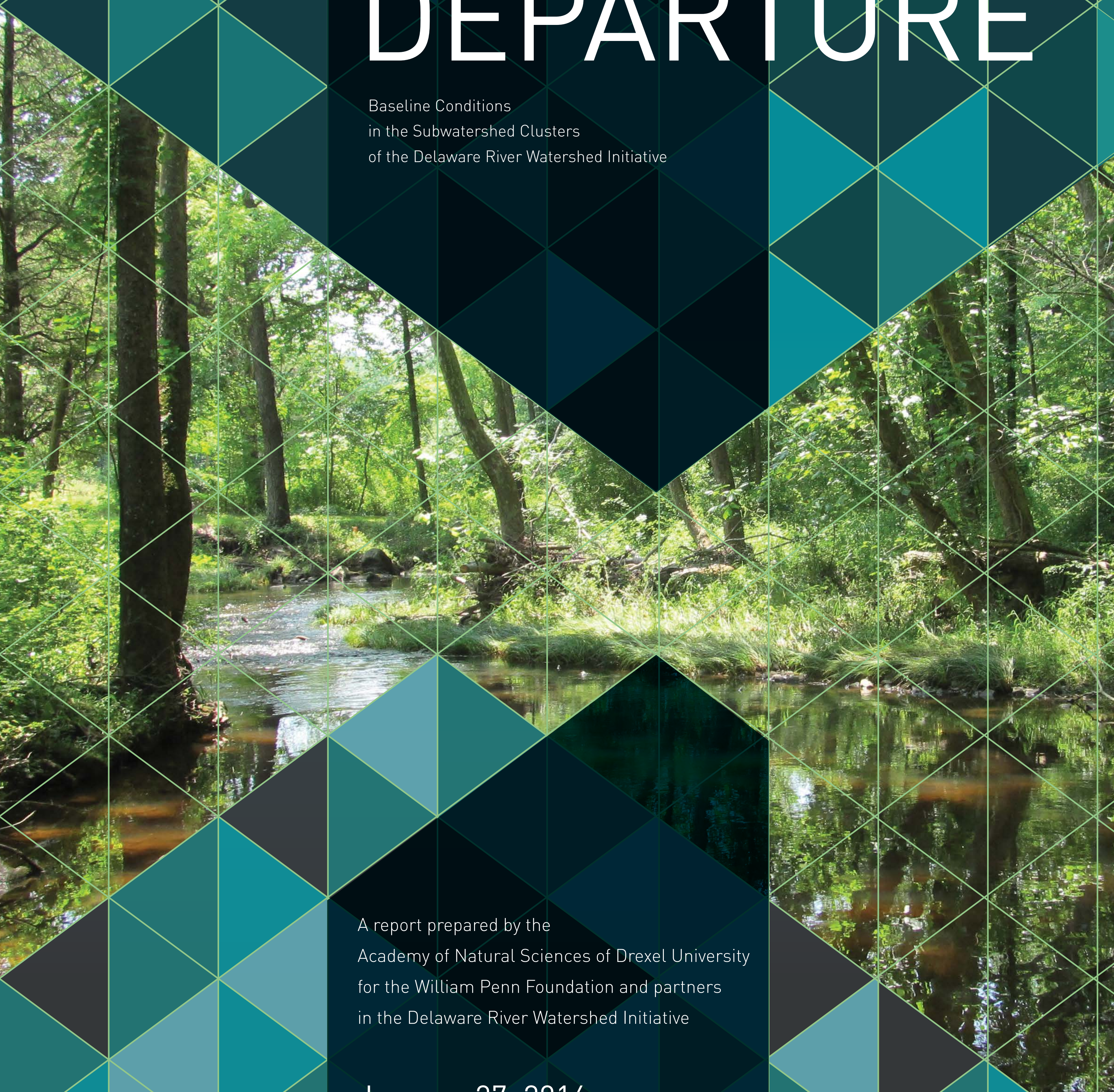
POINTS of DEPARTURE

Baseline Conditions
in the Subwatershed Clusters
of the Delaware River Watershed Initiative



A report prepared by the
Academy of Natural Sciences of Drexel University
for the William Penn Foundation and partners
in the Delaware River Watershed Initiative

January 27, 2016

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Acronyms

Delaware River Watershed Initiative Clusters

KC	Kirkwood-Cohansey Aquifer
PKC	Poconos-Kittatinny
BWC	Brandywine-Christina
MSR	Middle Schuylkill
SHC	Schuylkill Highlands
USP	Upstream Suburban Philadelphia
NJH	New Jersey Highlands
ULC	Upper Lehigh

Additional Acronyms

ANOVA	Analysis of Variance
ANS	The Academy of Natural Sciences of Drexel University
BMP	Best Management Practice
CPUE	Catch Per Unit Effort
DRBC	Delaware River Basin Commission
DRWI	Delaware River Watershed Initiative
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
LU/LC	Land Use/Land Cover
MAIS	Macroinvertebrate Aggregated Index for Streams
MMI	Multi-Metric Index
NFWF	National Fish and Wildlife Foundation
NJDEP	New Jersey Department of Environmental Protection
OSI	Open Space Institute
SWRC	Stroud Water Research Center
WPF	William Penn Foundation

Executive Summary

The Delaware River Watershed Initiative (DRWI) was designed from its inception to assess its own impact. To accurately quantify changes resulting from DRWI activities and to distinguish those from changes unrelated to the Initiative's effort, we need to know where we are starting from–the ***baseline conditions*** across the subwatershed clusters where DRWI activities are concentrated.

Two types of sites are at the core of DRWI monitoring efforts. ***Project sites*** are located at or directly downstream of DRWI projects and are intended to illuminate local-scale changes resulting from on-the-ground DRWI preservation and restoration activities. ***Integrative sites*** sit at more downstream locations and are designed to capture overall cluster conditions.

The Academy of Natural Sciences of Drexel University (ANS), in conjunction with Stroud Water Research Center (SWRC), collected baseline data from 35 integrative sites in 2013 and from 77 project sites in 2014. Additional 2014 sampling by partner organizations brings the number of project sites close to 300 and the number of sampling events to over 800.

ANS has employed a range of analyses on the baseline data, with the dual objectives of identifying a streamlined set of stream health indicators tailored to the Delaware Basin, and of characterizing pre-project conditions using metrics that allow for setting targets for future ecosystem response to project activities. When waterways are in good condition, water chemistry, habitat measures, and the living organisms within them tell a holistic story of sustained ecosystem functioning over time. The DRWI's monitoring approach examines all three types of indicators and emphasizes living organisms, which are the best barometers of a healthy ecosystem and can give additional information about stressors.

Our assessment to date shows that in-stream communities and habitat quality are closely related to a combination of watershed land use (forested, urban or agricultural) and the natural geographic distribution of species. Different taxa fill in different pieces of the puzzle, and algae, macroinvertebrates, and fish each have subsets of organisms that are closely related to specific stressors. Our analyses and the literature suggest that the indicator sets taken together are the best way to show stream changes over different temporal and spatial scales.

Our first set of results confirm that initial conditions are poorest in urban areas, yet all the sampled streams, including those assessed as having the best ecological health, show potential for improvement. The magnitude of that potential is linked to the size of the catchment draining to the site—larger streams draining larger catchments will likely be subject to impacts beyond the scope of the DRWI—as well as to current land uses in those catchments and the proximity of sites to implemented projects. Our next analyses will focus on refining our understanding of these relationships and determining the best use of baseline data to project where and how the DRWI can make the most substantial improvements in stream ecosystem quality, and the extent to which additional investment beyond the DRWI will be necessary to achieve conservation goals.

Science of the Delaware River Watershed Initiative

Data-driven research and analysis are foundational to the Delaware River Watershed Initiative

Data-driven research and analysis are foundational to the Delaware River Watershed Initiative (DRWI), whose mission is to ensure the availability of sufficient, high-quality water provided by healthy ecosystems. Without the William Penn Foundation's investment in science, it would be impossible to rigorously evaluate the DRWI's goal of maintaining and improving water quality within the Delaware Basin. The Academy of Natural Sciences of Drexel University (ANS), the lead organization for DRWI science, is collaborating with the Stroud Water Research Center (SWRC) and partner groups implementing projects on the ground to turn the Initiative's bold science vision into reality.

That vision began with a science-based framework. At the Initiative's outset, experts from ANS and SWRC as well as from partner organizations the Open Space Institute (OSI) and the National Fish and Wildlife Foundation (NFWF) used available data on ecological conditions and land use characteristics, along with social science information, to identify eight sub-watershed 'clusters' where project activities would be concentrated (Figure 1). Within these clusters, they then selected 35 *integrative sites*—so-named because they integrate upstream conditions. These integrative sites, identified to capture typical or unique characteristics of cluster waterways, are receiving intensive, long-term sampling over the course of the project and form the backbone of a more extensive monitoring effort within the clusters.

DRWI interventions are designed to maintain good water quality and healthy streams and to improve degraded systems. But what constitutes a healthy system, and how do we measure it? ANS, working with SWRC, has identified a set of indicators, summarized in this report and detailed in the *Coordinated Monitoring Plan for the Subwatershed Clusters*[1] designed to answer these questions. These indicators, and the analyses conducted on them, tell us not only about individual measures of water quality but also about ecological integrity. We examine ecological integrity, a holistic measure of health, because healthy streams and watersheds are important both for the species they support and for the wealth of ecosystem services, including clean water, that they provide to people.

1. Monitoring Plan: http://bit.ly/1lHBHWF

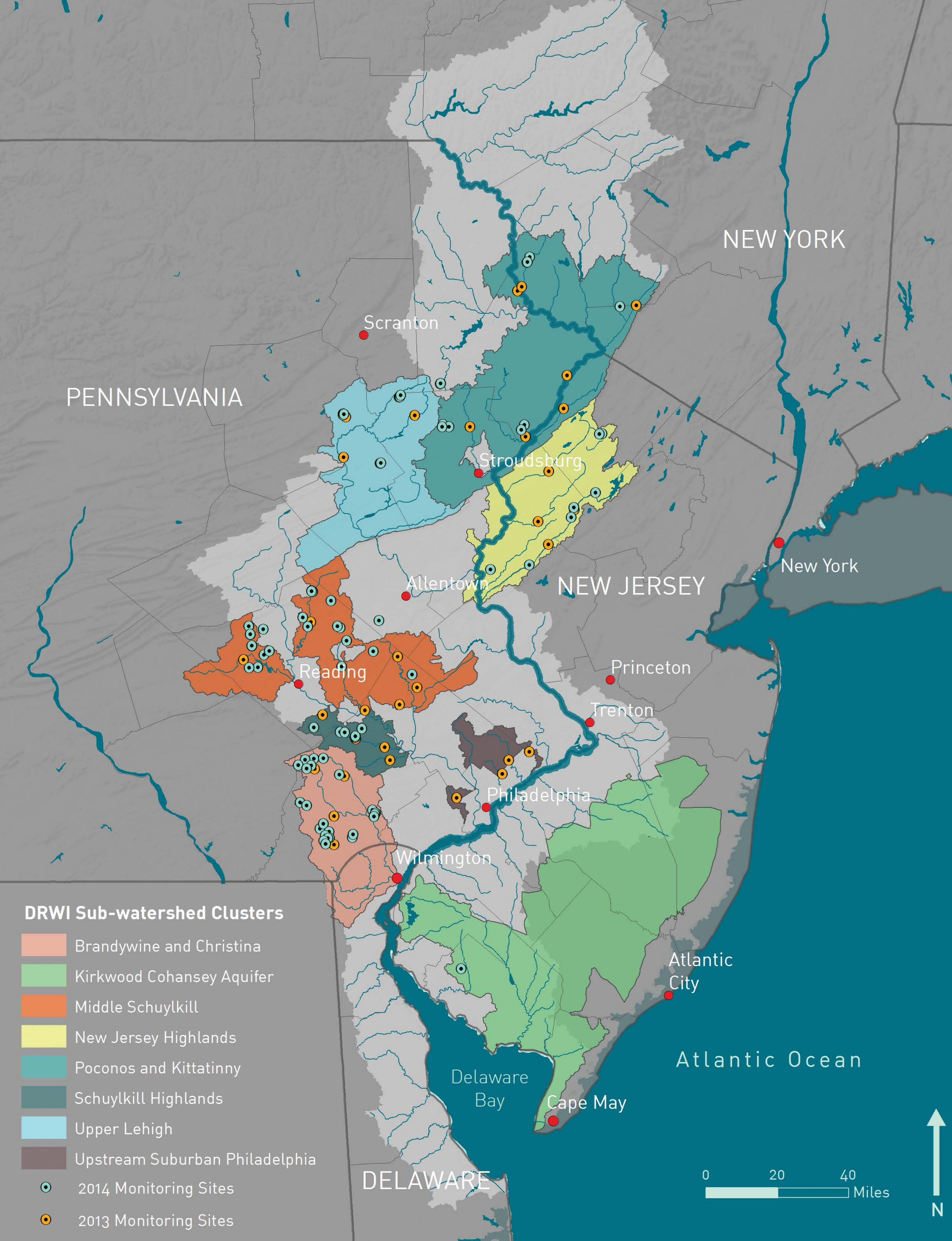
Restoration activities aimed at reducing pollutants in agricultural and urban runoff may result in near-term reductions in measured sediment, nutrients and other chemical parameters, but lasting change is evidenced in a restoration of ecosystem function. A manifestation of this function is the composition of aquatic living communities.

The monitoring strategy by DRWI partner organizations will become the most comprehensive standardized dataset on stream conditions throughout the Delaware River Watershed.

The indicators are part of a larger monitoring strategy that, through its implementation by ANS, SWRC, and DRWI partners, will result in the most comprehensive and standardized dataset describing basin-wide stream conditions in the Delaware River Watershed. The William Penn Foundation has made an unprecedented investment in monitoring long-term effects of restoration, which will provide critical empirical data for testing the theories behind restoration ecology.[2] ANS is building a first-of-its kind database for collecting, organizing, and analyzing these data, and for making them broadly available to DRWI partners and anyone else with an interest in the basin's health. The monitoring strategy has been vetted by ecologists at regional agencies and universities and is underpinned by a set of research questions, outlined in this report. Exploration of these questions will allow for refining the monitoring strategy as the DRWI evolves.

To accurately quantify changes resulting from the DRWI, and to distinguish those from changes unrelated to the Initiative's effort, we need to understand how the clusters are similar to and different from each other, both in terms of their ecology and their current condition. In sum, we need to know where we are starting from – the baseline conditions across clusters. The first phase of DRWI monitoring, then, has focused on documenting and describing those baseline conditions, and here we detail the methodology and summarize the cluster-by-cluster results. Baseline condition data from ANS, SWRC and our monitoring partners, along with data from the Pennsylvania and New Jersey Departments of Environmental Protection, among other agencies and organizations, can be used to characterize the natural variability of these systems. From the baseline conditions we then suggest what future success in individual clusters might look like, and we highlight key elements of future monitoring for measuring progress toward those goals.

2. Palmer, M. A., et al. (2005). Standards for ecologically successful river restoration. *Journal of applied ecology*, 42(2), 208-217.



ANS Research Questions

The DRWI was designed from its inception to assess its own impact. To this end, ANS scientists consulted with colleagues to develop a set of research questions that underpin the design of the monitoring program.

Through consultation with experts, ANS scientists developed a set of research questions that underpinned the design of its DRWI monitoring program. Exploration of these questions will also generate findings for improving future iterations of the monitoring program. Delaware Basin concerns drive the research, but a subset of results should have relevance for conservation efforts in neighboring basins and beyond. Answering most of these questions will require a long-term commitment to restoration and monitoring in the Delaware Basin.

The research agenda is built around two sets of overarching questions, within which more targeted questions nest. These questions represent work that is essential to designing better restoration projects. They encompass selecting the best indicators, aligning the scale of project implementation with the scale of impact, and targeting types and locations for future projects. Several 'special research topics,' being explored through pilot projects, are marked with * below.

1. What are the baseline conditions and how can we use them to set objectives for restoration project outcomes?

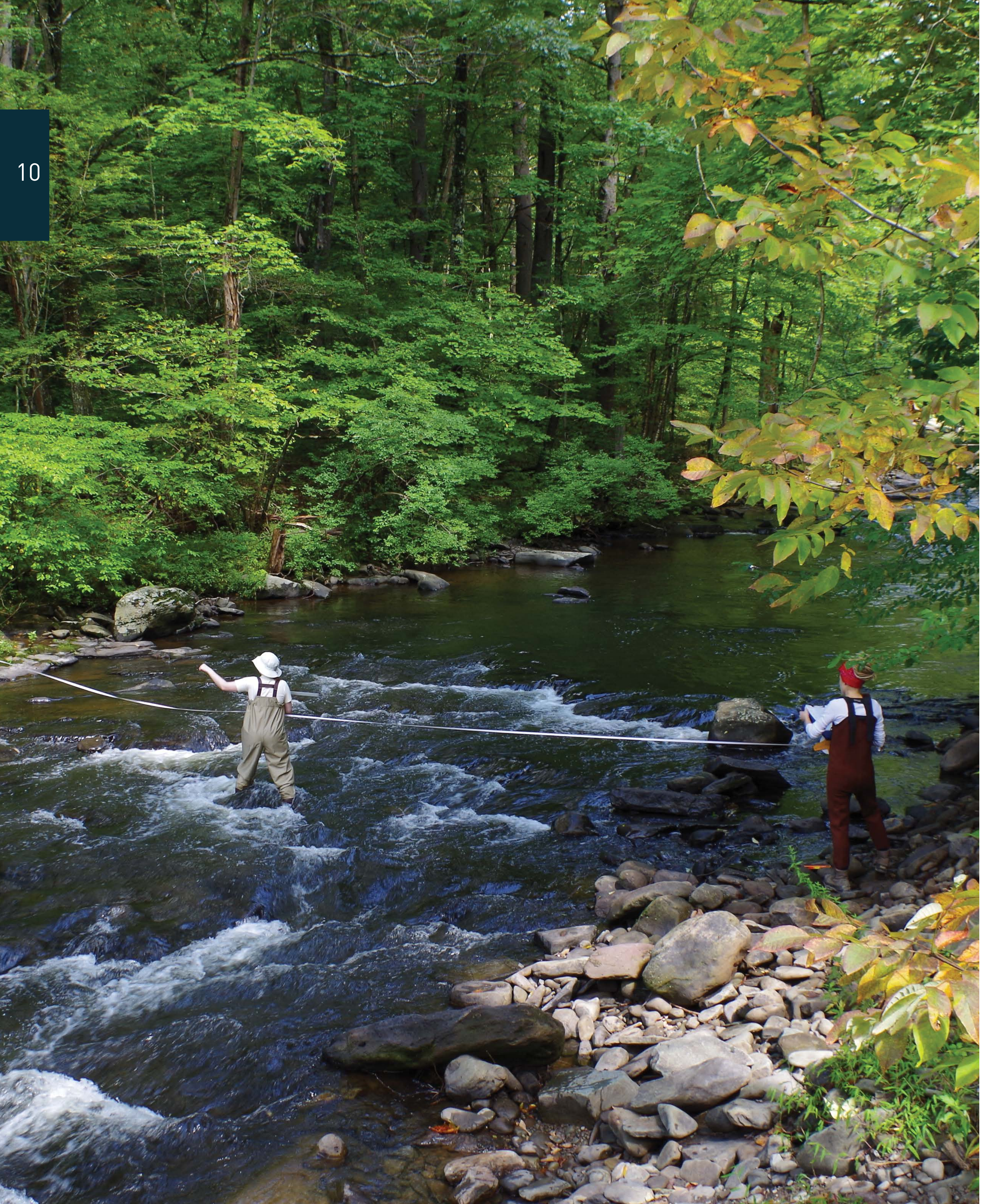
   a. What is the status of DRWI streams before project implementation?

   b. What are the main causes of stream impairment at each site and within each cluster?

   c. How does quality in wadeable streams sampled by ANS and others relate to the mainstem, sampled by the Delaware River Basin Commission (DRBC), and what analyses can be used to best demonstrate these connections across scale?

   d. How do assemblages of fish, macroinvertebrates and algae vary from year to year at integrative sites?

Figure 1. Map of DRWI clusters and sites sampled by Academy of Natural Sciences and Stroud Water Research Center in 2013 and 2014. Orange circles represent integrative sites; blue circles are sampling sites near project locations. Red circles are major cities.



2. How are in-stream ecosystems responding to on-the-ground actions? How can monitoring results inform the DRWI and similar work in the future?

   a. What scale of action produces measurable results; what is the "critical mass" of projects needed to have measurable effects at small watershed scales and across the basin as a whole?

   b. How soon do streams respond to reductions in sediment, nutrients and other preventable agricultural inputs, and what is the lag time for response of in-stream organisms?

   c. How much improvement do we expect to observe over time, given each project's characteristics, including the combination of actions taken, location of actions relative to stream, watershed size, stream size, and current quality of nearby streams?

   d. Where are land preservation activities best targeted to affect water quality?

   e. How can monitoring data be used to target restoration where it will have the most impact?

   f. How do forested, small ("adventive")[3] streams affect the quality of larger streams?*

3. Which indicators best respond to current stressors and conditions as well as to potential changes in water quality (and ecosystem quality) over time?

Sampling follows the same protocols at all sites, producing comparable and complementary data that over time can give a comprehensive picture of ecosystems within the basin at different spatial scales.

   a. What taxa from fish, macroinvertebrate, and algae communities give the most information about the basin as a whole as well as individual clusters?

   b. How can these groups be used to refine Indices of Biotic Integrity (IBIs), a metric of ecological integrity, and ultimately sampling approaches for the next phases of the DRWI?

   c. Can we observe any changes in nutrients, turbidity and sediment inputs, or other indicators in the short-term?

   d. What indicators are more important in preservation areas for showing maintenance of good condition, and do these differ from indicators showing changes in restoration areas?

   e. What "novel" indicators are more effective for assessing ecosystem health than traditional measures (e.g. fish biomass as opposed to diversity, macroinvertebrates in slow-moving waters in addition to fast-flowing riffles)?*

   f. What indicators can show urban impairment better than IBIs, which differentiate impaired and non-impaired streams but don't provide more detailed information for streams within those categories?

   g. How can salamanders be better used as indicators of stream health?*

   h. What are the most important habitat measures for monitoring the effects of restoration?

3. An adventive stream is defined, for the purposes of the DRWI, as a first or second-order stream flowing into a stream at least two orders larger.

Monitoring Overview

The DRWI monitoring program collects various types of data. This approach allows researchers to understand how the ecosystems may be changing progressively over time due to natural variability or in response to on-the-ground actions.

In 2013, 2014 and 2015, ANS and SWRC field teams collected baseline data on current stream conditions at two sets of sites. As described above, integrative sites capture larger areas of the cluster drainage and were sampled to characterize the overall condition of subwatershed clusters. Baseline sampling also occurred at *project sites*—those in close proximity to on-the-ground projects, where streams are smaller and we would expect improvement of degraded waters or maintenance of good conditions as a result of DRWI activities. Sampling follows the same protocols at both sets of sites, producing comparable and complementary data that over time can give a comprehensive picture of ecosystems within the basin at different spatial scales. At additional sites, ANS and SWRC addressed the three special research topics.

Baseline data were collected from 35 sites in 2013, 77 sites in 2014 and 80 sites in 2015 (Table 1, Figure 1). Additional sampling by partner organizations brings the number of sites close to 300 and the number of sampling events (visits to a site to collect samples) to over 800. Sampling will continue at these sites at appropriate intervals in the future.

Type of Site	# of Sites	Year	Habitat	Water Chemistry	Salamanders	Fish	Macro-invertebrates	Lentic Macro-invertebrates	Algae
Project	77	2014	Summer	Spring, Summer	At a subset of sites	Summer-Fall	Spring	At a subset of sites	Summer
Integrative	35	2013, 2015	Summer	(quarterly every year)	At a subset of sites	Summer-Fall	Spring	No	Summer
Special Research Topic	45	2014, 2015	Summer	Spring, Summer	At a subset of sites, 3 seasons	At a subset of sites, Summer-Fall	Spring	No	Summer

Table 1. Summary of Phase I ANS and SWRC sampling

Sampling by all groups follows an ANS-developed *Quality Assurance Project Plan*[4] to ensure standardization. As ANS incorporates the data sets into its basin-wide database, it assigns each set to one of three 'tiers' based on the scientific rigor of its collection. This new categorization allows for all data to be made accessible while simultaneously providing guidance as to their appropriate use. The database is unique in its scope—multiple data types from across the entire Delaware River Basin and in its consistent collection methods, resulting in the most comprehensive picture of ecosystem function currently being collected.

