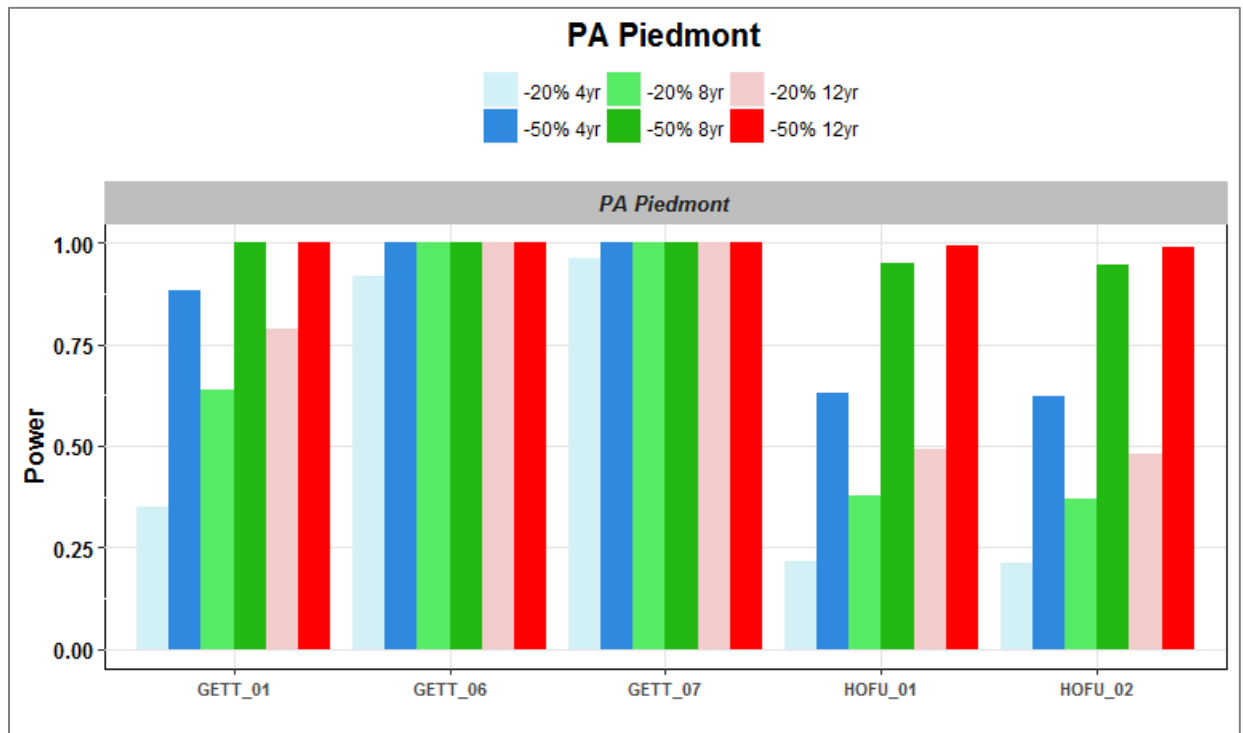


Figure A-2. Power to detect a 20% and 50% decrease in the PAIBI after 4, 8, and 12 years of sampling on a site by site basis in the Pennsylvania Piedmont ecoregion.

