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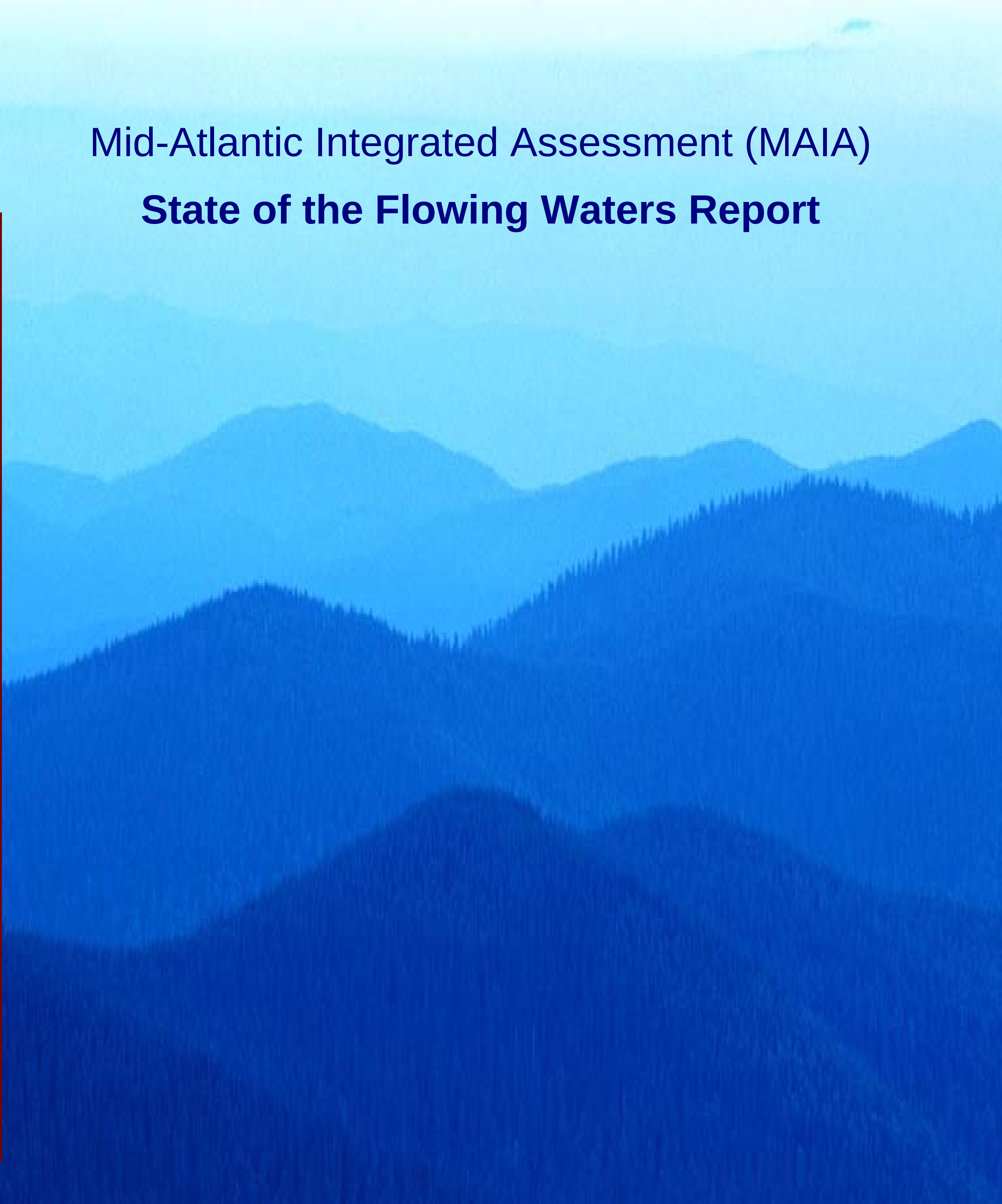
Mid-Atlantic Integrated Assessment (MAIA)

State of the Flowing Waters Report



MID-ATLANTIC INTEGRATED ASSESSMENT (MAIA)

STATE OF THE FLOWING WATERS REPORT

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EXECUTIVE SUMMARY

This assessment serves the purpose of a report card on the state of streams and rivers in the Mid-Atlantic region. It combines data from two sample surveys of flowing waters conducted in the region by the U.S. Environmental Protection Agency during the period 1993-98 (Figure 1). Two unique aspects of this assessment are very important: (1) it focuses first on the biological status of streams and rivers (to assess their ecological condition), and then on the stressors having both the greatest extent and the greatest effects on biological assemblages; and (2) it results from a sample survey design that allow us to present the results as though every stream and river in the region had been sampled. It provides the first statistically unbiased assessment of the health of the region's flowing waters.

Many will conclude from reading this report that the Mid-Atlantic region is getting a failing grade. The report relies on newly created Indices of Biotic Integrity (IBIs) to assess ecological condition. Biotic integrity can be described as "the capacity of an ecosystem to support and maintain a biota that is comparable to that found in natural conditions." The IBIs developed for three key biological assemblages in Mid-Atlantic streams and rivers—fish, macroinvertebrates and algae—all reach similar conclusions, and they are not encouraging. Roughly one-third of the region's stream length exhibits IBI scores that are classified as 'poor,' and forty percent are classified as 'marginal,' regardless of which assemblage is used to draw conclusions. Overall, only one-quarter to one-third of the stream resource of the Mid-Atlantic region exhibits good biotic integrity.

Biological Assemblage:	***Proportion of Stream Resource in Poor Condition***	***Primary Stressors****
Fish	31%	Non-native fish Lack of large wood
Macroinvertebrates	41%	Excess fine sediments Acidity
Algae	33%	Nutrients Excess fine sediments

** based on combination of high relative extent and high relative risk to assemblage*

What kinds of environmental stressors are associated with poor biotic integrity in the Mid-Atlantic? The most important stressors are those that share two characteristics: they are relatively widespread (occurring in a high proportion of stream length) and represent high relative risks to the biological assemblages (i.e., they are more likely to be found in streams with poor biotic integrity). When both characteristics are considered, each biological assemblage presents its own list of key stressors.

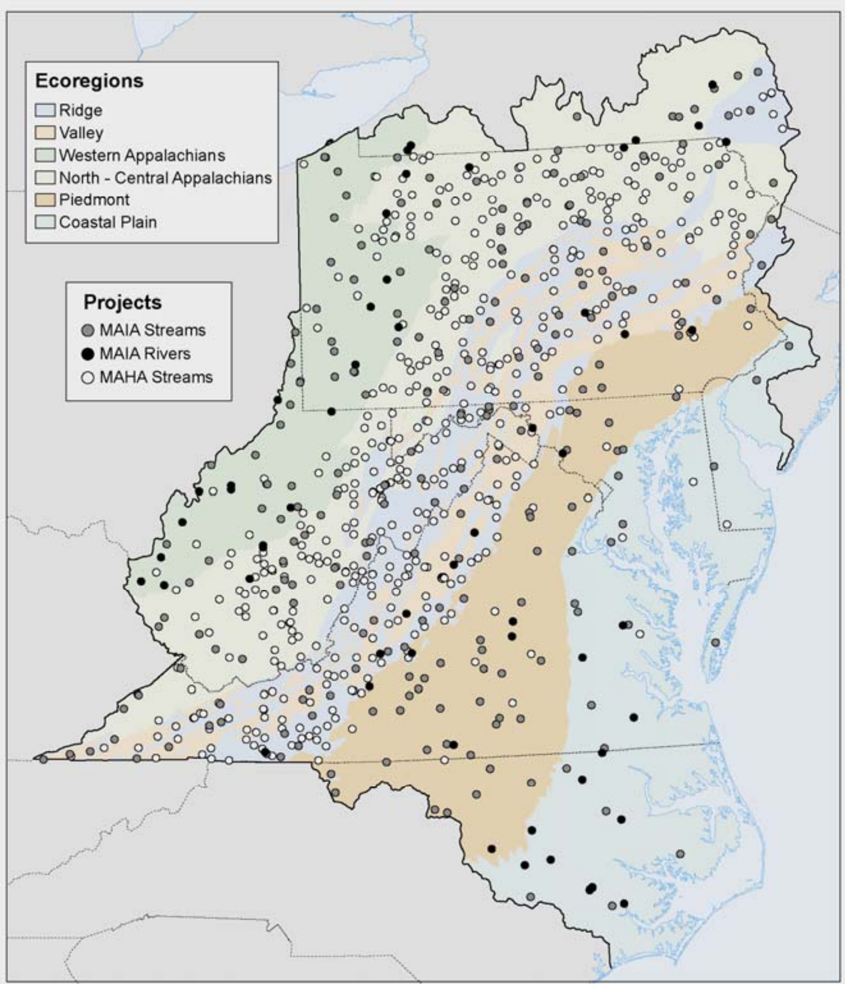

Figure 1. The Mid-Atlantic Integrated Assessment (MAIA) region, and the sampled streams and rivers used in this report. Shaded background colors illustrate the aggregated ecological regions used for reporting results in this report.

- For fish: the introduction of non-native fish species (occurring in 47% of the Mid-Atlantic stream resource) and lack of large woody material (necessary to maintain habitat complexity, and lacking in 26% of stream length) are both common stressors with high relative risks.

- For macroinvertebrates: the presence of excess fine sediments (occurring in 28% of the Mid-Atlantic stream resource) is the most common stressor with demonstrable effects on biotic integrity. Acidity, from either acid rain or acid mine drainage, appears to have significant deleterious effects on macroinvertebrate integrity when it occurs, but is relatively uncommon (<5% of stream length in the region).

- For algae: two nutrients, phosphorus and nitrogen, exhibit the highest relative risks of any stressors on any biological assemblage—both are relatively common in the region (14% to 18% of total stream length). As with macroinvertebrates, poor algal condition is also associated with excess fine sediments—the relative risk from excess sediments is lower than for nutrients, but they occur in a larger proportion of the stream resource (28%).