The DRWI monitoring program collects three main types of data in the field. First, **biotic sampling** of fish, macroinvertebrates, algae, and salamanders produces data on the number, type, and density of aquatic organisms; these data, in turn, can be analyzed together to provide a picture of ecological integrity, which is the end goal of DRWI conservation projects. This approach allows researchers to understand how the ecosystems may be changing progressively over time due to natural variability or in response to on-the-ground actions. Monitoring multiple indicators also allows researchers to better tease apart DRWI impacts from those of land use changes outside the Initiative's scope.

Second, **chemistry measurements** are taken from water samples collected twice annually from project and special research topic sites and on a quarterly basis from integrative sites. The more frequent monitoring at integrative sites seeks to characterize seasonal fluctuations of naturally occurring compounds as well as pollutants, whereas at project sites water samples are collected to help understand factors influencing the composition of the biological community. Taking water samples allows us to draw relationships between the biota and the geology, dissolved solids, and nutrient inputs from natural and anthropogenic sources.

Third, **instream habitat measurements** are taken concurrently with algae samples, in the same stream reaches where fish and macroinvertebrates are sampled during separate visits. Physical habitat (stream bed and bank conditions) and water chemistry interact to provide the conditions for fish, macroinvertebrates, algae and salamanders to thrive. By including habitat, we can begin to tease out whether water chemistry, habitat degradation, or other stressors are affecting aquatic communities, and that information in turn will allow us to focus in on identifying specific sources of that stress.

A last type of data, collected remotely and analyzed with Geographic Information Systems (GIS) software, describe **landscape-scale variables** such as geology, topography, land use and land cover (LU/LC), water intakes, point sources of pollution, and other information. These landscape variables are summarized at the local scale near integrative and project sites, as well as in sites' upstream catchments. These data help us understand land-based stressors on streams as well as where land preservation or restoration activities might be prioritized. Tracking LU/LC data over time will assist in distinguishing between ecological integrity changes resulting from DRWI activities and those occurring due to LU/LC characteristics well beyond Initiative project sites.

The biotic, water chemistry, habitat, and landscape-scale data are used in *indicators*, or *metrics*, of ecological integrity and water quality. Different indicators give information on different degrees and types of responses to the various stressors in the watershed. By collecting comprehensive data sets across the four data types, we can begin to narrow down which metrics best correspond to current conditions and are sensitive enough to track small changes over time resulting from project activities; we can model the most statistically likely projected changes; and we can find a subset of metrics that work best throughout the Delaware River Basin. Taken together, these steps will allow us to continue to monitor for changes with an increasingly streamlined and cost-effective approach.

4. QAPP: http://bit.ly/1OigSrk

Analyses

The analyses that ANS has conducted on the 2013-2014 data (Table 2) are intended to achieve multiple linked objectives. The samples collected in 2015 are being processed and will be included in future analyses. The objectives, with their relevant analyses, are:

- To determine the **general ecological integrity/health for areas of interest**
  - » Analyses: *Indices of Biological Integrity (IBIs)*. These metrics describe the structure and function of aquatic ecosystems and are calculated at a relatively coarse scale. This overall quality rating can then be used to probe more deeply into exactly which organisms are contributing to the IBI score and how they are related to ecosystem structure, function and changes over time. IBIs are often applied to determine watershed impairment according to the Clean Water Act.
  - » Input data: Lists of the types and numbers of fish, macroinvertebrates or algae; variables related to each organism's taxonomy or ecological functions.

- To determine **which specific metrics are most related to ecological conditions and most sensitive to dominant stressors**
  - » Analyses: *Ordination, regression* and *analysis of variance*. By understanding which organisms are important to our regional ecosystems, we can flag certain metrics and taxa—individual species or species groups—as especially good indicators and suggest monitoring and analysis that focuses on them. Because we are working in an area with multiple stressors, we expect different taxa to be related to different stressors, while some will indicate overall ecosystem degradation. Data from multiple taxonomic groups allow for a combined analysis that is powerful in detecting differences among clusters.
  - » Input data: Site-level lists of fish, macroinvertebrates, and/or algae; environmental variables.

- To determine **which metrics are most suitable indicators relative to stressors and project implementation** according to their prevalence (density) and sensitivity
  - » Analyses: *Indicator species analysis* and *species distribution models*. Once we have defined the best indicators, we will track their changes over time to see if and how communities shift from current, baseline conditions to better functioning, more intact natural communities. Using multiple indicator groups for this analysis is a novel approach.
  - » Input data: Site- and cluster-level lists of organisms in one or more indicator groups.

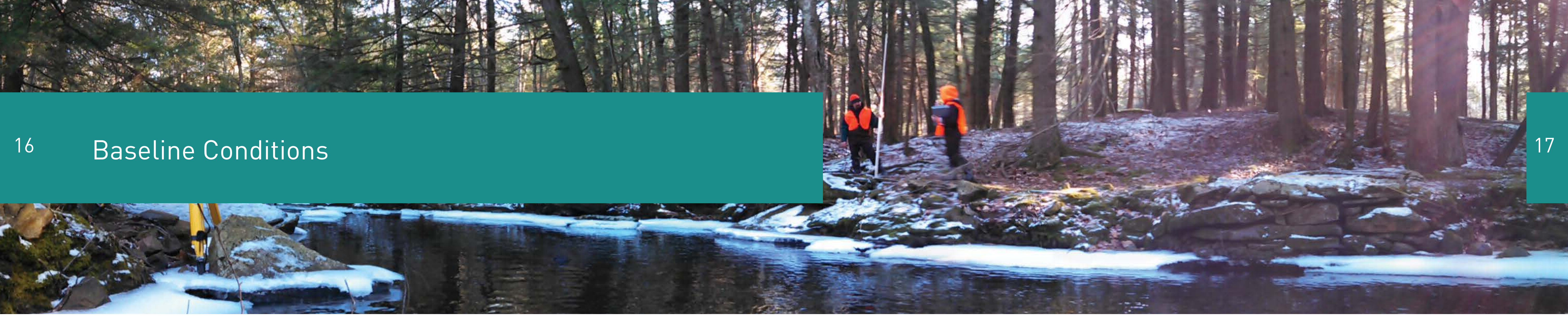
The goals of these analyses are to discover which stream health indicators best characterize our watershed, to determine pre-project conditions, and to set targets for ecosystem response to conservation actions.

Analysis	Description & inputs	Objective	Useful for	Not useful for
Index of Biological Integrity (IBI)	Uses information on organisms to describe ecosystem structure and function by assigning a score to organisms that add up to a score for a site. Calculating an IBI is a qualitative analysis but the results can be used in statistical analyses	Gives a general idea of quality to communicate to stakeholders	Determining whether a site is impaired vs. non-impaired, communicating overall quality	Fine-scale understanding of stressors affecting stream health, understanding specific organisms
Gradient analysis (ordination)	Statistical technique that analyzes how similar sites are according to input variables and uses a graph to represent their similarity in two dimensions (like a map). Statistical technique that explores relationships between data sets (e.g. organisms and environmental data)	To understand relationships of sites to each other and in relation to organisms and environmental variables and known stressors	Relating environmental and biological data, relating organisms to stressors, finding which variables classify sites best (reducing variables), developing hypotheses	Producing a quality rating or testing hypotheses
Indicator species analysis	Statistical technique that uses lists of organisms to define groups based on categories of sites (e.g. by cluster or by cluster type—restoration or preservation). Can be connected to environmental variables.	To find which organisms are related to certain pre-defined categories (streams/ ecosystems/ regions, etc.)	Identifying important organisms for understanding similarities and differences among groups of sites	Relating directly to water quality or environmental conditions; sometimes discrete sets of organisms are not produced.
Species distribution analysis	Statistical technique that uses locations of organisms and environmental variables to determine ranges and spatial patterns.	To look for potential targets for ecosystem improvement or areas where biota could move into from nearby sources	Classifying the biota for different regions for finding reference conditions and ranges	Producing a quality rating or testing hypotheses
Analysis of variance (ANOVA), regression	Statistical techniques to determine whether explanatory variables show patterns in environmental or biological (response) data. Requires informed decisions on input variables and groups before analysis.	To test hypotheses on categories or ranges of environmental variables (explanatory) in relation to other environmental variables or organisms (response)	Testing hypotheses on relationships between variables	Reducing input variables, exploring relationships of large data sets

Table 2. Analyses completed or in process using 2013-2014 monitoring data

An important additional objective is to identify **regional reference conditions in streams with natural, stable, healthy communities,** as a precursor to modelling the potential impacts of projects and how they might be reflected in changes in the aquatic community. Although we may not expect each degraded stream to return to a reference condition state, we can use information from reference streams to set goals for what ecosystem improvement might look like. Literature reviews and projections of potential changes in stream ecosystem communities are key inputs to identifying those goals. Still to be conducted on the 2013–2014 data are species distribution analyses, which will tell us where organisms may be expected to recolonize restored areas and how communities might change at the species level over time.

The use of qualitative approaches, like the identification of reference conditions and the generation of IBIs, coupled with statistical analyses like ordination and indicator species analysis, allows for a comprehensive approach that capitalizes on the strengths of each and makes full use of the range of available data.



Baseline Conditions

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Our assessment to date shows that in-stream communities and habitat quality are closely related to a combination of watershed land use (forested, urban or agricultural) and the natural geographic distribution of species. These findings are supported by the results of the IBI calculations (described in detail below and in Appendix 1), gradient analysis, analysis of variance (ANOVA), and regression. Through gradient analysis we see that fish assemblages are defined by stressors as well as geographic ranges; and macroinvertebrates and algae appear to be related to agricultural and urban land uses, but they respond differently to the effects of those stresses (see Appendix 2 for more detail). The results of ANOVA show a division between restoration and protection areas for baseline algae metrics and some habitat conditions, while regression shows macroinvertebrate IBI scores are closely related to % forest, agricultural and urban land uses in the watershed.

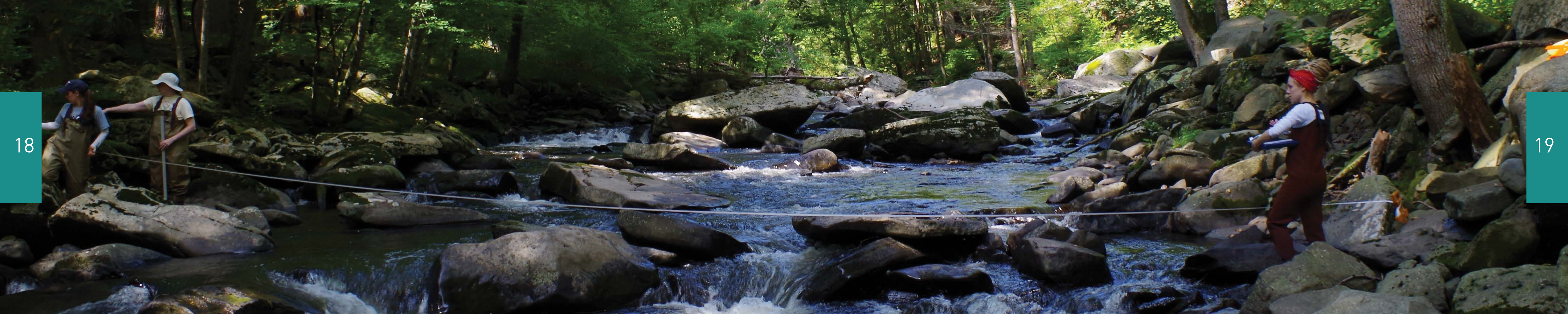
Our IBI findings demonstrate that different taxa fill in different pieces of the puzzle (Figures 2-4), and algae, macroinvertebrates, and fish each have subsets of organisms that are closely related to specific stressors. Our analyses suggest that the indicator sets taken together (Figure 5) are the best way to show stream changes over different temporal and spatial scales.

Our analyses suggest that the indicator sets taken together are the best way to show stream changes over different temporal and spatial scales.

The indicator species analysis tells us whether clusters contain distinct communities from one another, or whether they contain only ubiquitous "usual suspects." The macroinvertebrate indicator species analysis showed unique taxa for most clusters, which will be useful to future analyses of change over time. The fish indicator species analysis was less informative, and we found that grouping sites by project type (restoration or protection) was more powerful than grouping sites by cluster. The algae indicator species analysis is more complex statistically and is still in process.

Our first phase of results confirm that initial conditions are poorest in urban areas, yet most of the sampled streams show potential for improvement. In preservation cluster sites with lower scores, local-scale urban and agricultural land uses may override the effects of landscape-scale forested land cover, or the streams may drain small watersheds with converted land cover. However, low scores can in some cases be associated with intact ecosystems, which is why IBI scores must be interpreted with care.

The finding that most streams show potential for improvement, interesting in itself, may signal strong potential for stream health improvements as a result of DRWI project interventions. In many cases, existing BMPs and past restoration actions may have already led to some degree of improvement, but additional actions will be necessary to take that improvement to the next level and to larger scales. The potential for improvement will be linked to the size of the catchment draining to the site —larger streams draining larger catchments will likely require a greater investment upstream. New information on the most strategic areas for that investment can be included in targeting future DRWI work. Our next analyses, to be presented in subsequent reports in this series, will focus on refining our understanding of the relationships of stream health to various stressors and on continuing to determine the best use of baseline data to project, using statistical and spatial models, where and how the DRWI can make the most substantial improvements in stream ecosystem quality.



INDICES OF BIOLOGICAL INTEGRITY (IBIs)

An IBI is designed to give information about the biological condition of a water resource, based on a subset of taxa in the aquatic community. Tailored for use in a specific region, an IBI incorporates information on different organisms' tolerances of water chemistry parameters (e.g. overall pollution, organic pollution, pH, salinity) and habitat preferences (e.g. fast-flowing or slow-flowing waters, in the sediment or in the current), and information on the whole community, including measures of diversity. Each organism has a score for the metrics that make up the IBI, and the whole sample of organisms at a site produces an IBI score that gives an indication of stream health.

An IBI is designed to give information about the biological condition of a water resource, based on a subset of taxa in the aquatic community.

The components (metrics) of an IBI are sometimes as informative as the overall IBI score. Fish can reveal small-scale conditions of in-stream habitat, reach- and watershed-scale riparian forest condition, and overall watershed conditions (disturbances from land use and human activities), including pollution and temperature. The response of fish communities to different scales varies from one basin to the next, which is one reason that IBIs are developed regionally. Macroinvertebrates can also indicate large-scale and small-scale disturbance of land use, habitat and hydrology, including pollution. Algae go through ecological succession (after disturbance) more quickly than fish and macroinvertebrates, so they can be used to detect disturbance on very small time scales as well as small and large spatial scales. Diatoms have narrowly defined thresholds to concentrations of specific pollutants and can also indicate general watershed degradation.

These indicator groups have varying degrees of response to the same stressors, with responses sometimes differing from one region to another. For this reason, they can indicate different quality ratings when examined separately (see Appendix 1 for separate taxonomic IBI results). We are working to select metrics specific to the Delaware River Basin that considers multiple organism groups and gives a more refined and comprehensive picture of water quality in response to regional stressors.

IBIs are tailored to specific regions, incorporating information on different organisms' pollution tolerances, their habitat preferences, and information on the whole community, including measures of diversity.

Figures 2-4 show the average IBI ratings (color) and diversity (circle size) in each cluster, for fish, macroinvertebrates, and algae, respectively. The IBI averages represent the overall health of clusters, although sites range from poor to good in nearly all clusters (see Appendix 1 bar graphs). However, each cluster shows a range of conditions, and the full range must be used to set site-by-site targets for improvement. Diversity – a measure of abundance and/or number of species – is often but not always an indicator of ecosystem integrity. High diversity can indicate a healthy, functioning ecosystem, but low diversity can indicate low disturbance and a stable community as well. For example, ecosystem integrity might be good in streams draining forested catchments, but the stream communities may have low diversity and be dominated by trout. Both IBI and diversity scores give important information that should be complemented with other data, including the presence and absence of particular species, to give a more complete picture of ecosystem health. More detailed information on the IBIs and the nuances of their interpretation is provided in Appendix 1.

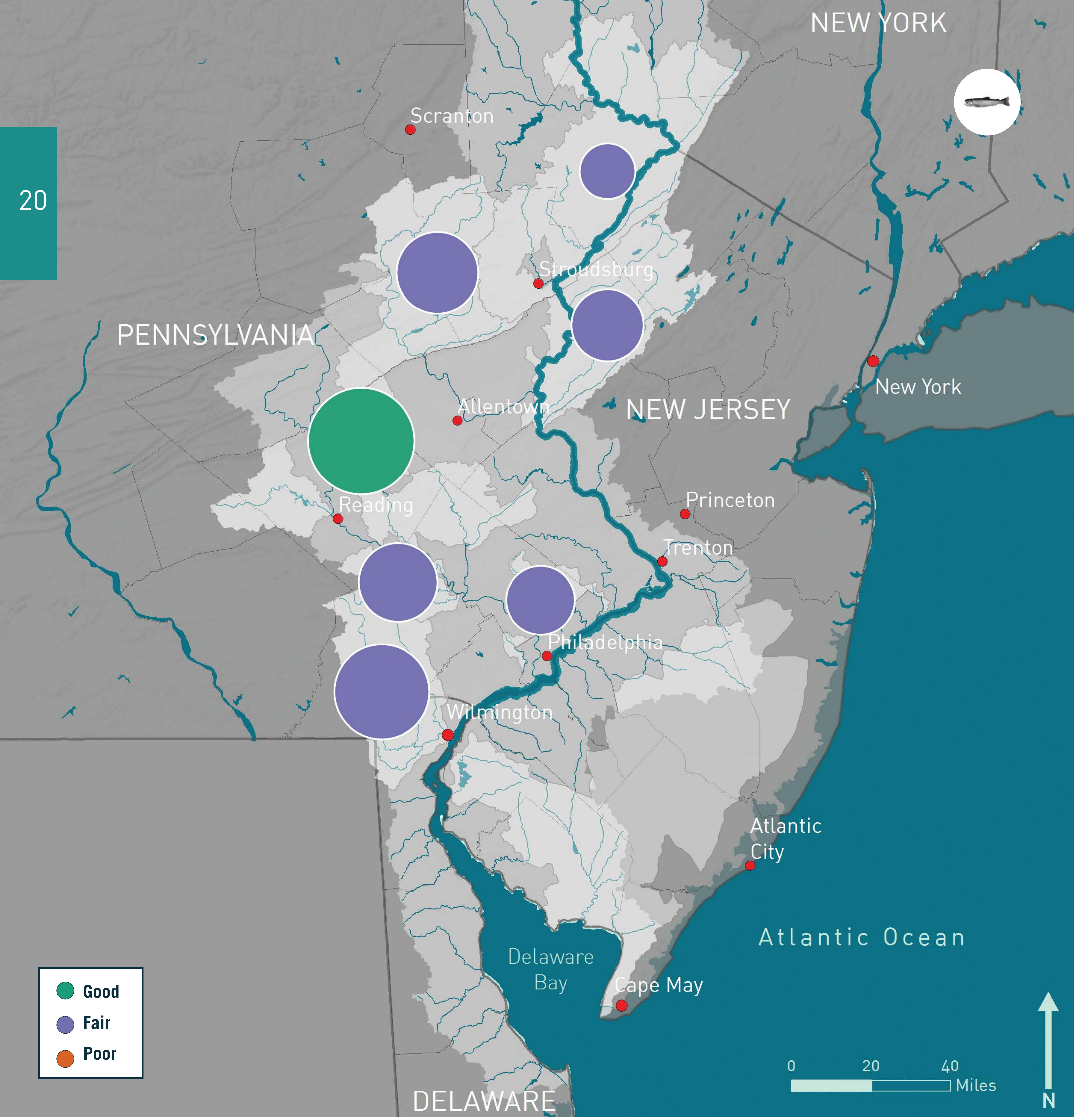


Figure 2. Fish IBI score and diversity, by cluster. Dot size represents the number of fish species. Color representation is based on Daniels IBI score: green = good, purple = fair, orange = poor. See Appendix 1 for details on Daniels IBI.

For fish, low diversity and a low IBI score do not always signify poor ecosystem quality. As shown in Figure 2, most clusters are "fair" and the Middle Schuylkill is "good." However, the trout-dominated streams in the northern clusters are not fully represented by a traditional IBI approach, and the higher average score in the Middle Schuylkill may be due to high diversity of habitat and watershed conditions. Several other metrics show low values in the Middle Schuylkill, and those will be the targets for measuring restoration impacts, especially reductions in sediment and nutrient inputs. These findings suggest that the fish IBI may need to be better calibrated for use in streams of different sizes, and adaptations should be made for dominant taxa that signal important aspects of watershed health (e.g. eels show good connectivity but are less informative about water quality).

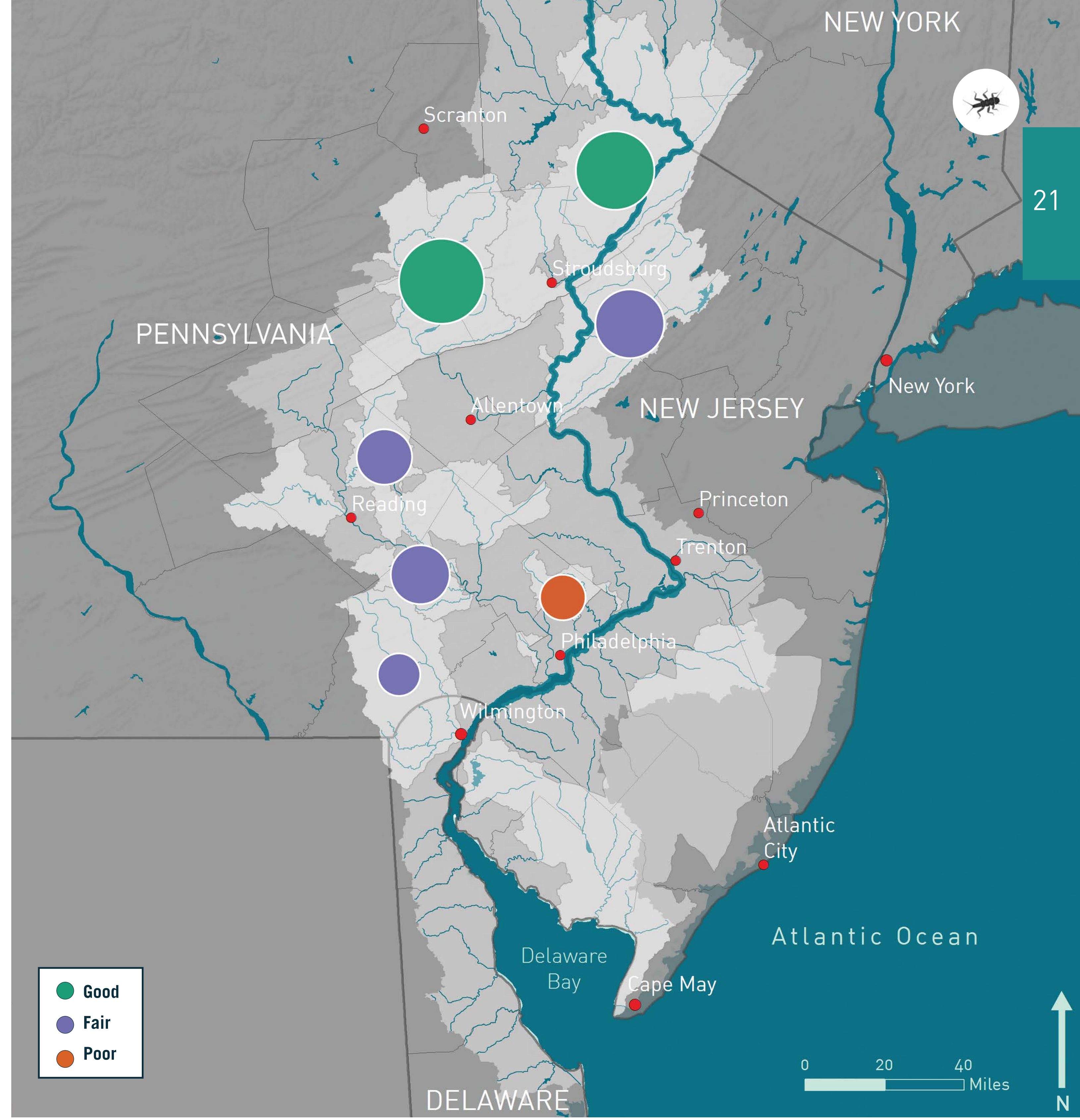


Figure 3. Macroinvertebrate IBI score and diversity, by cluster. Dot size represents species diversity, derived from Simpson's diversity index [5]. Color representation is based on MAIS IBI score: green = good, purple = fair, orange = poor. See Appendix 1 for details on MAIS IBI.