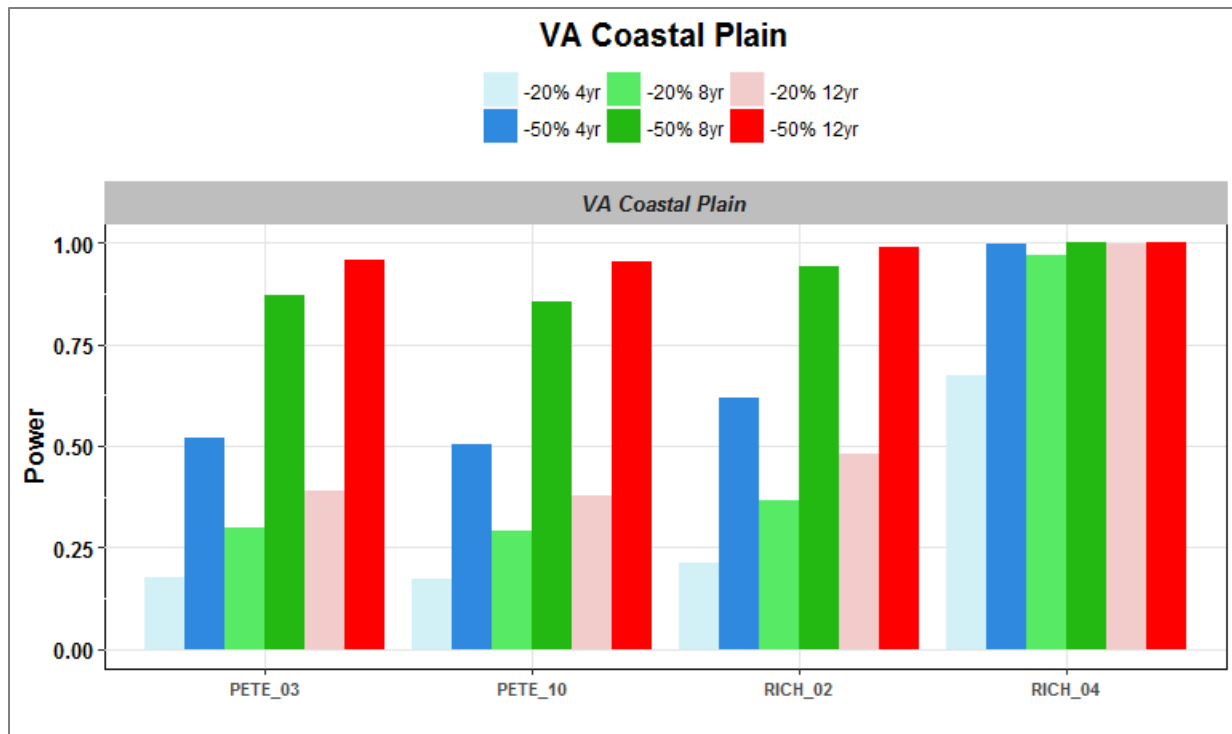


Figure A-3. Power to detect a 20% and 50% decrease in the VA CPMI after 4, 8, and 12 years of sampling on a site by site basis in the Virginia Coastal Plain ecoregion.

Conclusions

Generally, the power of our sampling protocol to detect small (20%) to large (50%) changes in the multimetric indices at individual sampling locations is strong over short (4 years) to long time periods (12 years). However, it is variable among sites due to the variation in macroinvertebrate composition among sites. Power to detect change is strongest among the least impaired and most stable benthic macroinvertebrate communities. For example APCO_02 had the highest multimetric score of all streams used in the analyses and was among the least variable across observations (Table 2). Power decreased in communities that were characterized by low diversity and abundance of macroinvertebrates. These streams included those found in the coastal plain ecoregion and/or were among those which had the lowest multimetric scores in the piedmont ecoregions. For example RICH_02 and FRSP_08 were among the stream locations with the lowest power to detect changes and are both characterized by unstable habitat which can both decrease multimetrics scores and increase the variability among observations.

It is important to note that the pilot data used for calculating metrics were based on sampled areas which were significantly smaller than the methods adopted in this protocol (e.g., 0.3 m² vs 2 m² for VA SCI, 5-10 jabs vs 20 for VA CPMI). The positive relationship between area sampled and the number of organisms, as well as taxa richness have been well established (Sovell and Vondracek 1999). The sampling methodology used during the pilot study likely decreased the observed taxa richness, relative to state based methods, and therefore depressed metric scores. In addition, sampling smaller areas can increase variability in metric scores due to the patchy distribution of organisms in

nature. Adopting the standardized state based methods will increase the total abundance of organisms collected and subsampling this larger sample can reduce issues introduced by increased variability in abundance and richness metrics observed during the pilot study. Collecting samples from a larger, more diverse area and then subsampling allows for both an efficient use of resources and stronger ability to detect long term change in community metrics (Barbour and Gerritsen 1996, Vinson and Hawkins 1996, Sovell and Vondracek 1999). Therefore we consider the power analysis conducted using the pilot data to be a conservative estimate of the ability of this protocol to detect changes in the benthic macroinvertebrate community over time.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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