Not surprisingly, neither ecological condition nor the relative importance of aquatic stressors is uniform across the Mid-Atlantic region. When monitoring data are analyzed according ecological regions (ecoregions), two subregions (the Ridge and North/Central Appalachian ecoregions) are clearly in better overall condition than the others, with more than 40% of the stream resource in good condition for at least one biological assemblage. Two ecoregions are clearly more degraded than the others (the Coastal Plain and Western Appalachian ecoregions), with more than 40% of their total stream length in poor condition for two or more biological assemblages—in both of these subregions, the assemblage in poorest condition indicates that more than 50% of the stream resource exhibits poor biotic integrity. In between these two extremes of ecoregional condition are two subregions in intermediate condition—the Piedmont and Valley ecoregions; both have more than 40% of their stream resource in poor condition for one of the biological assemblages.

Ecological Region:	***Summary of Condition***	***Biological Assemblage Most at Risk*** *(% of stream length in poor condition)*	***Primary Stressors****
Coastal Plain	Relatively Poor	Macroinvertebrates *(88%)*	Excess sediments Non-native fish
Piedmont	Intermediate	Macroinvertebrates *(42%)*	Non-native fish Nutrients
Valleys	Intermediate	Macroinvertebrates *(45%)*	Non-native fish Nutrients
Ridges	Relatively Good	Fish *(26%)*	Non-native fish Lack of large wood
North and Central Appalachians	Relatively Good	Fish *(40%)*	Non-native fish Lack of large wood
Western Appalachians	Relatively Poor	Algae *(51%)*	Excess sediment Lack of large wood

** based on relative extent of stressor in ecoregion*

We cannot assess relative risk to these assemblages at the ecoregion scale, due to insufficient numbers of sites, but we can determine which environmental stressors are most common in each ecoregion. An examination of those stressors found in the greatest extent of the stream resource should help make decisions about which environmental problems merit the greatest attention in these subregions:

- **Ecoregions in relatively poor condition:** The Coastal Plain and Western Appalachian ecoregions have a mix of physical and biological habitat indicators as their most common stressors. Excess fine sediments are a common stressor in both ecoregions (54% of stream length in the Coastal Plain, 38% in the Western Appalachians); presence of non-native fish (Coastal Plain, 55%) and lack of large wood (Western Appalachians, 41%) are only slightly less common.

- **Ecoregions in intermediate condition:** The Piedmont and Valley ecoregions share the two most common stressors: presence of non-native fish species (69% of the Piedmont stream resource, 57% in the Valleys) and nutrients (excessive phosphorus is found in 29% of Piedmont stream length, excessive nitrogen is found in 39% of the Valley stream resource).

- **Ecoregions in relatively good condition:** The two most common stressors in the Ridge and North/Central Appalachian ecoregions are identical: presence of non-native fish species (47% and 32% of stream length, respectively) and lack of large woody material (25% of the stream resource in both ecoregions).

An assessment of the type presented in this Report presents both a challenge and an opportunity to regional managers. The challenge is to take this report card, examine it in detail, and decide how best to improve the condition of the region's flowing waters—by focusing on the assemblages most at risk, the stressors that pose the greatest relative risks to those assemblages, and the subregions with the greatest problems (or greatest possibilities for protection). The opportunity is to use this assessment as a yardstick against which progress can be measured. If the regulatory actions, restoration and remediation efforts, and management decisions undertaken in the region are having their intended effect(s), then improvements in ecological condition should result. It only remains to be seen how effective we can be in improving the condition of Mid-Atlantic streams and rivers, given the compass that good data, like those presented in this Report, can provide.

FOREWORD

This Mid-Atlantic Integrated Assessment (MAIA) “State of the Flowing Waters Report” is an ecological assessment of non-tidal streams and rivers in the Mid-Atlantic region. It is based on the combined results of two unique and experimental monitoring programs implemented through the U.S. EPA’s Environmental Monitoring and Assessment Program (EMAP) during the years 1993-98. We present these results, presented in a way that we hope both environmental resource managers and the general public find useful, with two major objectives in mind: (1) to document, in as clear and unbiased a manner as possible, the overall condition of the vast network of flowing waters that drain the Mid-Atlantic region; and (2) to demonstrate the utility and flexibility of an EMAP-like approach to environmental monitoring at this regional scale.

The assessment is divided into two major categories. We first document the ecological condition of streams and rivers in the MAIA region, through the use of direct measures of their resident biological assemblages (fish, macroinvertebrates and algae). We then assess the relative importance of a long list of potential stressors on those assemblages, based on direct measures of their chemical, biological and physical habitat, and human use of the watersheds. We present the results in this way in order to inform readers about where the major current ecological problems occur in the region, what the most important threats to the current ecological condition are, and how much risk these stressors represent to aquatic ecosystems.

Our approach in collecting the data for this assessment has two major characteristics. First, it focuses as much as possible on direct measures of biological indicators, and on the chemical and physical properties of stream and rivers that are most likely to have effects on biological communities. Second, it uses an innovative statistical design that insures that the results are representative of the region, and allows us to extend this statistical certainty in the results to smaller areas within the region (e.g., to the major ecological regions within the MAIA region) where desired.

The report is organized into 5 sections and 2 appendices. After a short **Introduction** to the assessment, we describe the geographic diversity of the **Mid-Atlantic Region** and its streams and rivers. In Section 3 we present the results of sampling of the **Ecological Condition of MAIA Flowing Waters**, and in Section 4 we expand these results to include the relative importance of **Stressors in MAIA Flowing Waters**. Finally, we discuss how stream managers in the Mid-Atlantic might use the results of this assessment for **Geographic Targeting**.

This report is written for the public, for environmental managers, and for decision-makers. Much of the technical background for the report has already been published in the scientific literature, and we include a list of key publications in Appendix C at the back of the report. Readers who wish to learn more about the design, specific indicators, or other elements of the assessment are encouraged to consult this list and read the technical papers upon which this assessment is based.

Figure 2 The Mid-Atlantic Integrated Assessment (MAIA) region

INTRODUCTION

PURPOSE

The Mid-Atlantic Integrated Assessment (MAIA) Flowing Waters Assessment has a four-fold purpose:

1) Assess and report on the ecological condition of all flowing waters in the Mid-Atlantic region.
2) Use direct measures of biological assemblages to describe the ecological condition of MAIA streams and rivers.
3) Use supplemental measures of chemical, physical and biological habitat to identify and rank the relative importance of potential stressors affecting stream and river condition.
4) Influence how states design their monitoring programs, how they assess and report on the condition of flowing waters.

Working in partnership with the states (Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, and West Virginia), the U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), multiple universities, and Environmental Protection Agency (EPA) Region III, the EPA Environmental Monitoring and Assessment Program (EMAP) assembled crews in 1993 through 1998 to collect 1050 samples on 850 sites throughout the Mid-Atlantic region, including both wadeable streams and boatable rivers. All of the crews were trained to use identical sampling methods to facilitate comparisons across the region. This report explains our objectives, methods and results.

STREAM AND RIVER CONDITION

Most historic assessments of stream quality have focused on describing the chemical quality of streams and, occasionally, on sport fisheries impacts. As we have made progress in controlling chemical problems, it has become obvious that the ultimate concern is actually the health of the plants and animals that inhabit these streams and rivers.

In this assessment we have tried to address this concern not by ignoring physical and chemical measurements, but by shifting the focus to direct measurements of the biota themselves. In this assessment, the ecological condition of flowing waters is defined by biological indicators. The biological organisms in a stream integrate the many physical and chemical stressors and forces, including other biota (parasites, predators, or competitors), that are acting in, and on, the stream ecosystem. Stream and river condition can be determined by assessing appropriate biological indicators (Table 1), or combinations of these indicators called indices. Information on the ecological condition of flowing waters is supplemented by measurements of other stream characteristics, especially those physical, chemical, or other biological factors that might influence or affect stream condition. These stream characteristics allow us to assess the potential stressors of stream condition, based on expected signals from major environmental perturbations (e.g., physical habitat modification, mine drainage, acid rain, agricultural nutrients, etc.).

Table 1

Examples of ecological indicators measured in MAIA streams and rivers

Indicators of Ecological Condition	Rationale
Fish assemblages	Important indicators of stream and river condition; respond strongly to larger-scale disturbances in streams and watersheds, including channelization and riparian disturbance; middle to upper end of food web; accumulate contaminants that are then consumed by mammals and birds. Caution: some smaller streams may naturally lack fish. Absence of fish from small streams cannot be interpreted as an indicator of poor ecological condition.
Macroinvertebrate assemblages	Larval stages of macroinvertebrates (largely aquatic insects; also snails and some worms) are sensitive to disturbances to stream chemistry and in-stream habitat (particularly sedimentation). Because many adult stages are mobile, macroinvertebrate assemblages are thought to recover rapidly after conditions improve.
Algal assemblages	Attached algae (largely diatoms) grow on surfaces of rocks and fine substrates (e.g., sand) and are very sensitive to changes in chemistry (particularly nutrients and pH) and sedimentation; most species are cosmopolitan (occur throughout the world) and their environmental tolerances are therefore well known.
Indicators of Stress	**Rationale**
Acidity	Low values of pH and alkalinity result from both acid rain and acid mine drainage; can be directly or indirectly toxic (e.g., by mobilizing toxic metals) to fish and macro-invertebrates; leads to greatly simplified biological assemblages.
Nutrients	Excess amounts of phosphorus and nitrogen enter streams from fertilizer use and sewage; stimulate algal growth and simplify biological assemblages.
In-stream habitat	Excess supplies of fine sediments from watersheds fill spaces between gravels, cobbles and boulders that are normal habitat for macroinvertebrates and spawning fish; sediment movement downstream disturbs attached algae. Large wood (formerly Large Woody Debris) provides in-stream habitat complexity required for high biodiversity, and helps to stabilize fine sediments.
Riparian habitat	Stream bank alteration (removal of trees, shrubs, grasses; erosion of banks; stabilization of banks) affects shading and habitat complexity of streams.

The combination of biological and stressor indicators listed in Table 1 represents our best current understanding of the biological, physical and chemical factors that collectively determine stream and river quality. Many of the in-stream stressors listed have a direct impact on biological assemblages, and are in turn affected by human use and disturbance of the upstream landscape.

One of the unique aspects of this assessment is that it uses data from two statistical surveys (see below) of streams and rivers to describe the condition and characteristics of the population of flowing waters in the Mid-Atlantic region. It is intended to answer, in as direct and unbiased a way as possible, the question, “What is the condition of Mid-Atlantic streams and rivers?”