For macroinvertebrates, we see "good" IBI scores and high diversity in the Poconos-Kittatinny and Upper Lehigh clusters, with room for improvement in all remaining clusters with "fair" or "poor" quality and low diversity. Higher diversity indicates a better functioning ecosystem for macroinvertebrates.

5. Simpson, E. H. (1949). Measurement of diversity. Nature. Simpson, E. H. (1949). Measurement of diversity. Nature.

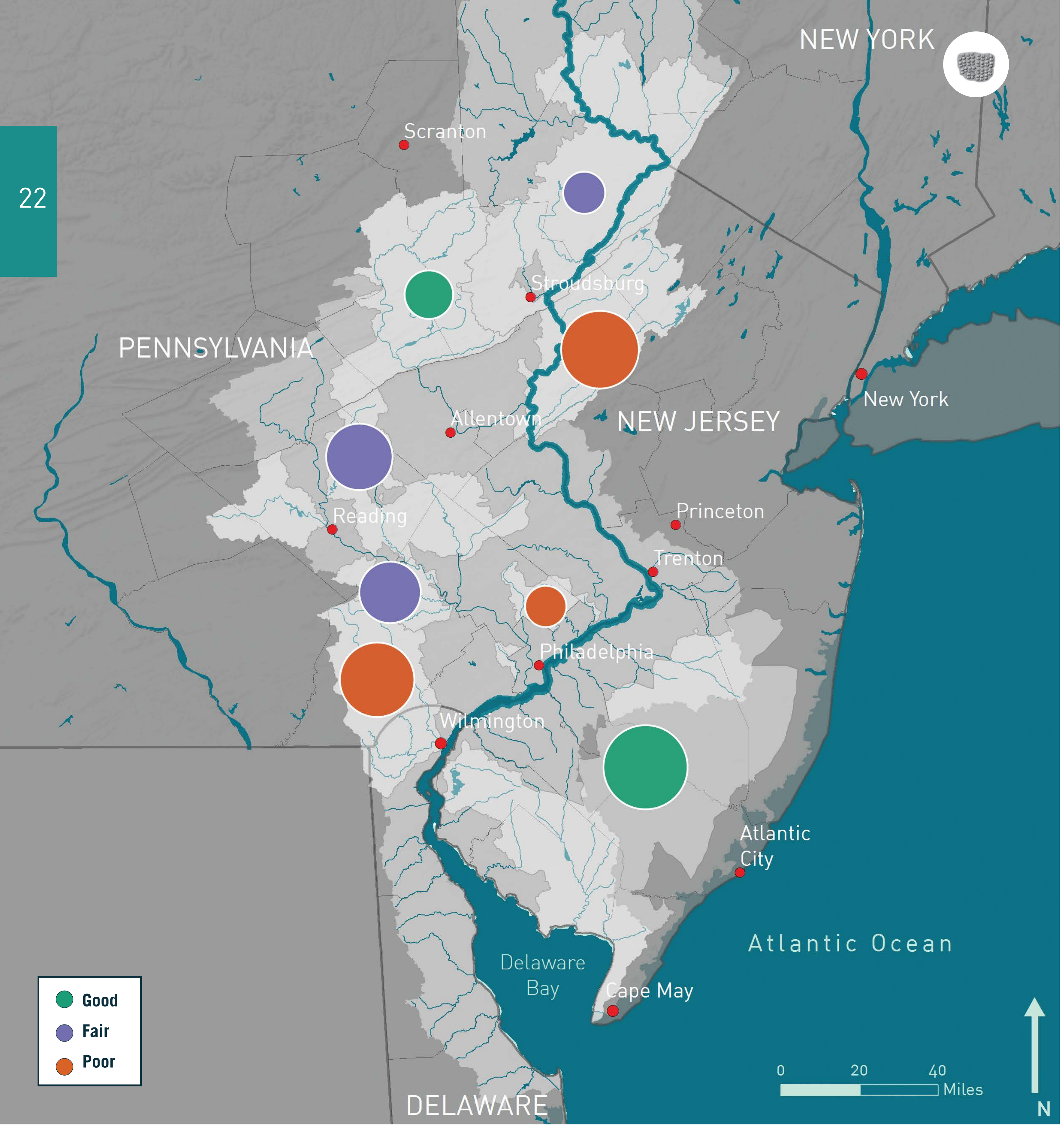


Figure 4. Biotic quality and diversity defined by the algal community, by cluster. Dot size represents number of species observed in the cluster. Color representation is based on MMI: green = good, purple = fair, orange = poor. See Appendix 2 for details on MMI.

Algae scores are closely tied to nutrient concentrations from agricultural and urban inputs. Despite high forest cover in the Poconos-Kittatinny, algae metrics show "fair" quality, perhaps due to point sources. "Poor" average quality in the NJ Highlands, Middle Schuylkill and Philadelphia reflect high nutrient concentrations, and in Philadelphia we see low diversity as well. The Kirkwood-Cohansey shows good quality, although only one site was sampled in 2014.

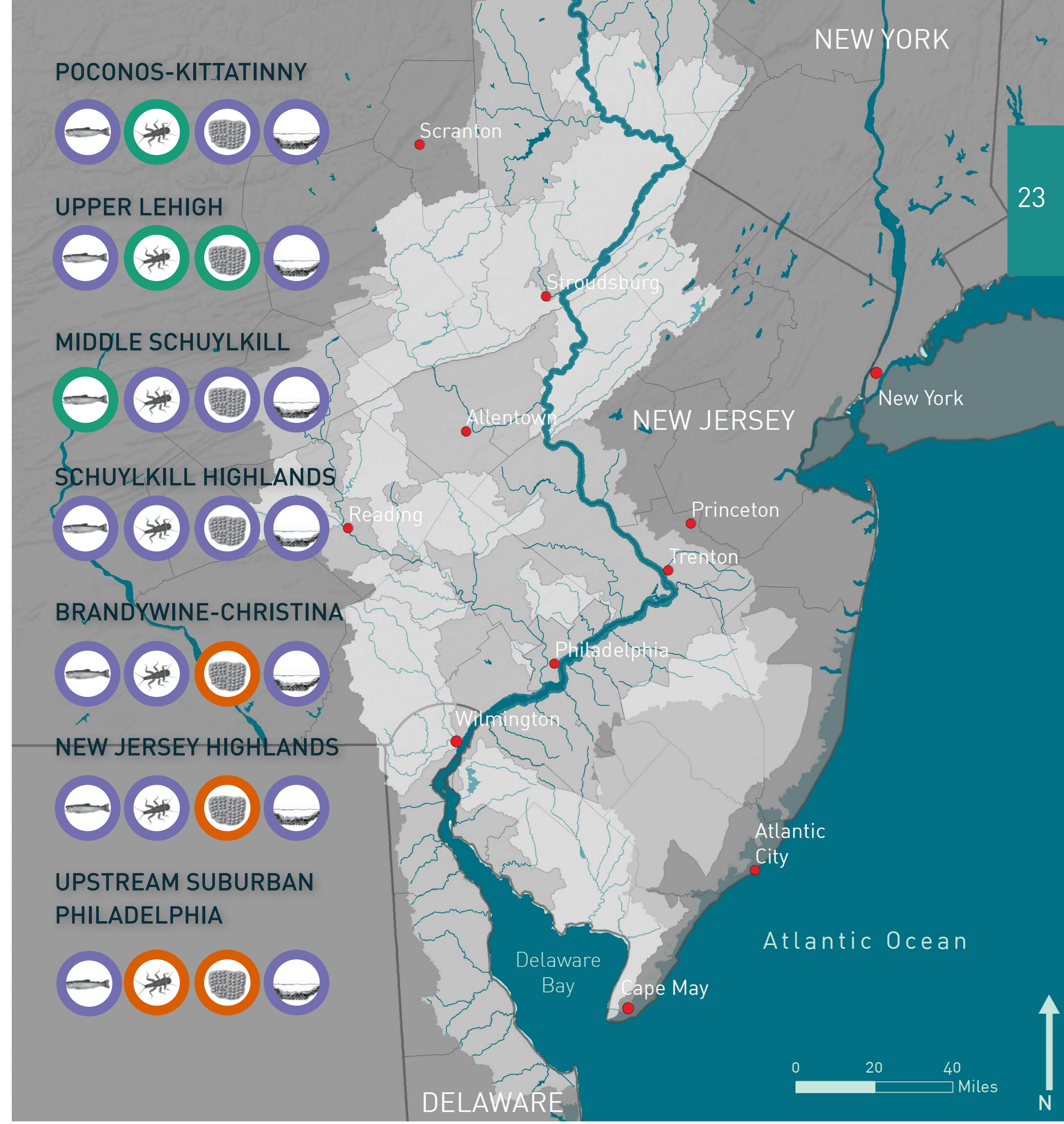


Figure 5. Habitat ratings and all biological community ratings, by cluster. Color representation: green = good, purple = fair, orange = poor.

Taken together, we see that the average IBI scores for clusters can vary based on the indicator group. One taxonomic group's score may trump the others because of its importance within the context of a particular cluster. Differences in IBI scores that may appear conflicting will inform the design of studies on stressors within each cluster and upstream of each site, to better understand how stream types and quality ratings may be affected by local conditions, including geology, stream type, and other variables. Contradictory scores make it difficult to assign a single quality rating, but this information is essential for determining which stressors are having the greatest effects on ecosystem integrity at each site.

THE FISH & MACROINVERTEBRATES THAT TELL THE STORY

Water quality and ecosystem integrity can be vague terms, but each relates to the species found in a given stream. We present those fish and macroinvertebrates that are important to each cluster using the results of qualitative analysis, ordinations and indicator species analysis. Each organism group provides information that practitioners and citizen groups can connect to their work. Fish are the most popular of our indicator groups, and fishermen and non-fishermen alike can relate to healthy fish communities in their rivers. Macroinvertebrates are becoming increasingly well-known to the general public, and their presence and diversity are often surprising to people. They can also be connected to the fish community as their main food source. And while the public tends to view algae in a negative light due to algal blooms and problems, the beauty of diatoms and their use as indicators of stream health are also becoming more well-known and of interest, as many people remember encountering them in their school studies.

Here we provide representative fish and salamander community descriptions for each cluster, and macroinvertebrate descriptions for groups of clusters. Species are listed roughly from highest to lowest abundance.

Poconos-Kittatinny Conservation (PKC) Cluster

The fish community in the Poconos-Kittatiny is comprised of cold-water fishes and is dominated by trout. The presence of Sea Lamprey and American Eel, which are both predators and migratory, signify the absence of structures (dams) inhibiting their migration.

Table 3. PKC fish and salamander community description

Brown Trout	Prefer cold water and serve as good indicators of thermal stress
Slimy Sculpin	Prefer, cool, good quality water with low silt substrate, and have small home ranges; particularly useful as bioindicators
Margined Madtom	Associated with good to fair water quality
Longnose Dace	Found in fast-flowing, cold, rocky rivers, common
Sea Lamprey and American Eel	Native diadromous fishes (migrate between saltwater and freshwater) and their presence indicates that their life-cycle migrations are not impaired by dams downstream
Redfin Pickerel	Prefer low gradient habitats, slow flows, with vegetation
Northern Two-lined Salamander	Somewhat tolerant compared to other amphibians, found in rocky streams with cold, relatively clean water

Upper Lehigh Conservation (ULC) Cluster

The fish assemblage in the Upper Lehigh ressembles that of the Poconos-Kittatinny, except that American Eel are very rare or absent due to dams of various sizes being present in the drainage. Some warm-water taxa are present due to the high number of ponds and wetlands throughout this cluster, which add to habitat diversity and, therefore, species diversity.

Table 4. ULC fish and salamander community description

Slimy Sculpin	Prefer, cool, good quality water with low silt substrate, and have small home ranges; particularly useful as bioindicators
Brown Trout	Prefer cold water and serve as good indicators of thermal stress
Sea Lamprey	Native diadromous fishes (migrate between saltwater and freshwater)
Margined Madtom	Associated with good to fair water quality
Longnose Dace	Common in high-velocity riffle
Cutlips Minnow	Found in diverse habitats, prefer warm, unpolluted rivers
Largemouth Bass	Introduced species, warm waters, voracious predators, found in ponds
Brown Bullhead	Tolerant of warm waters, pollution and low oxygen, widespread, found in ponds
Northern Two-lined Salamander	Somewhat tolerant compared to other salamanders, found in rocky streams with cold, relatively clean water

Schuylkill Highlands Conservation (SHC) Cluster

The fauna of the Schuylkill Highlands is dominated by introduced and invasive species and warm-water taxa. Streams have been known to have healthy trout populations in the past, and still have the potential to support trout, but current water temperatures and runoff patterns may be why there are few trout present. Eels are local and usually uncommon in the cluster because of partial migration blockage by dams on the Schuylkill River.

Table 5. SHC fish, salamander, and crayfish community description

Smallmouth Bass	Introduced species, prefers rocky rivers, sensitive to changes in flow, feeds on crayfish and insects
Largemouth Bass	Introduced species, warm waters, voracious predators
Rock Bass	Rocky rivers, warm or cool water, common species, predators
Bluegill	Warm waters, common species
Fallfish	Prefer clean, gravelly pools and slow flowing waters, but also require riffles to spawn
Cutlips Minnow	Found in diverse habitats, prefer warm, unpolluted rivers
Longnose Dace	Found in fast-flowing, rocky rivers, common
Rosyside Dace	Prefers fast-flowing, clean waters; the Delaware Basin is near the northern limit of this species' range
Spottail Shiner	Often abundant in large streams and rivers
Green Sunfish	Introduced, tolerant of temperature variation and sedimentation
Rusty Crayfish	Aggressive invasive species, common in diverse habitats

The macroinvertebrates of the three preservation clusters are similar and thus grouped together in the table below. These areas support cold-water, pollution-sensitive taxa as well as taxa that are ubiquitous and/or tolerate some level of pollution. The Poconos-Kittatinny supports macroinvertebrates representing the highest quality conditions, with low abundance of pollution-tolerant taxa. In the Schuylkill Highlands, diversity was lower and more pollution-tolerant insects were found.

Table 6. SHC, PKC, and ULC macroinvertebrate community description

Ephemerellidae	"Spiny crawler mayflies," found in diverse cold water habitats, pollution-sensitive.
Perlidae	"Common stoneflies," carnivores, pollution-sensitive, prefer cold, fast-flowing, oxygen-rich streams.
Oligoneuridae	"Torpedo mayflies," pollution-sensitive, some burrow into sediment.
Heptageniidae	"Flatheaded mayflies," often found under cobble, can be found in fast or slow waters, have a very streamlined body shape, somewhat pollution tolerant.
Leptophlebiidae	"Prong-gilled mayflies," pollution-sensitive, can be found in warm or cold waters.
Rhyacophilidae	"Green sedges," caseless caddisfly, found in cold water riffles, typically predators.
Capniidae	"Small winter stoneflies," these stoneflies are unique because they commonly emerge during the winter and early spring; pollution-sensitive, found in fast-flowing, cold streams and springs.
Baetidae	"Small minnow mayflies" / "Blue-winged olives," widespread, typically relatively pollution-tolerant and found in nearly all types of running waters. However, they appear to be more strongly associated with low pollution in this region.

Brandywine/Christina Restoration (BWC) Cluster

The Brandywine-Christina cluster supports warm-water, pollution-tolerant fishes. Diversity is relatively high and migratory American Eel are present, which is somewhat surprising because of the presence of dams downstream. Overall, the quality is fair, with room for improvement through investment in restoration through the DRWI and other programs.

Table 7. BWC fish community description

Spottail Shiner	Introduced species, sensitive to sedimentation, prefers sandy or gravelly streams
Green Sunfish	Warm waters, tolerant of sedimentation
Swallowtail Shiner	Most common in small streams over partly sandy or silty substrate; relatively tolerant of sedimentation
Satinfin Shiner	Prefers pools and flowing waters in small streams
Banded Killifish	Generalist feeders, tolerant of water pollution
Rock Bass	Rocky rivers, warm or cool water, common species
Rosyside Dace	Prefers fast-flowing, clean waters; the Delaware Basin is near the northern limit of this species' range
Smallmouth Bass	Introduced species, prefers rocky rivers, sensitive to changes in flow, feed on crayfish and insects
Fallfish	Prefer clean, gravelly pools and slow flowing waters
Cutlips Minnow	Found in diverse habitats, prefer warm, unpolluted rivers
American Eel	Native diadromous fishes
White Sucker	Pollution-tolerant, highest abundance in this cluster

New Jersey Highlands Hybrid (NJH) Cluster

Diversity and quality in the NJ Highlands are fair; there are few cold-water, pollution-intolerant species. Data from New Jersey's Department of Environmental Protection's (NJDEP) routine biological monitoring, yet to be received, will be used to augment data collected by ANS to describe this cluster. American Eel and Sea Lamprey were present at only one site, likely due to the presence of dams downstream on several rivers connected to those in this cluster.

Table 8. NJH fish community description

Blacknose Dace	Found in fast-flowing, cold, rocky rivers, common
White Sucker	Pollution tolerant, highest abundance in this cluster
Margined Madtom	Associated with good to fair water quality

The macroinvertebrates in the Brandywine-Christina and New Jersey Highlands, grouped together in the table below, indicate pollution from nutrient levels and warm streams mixed with cooler headwaters. They support calcareous indicators such as snails, many of which comsume algae that flourish under high nutrient levels. Some taxa that thrive in well-oxygenated waters are present, and diversity is fair.

Chironomidae	"Midges" have a wide range of pollution tolerance within the family; high densities can be related to pollution but high diversity can indicate good ecosystem quality.
Amphipoda	"Scuds," typically found in calcareous streams, ponds or lakes as well as in groundwater, relatively pollution tolerant.
Gastropoda	"Snails," relatively pollution tolerant, more abundant in calcareous streams, eat algae.
Helicopsychidae	"Snail case caddisfly; eats algae, can be present in nutrient-enriched waters and deep in-stream substrate but may be sensitive to fluctuating temperatures.
Elmidae	"Riffle beetles," live as larvae and adults in water, prefer fast-flowing, well-oxygenated streams.
Lepidostomatidae	"Little brown sedges" (caddisflies), present in cold streams and springs, eat detritus.
Brachycentridae	"Humpless casemaking caddisflies," can be found in diverse waterway types, typically pollution intolerant, known for square cases.
Psepheniidae	"Water pennies" beetles that are flattened and attached to cobble, also in fast flowing, well-oxygenated streams.
Leptoceridae	"Long-horned caddisflies," very diverse case types and habitats.

Table 9. BWC & NJH macroinvertebrate community description

Middle Schuykill Restoration (MSR) Cluster

The fish community in the Middle Schuylkill is similar to that in the Schuylkill Highlands as well as the Brandywine-Christina due to proximity as well as conditions related to warm waters and nutrient pollution.

Smallmouth Bass	Introduced species, prefers rocky rivers, sensitive to changes in flow, feed on crayfish and insects
Rock Bass	Rocky rivers, warm or cool water, common species
Green Sunfish	Warm waters, tolerant of sedimentation
Bluegill	Warm waters, common species
Fallfish	Prefer clean, gravelly pools and slow flowing waters
Cutlips Minnow	Found in diverse habitats, prefer warm, unpolluted rivers
Rosyside Dace	Prefers fast-flowing, clean waters; the Delaware Basin is near the northern limit of this species' range
Spottail Shiner	Introduced species, sensitive to sedimentation, prefers sandy or gravelly streams
Longnose Dace	Found in fast-flowing, cold, rocky rivers, common
Banded Killifish	Generalist feeders, tolerant of water pollution
Rusty Crayfish	Aggressive invasive species, common in diverse habitats

Table 10. MSR fish and crayfish community description

Upstream Suburban Philadelphia Restoration (USP) Cluster

Philadelphia streams mainly rank "poor" for the fish community, but there is high biomass of the migratory American Eel as well as minnow species. These taxa can survive and recolonize after stormwater flooding events as well as tolerate high temperature and pollutant levels.

American Eel	Native diadromous fishes
Western Mosquitofish	Highly invasive fish
Comely Shiner	Found in flowing water with sand or gravel substrate
Swallowtail Shiner	Found in small, cool water streams
Satinfin Shiner	Prefers pools and flowing waters in small streams
Redbreast Sunfish	Warm waters, tolerant of sedimentation
Green Sunfish	Warm waters, tolerant of sedimentation
Spottail Shiner	Introduced species, sensitive to sedimentation, prefers sandy or gravelly streams
Banded Killifish	Generalist feeders, tolerant of water pollution

Table 11. USP fish community description

The macroinvertebrate communities in Philadelphia and the Middle Schuylkill indicate very low diversity and high tolerance to different types of pollution. Diversity is higher in the Middle Schuylkill.

Isopoda	"Pillbugs, sowbugs," feed on detritus; can be present in springs, streams or ponds; some can tolerate nutrient rich waters and are often found in vegetation or in cobble.
Oligochaeta	"Worms," can inhabit polluted, nutrient-enriched and low oxygen waters (and can also be found in higher quality waters, but are typically less abundant).
Chironomidae	"Midges" have a wide range of pollution tolerance within the family; high densities can be related to pollution but high diversity can indicate good ecosystem quality.

Table 12. USP & MSR macroinvertebrate community description

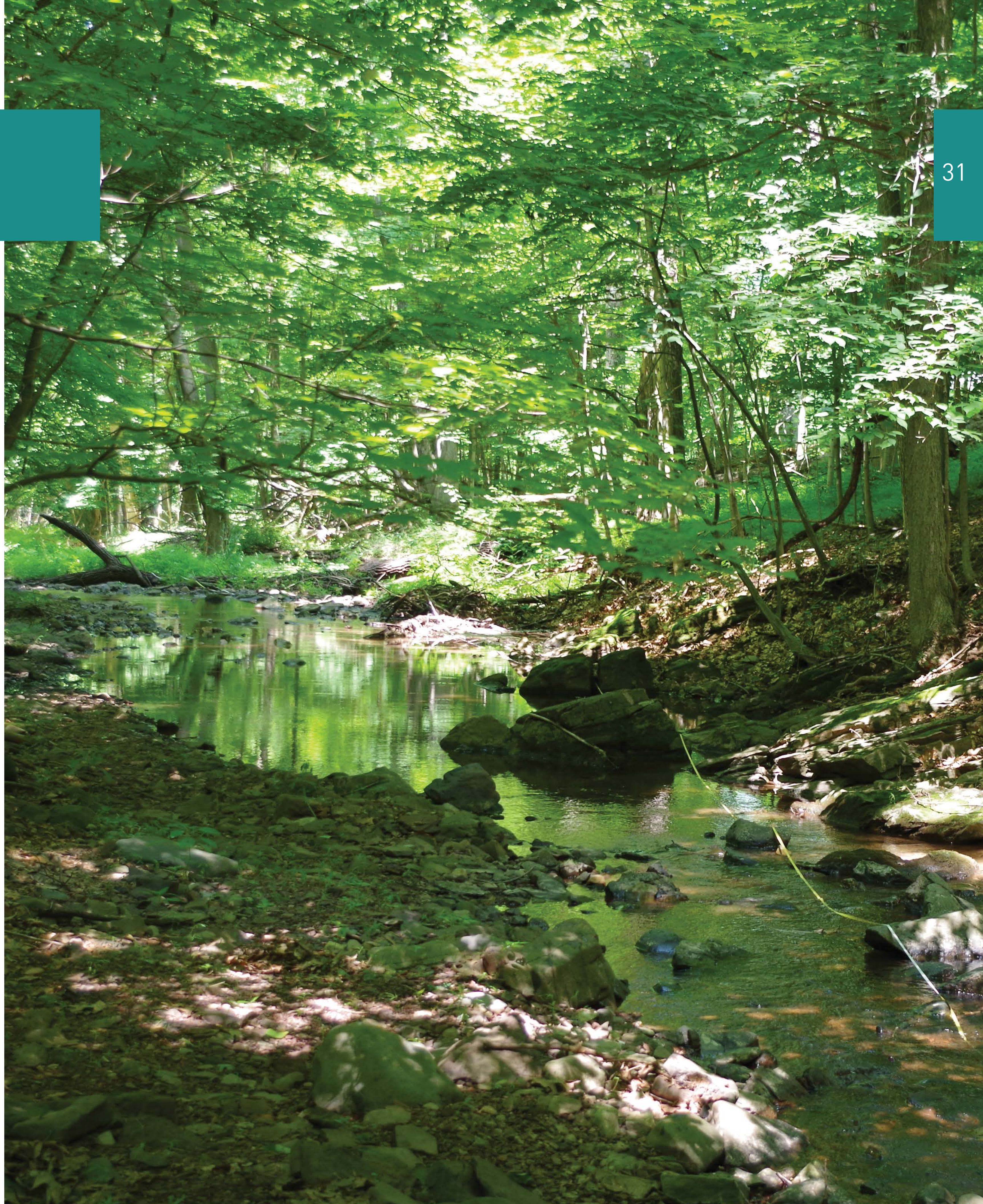
The migratory American Eel and minnow species can survive and recolonize after stormwater flooding events as well as tolerate high temperature and pollutant levels.