REGIONAL STATISTICAL SURVEYS

In the past, EPA and the states addressed municipal and industrial point sources of chemicals as major threats to streams and rivers. This led to focusing monitoring, assessments, and controls very locally on individual segments of streams above and below known point source discharges. Monitoring locations were selected to evaluate the effectiveness of improved treatment of these municipal and industrial discharges. As these point sources were cleaned up, it became apparent that additional stressors were threatening our aquatic resources. Some attempts were made to aggregate existing data and use them in regional assessments, but the limitations of this approach became apparent because the local sites were not representative of other flowing waters or areas in the region, and consistent sampling and analysis methods were rarely used. Another approach was needed to assess stream quality on a regional basis.

EPA and the states, working first on small streams in the Mid-Atlantic Highlands, and later expanding to both rivers and streams throughout the Mid-Atlantic region, wrestled with these problems and came up with a different approach for stream/river monitoring. In addition to implementing direct measures of the ecological condition of the biota themselves, they devised a way to pick monitoring locations that do not focus on known problem areas (e.g., sewage outfalls). Instead, monitoring sites were chosen through a statistical approach that provides, in aggregate, a clear and objective view of the condition of all flowing waters. It is hoped that this approach, and this assessment, can serve as models for future National Water Quality Inventories. These biennial reports (also known as 305[b] reports, after the section of the Act that mandates them). to Congress are required by the Clean Water Act, and are often criticized for their lack of objectivity.

During the years 1993 and 1994, EPA researchers used sample survey techniques to identify representative small streams (1st through 3rd order) throughout the upland portions of the Mid-Atlantic region. The biological, chemical and physical habitat sampling of those streams resulted in the *Mid-Atlantic Highlands Streams Assessment* (see Appendix C), the first comprehensive assessment of the ecological condition of streams in any region using both statistical site selection and biological indicators. Work in the Highlands (referred to as MAHA) continued in 1995 and 1996, and those additional data are used in this report.

In 1997 and 1998, data collection was expanded to all non-tidal streams of the Mid-Atlantic region (Figures 2 and 3), and for the first time the unique aspects of EMAP sampling (biological indicators and statistical design) were extended to include large (non-tidal) rivers. This larger-scale project was known as MAIA. A major emphasis in MAIA was to extend the sampling methods developed for wadeable streams in MAHA to the large rivers included in MAIA. The result is a set of sampling protocols, all based on identical principles and producing identical information, for all sizes of flowing waters (see Lazorchak references in Appendix C).

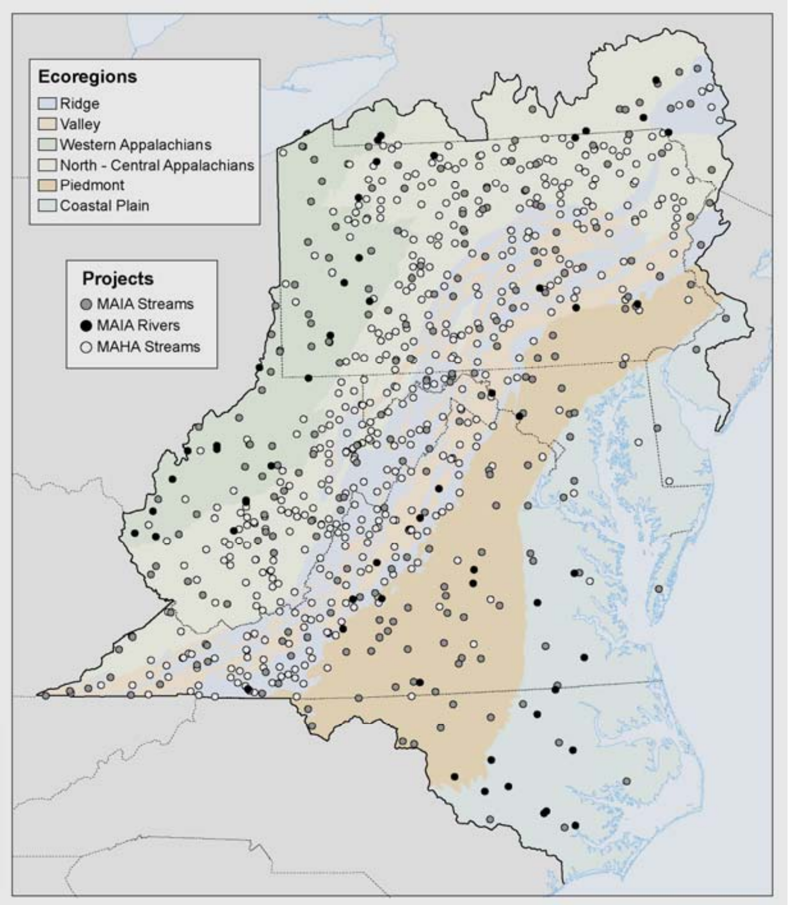

Figure 3. The MAIA region with sampling sites on small upland streams (open circles, sampled as part of the MAHA project), small regional streams (grey circles, sampled as part of MAIA) and large rivers (black circles, MAIA).

Because of the unique statistical properties of the EMAP sample surveys, we are able to combine results from both MAHA and MAIA in this assessment, and produce unbiased estimates of the condition of all flowing waters in the Mid-Atlantic region for the period from 1993 to 1998. In total, the MAHA and MAIA projects collected 1050 samples on 850 sites in the region. These data are used to estimate such regional characteristics as the proportion of stream miles that are impaired or degraded biologically, the relative importance of potential stressors (such as mine drainage or stream sedimentation) in the region, and the relative risk that these stressors pose to biological assemblages.

A statistical survey of flowing waters operates in the same manner as the public opinion polls used to project winners and losers of political elections. A sample of stream reaches is selected at random to represent the population of flowing waters in a region, just as the sample of individuals in a public opinion poll is selected to represent the voting population as a whole. Regional statistical surveys have been used for many years in forestry and agricultural monitoring programs to determine the condition of forests and agricultural lands, but their use in assessments of aquatic ecosystems is just beginning. Additional information on the EMAP stream design can be found in the references listed in Appendix C.

One of the advantages of a regional statistical survey is that, for any estimate of stream and river condition (e.g., the proportion of stream length in degraded condition), we can also estimate “confidence intervals” around the estimate. Confidence intervals are measures of uncertainty, and are exactly analogous to the “margins of error” that accompany public opinion polls (e.g., Candidate A leads Candidate B by 10%, with a margin of error of ± 4%—meaning that the true lead is somewhere between 6% and 14%). These margins of error are smaller when we use larger sample sizes (e.g., the number of people taking part in a poll, or the number of flowing waters sampled), and are smaller when our population estimates are near one of the extremes (e.g., near 1% or 99%). The greatest uncertainty occurs when the sample size is small (e.g., fewer than 50 sites) and the population estimate is near 50%—analogous to a dead heat in a political poll. Because the number of sites sampled in MAHA and MAIA varies with different indicators (the largest number of sites have chemical data; the smallest number of sites have fish data) and the regions or sub-regions assessed (e.g., the MAIA region as a whole has the highest number of sites; the Coastal Plain ecoregion has the lowest number), the confidence intervals are slightly different for each estimate of condition that we present. Rather than cluttering the report with hundreds of confidence intervals, we have chosen to present a single, general “margin of error” for each indicator and each subregion assessed. Each estimated margin of error is the 90% confidence interval calculated from the actual sample size for each estimate, but assuming a population estimate of 50% across the board. Readers of this report may want to keep these confidence intervals in mind as they contemplate the results (e.g. given a margin of error of plus or minus 15%, are apparent differences between subregions significant?).

THE MID-ATLANTIC REGION

BACKGROUND

The Mid-Atlantic region encompasses approximately 180,000 square miles and extends from the Atlantic Ocean in the east to the Ohio River in the west, and from the headwaters of the Delaware and Susquehanna drainages in New York in the north to the Neuse River drainage in North Carolina in the south (Figure 2). It includes all of EPA’s Region III, all of the states of Delaware, Maryland, Pennsylvania, Virginia and West Virginia, and parts of New Jersey, New York and North Carolina.

The Mid-Atlantic region is a diverse place with dramatic changes in geology, elevation, climate, vegetation, land cover and demographics. These characteristics work together to create interesting patterns in the landscape. It is helpful to consider these patterns, because they provide a context to discuss and understand the health of the region’s rivers and streams.

To the east, the low-lying, flat Coastal

Plain is characterized by many shallow inland bays and meandering tidal rivers. Chesapeake Bay, the nation's largest estuary, dominates the landscape and provides both commercial and recreational opportunities to millions of people. Agriculture is the dominant land cover on the Delmarva peninsula and the eastern shore of Maryland. This area has the smallest amounts of forested land cover in the region.

Most of the people in the Mid-Atlantic region live in the urban corridor between the District of Columbia and Philadelphia, and in the Pittsburgh area. Population growth is highest in the Coastal Plain, near the ocean and the estuaries; growth is flat or negative in the western areas of the region. Historically, people have settled where rich farmland and navigable rivers offer abundant food and easy transportation. Philadelphia is located on the Delaware River; Harrisburg on the Susquehanna River; Pittsburgh on the Ohio, Allegheny and Monongahela Rivers; Baltimore on the Patapsco River; Washington, D.C. on the Potomac River; Richmond on the James River; and Norfolk directly on the Chesapeake Bay.

As one travels west across the region, the low, rolling hills of the Piedmont appear. These hills are like stair steps leading to the Blue Ridge and the Appalachian Mountains farther west. The Blue Ridge Mountains form the first barrier to the western landscape. They appear as a sharp, forested ridge. Once beyond that ridge, the Great Valley of the Shenandoah opens up. Farmland once again dominates the landscape. These fertile soils have been farmed for centuries.

Continuing westward, the Appalachian Ridge and Valley province appears, with sharp-crested ridges running from northeast to southwest in clean parallel lines like long waves on an ocean. These ridges were formed by the folding of the landscape, and the road cuts offer excellent opportunities to view the deformed layers of sedimentary rocks. As one might expect, the ridges of this region remain largely forested. The slopes are steep, the soils are thin, and they are not ideal for either farming or urban development. The valleys of the Ridge and Valley Province are intensively farmed. The landscape is fairly flat in the valleys, and the soil is deep and fertile.

Farther to the west and south, the Allegheny Escarpment rises abruptly. At the top of this escarpment, the layers of sedimentary rock lie relatively flat and undisturbed. This is the Allegheny Plateau. Unlike the long, broad, parallel valleys and ridges to the east, the creeks and rivers here dissect the flat plateau to form deep and twisting gorges. The valley bottoms are much narrower than those to the east.

The largest tracts of forest in the Region are found on the Plateau, to the north in Pennsylvania, and to the south in West Virginia. Some of these forests are the largest tracts of public land in the region and offer significant recreational opportunities to hikers, hunters, fisherman, and others. In the Mid-Atlantic region, many of these forested areas remain forested because they have steep slopes with poor soils that are unsuitable for agriculture and urban development. These characteristics make the areas more susceptible to the effects of acid rain. Portions of the Allegheny Plateau and Ridges are particularly sensitive to acid rain.

The Western Allegheny Plateau and Central Appalachians are made up of bedrock containing significant amounts of coal. Bituminous coal fields, where high sulfur coal is found, are found primarily in the West—western Maryland, western Virginia, Pennsylvania and northern West Virginia—and can cause significant acid mine drainage problems when mined. Lower sulfur, cleaner burning coal is found farther south in southern West Virginia. Much of the mining activity in recent years has shifted south to extract the lower sulfur coal as a result of tightening clean air regulations. This coal is often mined by the "valley fill" process which removes whole mountain tops to reach the coal-bearing strata, and fills adjacent river valley with spoils. Nearly all of the anthracite coal in the United States is found in eastern Pennsylvania. Anthracite coal is found folded in discrete layers between layers of sandstone, and results from the great deformation and movement of rock that produced the Allegheny mountains.

These regional patterns provide important context for understanding the health of rivers and streams at a broad regional scale. Streams in the valleys and on the Delmarva Peninsula, with intense agricultural land use, might have higher nutrient, pesticide and bacteria concentrations and problems with sedimentation. Streams and rivers in the highly urbanized areas might be impaired by point source and storm water runoff. Streams on the forested ridges and in the low-lying southern Piedmont and Coastal Plain areas that have naturally low buffering capacity might be impaired by acid rain. Streams in the coal mining areas of the region might suffer from acid mine drainage, increased metals and sediment, and larger scale habitat impacts that result from mining. These patterns only indicate the potential impacts and stressors. We must take a step further and consider data on stream ecological health, water quality and physical habitat quality to determine whether actual impacts exist.

ECOLOGICAL REGIONS

Ecological regions (or ecoregions) are areas that have similar soils, vegetation, climate, and physical geography. An ecoregion perspective highlights the differences, for example, between mountain areas with their steep slopes, shallow soils, and cooler climate, and valley areas that are relatively flat, have deep soils, and warmer temperatures; ecoregions permit us to have different expectations of flowing waters in these very different areas. An ecoregion perspective also helps us understand why streams respond to various human disturbances as they do and which management solutions might be applicable. Ecoregional differences play a major role in determining which flowing waters have been affected by, or are susceptible to, different stressors. Management practices within an ecoregion typically are applicable for many of the flowing waters with similar problems because the characteristics of the streams in the ecoregion are similar.

Ecoregions have been developed at many different scales for the entire U.S., and for smaller regions like the Mid-Atlantic. For the purposes of this assessment, we have combined various levels of ecological regions into the six ecoregions described in the next section. We feel these ecoregions do a good job of capturing the intra-regional variability of the Mid-Atlantic. They include the: (1) Coastal Plain; (2) Piedmont; (3) Valleys; (4) Ridges; (5) North and Central

Appalachians; and (6) Western Appalachians (Figure 4). A more complete description of ecoregions can be found in the references of Omernik and Woods in Appendix C.

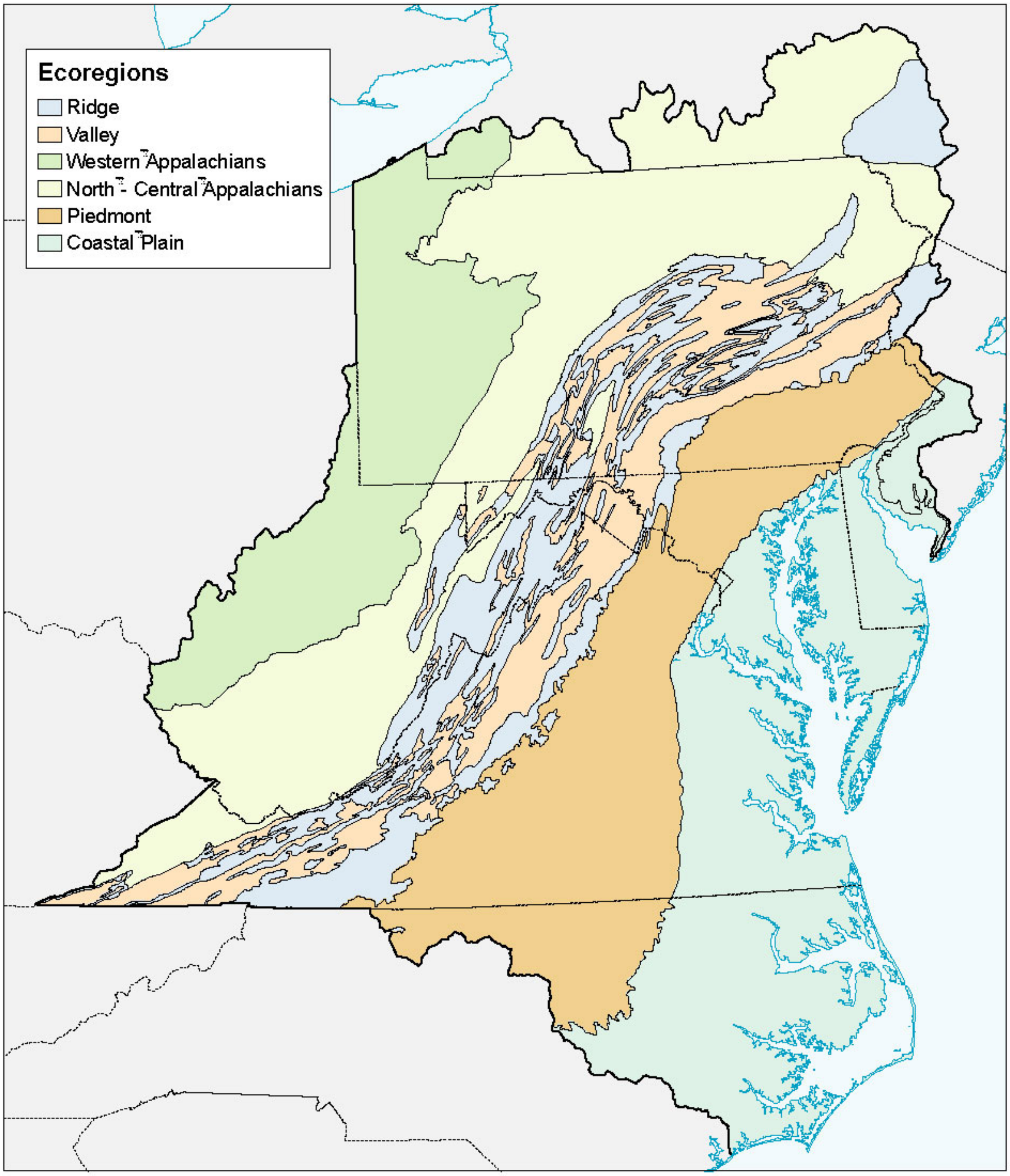

Figure 4. Ecological regions (ecoregions) of the Mid-Atlantic region. Ecoregions are areas with similar physical geography, soils, climate and vegetation types. We use six aggregated ecoregions to classify and assess stream sites in this report.

COASTAL PLAIN ECOREGION

For the purposes of this assessment, the "Coastal Plain" comprises both the Middle Atlantic Coastal Plain ecoregion and the Southeastern Plain ecoregion. It consists of low elevation flat plains, with many swamps, marshes, and estuaries to the east, and a mosaic of cropland, pasture, woodland, and forest to the west. It contains many of the urban centers of the Mid-Atlantic region, including Washington D.C., Baltimore and Richmond. Forest cover in the region is predominantly longleaf and shortleaf pine, with smaller areas of oak, hickory, gum, and cypress near major streams. Poorly drained soils are common. Elevations and relief are generally less than in much of the Piedmont. Streams in this area are relatively low-gradient and sandy-bottomed.

PIEDMONT ECOREGION

The "Piedmont" (for the purposes of this assessment) consists of both the Piedmont ecoregion proper, and the Northern Piedmont ecoregion—physiographers consider it the non-mountainous portion of the old Appalachian highlands. It comprises a transitional area between the mostly mountainous ecoregions of the Appalachians to the northwest and the relatively flat Coastal Plain to the southeast. It is a complex mosaic of metamorphic, igneous and sedimentary rocks, with finer-textured soils than in Coastal Plain. Once largely cultivated, much of this region has reverted to pine and hardwood woodlands, and more recently has seen increasing conversion to urban and suburban landuse.

VALLEY ECOREGION

The Valley ecoregion, including the "Great Valley," extends from eastern Pennsylvania southwesterly through southwestern Virginia. The valleys generally fall into two types, those underlain by limestone and those with shale. The nutrient rich limestone valleys contain productive agricultural land. By contrast, the shale valleys are generally less productive, more irregular, and have greater densities of flowing waters. Most of the streams in the limestone valleys are colder and flow all year, whereas those in the shale valleys tend to lack flow in dry periods. Dense concentrations of poultry operations can be found in many parts of the valleys. Many of the flowing waters in this report are located in the Valley ecoregion, but drain watersheds that extend onto the Ridges. Most ecological classifications combine the Valleys and Ridges into a single ecoregion.

RIDGE ECOREGION

The Ridge and Blue Ridge ecoregion is a series of linear mountainous ridges, with elevations from approximately 1,000 feet to 5,700 feet, running between lower elevation valleys. This mostly forested ecoregion contains high gradient, cool, clear streams occurring over mostly sandstone and shale bottoms. The ecoregion has no major urban areas and has a low population density. However, due in large part to the close proximity of metropolitan areas in the Coastal Plain and Piedmont regions to the east, recreational development in the region has increased considerably in recent years.