What Will Success Look Like?

If current and future DRWI projects are successful in restoring water quality in degraded streams and in maintaining healthy systems where they already exist, we would expect those results to manifest themselves in fish, salamander, crayfish, macroinvertebrate, and algae communities, all else being equal. Potentially confounding factors, like development upstream of a project site or shifts in precipitation and temperature from climate change, can complicate our interpretation of project impacts. However, ANS is monitoring *control sites*—sites of low disturbance that are not receiving any DRWI 'treatment'—alongside a subset of project sites, to tease out project impacts from other factors to the greatest extent possible. Observable changes in stream ecosystems will require sufficient, sustained restoration activities, with the amount of change dependent in part on stream and watershed size.

Macroinvertebrates have been found to take a decade or longer to change after significant restoration projects; fish communities may take a similar time to respond.

Given what we know about baseline conditions in the clusters, we can project abundance changes that we would expect to see for particular species, or composition changes for overall communities (Figures 6-13). It is difficult to say exactly which species might change—that is, what the ecosystem *composition* will ultimately be. Long-term monitoring of restoration projects is a discipline in development, and there are few examples upon which we can draw. However, we can begin to predict how ecosystem *function*, or the roles being played by various species, may change. Community-level changes are the end goal of the DRWI as indicators of overall ecosystem health and water quality.



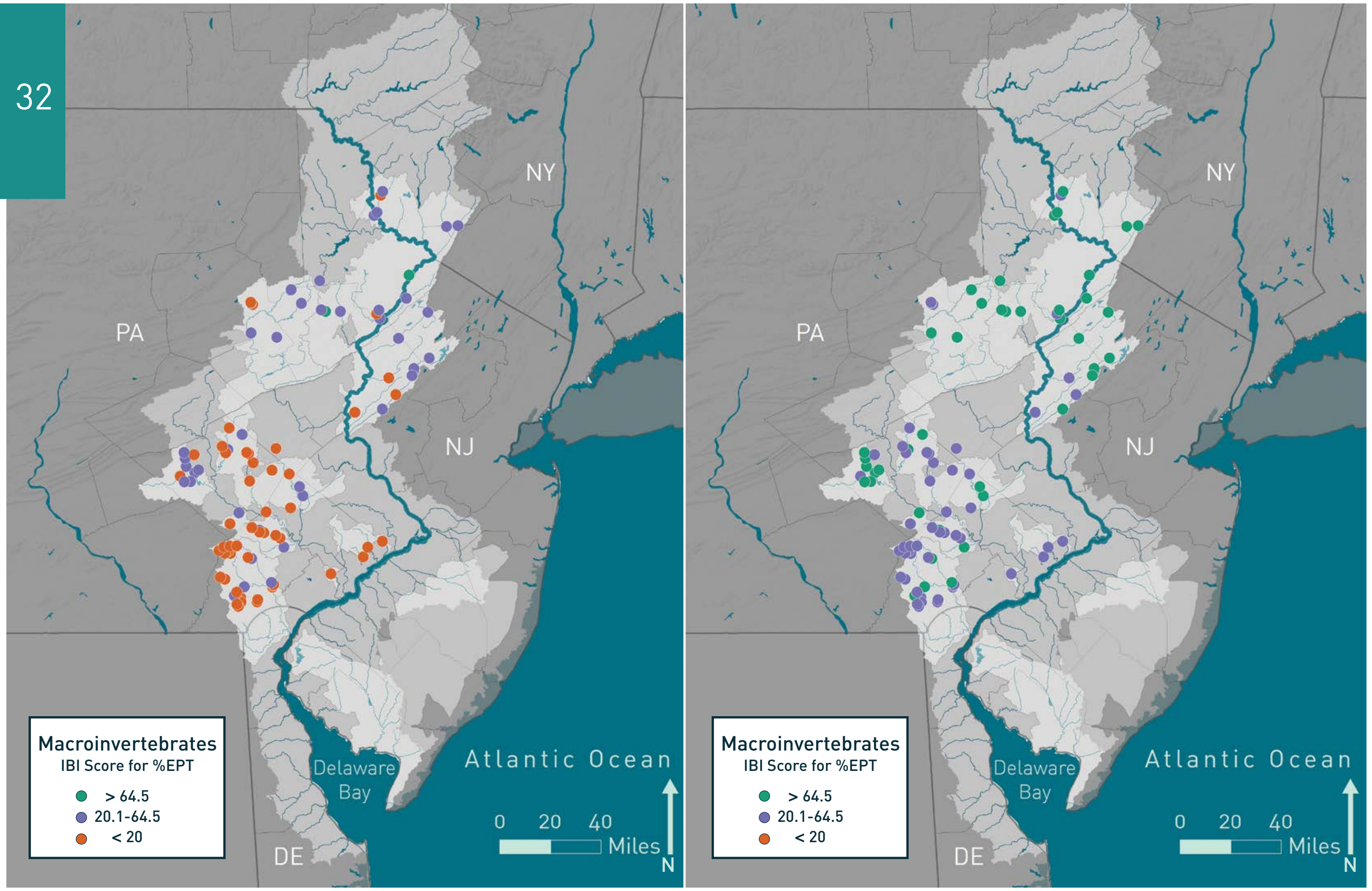


Figure 6. Baseline and potential percent EPT. Left: Baseline (current). Right: Hypothesized potential for improvement.

The diversity of macroinvertebrates would be expected to improve wherever source populations can colonize restored habitats. Specifically, we would expect to see improvements in ecosystem health and water quality indicated in several metrics: the Hilsenhoff Biotic Index (HBI); percent haptobenthos; and percent Ephemeroptera, Plecoptera and Trichoptera [6] (EPT; Figure 6). HBI is a pollution index that would improve with a reduction in pollution-tolerant macroinvertebrates and an increase in pollution-sensitive taxa. Haptopbenthos, organisms which indicate quality habitat in riffles, should show increases in abundance.

EPT are sensitive taxa from mayfly (Ephemeroptera), stonefly (Plectoptera) and caddisfly (Trichoptera) orders. The proportion of EPT in the whole macroinvertebrate assemblage should improve. In preservation areas, we would expect an increase to the higher end of the "fair" category to "good," while in restoration clusters, increasing the quality score would reflect lower nutrient and sediments loads in area waterways. EPT is shown in Figure 6 as an example of these potential responses to restoration. This metric is more likely to improve in smaller streams where significant reductions in runoff and stream temperature can allow for these macroinvertebrates to become more abundant and replace worms, midges and other organisms that tolerant greater pollution and habitat disturbance. This change would be reflected in HBI score as well as % haptobenthos.

6. Pollution-tolerant caddisflies (Trichoptera) must be considered separately in these potential changes.

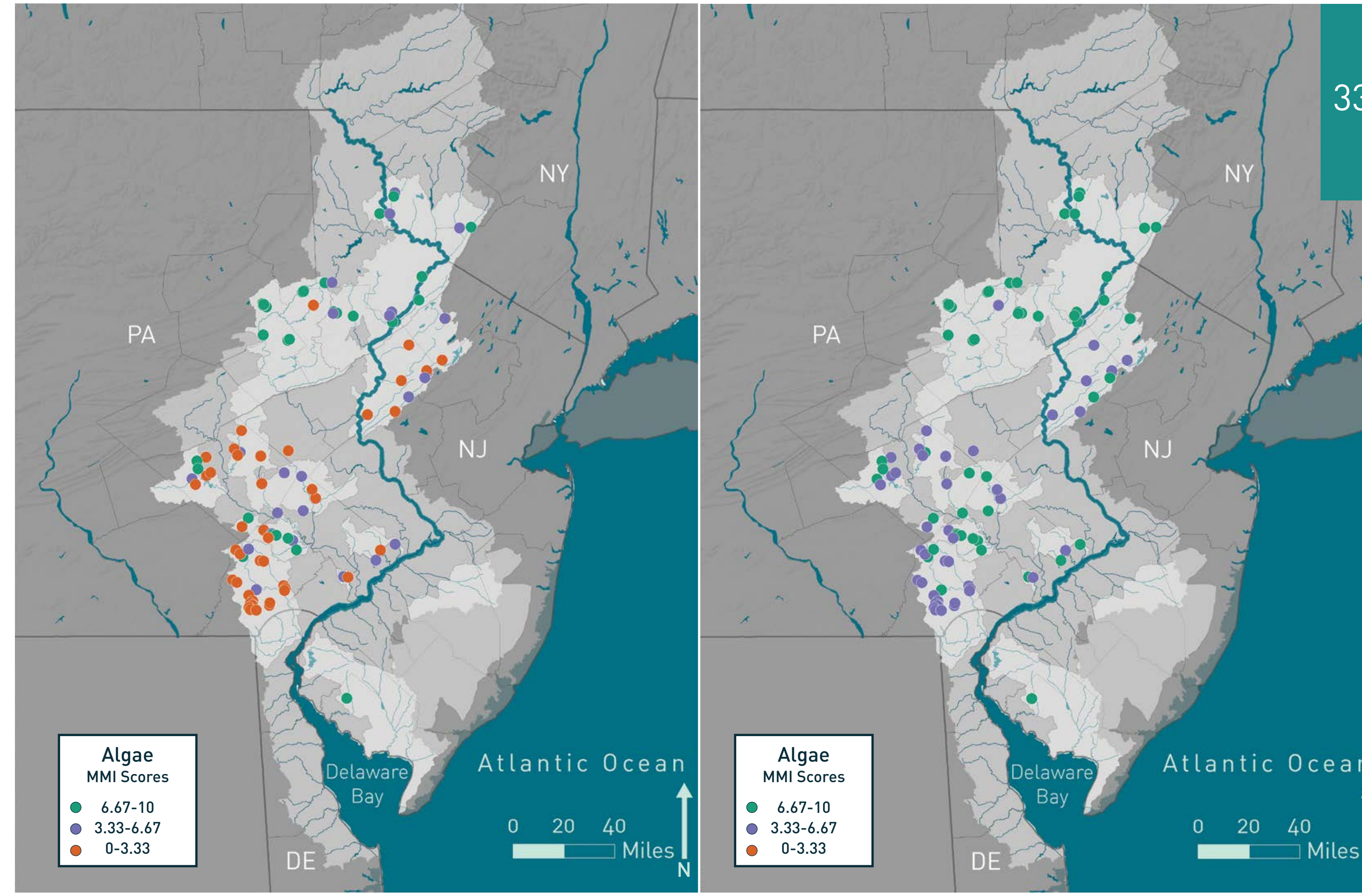


Figure 7. Baseline and potential algae MMI. Left: Baseline (current). Right: Hypothesized potential for improvement

The algae MMI includes metrics related to overall pollution, nutrient pollution, and conductivity (related to salinity and dissolved solids), and high scores indicate better ecological integrity. Sites in the Poconos-Kittatinny and Upper Lehigh show high values, with some streams that could improve, especially with restoration activities connected to preservation in some areas (Figure 7). Where point sources may be a source of pollution in the northern clusters, we may not see improvement of "poor" ratings for metrics and indices related to nutrients without actions outside the DRWI. A range of baseline conditions occurs in the restoration clusters and in the Schuylkill Highlands Preservation cluster, and many streams currently ranking "poor" could shift to "fair" with agricultural and urban BMPs that reduce sediment and nutrients in runoff.

For Philadelphia, we would hope to see improvement in the percent generalists (a decrease) (Figure 8) and percent insectivores (an increase) scores, which would mean the trophic web is becoming more complex, and fish with specific food and habitat needs would be supported (not just generalists, tolerant to either varying food sources or low quality conditions for water chemistry and habitat). We would also like to see an increase in the percentages of pollution-sensitive fish (Figure 9). Improvement in the macroinvertebrate community would likely be a prerequisite for fish community recovery in this cluster.

For fish communities, in the Poconos-Kittatinny and Lehigh clusters we expect metric scores and communities to be maintained as the DRWI continues to focus on conservation in these areas. Although abundance (or biomass) may vary from year to year, we generally expect the abundance (or biomass) of these communities to stay the same as nutrient levels remain low. We also expect maintenance of sensitive benthic species such as slimy sculpin, cutlips minnow, shield darter, and margined madtom. These species are indicative of clear and cool to cold water with coarse substrates. If upstream conditions remain similar, we expect fish communities to be maintained in these clusters.

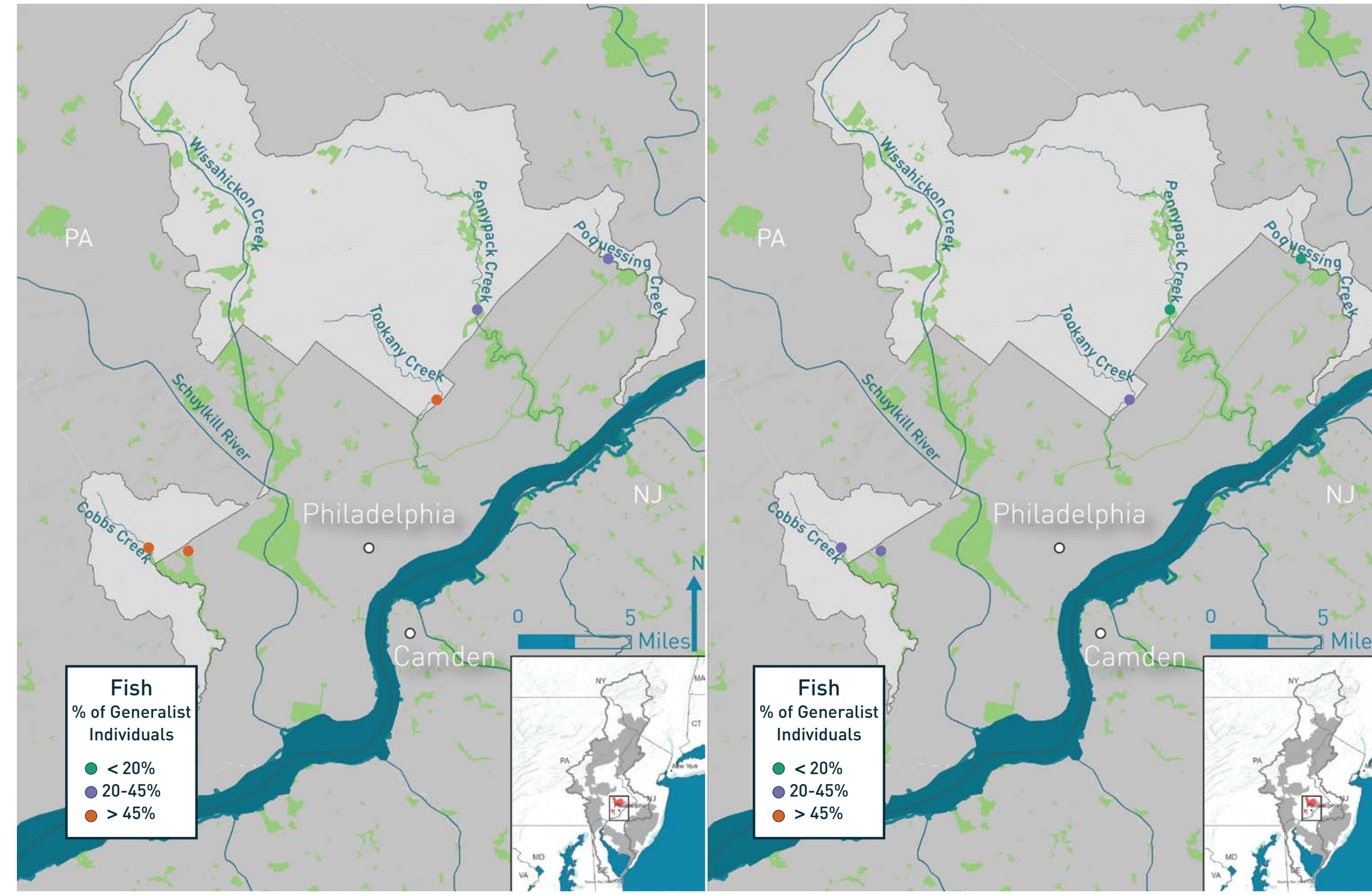


Figure 8. Baseline and potential number of generalist fish species as percentage of community, Upstream Suburban Philadelphia cluster. Left: Baseline (current). Right: Hypothesized potential for improvement.

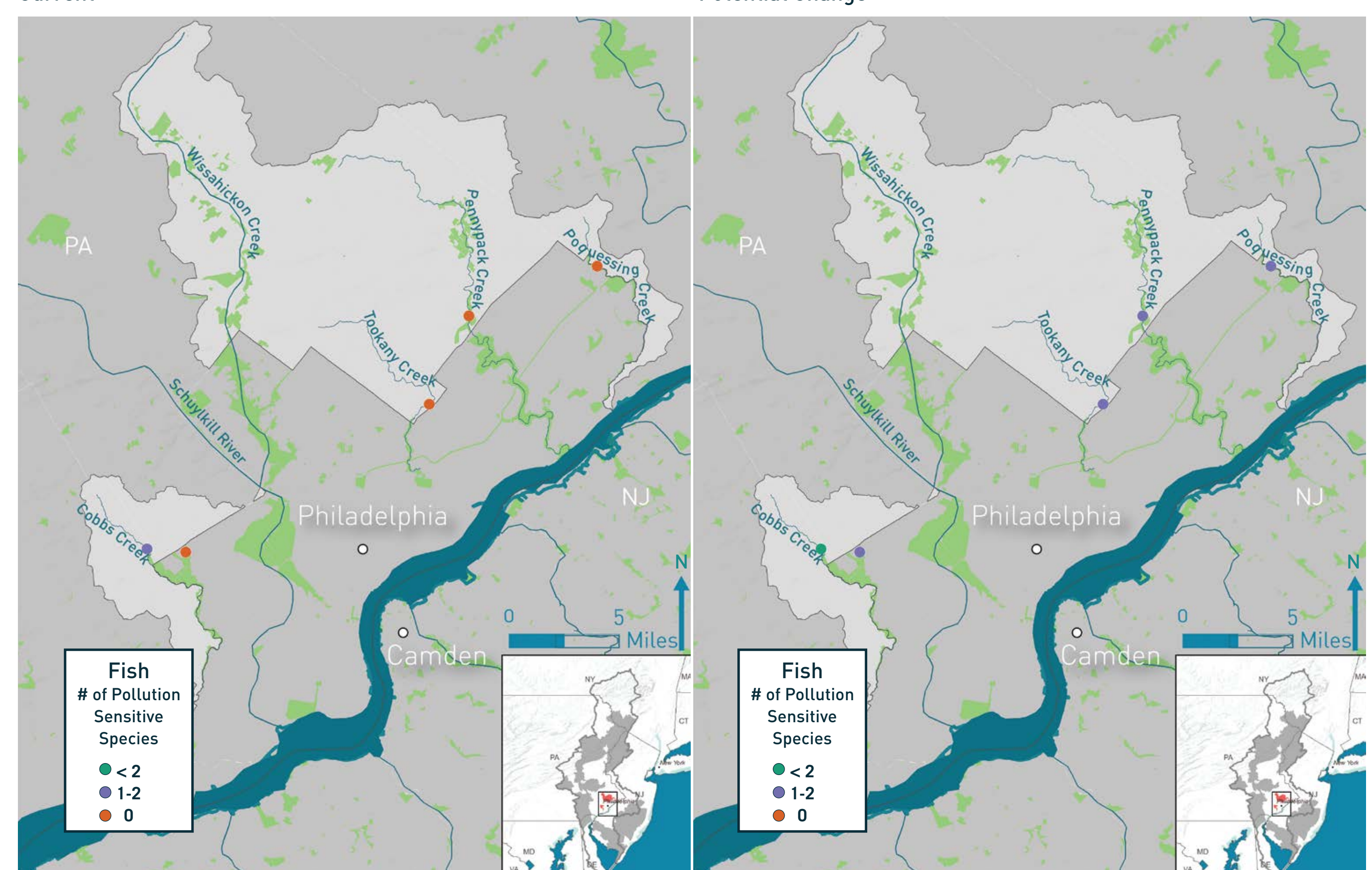


Figure 9. Baseline and potential number of pollution-sensitive fish species based on NJ IBI, Upstream Suburban Philadelphia cluster. Left: Baseline (current). Right: Hypothesized potential for improvement. Scores based on watershed size. Average watershed size for the Upstream Suburban Philadelphia is 32 km. See Appendix 1 for description of NJ IBI.

For all other clusters, we expect decreased abundance (or biomass) in response to decreased eutrophication (Figure 10). We would expect an increase in the number of benthic insectivores that are also sensitive and a corresponding decrease in the number benthic insectivores that are pollution-tolerant. As a result of the above changes, we would expect the fish community to be more even or balanced and therefore we expect the percent dominant species to decline. A decline in percent dominant species would indicate higher diversity and abundance of different fish species in restoration clusters (Figure 11). Sites with a high percentage of just a few dominant species reflect high disturbance and colonization by tolerant pioneer species rather than a diverse, stable community. The metric for percent generalist feeders could also improve (i.e. decrease in percentage). This would indicate that fish with specific dietary needs were supported in the ecosystem, rather than only opportunist species that can consume a broad range of food types.

A decline in percent dominant species would indicate higher diversity and abundance of different fish species in restoration clusters.

The very few studies documenting the recovery of fish, macroinvertebrates, or algae after implementation of restoration and protection projects suggest that we should expect substantial lag times in species and ecosystem response. Macroinvertebrates have been found to take a decade or longer to change after significant restoration projects; fish communities may take a similar time to respond. Although there is even less documentation on algae recovery, we might expect community shifts within less than a decade. These time lags are due to several factors. These include a lag in the release of legacy sediment long after restoration, the presence (or lack thereof) of "seed" communities to recolonize the restored area, and the time required for a stepwise response, from water chemistry to habitat and finally biota. In DRWI clusters habitat is in the optimal or suboptimal (not degraded) categories at nearly all sites. Because we will expect a stepwise response of the ecosystem, starting with physical and chemical attributes and moving through food chains and organism types, the presence of good quality habitat may indicate that some of the steps are already in place. Therefore, if water quality and flow-related impacts of runoff are mitigated, the stream may be able to respond more quickly than it would if habitat were also degraded.