NORTH AND CENTRAL APPALACHIAN ECOREGION

The North and Central Appalachians in northern and central Pennsylvania and central West Virginia are a vast elevated plateau of high hills, open valleys, and low mountains with sandstone, siltstone, and shale geology, and coal deposits. The northern and eastern portions of this ecoregion are the only glaciated areas in this Report. Much of the eastern part of the ecoregion is farmed and in pasture, with hay and grain for dairy cattle being the principal crops. There also are large areas in oak and northern hardwood forests. Land use activities are generally tied to forestry and recreation, but some coal and gas extraction occurs in the northwestern part of the region.

The southern part of the ecoregion in West Virginia is primarily a forested plateau composed of sandstone and shale geology and coal deposits. Due to the rugged terrain, cool climate, and infertile soils, this area is more forested and contains much less agriculture than the Valley and Western Appalachian ecoregions. Coal mining is a major industry in this part of the region. Acid mine drainage and stream sedimentation associated with coal mining are possible stream impacts.

WESTERN APPALACHIAN ECOREGION

The Western Appalachian ecoregion runs from western Pennsylvania into western West Virginia. The hilly and wooded terrain of this ecoregion is less rugged and not as forested as the ecoregions to the east (North and Central Appalachians). Much of this region has been mined for bituminous coal. Once covered by a maple-beech-birch forest, this region is now largely in farms, many of which are dairy operations. This ecoregion is characterized by low rounded hills, low gradient streams and extensive areas of wetlands.

STREAM SIZE

Along with ecoregional differences, and differing amounts of human disturbance, potential stream condition is strongly affected by stream size. In order to standardize the concept of stream size when comparing streams across large areas, stream sizes are often broken up into Strahler orders (Figure 5). This is a convenient, and consistent, approach to classifying streams according to size, with headwater streams (throughout the world) being classified as first order, and larger orders referring to larger streams. For the EMAP data collection effort In the Mid-Atlantic, where 1:100,000 scale U.S.G.S. maps were used to specify the stream network, the largest rivers are eighth order.

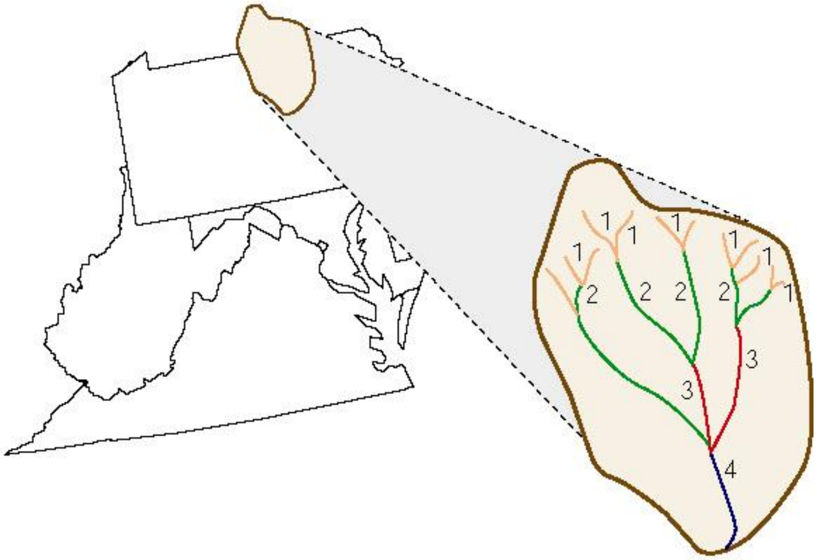

Figure 5. Stream sizes are categorized by Strahler orders, demonstrated here for a hypothetical watershed in the Mid-Atlantic. The confluence (joining) of two 1st order streams forms a 2nd order stream; the confluence of two 2nd order streams forms a 3rd order stream, etc.

The size (or order) of a stream not only affects its natural characteristics, but also its capacity to handle both point source and non-point source pollutants (Figure 6). Stream size frequently affects the size and type of biotic community present, particularly for fish, and may control the relative importance of factors to which the biota respond. Very small streams (first-order, headwater streams) are often quite clear and shaded by trees; they are likely to be dominated by aquatic insects in the stream bottom and with small fish that feed on these bottom organisms. Large streams (sixth- to seventh-order rivers) are often muddy with canopy cover only along the banks, and are dominated by larger fish that are omnivorous (feeding on plants and animals) and/or piscivorous (feeding on smaller fish).

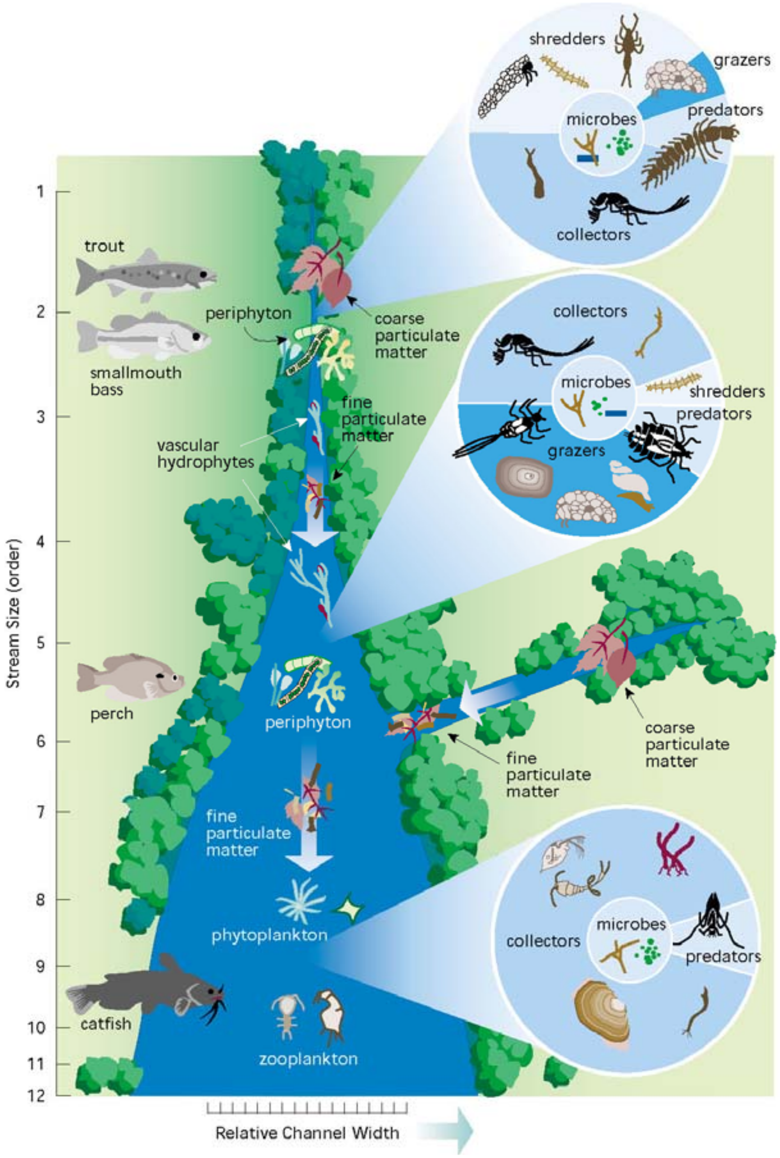

Figure 6. Stream characteristics change as the size or order of the stream increases. Smaller streams (1st through 3rd order) dominate in the region. This "State of the Flowing Waters Assessment" includes sites throughout the range of stream orders illustrated.

Small, first-order streams are the dominant stream class in the Mid-Atlantic region and throughout the world; over 125,000 stream kilometers (i.e., almost 60% of the total length) are classified as first-order streams (Figure 7). Second-order streams are larger and start at the point where two first-order streams come together. Over 35,000 kilometers of streams in the Mid-Atlantic (i.e., 17%) are second-order streams. Almost 90% (199,000 km) of flowing waters in the region are small first- through third-order streams. Because small streams contribute most of the stream length, their condition has a dominant effect on any assessment that presents its results on the basis of stream length (like this one, and the National Water Quality Inventories required by the Clean Water Act).

Historically, management practices have focused on large streams, which are best known to the public due to their use in navigation and boating, and their visibility from major road crossings. Small streams, on the other hand, dominate the total stream length in the region, contribute to the quality and condition of larger streams and rivers, and are critical to determining the condition of all flowing waters in the Mid-Atlantic.

The stream network used for selecting sampling sites in this assessment, and for estimating the total length of flowing waters in the region, was the EPA River Reach File, Version 3. This digital database includes all flowing waters that are represented on USGS maps at a scale of 1:100,000. The map scale used is important because it affects the estimate of stream length and stream order. The stream network shown on 1:100,000 scale maps was considered a good representation of the population of Mid-Atlantic flowing waters—official estimates of stream length (e.g., in each state) by EPA's Office of Water are based on this map scale.

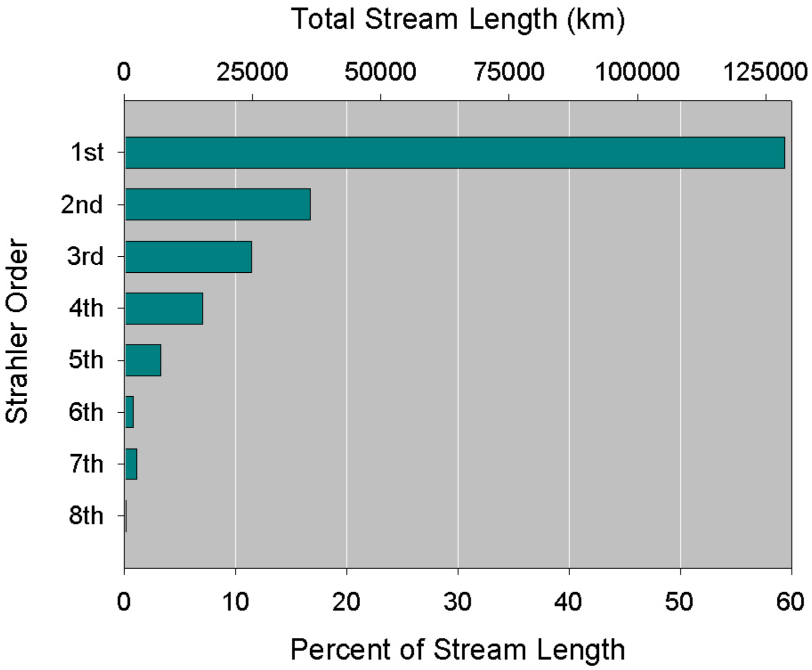

Figure 7. Lengths of streams (both in km and as a percentage of the total) in different stream orders in the Mid-Atlantic region. Almost 90% of the region's stream length is in small first- through third-order streams. Large rivers (fifth- through eighth-order) make up about 5% of the total length of flowing waters.

ECOLOGICAL CONDITION

To assess the overall condition of MAIA flowing waters, we looked at multiple biological, chemical and physical habitat indicators. To answer the specific question "**What is the ecological condition of Mid-Atlantic streams and rivers?"** we rely on direct measures of the biological communities that inhabit the streams and rivers. Throughout this report, ecological condition—good, marginal, or poor—is determined by biological indicator or index scores. The fish, algae, aquatic insects, and other animals and plants in a stream serve as "integrators" of the multiple stressors to which they are exposed. The biota respond to the cumulative effects of chemical contaminants, modification of their physical habitat, and changes in both the amount and the timing of the flow of water.

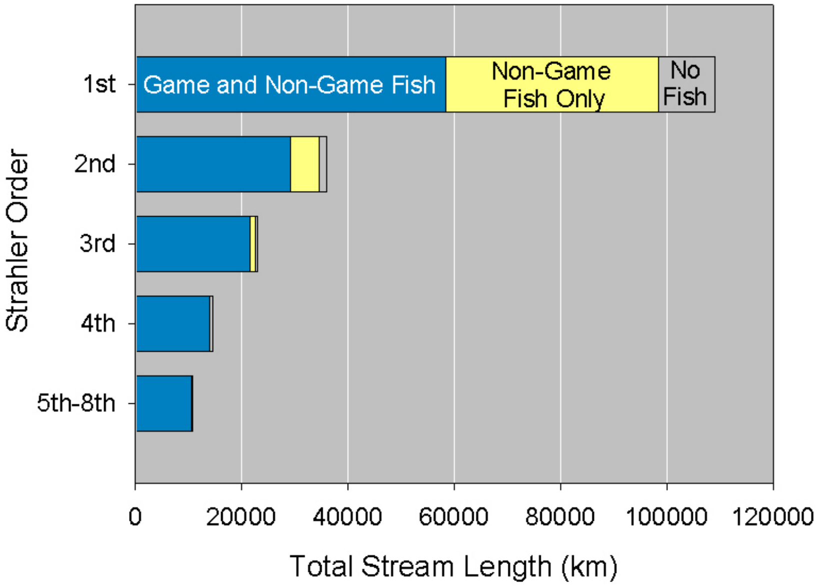

Figure 8. Distribution of flowing waters with game and non-game fish, non-game fish alone, and no fish, across the range of stream orders in the Mid-Atlantic. Small streams, especially first-order streams, are a very important resource for both game and non-game fish species.

Historically, game fish have been the primary biotic component of interest to the public, and an emphasis has been placed on the condition of game fisheries in larger rivers. This emphasis on game fish and large rivers has resulted in a narrow, incomplete view of the status of Mid-Atlantic flowing waters, where large rivers make up only about 5% of the total stream length. Some people have defended this large river/game fish perspective by claiming that small streams do not support fish. While it is true that a much larger proportion of small streams lack fish than larger streams, small streams are nonetheless an important resource for fish (Figure 8). There are more than 120,000 kilometers of streams in the Mid-Atlantic with game fish, roughly half (58,000 km) are first-order streams, while only 9% (10,600 km) are fifth-order and larger rivers. If both game fish and non-game fish are considered, 54% of the stream length with fish present is in first-order streams, and 6% in fifth-order and larger rivers (of course, a conclusion based on water volume would be much different).

By sampling multiple biological assemblages (fish, macroinvertebrates and algae) throughout the Mid-Atlantic, we have the opportunity to move beyond a narrow, game fisheries focus, and look instead at the biological integrity of stream and river ecosystems. Biotic integrity has been defined by Jim Karr (a leading proponent of the concept) as, “the ability to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity and functional organization comparable to those of natural habitats within a region.” Most people would agree that maintaining the biotic integrity of flowing waters—also a stipulation of the Clean Water Act—is a laudable goal. This assessment is one of the first steps toward achieving that goal.

FISH ASSEMBLAGES

Streams and rivers must meet a number of requirements if they are to support healthy fish assemblages—providing a sufficient variety of foods and spawning areas, and a habitat with diverse forms of fish cover, among others. The fish data collected in MAHA and MAIA include a list of the species found at each site, and a measure of their relative abundances. These data allow us to calculate a number of characteristics, or metrics, for the fish assemblages—for example, the total number of species, the number of native species, the number and proportion of pollution tolerant and intolerant species, etc. The best of these metrics (i.e., those that are repeatable, responsive to human disturbance), and that contain the most information about the health of the fish assemblages) have been combined into an overall Index of Biotic Integrity (IBI), whose values range from 0 to 100 (more information on the fish IBI is listed in Appendix A). Our assessments of ecological condition (i.e., for fish, macroinvertebrates and algae) are all based on similarly constructed IBIs.

The critical step in the process of developing a fish IBI is the setting of expectations for each metric used (e.g., How many native species do we expect to find? How many benthic species? How many intolerant species?), and for the final IBI. When dealing with a region as large and diverse as the Mid-Atlantic, the setting of expectations takes on a critical role in determining the validity of our assessment. We need to know if the expected number of native species, for example, changes as we move from one ecoregion to another (it does), or from small streams to large streams (as it also does). In order to set expectations, EMAP relies on estimates of reference condition (see box). Conceptually, the idea of a reference condition for flowing waters is simple—it is the condition of streams (and particularly their biota) in the absence of significant human alteration or degradation. In practice, the concept of reference condition becomes much more muddy—how much human alteration is “significant”, is it equivalent to “pristine” condition, what do we do in areas where all streams have been degraded to some degree—and numerous methods have been developed to estimate it. For this assessment, we have chosen to use a reference site approach, where the least disturbed sites in each ecoregion (and across a range of stream sizes) were sampled and their data used as estimates of reference condition. Alternative approaches include the use of historical data (where available), best professional judgment, and models.

What is Reference Condition?

The concept of establishing reference conditions is relatively simple—we want to know what sorts of conditions we would find in streams and rivers in the absence of any significant human disturbance. In practice, reference condition is much more complicated. There exist multiple definitions of the term “reference condition” – each has merit and each has some historical precedent. For example, each of following categories (and definitions) of reference condition are being used in various monitoring and assessment programs today:

Minimally Disturbed Condition (MDC) – this term describes the condition of streams in the absence of significant human disturbance, and is probably the best approximation or estimate of biotic integrity. One important aspect of MDC is the recognition that some natural variability in indicators will always occur, and this needs to be taken into account when describing MDC. Long-term climatic, geologic and ecological fluctuations will inevitably change the characteristics of individual sites, but the regional range of MDC should be nearly invariant, and its distribution can serve as an anchor by which to judge current condition. It may serve as a benchmark against which all other definitions of reference condition can be compared.

Least Disturbed Condition (LDC) – this condition is found in conjunction with the best available physical, chemical and biological habitat conditions given today’s state of the landscape. It is ideally defined by a set of explicit criteria to which all reference sites must adhere. These criteria will vary from region to region, and are developed iteratively with the goal of establishing the minimum amount of ambient human disturbance in the region under study. The specifics of these criteria will vary across ecoregions, as ecological characteristics of the landscape, and human use of the landscape, vary. Because the condition of the environment changes over time, as either degradation or restoration proceeds, LDC may vary with time. As the ecological condition of the very best available sites changes through time, so will our measure of LDC.

Best Attainable Condition BAC) – this is equivalent to the expected ecological condition of least disturbed sites if the best possible management practices were in use for some period of time. Sites in BAC would be places where the impact on biota of inevitable land use is minimized. This is a somewhat theoretical condition predicted by the convergence of management goals, best available technology, prevailing use of the landscape, and public commitment to achieving environmental goals. The upper and lower limits on BAC are set by the definitions of MDC and LDC respectively (Figure 2). It is unlikely that it will ever be “better” than MDC, nor “worse” than LDC, but may be equivalent to either, depending on the prevailing level of human disturbance in a region. As is the case with LDC, BAC is not invariant, because all of the factors influencing it (e.g., available technology, public commitment) will vary over time.

Ideally, we would like to know how our estimates of stream condition would change if we were to adopt each of these alternative views of reference condition, but this is often not possible. The lack of historical data for any biological assemblage other than fish makes the estimation of historical condition, and therefore any estimation of Minimally Disturbed Condition, very difficult. Estimates of Best Attainable Condition cannot currently be made with real data—they rely on best professional judgment—and are therefore open to criticisms about their validity and potential for bias.

The Environmental Monitoring and Assessment Program (EMAP) approach to reference condition (used in this assessment) is to rely on the “Least Disturbed Condition” definition, and to use data from sites that meet the least-disturbed criteria to estimate reference condition. As we adopt this definition, we need also to recognize that the “Least Disturbed Condition,” in today’s world, may be considerably disturbed.

One important aspect of the EMAP approach is that the reference state (i.e., whether an individual site is in reference condition) is defined by the condition of the physical, chemical and biological ***habitat***, and not by the biological assemblages themselves. This avoids some of the circularity (e.g., using biological data to define reference sites for use in interpreting those same biological data) that can permeate the process of estimating reference condition. Once the sub-population of sites that meet pre-identified criteria is identified, then the biological metric or ecological index scores measured at those sites can be used to define the distribution of biological reference conditions for the region (see “Setting Expectations” box, and Appendix A).

In the Mid-Atlantic region as a whole, 21% of the total stream length would be considered to have fish assemblages in good condition (Figure 9) that is, their IBI scores indicate biotic integrity similar to the upper 75% of reference sites. A larger proportion of stream length, 31%, has fish assemblages in poor condition, and the largest proportion, 42%, are in marginal condition. Importantly, we could not calculate IBI scores for about 6% of the Mid-Atlantic stream length, because all of these streams drain very small watersheds (i.e., less than two square kilometers) and contained too few fish when sampled. Because of their small size, we are unable to determine whether the low numbers of fish is due to anthropogenic or natural causes, and they are left out of the estimates of stream condition based on fish (Figure 9).