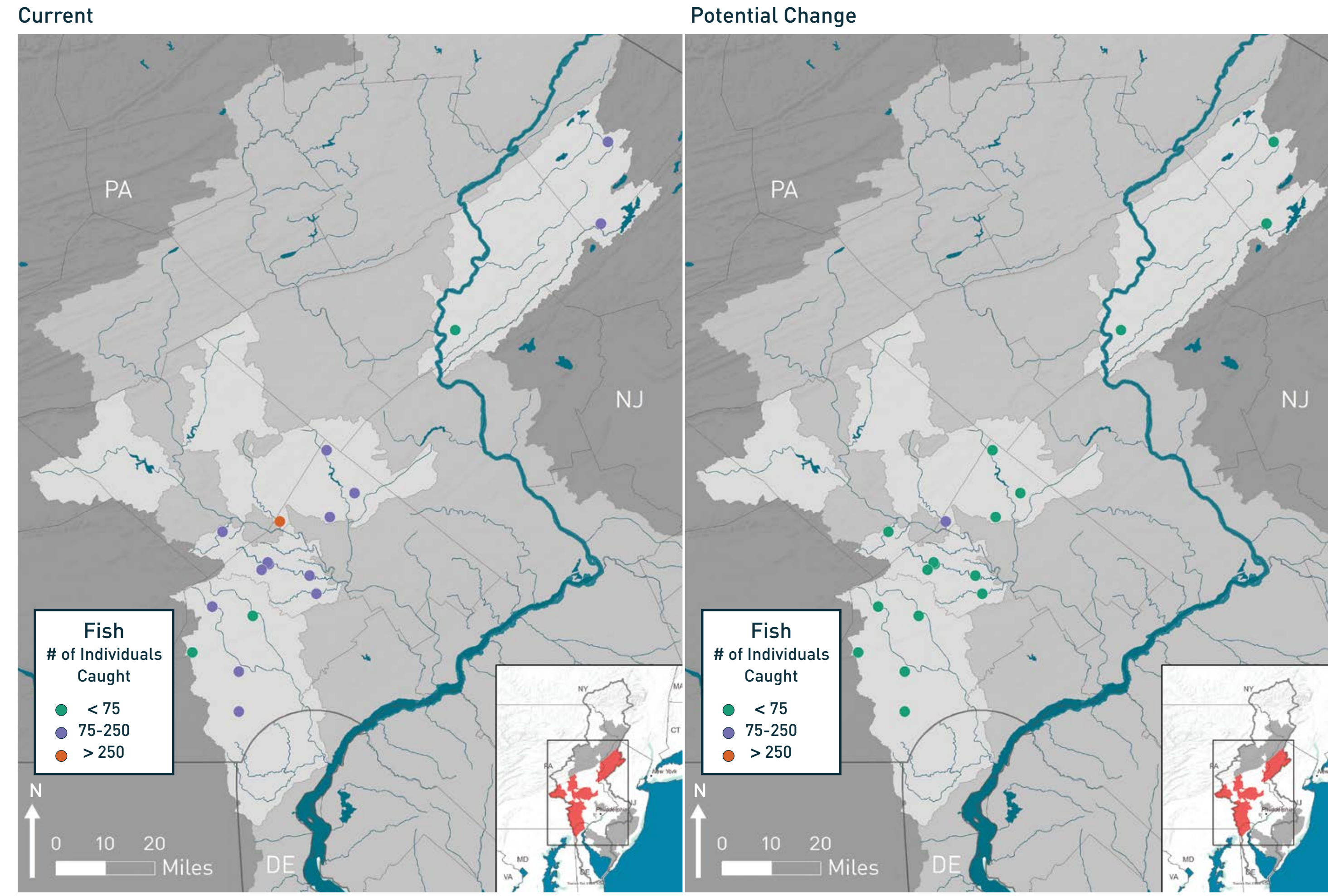


Figure 10. Baseline and estimate of total number of fish (abundance). Left: Baseline (current). Right: Hypothesized potential for improvement.

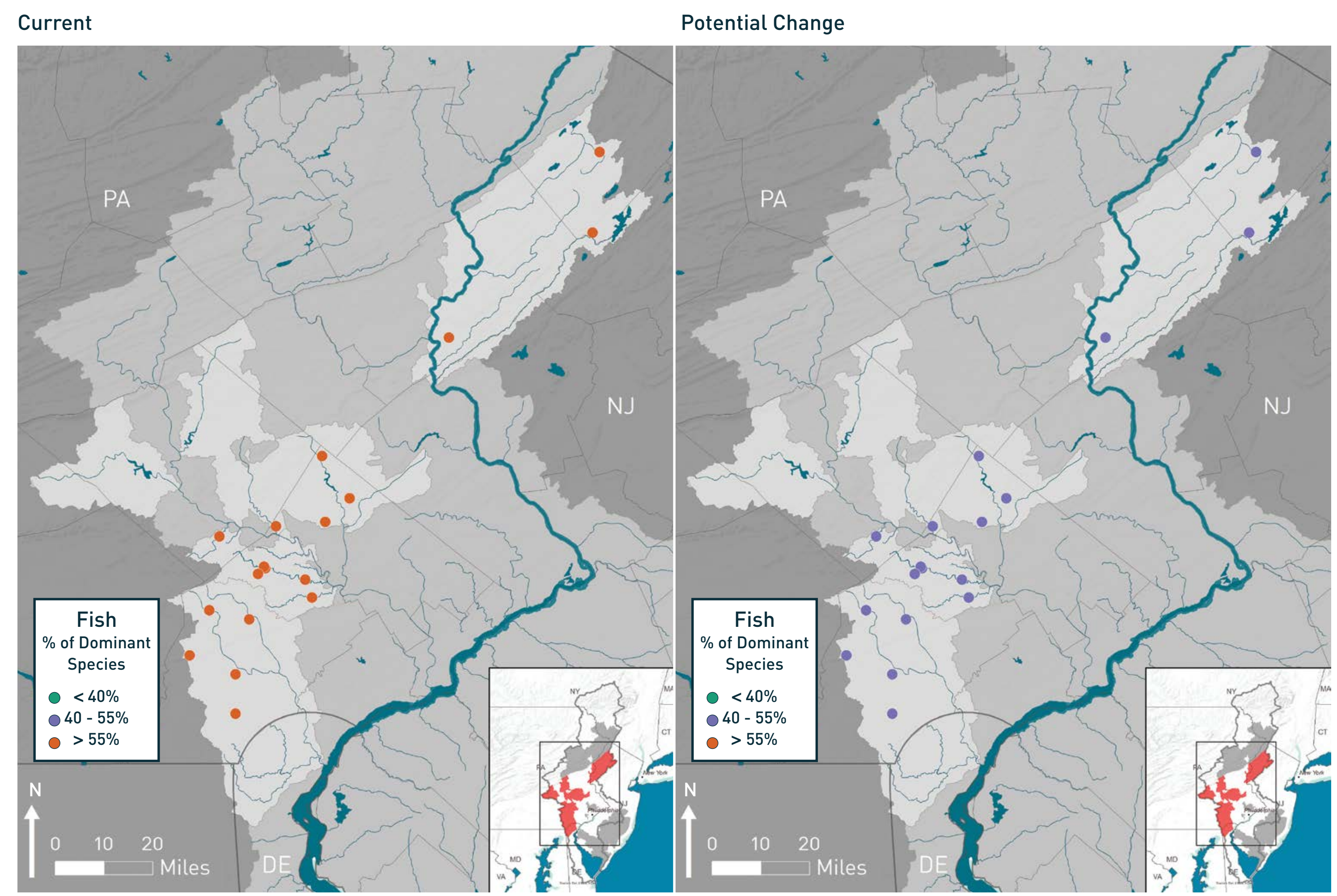


Figure 11. Baseline and potential dominant fish species as percentage of total. Left: Baseline (current). Right: Hypothesized potential for improvement.

Table 13. Baseline and projected species-based indicators, by cluster

	Cluster	Stream type	Algae NOW	Algae FUTURE	Macroinvertebrates NOW	Macroinvertebrates FUTURE	Fish NOW	Fish FUTURE
Restoration	New Jersey Highlands	Calcareous, agriculture-dominated streams	All sites dominated by high nutrient and pollution-tolerant taxa	Reduce dominance by tolerant taxa, increase from “poor” to “fair”	Tolerant, low mayfly, low diversity, low “flow-sensitive”	Higher in nearly all metrics	No eels, lamprey, warm water fishes	Greater diversity, more cool water fishes
	Brandywine-Christina	Agriculture-dominated streams	All but 1 site “poor,” high percentage of indicators of high nutrient and ion concentrations	“Fair” IBI scores, with fewer nutrient-tolerant taxa			Warm water assemblages, site-dependent, some cool water fishes (reproducing and stocked trout)	Greater diversity, decreased biomass, more cool water fishes, more reproducing trout, increases inpollution-intolerant insectivores
	Middle Schuylkill		High nutrient and ion-tolerant taxa	Higher index values (fair-good) with lower nutrient-tolerant taxa				
	Upstream Philadelphia	Urban	All but 1 site “poor,” high percentage indicators of high nutrient and ion concentrations	“Fair” IBI scores, with fewer nutrient-tolerant taxa	All metrics low	Higher in nearly all metrics	Low diversity	More diversity, stable functioning and biomass
	Kirkwood-Cohansey	Coastal plains streams	Not analyzed; to be included in 2015	Not analyzed; to be included in 2015	Some sites low diversity	Maintain high diversity in good sites, increase diversity in others	Not analyzed; to be included in 2015	Not analyzed; to be included in 2015
Protection	Schuylkill Highlands	Intermediate development & forested streams	Range of percentages of tolerant taxa, some sites low quality	Low quality sites: higher index range, Good sites: maintain quality	Tolerant, few “flow-sensitive” taxa, low diversity	Fewer pollution-tolerant taxa, higher diversity	Trout in few sites, warm water fishes	More trout & other cool water fishes
	Upper Lehigh	Forested watersheds with dams	All sites have high scores for nutrients and ions	Maintain high scores	Low % EPT, mayfly, relatively high pollution tolerant	Improve in EPT, lower pollution tolerant, maintain overall	Lehigh & Poconos (for fish) — Large streams: No eels, lamprey, some warm water fishes (ponds)	Maintenance of communities, more reproducing trout
	Poconos-Kittatinny	Forested watersheds	Range of percentages of tolerant taxa, some sites low quality	Low quality sites: higher index range, Good sites: maintain quality			Lehigh & Poconos (for fish) — Small streams: Sculpin, natural and stocked trout	Maintenance of communities, more native Brook Trout, more pollution-intolerant fish

Moving from Baselines to DRWI Impacts

The first phase of DRWI monitoring, from 2013-2014, was devoted to establishing baseline conditions. The next phase, from 2015-2017, will refine our understanding of baseline conditions and continue to explore key research questions, with a focus on tracking and understanding the on-the-ground impacts of DRWI activities as they manifest over time. Key research questions that drive this second phase of monitoring include how assemblages of fish, macroinvertebrates and algae vary from year to year at integrative sites, and whether changes in nutrients or other indicators have been observed in the short-term. In addition, reviewing the science of restoration and protection is driving realignment of DRWI approaches regarding the ability to have an impact on water quality through on-the-ground actions.

Our next analyses will focus on projecting where and how the DRWI can make the most substantial improvements in stream ecosystem quality.

IN-DEPTH ANALYSES

ANS and SWRC researchers are designing the next set of analyses to make use of the DRWI's large and comprehensive data set. A greater emphasis will be placed on using fish abundance data, which we expect to be closely related to habitat condition and type. The typical fish, macroinvertebrate and algae communities we have identified in each cluster will also be analyzed more in-depth in relation to current conditions. We will be connecting the in-stream data to the larger watershed context to refine the expected impacts of projects and understand the full watershed context influencing the aquatic communities at each site. Using these baseline communities as a starting point, we will be able to refine our projections of the types of communities we would expect to find as a result of large-scale watershed improvements.

In addition, we envision using DRWI data, along with existing data collected across the basin by state and other agencies, to use the Pennsylvania Natural Heritage Program's Aquatic Community Classifications and explore the possibility of a basic Delaware Basin stream biota classification akin to forest classifications used in the U.S. and beyond (e.g. spruce-fir, oak-pine). Through creation of a similar stream biota typology for DRWI subwatersheds we could examine how similar all streams in our studies are to each other, and what might cause them to differ from our expectations.

CUSTOMIZED DATA SYNTHESIS AND ANALYSIS

ANS will continue to invest in making DRWI data widely available, and available in formats of greatest use to key audiences. Among those formats will be cluster-specific 'data packets,' which ANS will distribute for use by any stakeholder interested in the integrity of cluster streams. These synthesized data should be especially useful to cluster groups for their external communications. We will also be developing the ANS database to enable production of reports on individual sampling sites, on specific types of sites, or on other site classifications, all with the objective of facilitating analysis, visualization, and communication of results to non-scientific audiences.

Appendix 1: Indices of Biotic Integrity

FISH IBIS

As an indicator group, fish can reveal small-scale in-stream habitat conditions, reach- and watershed-scale riparian forest conditions, and overall watershed conditions. The response of the fish community to these different scales varies from one watershed to the next, which is one reason that IBIs are developed regionally. Fish IBI values can tell us about baseline conditions relative to the types of species we currently find in the subwatershed clusters and how this relates to geographic distribution of fish species, ecosystem function (see below for metrics related to feeding guild patterns, which relate to food web structure), degree of pollution (pollution tolerant species), whether the stream would be considered a cold- or warm-water fishery, and how we would classify the site according to ecosystem stability, diversity and interactions with stressors.

For the 2013 data, we used the New Jersey DEP Fish IBI, which includes the following components:

1. Number of Species (species richness)
2. Number of Benthic Insectivorous Species (fish that feed on insects that live on the stream bottom)
3. Number of Trout and/or Sunfish Species
4. Number of Pollution Sensitive Species
5. Proportion of Pollution Tolerant Individuals
6. Proportion of Habitat & Feeding Generalists
7. Proportion of Insectivorous Cyprinids (insect-eating carp and minnows)
8. Proportion of Trout OR Proportion of Piscivores (top carnivores – fish-eating fish; excluding American eel)
9. Number of Fish Caught
10. Proportion of Fish with DELT Anomalies (Deformities, Eroded fins, Lesions and Tumors)

As an indicator group, fish can reveal small-scale in-stream habitat conditions, reach- and watershed-scale riparian forest conditions, and overall watershed conditions.

The NJ DEP IBI was inappropriate for some sites sampled in 2014 because it was not developed for small streams, so we applied the 'Daniels IBI' to those data[7]. The Daniels IBI metrics are similar to the NJ DEP IBI but the scores are not well correlated: Daniels IBI scores are higher for some sites and lowers for others than NJ DEP IBI scores.

2013 Integrative Site Fish IBI Scores: NJ DEP IBI

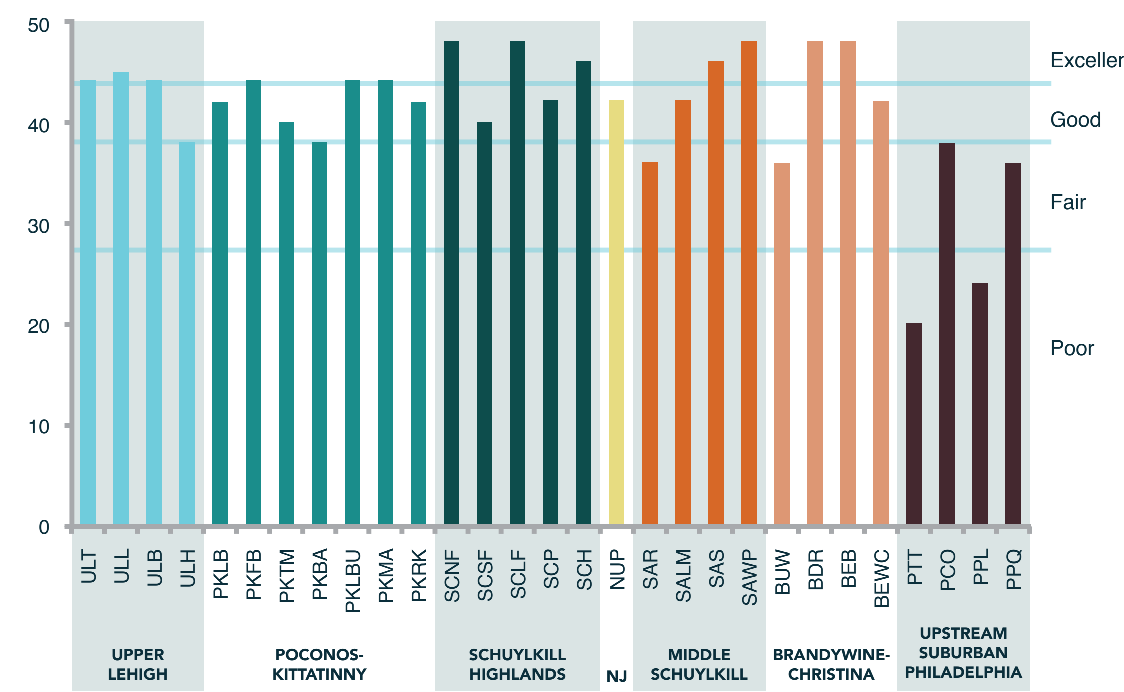


Figure 12. Fish IBI scores using NJ DEP IBI for integrative sites sampled in 2013.

Daniels IBI metrics:

1. # Fish species
2. # Bethic insectivorous[8] fish species
3. # Water column[9] species
4. # Terete minnow[10] species
5. % Dominant species
6. % White suckers
7. % Generalist feeders
8. % Insectivores
9. % Top carnivores
10. # Fish per sample
11. % Species represented by two size classes[11]
12. % of fish with DELTs

7. Daniels, R. A., Riva-Murray, K., Halliwell, D. B., Vana-Miller, D. L., & Bilger, M. D. (2002). An index of biological integrity for northern mid-Atlantic slope drainages. *Transactions of the American Fisheries Society*, 131(6), 1044-1060.

8. Fish that dwell in the stream bottom and feed on insects.

9. Fish that are not found on the stream bottom and are typically found within the water column and in pools.

10. These minnow species are grouped by their body shape and are typically long-lived, and sensitive to habitat degradation and chemical pollution.

11. This indicates different age classes as a metric for natural reproduction (vs. fish hatchery stocking).

2013 Integrative Site Fish IBI Scores: Daniels IBI

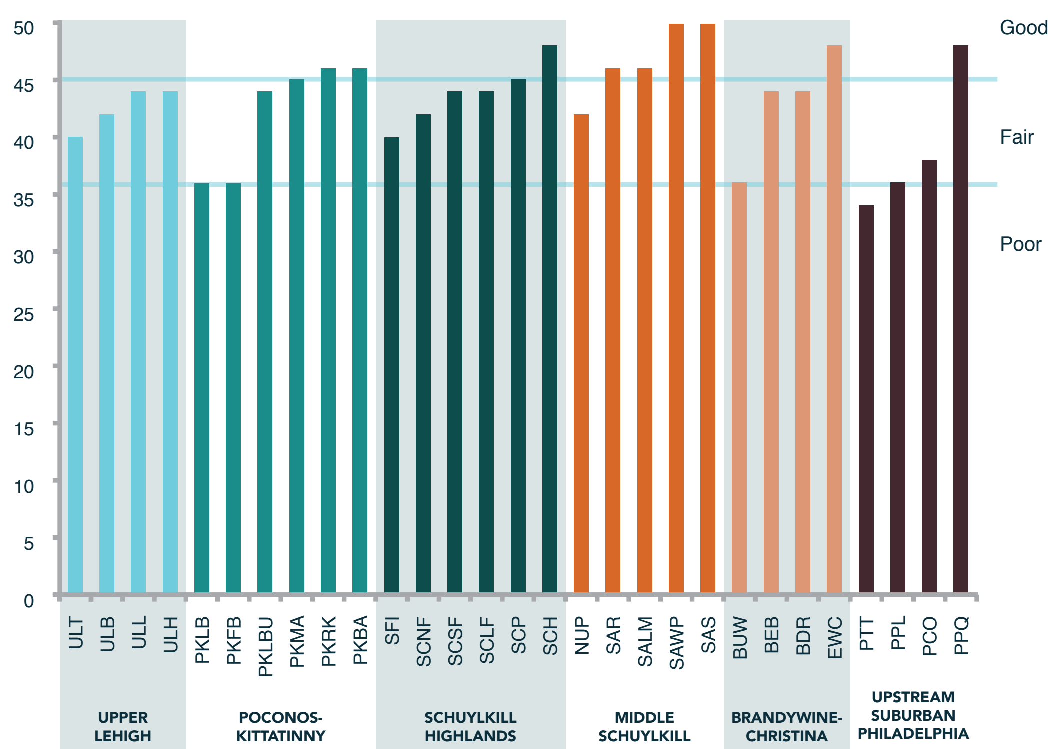


Figure 13. Fish IBI scores using the Daniels IBI, for sites sampled in 2013

Looking at the NJ DEP IBI and Daniels IBI scores side by side for 2013 sites, differences between scores generated by the two indices become obvious. For instance, no sites reach "Excellent" status with Daniels, while many sites achieve this rating using the NJ DEP IBI. This disparity has catalyzed discussions about how best to describe the fish communities in the Delaware River Basin, and researchers at ANS are considering assessment methods other than IBIs that best reflect ecological integrity.

In 2014 we also began asking how very small tributaries might affect the water quality of somewhat larger tributaries (but still small streams). Research to date on headwaters has often focused on the small streams that flow into other small streams, which continue to come together to make larger streams. Here, we are looking at a type of stream – what we call 'adventive' -- that has rarely been studied. ANS and other partners in the DRWI want to know whether these small 'adventive' streams should become priorities for improving degraded reaches below headwaters (Figure 14).

Figure 14. Schematic of an adventive stream. The light green stream represents the adventive stream, a stream that is much smaller (by at least 2 stream orders using the Strahler stream order system) flowing into a larger receiving stream.

The preliminary results suggest that adventive streams are indeed influencing the quality of streams into which they are flowing. Adventive streams draining forested watersheds appear to be improving downstream water quality, whereas small streams draining developed watersheds are having a negative impact downstream. IBI results from adventive stream site sampling are shown in Figures 15 and 18, with the color scheme following Figure 14.

Fish IBI scores for 2014 sites: Adventive and Project Sites

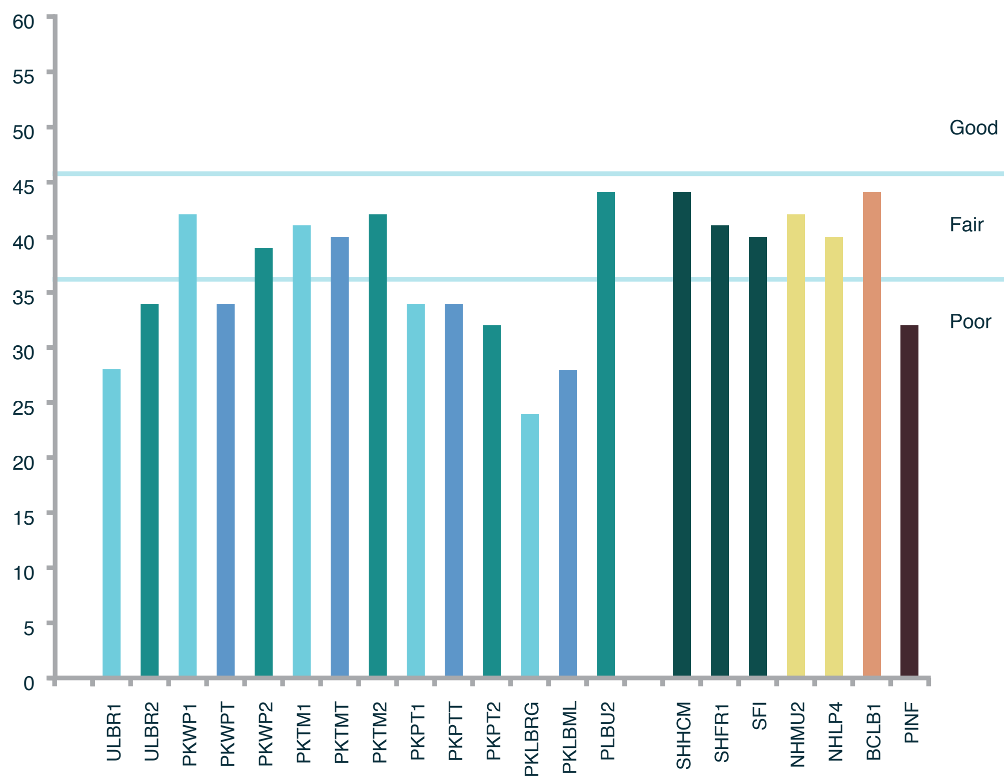


Figure 15. Daniels Fish Index of Biological Integrity scores for sites sampled in 2014. Adventive study sites are shown on the left of the graph, with the color scheme following Figure 14. The sites on the right are project sites, with the same color scheme relative to clusters as seen in Figures 12 and 13 (and below for macroinvertebrate IBIs).