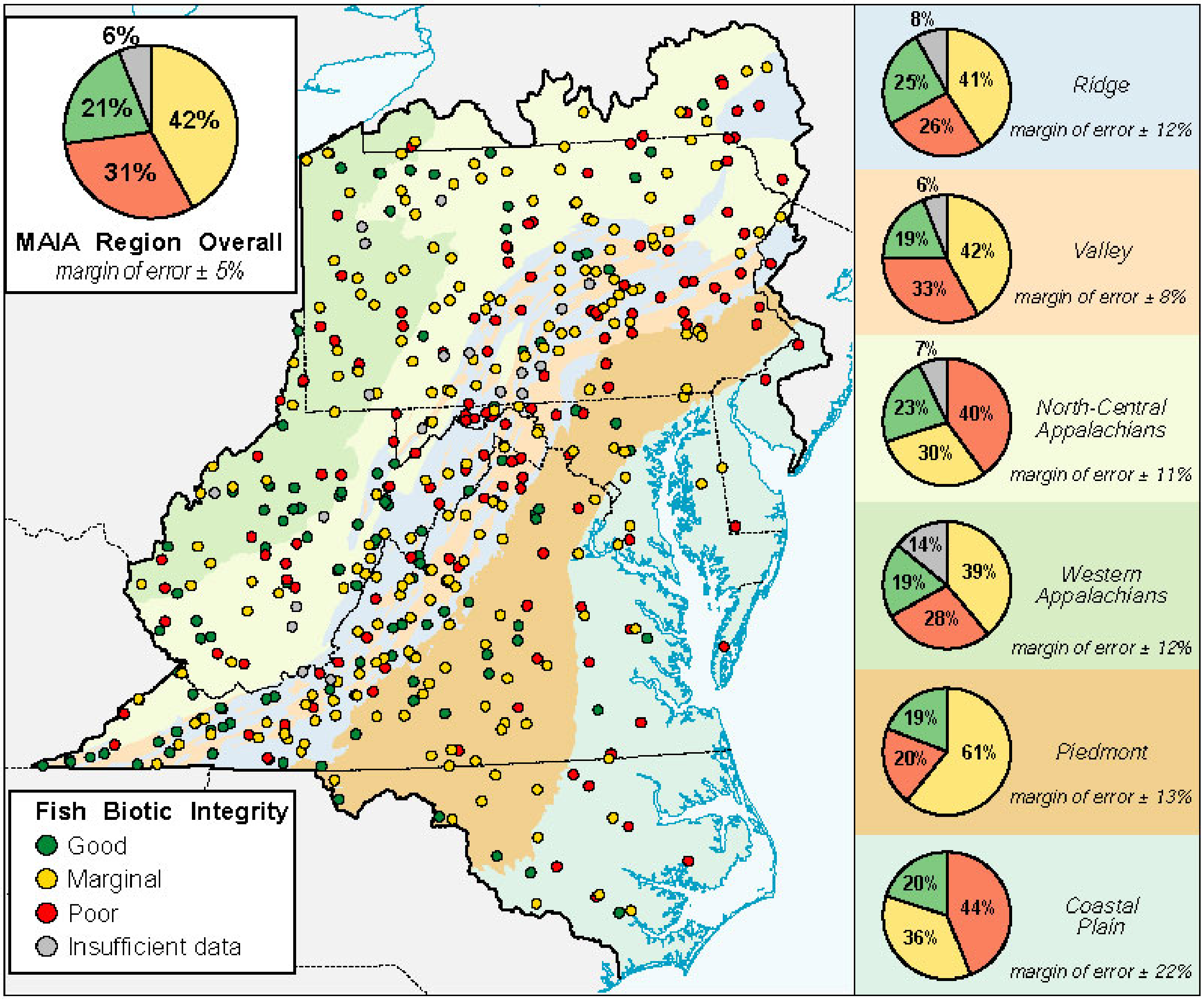

Figure 9. Fish IBI scores in Mid-Atlantic flowing waters, and the proportion of the total stream length in good, marginal and poor condition. Red, yellow and green markers on the map indicate the locations of individual sites that contribute to the estimates of stream length in each condition. About 31% of the Mid-Atlantic stream length has fish assemblages in poor condition. Roughly 6% of stream sites had few or no fish, but were located in watersheds too small for us to determine reliably whether they should be expected to have fish. Of the six ecological regions, the Coastal Plain ecoregion has the highest proportions of stream length in poor condition (44%).

Not surprisingly, sites with poor biotic integrity for fish are not evenly distributed in the six ecoregions of the Mid-Atlantic (Figure 9). The Coastal Plain has the highest proportion in poor condition (44%), followed by the North and Central Appalachians (40%) and the Valley ecoregion (33%). The Piedmont ecoregion has a relatively small proportion of stream length in poor condition (20%), and almost 80% in either good or marginal condition. The ecoregion with the largest proportion in good condition is the Ridge ecoregion—more than two-thirds (67%) of stream length in the Ridge ecoregion has fish assemblages in either good or marginal condition. The two coal mining regions (North and Central Appalachians, and Western Appalachians) had the smallest proportion of stream length in the combined good/marginal classes (53% and 58%, respectively).

Setting Expectations for Ecological Condition

How do we use reference sites (once they are identified) to help set our expectations for biology? To help explain this process, it is useful to employ a familiar analogy. Suppose that you wanted to use human body temperature as an indicator of human health (as is commonly done). One of the first things you would need is information on the normal range of temperatures. In order to estimate this range, or distribution, you might draw a subsample of the human population that is considered 'healthy.' The range of temperatures measured in this subsample is an estimate of reference condition for this indicator. Next, we'd want to know how far away from this distribution (or how extreme) a temperature needs to be before we'd consider it to be unhealthy. In the case of body temperature, we might have very high confidence that we've correctly identified a healthy subpopulation, and the range of temperatures might be fairly small. In this case, we could use something like the ends or extreme values from the reference distribution (e.g., the lowest 1% or the highest 1% of body temperatures measured from a large group of people), as thresholds beyond which we identify a temperature as unhealthy.

We use a similar approach for the biological data we report for the Mid-Atlantic region—identifying a healthy subsample of sites (i.e., reference sites), collecting indicator information on each one, and describing a distribution of reference condition values. But we have less confidence that all of the sites we identify as 'healthy' truly are. We can't know to what extent we've missed unknown or unobserved stressors to ecological condition, or the degree to which small amounts of degradation at our reference sites influence the distribution of metric and index scores.

For this reason, we use more conservative thresholds than we used in the body temperature example. Commonly, the 25th percentile value (of the reference distribution) is used as a threshold between sites in good condition, and those in fair or marginal condition. We also adopt the 1st percentile as the threshold between sites in marginal condition and those in poor condition. For these sites, we can be 99% confident that their biotic integrity is lower than anything found in our subsample of sites in least disturbed condition (more information on setting expectations can be found in Appendix A).

MACROINVERTEBRATE ASSEMBLAGES

An additional picture of stream and river condition can be derived from examining the macroinvertebrates (aquatic insects, snails, worms and other benthic invertebrates) in streams and rivers. These animals provide food for fish and other wildlife, and serve as a link between the algae and higher levels of the ecological food web. Macroinvertebrates are considered to be very good indicators of chemical stresses (e.g., acidity) as well as excess inputs of fine sediment from local landuse.

We use an approach identical to that for fish to develop an Index of Biotic Integrity for macroinvertebrates—finding metrics or characteristics (e.g., the number of mayfly species, the number of caddis fly species, the pollution tolerance of the species) of the assemblages that are repeatable, responsive to human disturbance), and that contain the most information about the health of the assemblage, and combining them into a single IBI score. And as with fish, we use reference sites to set expectations for the individual metrics and the IBI itself (more information in Appendix A).