With the exception of Indian Run in Philadelphia, which rates as "poor," all project sites have "fair" fish IBI scores, indicating room for improvement. In the Schuylkill Highlands, the quality is also "fair" for fish, indicating potential for restoration as well as land protection. However, these values should be considered with reasonable caution, as they do not tell the complete picture of ecosystem health. Fish communities can be stable and healthy at lower levels of diversity than would be expected of macroinvertebrates or algae. IBI scores (for fish or any indicator) give a broad idea of quality across a large quality gradient, but do not distinguish small differences among sites within categories.

> Macroinvertebrates can indicate large-scale and small-scale disturbance from land use which include pollution and changes to habitat and hydrology.

2013 Integrative Sites: MAIS Index of Biological Integrity Scores

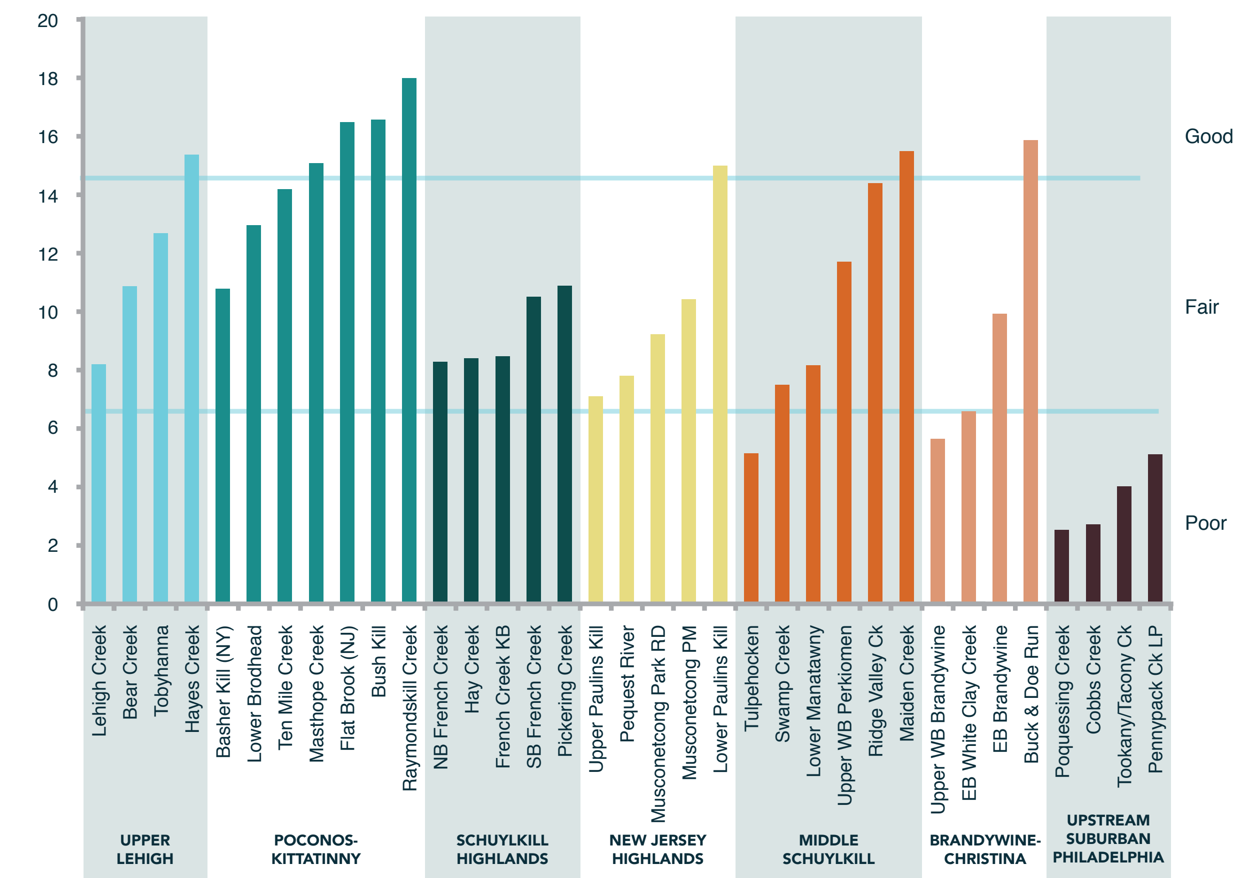


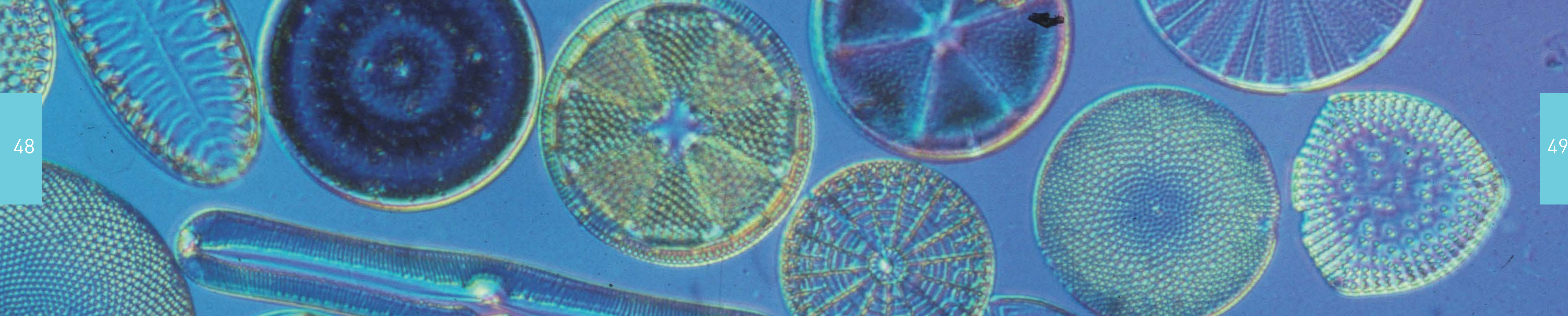
Figure 16. MAIS IBI scores for integrative sites, sampled in 2013

MACROINVERTEBRATE IBIS

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a rapid bioassessment protocol designed by Smith and Voshell (1997) based on benthic macroinvertebrate data collected from Maryland, Pennsylvania, and Virginia. It is used by many agencies in the Eastern US and provides family-level aggregated macroinvertebrate metrics. Nine metrics are used in MAIS to describe the condition of a stream:

1. # Ephemeroptera (Mayfly)
2. # EPT Mayfly, Stonefly and Caddisfly)
3. # Pollution Sensitive Taxa
4. % Ephemeroptera
5. % 5 Dominant Taxa
6. Simpson Diversity Index
7. HBI (Hilsenhoff Biotic Index)
8. % Scrapers
9. % Haptobenthos

The 2013 data from integrative sites show "fair" and "good" quality in all clusters except for Upstream Suburban Philadelphia. These sites cover the range of conditions found in the subwatershed clusters, so it is appropriate that "fair" rated sites would be present in each cluster. The project sites also show this range of conditions (SWRC did not sample macroinvertebrates in Suburban Philadelphia streams in 2014 because many of our partners performed sampling there; results will be shared soon).



2014 MAIS Scores: Project Sites

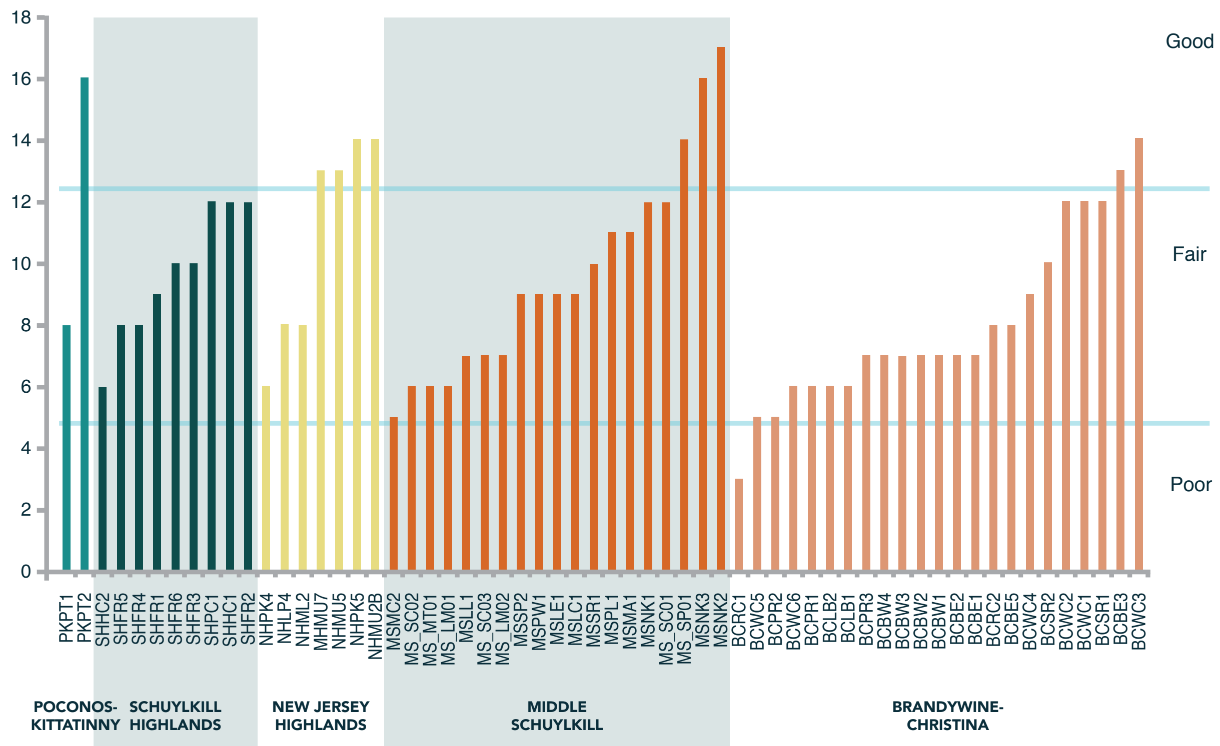


Figure 17. MAIS IBI scores for project sites, sampled in 2014

Not unexpectedly, a number of streams sampled in 2014 rate "poor" using MAIS (Figure 17). Many project sites are located in agricultural landscapes where BMPs are being implemented on farms as part of the DRWI.

2014 MAIS Scores: Adventive sites

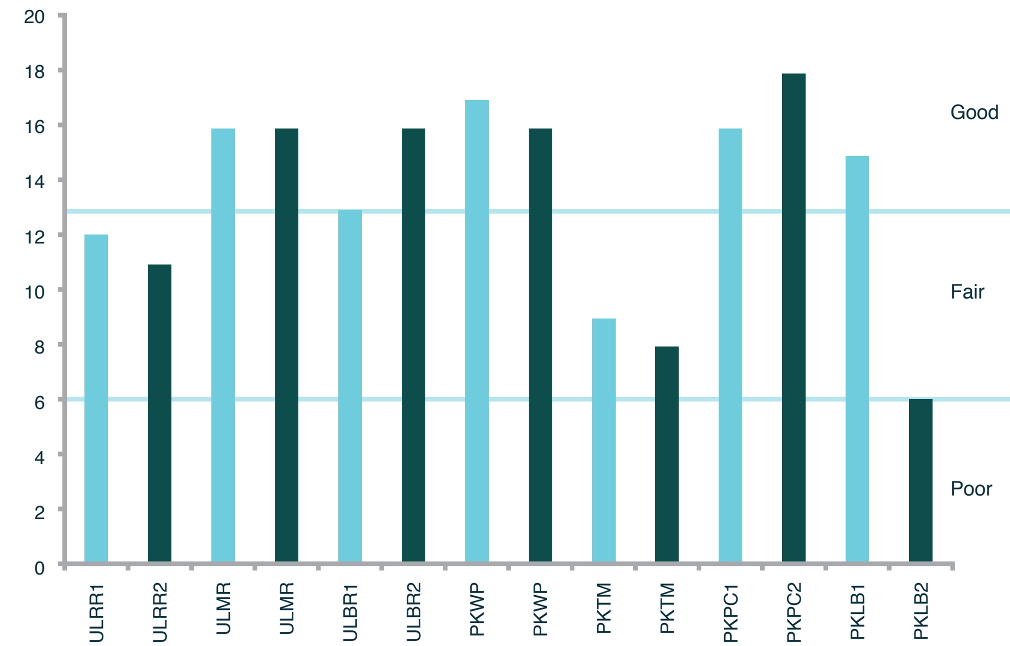


Figure 18. MAIS IBI scores at adventive sites, sampled in 2014. Light teal bars represent sites located upstream of the tributary, and dark teal are downstream (same as Figure 15). The adventive tributaries were not sampled for macroinvertebrates.

A first look at the macroinvertebrate data at adventive sites shows that quality varies largely as expected from one tributary confluence to the next, based on land cover/land use in the adventive sites' watersheds. In 2015 we will focus the adventive stream study more narrowly, examining only those sites draining highly forested watersheds and flowing into streams draining less forested landscapes, to better determine how forested headwaters may mitigate degradation from development.

Appendix 2:
Algae Metrics

Diatom and other algae taxa are closely related to nutrients and contaminants, making them useful for indicating specific levels of contaminants, especially as derived from agriculture. Some of these chemical associations refer to natural geology (calcium-associated diatoms), while others relate to pollution (chloride, nitrogen, phosphorus, nutrients).

The charts below show the percentage of diatoms that are related to low (orange) or high (teal) concentrations of the compounds. The remaining percentages (not shown; area missing to 100%) are made up of diatoms without defined thresholds for these compounds.

The calcium data show that the Upper Lehigh and Kirkwood-Cohansey clusters are standouts, with high percentages of low-calcium taxa. These findings are to be expected, based on what we know of water chemistry in those clusters. The other clusters have greater percentages of high-calcium taxa, which is related to natural geology. Calcium can help a stream buffer against changes in pH, and therefore against the effects of warmer temperatures (and lower oxygen levels) as well. It can be useful for indicating the ability of a stream to resist the effects of climate change or acidification.

All clusters show an abundance of low-chloride taxa, which suggests that wastewater effluent has not introduced chloride into the streams. However, these data do not represent winter conditions, when some areas may be affected by road salt entering aquatic systems. Salinity can have a large impact on sensitive taxa, and all freshwater taxa have tolerance levels for salinity. Road salt in the winter has been found to affect in-stream communities in New York and other nearby areas.

Diatom and other algae taxa are useful for indicating specific levels of contaminants, especially as derived from agriculture.

For nutrients, the Upper Lehigh and Poconos-Kittatinny clusters both have predominantly low-nutrient-tolerant taxa. Although it is a preservation cluster, the Schuylkill Highlands shows levels similar to the Middle Schuylkill and New Jersey Highlands, likely due to levels of agriculture and development.

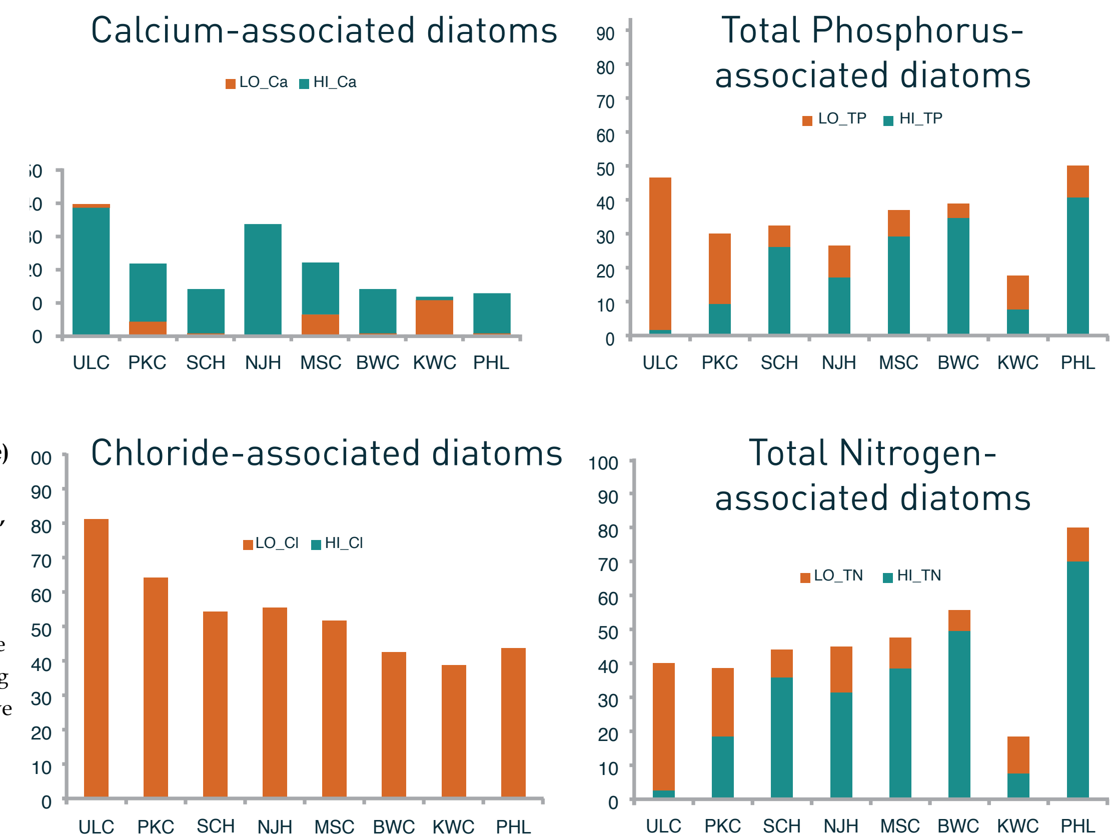


Figure 19. Percentages of diatoms that are found in water with low (orange) and high (teal) concentrations of calcium, chloride, phosphorus and nitrogen. The percentages come from taxa lists from each sample in 2013 and 2014, including both project and integrative sites, and information on known diatom values for these characteristics.

12. Potapova, M, and Carlisle, D.M. 2011. Development and application of indices to assess the condition of benthic algal communities in U.S. streams and rivers: U.S. Geological Survey Open File Report 2011–1126, 40 p. Available online at: http://pubs.usgs.gov/of/2011/1126/

MULTI-METRIC INDEX

In addition to analyzing the types of algal species found in each cluster, we have applied a multi-metric index (MMI) to the 2013-2014 diatom data. This particular MMI was developed by Potapova and Carlisle (2011)[12] for use at National Water Quality Monitoring Assessment (NAWQA) Program sampling sites. MMIs incorporate several metrics into a single index to represent different structural and functional aspects of communities and ecosystems.

The Potapova and Carlisle MMI combines existing metrics and reduces them into two categories, “impaired” and “reference.” The metrics, which are unique to the land cover conditions in the Eastern Highlands ecoregion (where the Delaware River Watershed lies), include: %brackish-freshwater taxa, low oxygen-tolerant and high oxygen-requiring taxa, oligo- + oligomesotraphentic and eutra- + hypereutraphentic taxa (a ratio of eutrophication indicator taxa), the sum of alpha-mesosaprobic to polysaprobic taxa (indicators of organic enrichment), as well as indicators of nutrient enrichment and elevated conductivity (the ratio of low:high total phosphorus (TP), total nitrogen (TN), and conductivity indicator taxa).

2013 Integrative Site Diatom Index Scores

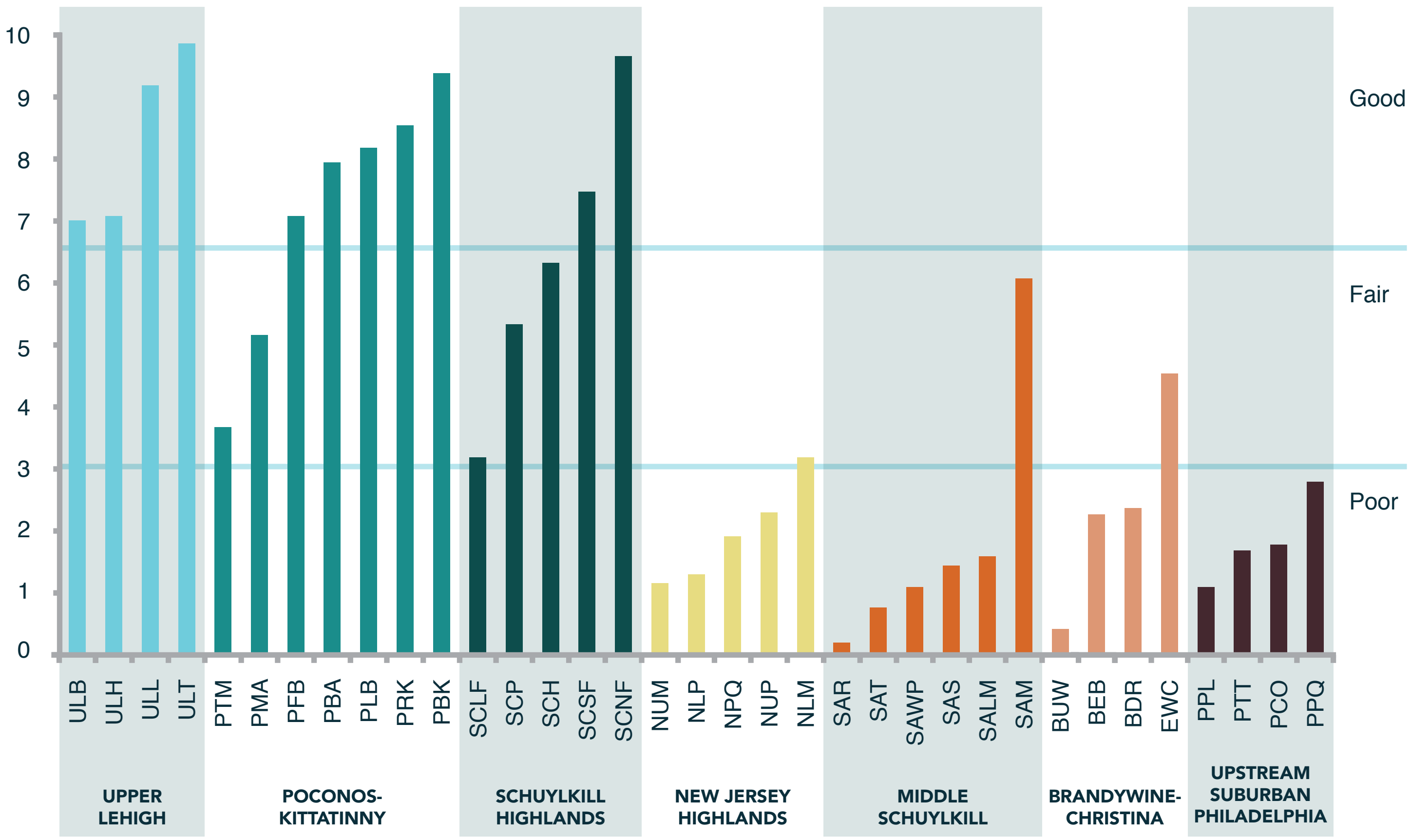


Figure 20. Diatom multimetric index for integrative sites

2014 MMI of Algal Integrity Scores

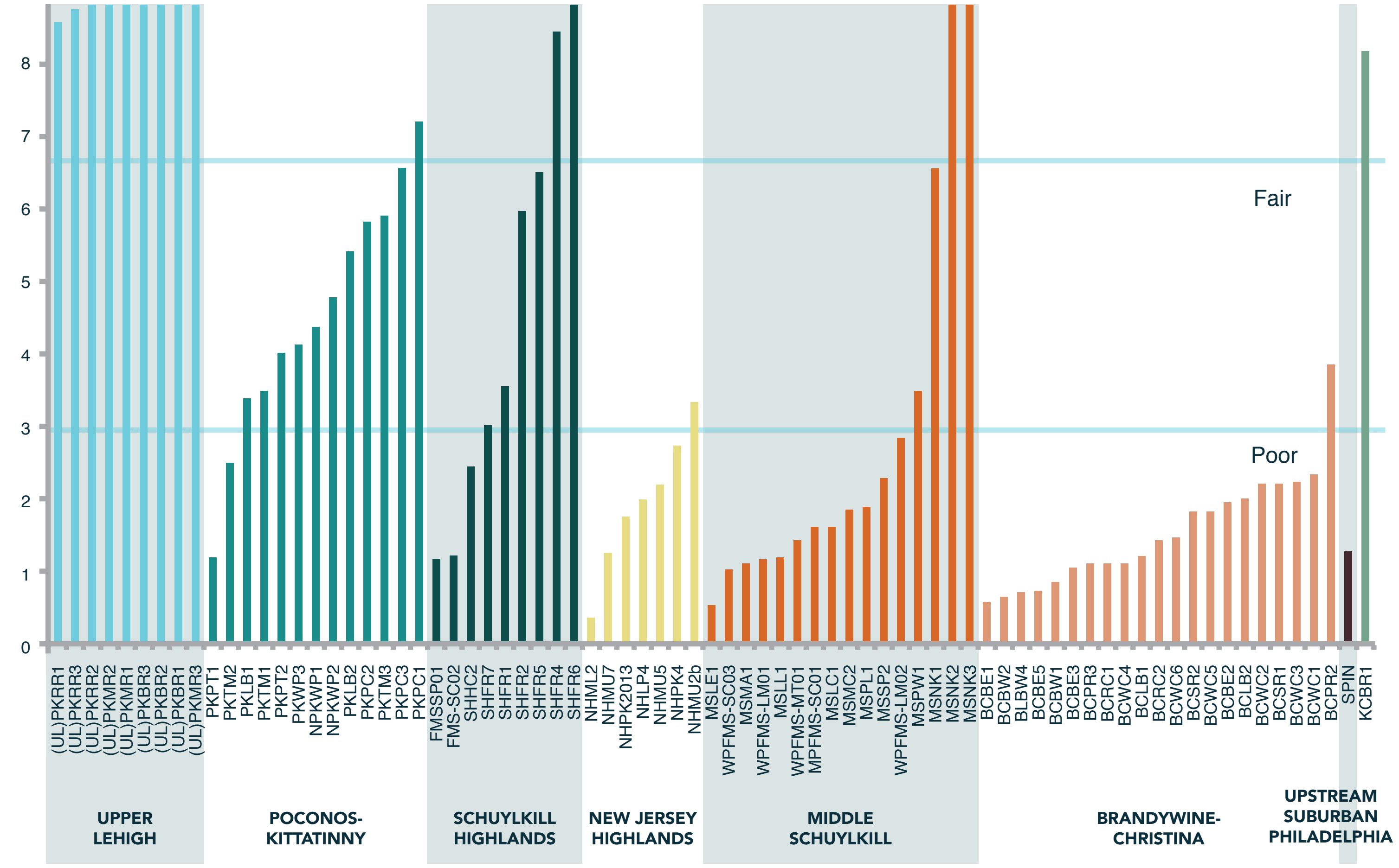


Figure 21. Diatom multimetric index for project sites

Appendix 3:

Gradient Analysis /Ordination

Gradient analysis (or *ordination)* is used to explore data and to identify patterns, without necessarily having an *a priori* hypothesis. It is a trusted technique for reducing large data sets to the variables that best explain the patterns in the data.

As employed in our data analysis, ordination allows us to explore similarities between and among sites. One or multiple variables can be included (organisms, habitat, landscape variables, etc.). The resulting diagram is a "map" of how similar sites are, while the axes express the variables that contribute most to the sites' similarities. Axis 1, the x axis, contains the greatest amount of the variation in the model, while the y axis contains less variation, and each subsequent axis explains less of the variation. Typically the first two axes are presented, but more axes can also be provided if they show important relationships in the data.

Redundancy Analysis also identifies which members of the community appear to have the greatest influence on the similarities and differences among the sites. This "map" of the composition of the biotic community can indicate natural to stressed ecological gradients, and can also show separation of sites according to stressor type (nutrients, flow alteration, degraded habitat, urban inputs) or variations due to other factors (climate, geology, etc.).

We used ordination analysis with the technique Redundancy Analysis (RDA) to examine how each group of organisms classified streams within the subwatershed clusters. In our analysis, environmental gradients (an understanding of the range of low to high amounts for conditions such as developed land, or low to high calcium geology, etc.) are derived using expert knowledge and information on the biological community. The gradients can run along the x or y axes, or along a diagonal through the graph. In this case, the subwatershed clusters were introduced as an environmental variable for grouping sites in these preliminary analyses.

Gradient analysis is helping us to see that the living organisms are not completely different in each cluster, and that it is useful to know which clusters and sites overlap. These analyses have shown us that it is more useful to break sites into categories of main stressors rather than subwatershed clusters. This can be seen in the figures that follow, where the different colored circles (each color representing a subwatershed cluster) overlap rather than being spatially distinct.

Different groups of organisms can indicate different types and severity of impact from human disturbance. For example, fish show regional patterns, while macroinvertebrates and algae classify the clusters based on overall nutrient and ecosystem degradation, but still show slightly different results for the relationships among clusters. Therefore, RDA analyses have been performed separately for each organism group as a first step to developing an indicator set that will uniquely identify stressor types and degree of impact within the Delaware River Watershed. The following results are the first analyses in a group of studies being developed at ANS. These analyses will be expanded to include 2015 fish, macroinvertebrate, and algae data as well as water chemistry, landscape, and habitat variables.

2013 FISH ORDINATIONS

As shown in the figures below, fish gradient analysis reveals a substantial degree of grouping by cluster type: agriculture-dominant restoration, urban-dominant restoration, and forest-dominant preservation. The Poconos-Kittatinny and Upper Lehigh sites form one group with the one site sampled in the New Jersey Highlands, while the Middle Schuylkill and Brandywine-Christina restoration clusters show regional affinity with the fish communities in the Schuylkill Highlands, which stand apart from Philadelphia streams.

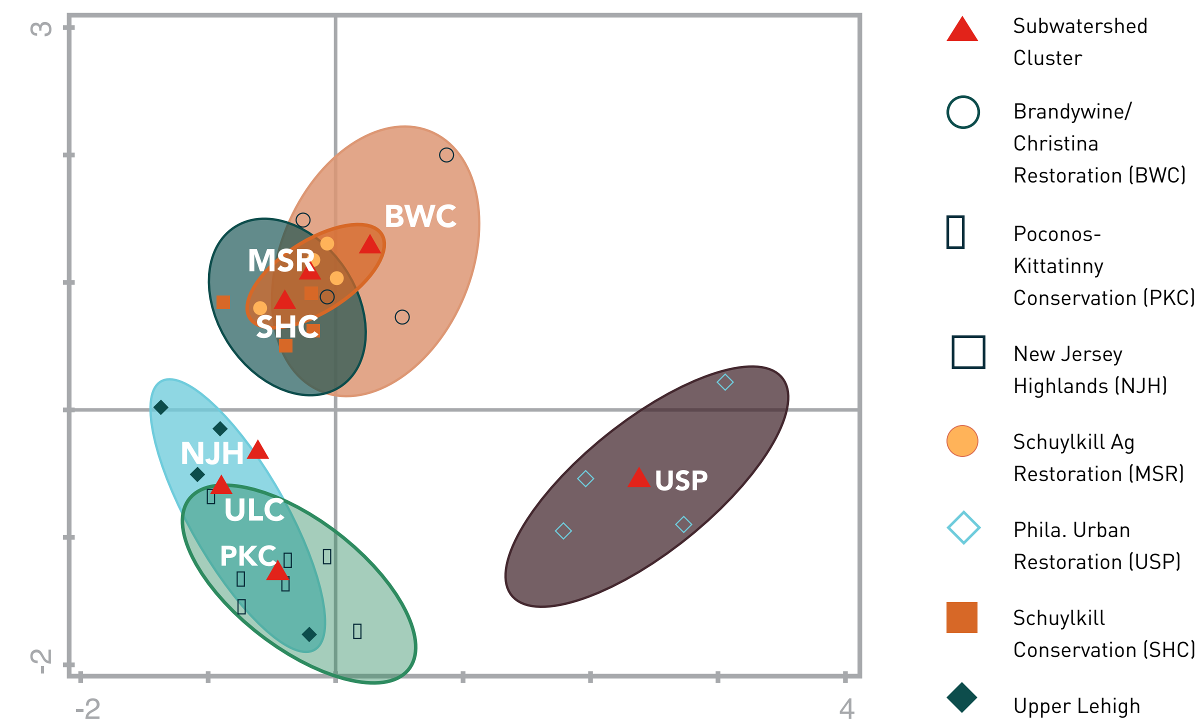


Figure 22. RDA sample classification diagram of fish species compostion and cluster scores calculated using fish abundances (number per hectare) per integrated site. Fish species compostions were constrained by cluster group (BWC = Brandywine-Christina Restoration, NJH= New Jersey Highlands Hybrid, USP= Upstream Suburban Philadelphia Restoration, PKC=Poconos-Kittatinny Conservation, SHC=Schuylkill Highlands Conservation, ULC=Upper Lehigh Conservation, MSR= Middle Schuylkill Restoration). **Enclosed elipses represent clusters.**

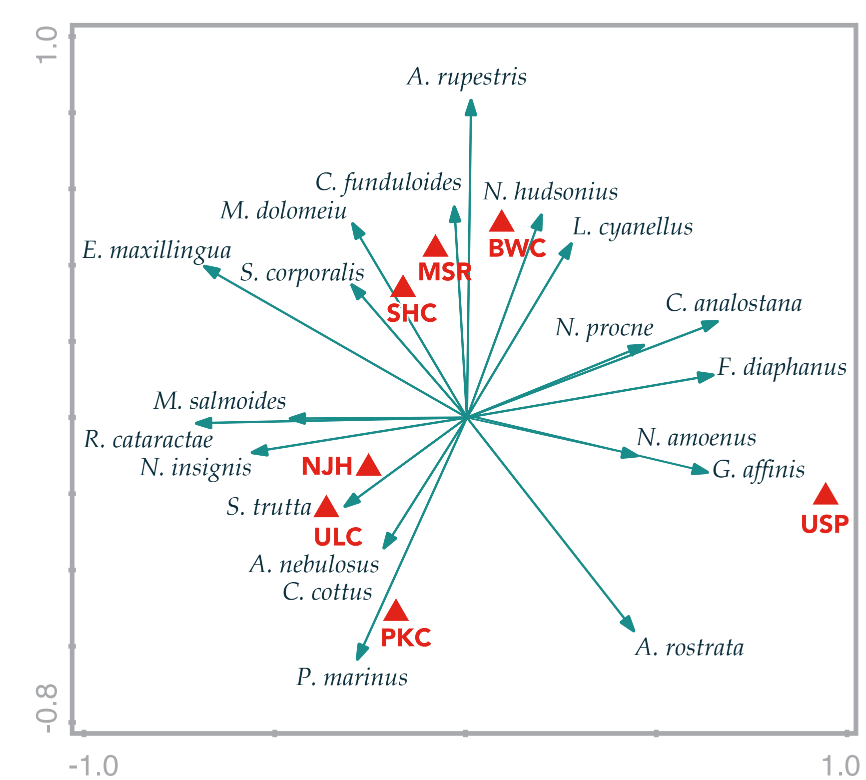


Figure 23. RDA biplot of fish species and cluster scores calculated using fish abundances (number per hectare) per integrated site. Twenty species best fitting axes 1 and 2 are shown. Fish species compostions were constrained by cluster group.

2013 MACROINVERTEBRATE ORDINATION: FAMILY LEVEL

The subwatershed clusters show a good deal of overlap among macroinvertebrates at the family level. The New Jersey Highlands and Philadelphia clusters stand out as most distinct. The NJ Highlands has a more calcareous geology and a combination of agricultural inputs and natural areas. Philadelphia clearly shows the greatest amount of degradation. The Poconos-Kittatinny, Upper Lehigh and Schuylkill Highlands ellipses overlap but form a group of three. The Poconos and Upper Lehigh have fairly intact ecosystems with high ecological integrity and are located near each other; they also share similar geology. The Schuylkill Highlands is also dominated by forested lands, but shows overlap with agricultural clusters Brandywine-Christina and Middle Schuylkill because of periodically high nutrient concentrations and stormwater-related impacts, as well as geographic proximity.

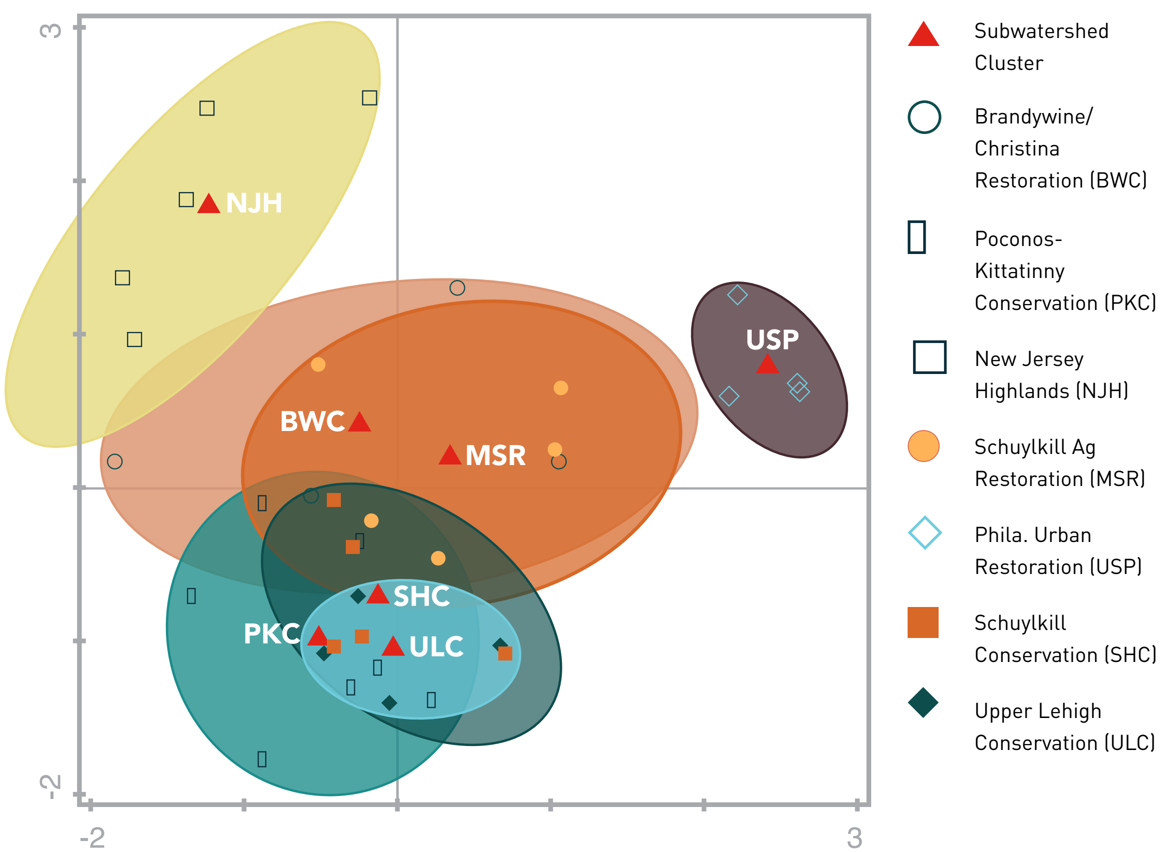


Figure 24. RDA sample classification diagram of macroinvertebrate family compostion. Macroinvertebrate assemblages were constrained by cluster group, represented by enclosed elipses.

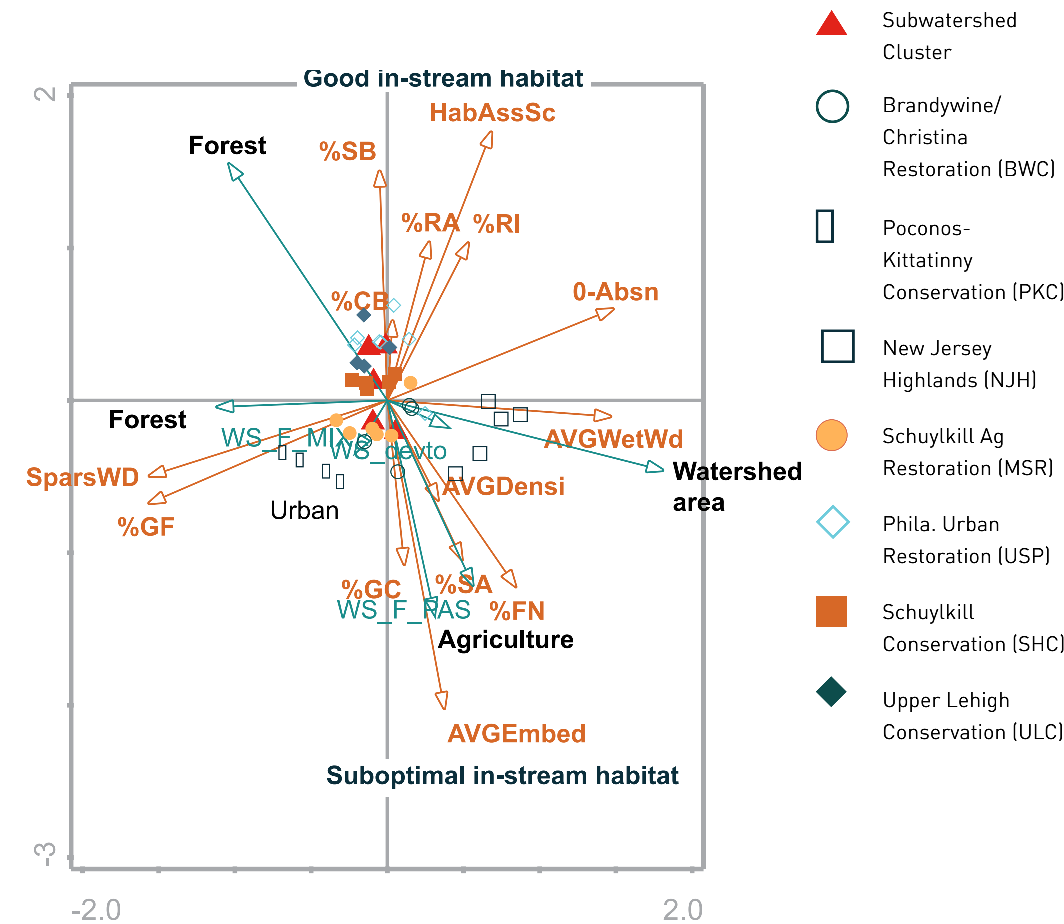


Figure 25. Ordination showing the relationship of cluster sites to environmental variables. The black labels simplify the abundance of information in the ordination diagram.

As in the previous ordinations, the sites from preservation clusters are grouped, and then the NJ Highlands, Brandywine-Christina, Philadelphia and Middle Schuylkill clusters separate out in the area below the center. The environmental gradient we are seeing goes from high amounts of quality habitat characteristic of headwaters and small, forested streams, with stable, rocky stream bottom substrate and high overall habitat scores in the top, to suboptimal stream habitat dominated by sand and gravel (unstable substrate) at the bottom.

The Brandywine-Christina sites (black circles) are spread out between the Middle Schuylkill and NJ Highlands; and the Philadelphia and New Jersey sites are distinguished from the others in distinct groups, which suggest they have a stronger difference in habitat and macroinvertebrates (and thus, overall conditions). We should not place a quality rating on ordinations—they show the range of conditions present in the study, but they do not necessarily allow us to group sites as good or poor, as the IBIs do.

Overall, the macroinvertebrates that have the strongest influence in the RDA show environmental gradients that support Figure 25. The taxa found at sites in the top left (data not shown; positive values on y and negative value on x axis) are organisms that require cold water and pristine conditions; taxa on the bottom right (positive x and negative y values) tolerate a good deal of stress from pollution and high temperatures. Taxa on the right may tolerate small amounts nutrient pollution or higher water temperatures, or may be specific to the geology. These relationships will be explored further with species-level data and environmental variables included in analyses.

2013 ALGAE ORDINATION

The algae ordination in some cases confirms findings from the fish and macroinvertebrate ordinations, and in other cases suggests different relationships. The Poconos-Kittatinny and Upper Lehigh clusters stand apart; their overlap with the Schuylkill Highlands is similar to macroinvertebrate patterns but greater than for fish. Separation between Brandywine-Christina and the Middle Schuylkill reflect fish communities, but similarities between Philadelphia and Brandywine-Christina that are apparent in the algal community are not seen with fish or macroinvertebrates.

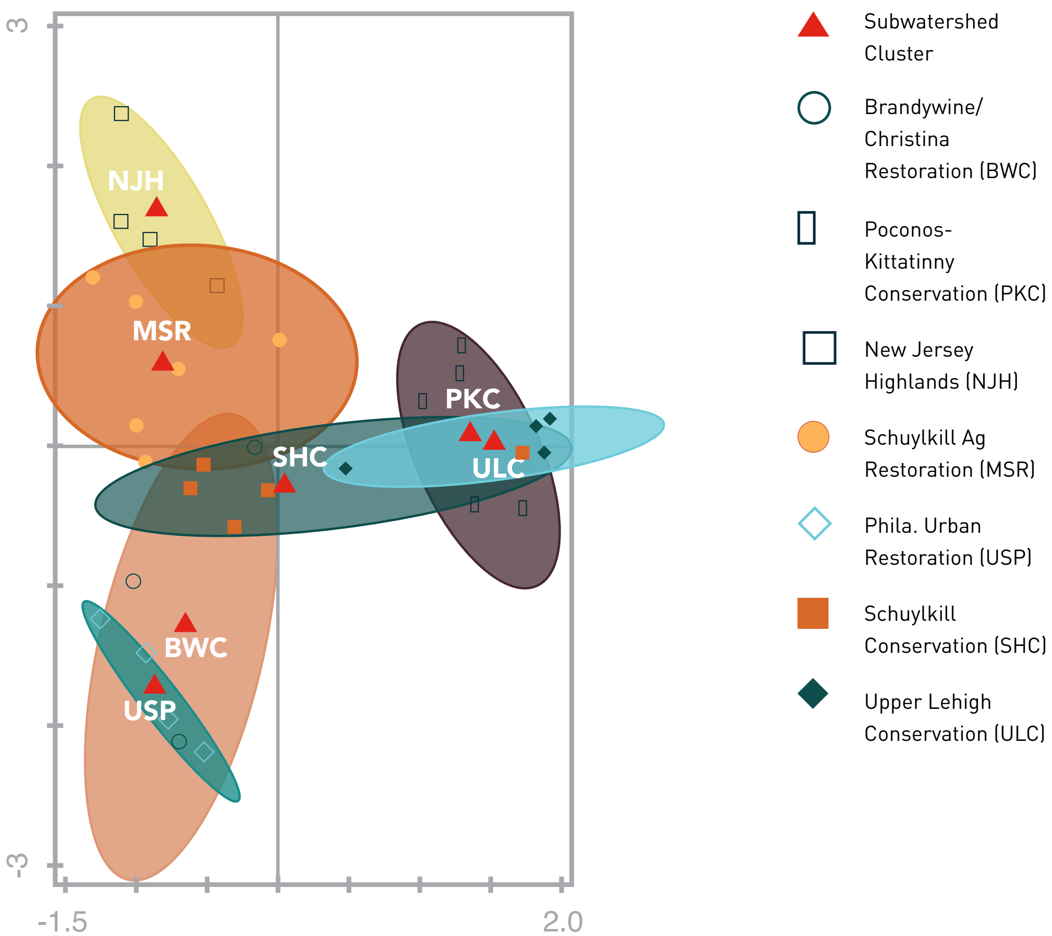


Figure 26. RDA sample classification diagram of diatom species compostion. Diatom species assemblages were constrained by cluster group, represented by enclosed elipses.

2013 & 2014 ORDINATION: COMBINED DATA SETS

We combined data for 2013 and 2014 for all biological indicators (fish, macroinvertebrates and algae) and analyzed all taxa to find those that contributed most to differentiating the quality among sites. Next, we ran an ordination analysis on the top 100 organisms to determine how land use, habitat, and water chemistry were related to this subset of fish, macroinvertebrates, and diatoms. The resulting ordination separated sites better than the ordinations run on the data sets separately, and highlighted four general categories for sites, represented in Figure 27.

The ordination allows us to return to the raw data and identify which members of the fish, macroinvertebrate and algae community are driving similarities and differences, and to set objectives for improvements for sites. For example, sites in the top left of Figure 27 would be considered to have improved ecological integrity when they become able to support species found in top right sites. This information will be used to further refine indicators and IBI metrics used in the next analyses.

Indicator Group Ordination

100 taxa: Fish, macroinvertebrates, diatoms
Combined MDS with land use, habitat, chemistry ordination scores
Top 100 diatom, macroinvertebrate, fish Combined MDS

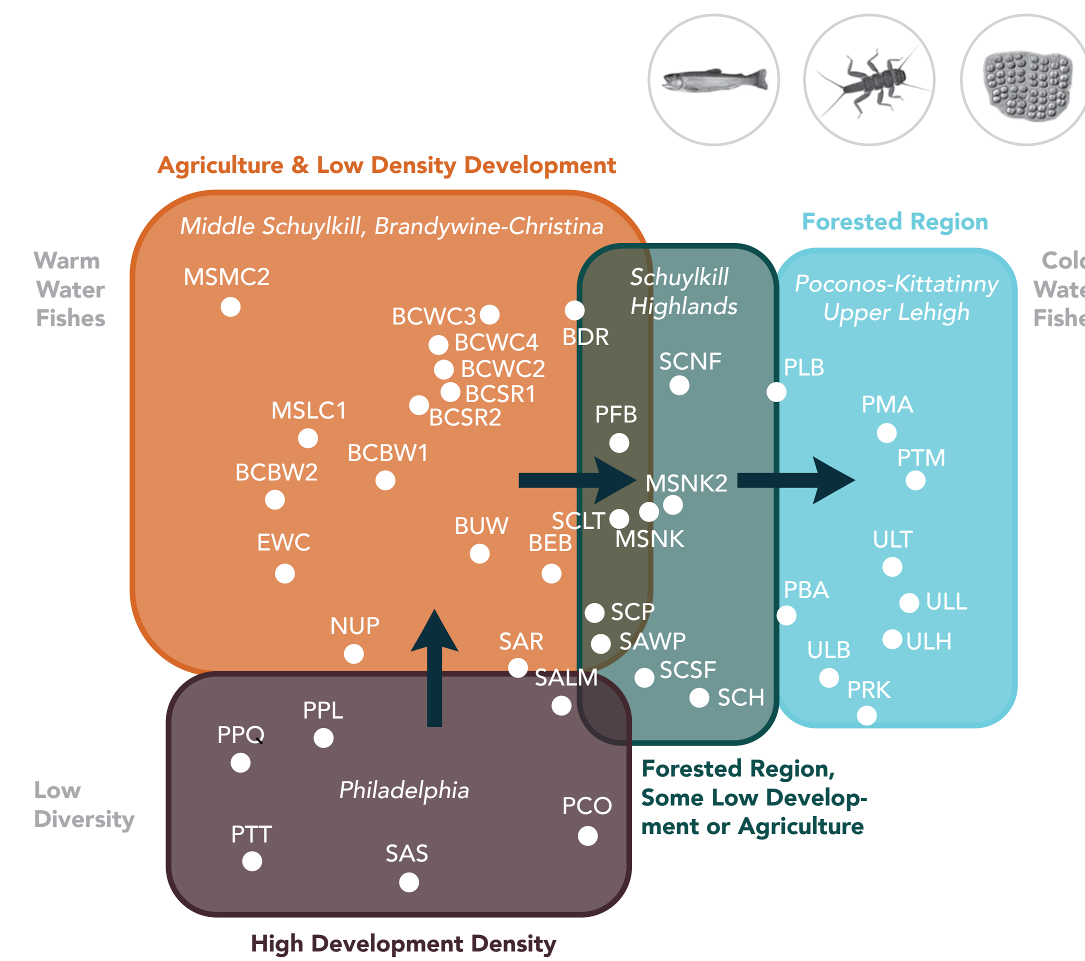


Figure 27. Ordination of the 100 most influential fish, macroinvertebrate and diatom taxa combined with land use, habitat, and chemistry data.

Appendix 4:
Water Chemistry

Water chemistry measures tell us the dominant water chemistry components and the concentrations of the chemicals analyzed. Natural compounds as well as pollutants are equally important in characterizing the chemistry of sites within the subwatershed clusters. Water chemistry samples were analyzed for major ions (typically most prevalent) and nutrients (nitrogen and phosphorus compounds) as well as temperature, pH and salinity (usually measured as conductivity; these two are not synonymous but are related). If DRWI interventions are effective, we would expect to see trends such as decreases in nitrogen and phosphorus compounds as well as sediment, and for riparian buffers we would expect decreases in temperature.

Here we present average values for naturally-occurring compounds (calcium and magnesium) as well as common pollutants that enter waterways through agricultural runoff or wastewater treatment plant discharge (nitrogen compounds such as ammonia and nitrate; phosphorus; total suspended sediment, chloride, some other ions). It is important to note the difference in the y axis from one chart to the next, as different compounds and pollutants can affect stream biota at markedly different concentrations.

Calcium and magnesium are the dominant natural chemical compounds in streams, and they affect stream pH and other aspects of water chemistry, which in turn determine which biota live within a given stream.

Philadelphia sites had the highest amounts of calcium and magnesium, followed by streams in the Middle Schuylkill, Brandywine-Christina, and New Jersey Highlands. This means that these streams may be able to buffer against changes in pH better than sites with lower amounts of calcium. Streams in the Poconos-Kittatinny cluster are more calcareous than the Schuylkill Highlands and Upper Lehigh streams. Diatoms correspond more strongly with high calcium in the New Jersey Highlands than Philadelphia, the Middle Schuylkill and Brandywine-Christina, where other factors may be influencing algae communities more.

Phosphorus can affect stream ecosystem biota at very low levels but should be below 0.05 mg/L. The only cluster where the arithmetic average exceeds this level is Philadelphia, likely as a result of wastewater treatment plant effluent (Figure 29). Ammonia concentrations appear to be within acceptable ranges, as ammonia toxicity is related to temperature and pH.

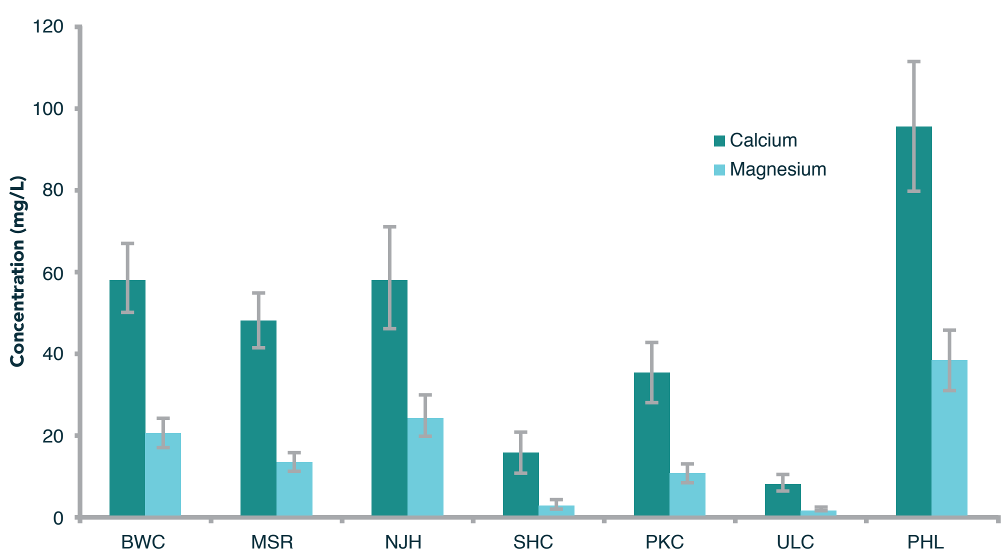
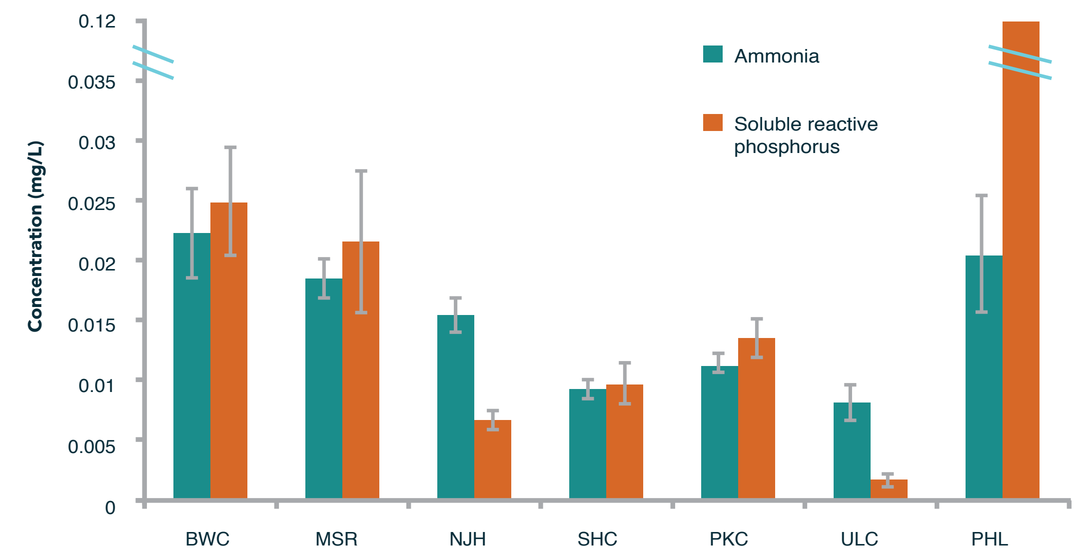


Figure 28. Average concentrations (plus standard error bars) of calcium and magnesium across the clusters in sites sampled seasonally in 2013 – 2014.

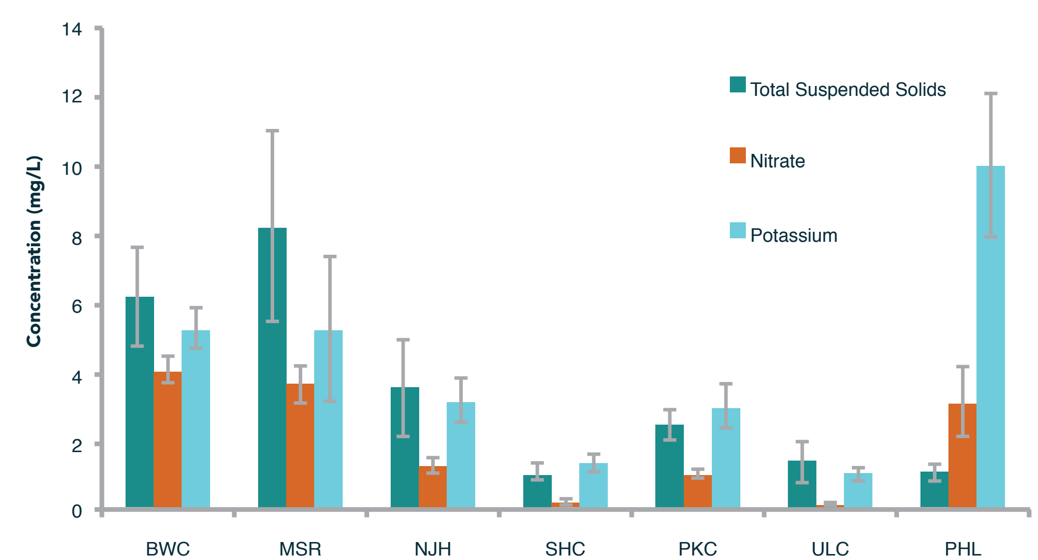
Total suspended solids (TSS) are highest in the Brandywine-Christina and Middle Schuylkill clusters, where agricultural activity is high, followed by the New Jersey Highlands. Potassium, which can come from fertilizer runoff or urban sources, is highest in Philadelphia, followed by the restoration clusters, although it is similarly high in the Poconos-Kittatinny sites, which may be due to wastewater or other point sources. Nitrate, whose source is likely agricultural activity, is approaching the maximum safe level (5 mg/L) in the Brandywine-Christina and Middle Schuylkill clusters. TSS is higher in agriculture-dominated clusters than either Philadelphia or the preservation clusters.

Figure 29. Average concentrations (with standard error bars) of ammonia and phosphorus in sites sampled seasonally in 2013 -2014. Blue slashes on the y axis represent a "broken" axis to show more detail at lower levels while including the maximum value that is much higher for one variable (PHL soluble reactive phosphorus: average concentration is 0.12).



These chemistry data cannot be relied upon alone to describe the water quality of a site because they can be heavily influenced by high (or low) concentrations during a specific event like a storm or spill. However, there are typically consistent relationships between water chemistry parameters and the presence or absence of certain fish, macroinvertebrates, or algae, and the paired collection of water chemistry and biotic data allow for more nuanced interpretations of why biotic communities might deviate from expectations, and also of what stressors may be at work. We will continue to analyze water chemistry data to ascertain whether desired trends are occurring in response to project investments.

Figure 30. Average concentrations (with standard error bars) of total suspended solids, nitrate and potassium in all 70 sites sampled seasonally in 2013 - 2014.



Appendix 5:
Habitat Index

A habitat index score is a measure of the availability of habitat known to support aquatic life, including stable substrate (material in the river bottom), stable banks with intact riparian buffers, and diverse habitat types. It can tell us about hydromorphological functioning (a natural or unnatural amount and degree of flooding) and is more related to hydrologic cycles than water quality typically is. Land use, water quality and habitat quality are linked. For example, agricultural land yields more sediment in runoff than urban or forested land, and sediment affects habitat by filling spaces between larger rocks and providing habitat for burrowers, but it can also degrade habitat for algae (via sediment in the water creating turbidity) and clog fish gills. In streams with high percentages of developed land, flow changes will affect habitat more than they will affect sedimentation. The habitat index is designed to incorporate the effects of eroded banks, reduced riparian cover, homogeneous habitat, and scouring (very deep areas dug out by floods) or exposed river beds (due to drought). The presence of woody debris, on the other hand, indicates natural progression on stream banks and forests with sustainable erosion rates.

Habitat Index Score, all sites (2013-2014)

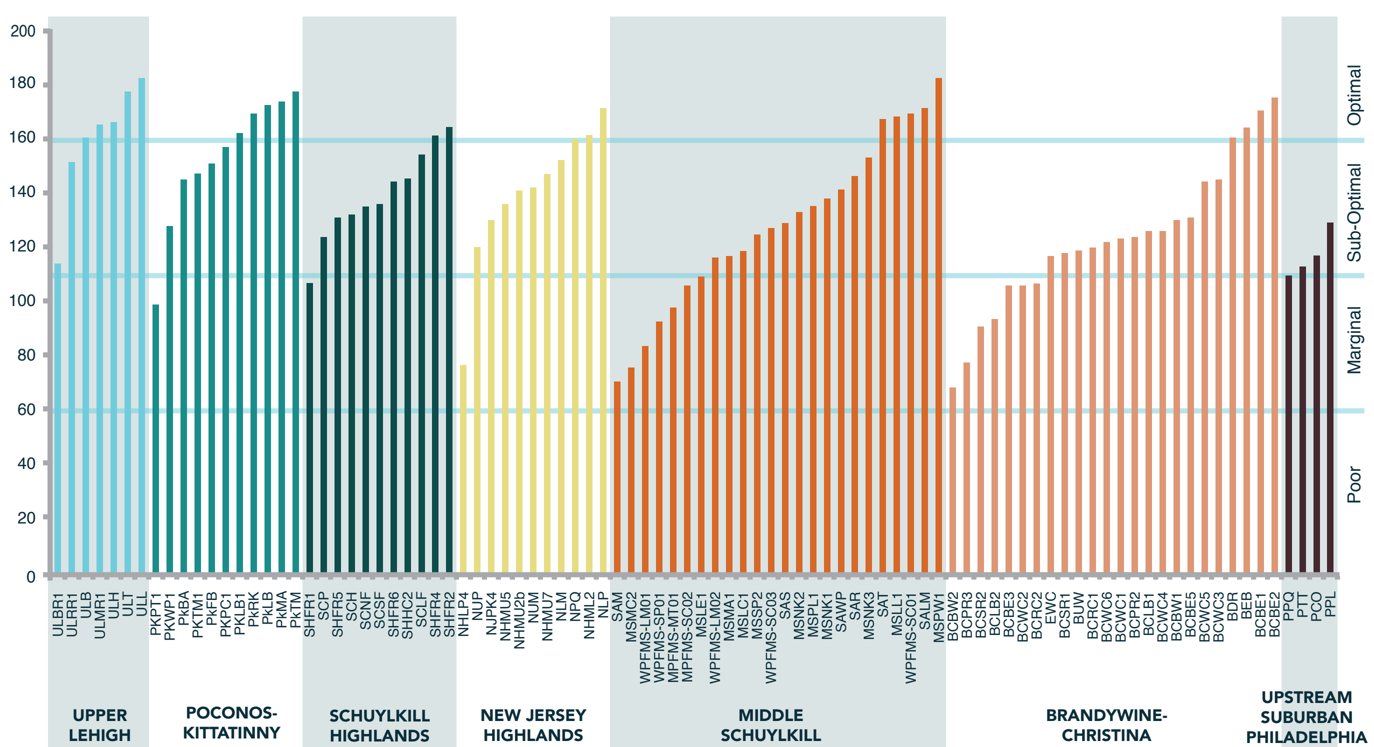


Figure 31. U.S. EPA In-stream Habitat Index[13] scores for all project, adventive and integrative sites sampled in 2013 and 2014.

13. Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers. *USEPA, Washington.*

In most cases, the habitat quality ratings match expectations from land use: more forested areas have higher scores (optimal-suboptimal), with lower scores (marginal) in agricultural and urban streams.

Through our sampling we found that each cluster had a variety of substrate types (sand, gravel, cobbles, boulders). Substrate is important for defining the biota found in a stream, but our first examination of the data suggest that dominance of one substrate over another cannot be used solely to indicate overall habitat quality. In sites in the Middle Schuylkill and Brandywine-Christina, riffles were less dominant than glides compared to the other clusters. (A glide is fast-flowing water with little disruption on the surface; a riffle shows "whitecaps" as it flows quickly over relatively shallow, rocky substrate). Woody debris (logs, small sticks, etc.) was more abundant in the Schuylkill Highlands, Poconos-Kittatinny and Upper Lehigh clusters, where riparian forests are more intact. Cold water, rocky streams in these clusters provide excellent cover for fish and unique habitat for certain macroinvertebrates.

In most cases, the habitat quality ratings match expectations from land use: more forested areas have higher scores (optimal-suboptimal), with lower scores (marginal) in agricultural and urban streams. However, Philadelphia sites received a "suboptimal" rating, which is higher than expected given that those areas do not support diverse biological assemblages due to water chemistry. This may indicate that flooding does not degrade habitat as much as might have been assumed, and that the physical structure of the stream can support biotic communities, but water chemistry is more of a limiting factor.

These physical habitat data will be considered along with chemical data (equally important to understanding habitat quality) to give a complete picture of the physical and chemical components of habitat, related to the needs of the biota.

Appendix 6:

Species Scientific Names

Below are scientific names for those species identified as characteristic of clusters.

Common name	Scientific name
American Brook Lamprey	*Lampetra appendix*
American Eel	*Anguilla rostrata*
Banded Killifish	*Fundulus diaphanus*
Blacknose Dace	*Rhinichthys atratulus*
Bluegill	*Lepomis macrochirus*
Bluespotted Sunfish	*Enneacanthus gloriosus*
Bluntnose Minnow	*Pimephales notatus*
Brook Trout	*Salvelinus fontinalis*
Brown Bullhead	*Ameiurus nebulosus*
Brown Trout	*Salmo trutta*
Chain Pickerel	*Esox niger*
Channel Catfish	*Ictalurus punctatus*
Comely Shiner	*Notropis amoenus*
Common Shiner	*Luxilus cornutus*
Creek Chub	*Semotilus atromaculatus*
Creek Chubsucker	*Erimyzon oblongus*
Cutlips Minnow	*Exoglossum maxillingua*
Eastern Mudminnow	*Umbra pygmaea*
Fallfish	*Semotilus corporalis*
Fathead Minnow	*Pimephales promelas*
Golden Shiner	*Notemigonus crysoleucas*
Green Sunfish	*Lepomis cyanellus*
Ironcolor Shiner	*Notropis chalybaeus*
Largemouth Bass	*Micropterus salmoides*
Longnose Dace	*Rhinichthys cataractae*
Margined Madtom	*Noturus insignis*
Northern Hog Sucker	*Hypentelium nigricans*
Pumpkinseed	*Lepomis gibbosus*
Rainbow Trout	*Oncorhynchus mykiss*
Redbreast Sunfish	*Lepomis auritus*
Redfin Pickerel	*Esox americanus*
Rock Bass	*Ambloplites rupestris*
Rosyside Dace	*Clinostomus funduloides*
Satinfin Shiner	*Cyprinella analostana*
Sea Lamprey	*Petromyzon marinus*
Shield Darter	*Percina peltata*
Slimy Sculpin	*Cottus cognatus*
Smallmouth Bass	*Micropterus dolomieu*
Spotfin Shiner	*Cyprinella spiloptera*
Spottail Shiner	*Notropis hudsonius*
Swallowtail Shiner	*Notropis procne*
Tessellated Darter	*Etheostoma olmstedi*
Western Mosquitofish	*Gambusia affinis*
White Sucker	*Catostomus commersonii*
Yellow Bullhead	*Ameiurus natalis*
Yellow Perch	*Perca flavescens*

Table 14. Common and scientific names for fish species found in DRWI clusters.

Common name	Scientific name
Allegheny Crayfish	*Orconectes obscurus*
Allegheny Mountain Dusky Salamander	*Desmognathus ochrophaeus*
Bullfrog	*Lithobates catesbeianus*
Common Crayfish	*Cambarus bartonii*
Common Snapping Turtle	*Chelydra serpentina*
Dusky Salamander	*Desmognathus fuscus*
Eastern American Toad	*Anaxyrus americanus*
Green Frog	*Lithobates clamitans*
Long-tailed Salamander	*Eurycea longicauda*
Northern Water Snake	*Nerodia sipedon*
Painted Turtle	*Chrysemys picta*
Pickerel Frog	*Lithobates palustris*
Red Salamander	*Pseudotriton ruber*
Redback Salamander	*Plethodon cinereus*
Red-spotted Newt	*Notophthalmus viridescens*
Rusty Crayfish	*Orconectes rusticus*
Spinycheek Crayfish	*Orconectes limosus*
Spring Salamander	*Gyrinophilus porphyriticus*
Two-lined Salamander	*Eurycea bislineata*
Virile Crayfish	*Orconectes virilis*
White River Crawfish	*Procambarus acutus*
Wood Frog	*Lithobates sylvaticus*
Wood Turtle	*Clemmys insculpta*

Table 15. Common and scientific names for reptile, amphibian and crayfish species found in DRWI clusters.

THE ACADEMY
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Patrick Center for Environmental Research
1900 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103

For more information please contact our Delaware River Watershed Initiative team
at 215-299-1106 | ansp.org/drwi

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Written by: Stefanie A. Kroll, PhD. and Robin Abell
Designed and Illustrated by: Ladderback Design and Lin B. Perez
Edited by: Nathan Boon, Richard J. Horwitz, Ph.D., David Keller, John Jackson, Ph.D., Roland Wall, Carol Collier, Alison Minerovic, Michael Campagna, Mary Alice Hartstock

Produced with the generous support of the William Penn Foundation