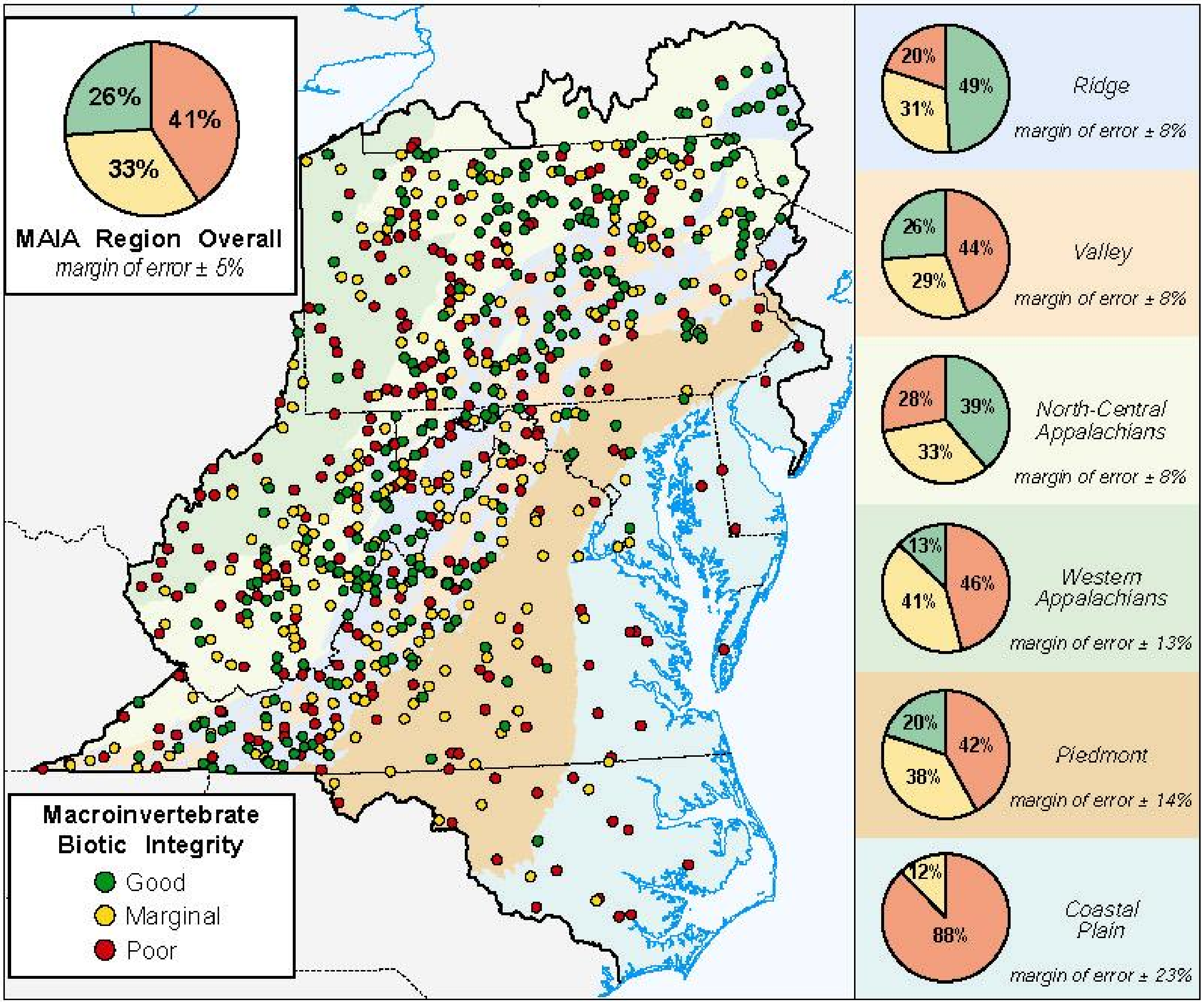

Figure 10. Macroinvertebrate IBI scores in Mid-Atlantic flowing waters, and the proportion of the total stream length in good, marginal and poor condition. Red, yellow and green markers on the map indicate the locations of individual sites that contribute to the estimates of stream length in each condition. About 41% of the Mid-Atlantic stream length has macroinvertebrate assemblages in poor condition. The Coastal Plain ecoregion has the highest proportion of stream length in poor condition for macroinvertebrates (88%), while the Ridge ecoregion has the highest proportion in good condition (49%).

For the Mid-Atlantic region as a whole, 26% of the stream length was in good condition with respect to macroinvertebrate assemblages (Figure 10). More than 41% of the stream length had poor macroinvertebrate integrity, and 33% of the stream length was in marginal condition.

There is a more uneven distribution of macroinvertebrate IBI scores across Mid-Atlantic ecoregions than was the case for fish (Figure 10). Both the Coastal Plain (88%) and Western Appalachian (46%) ecoregions have relatively large proportions of stream length in poor condition (and only 0% and 13% in good condition, respectively). The ecoregions with the highest biotic integrity for macroinvertebrates are the Ridge ecoregion (nearly 80% in good or marginal condition) and the North and Central Appalachians (more than 72% in good or marginal condition).

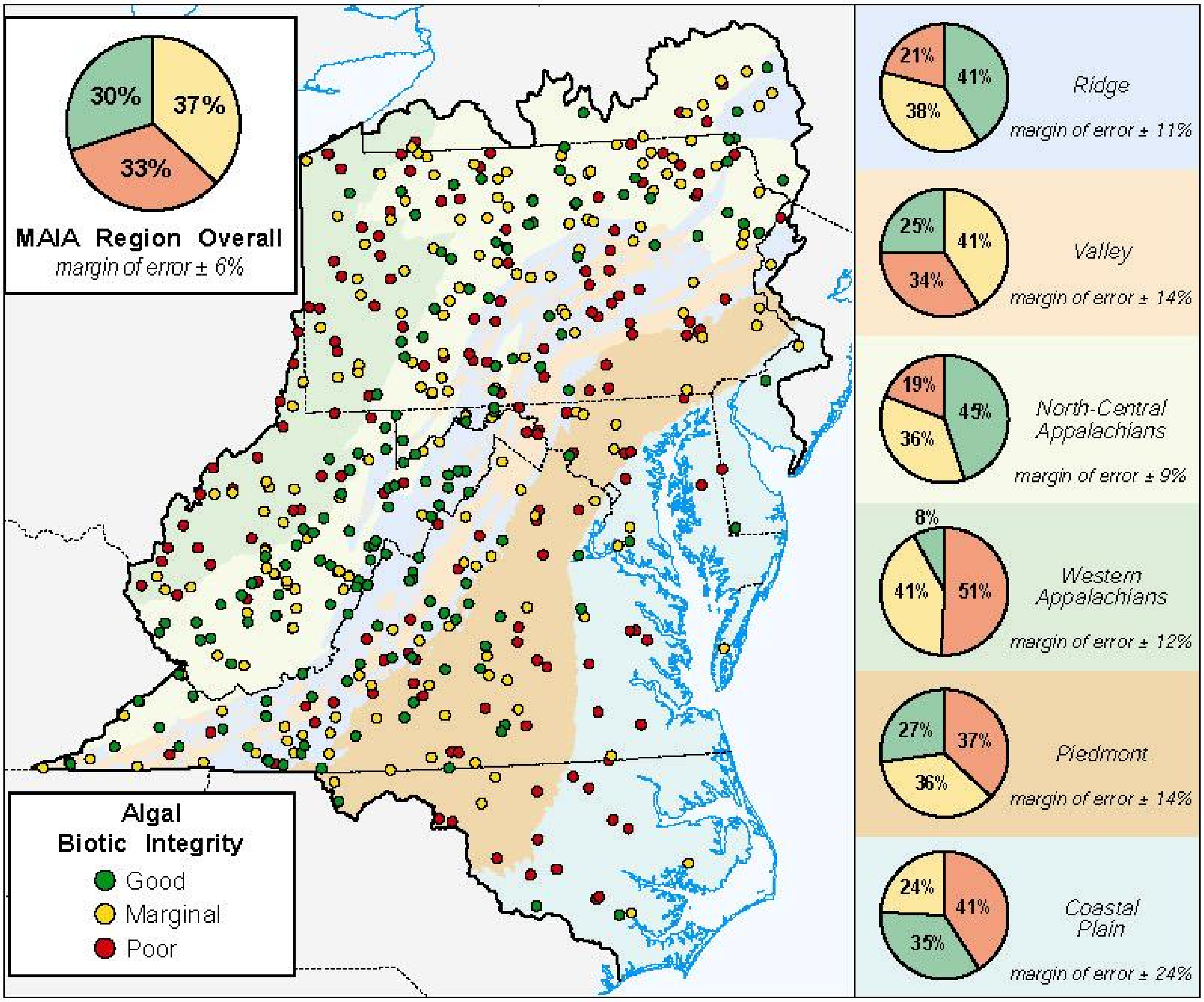

Figure 11. Algal IBI scores in Mid-Atlantic flowing waters, and the proportion of the total stream length in good, marginal and poor condition. Red, yellow and green markers on the map indicate the locations of individual sites that contribute to the estimates of stream length in each condition. About 30% of the Mid-Atlantic stream length has algal assemblages in poor condition. The Western Appalachian ecoregion has the highest proportion of stream length in poor condition for attached algae (51%), while the North and Central Appalachians have the highest proportion in good condition (45%).

ALGAL ASSEMBLAGES

Attached algae in streams grow on surfaces such as rocks, submerged wood, and on individual grains of sand and gravel. We include them as an indicator of biotic integrity in EMAP because they yield additional information and a different perspective on the ecological condition of streams and rivers. Algae are known ecologically as primary producers, meaning that they produce biomass solely through the process of photosynthesis. They are more directly affected by excess nutrients, like phosphorus and nitrogen (needed for algal growth), than either fish or macroinvertebrates. Like macroinvertebrates, algae have strong responses to other chemical stresses (like acidity) and disturbances to stream substrates (i.e., sedimentation).

The same approach to building an Index of Biotic Integrity was used for attached algae as we used for fish and macroinvertebrates. For the Mid-Atlantic region as a whole, 30% of the stream length was in good condition with respect to algal assemblages (Figure 11). A similar proportion of stream length had poor algal integrity (33%), and 37% of the stream length was in marginal condition.

On an ecoregional basis, algae suggest that the Western Appalachians have the poorest biotic integrity (51% of stream length in poor condition), followed by the Coastal Plain (35% in poor condition) and Piedmont (37% in poor condition) ecoregions (Figure 11). The algal IBI suggests that the mostly forested, upland ecoregions (the North and Central Appalachian, and Ridge ecoregions) have the best biotic integrity (81% and 79% in either good or marginal condition, respectively. These results are consistent with the types of human disturbance to which we expect algal assemblages to respond; both upland ecoregions have relatively small amounts of agricultural landuse, which helps to keep stream nutrient levels low, and relatively little human uses of the land that contribute fine sediments to streams (e.g., agriculture and mining).

COMPARISON OF FISH, MACROINVERTEBRATE, AND ALGAL SCORES

Differences among estimates of ecological condition based on fish, macroinvertebrates and algae are expected, because these three groups of organisms respond to different disturbances in the environment. For the region as a whole, macroinvertebrates suggest the poorest biotic integrity, with 41% of Mid-Atlantic stream length in poor condition according to the macroinvertebrate Index of Biotic Integrity (Table 2). At the level of individual ecoregions, the fish IBI tends to suggest the fewest miles of stream in good condition. The only exceptions to this general pattern are the Coastal Plain and Western Appalachians, two highly modified ecoregions with substantial urban (Coastal Plain) and agricultural/mining (Western Appalachians) land use. None of the streams sampled in the Coastal Plain exhibited good macroinvertebrate integrity, and only 8% of stream length in the Western Appalachians had good algal integrity.

Such differences can be attributed to a number of factors. As already stated, fish and macroinvertebrates are expected to respond differently to stresses, and the differences in the relative scores of the fish and aquatic insect scores in different ecoregions (where different stresses are known to dominate) may be indicative of this.

Table 2

Comparison of fish, macro-invertebrate and algal IBI results for Mid-Atlantic flowing waters, and the six ecological regions.

Region	% in Good Condition			% in Poor Condition		
	Fish	Macro-invertebrates	Algae	Fish	Macro-invertebrates	Algae
Mid-Atlantic Region	21	26	31	31	41	33
Coastal Plain	20	0	35	43	88	41
Piedmont	20	20	27	20	42	37
Valleys	19	26	25	33	45	34
Ridges	26	49	42	26	20	21
North/ Central Appalachians	23	40	45	40	28	19
Western Appalachians	19	13	8	28	46	51

Even if the condition estimates for the three biotic assemblages are fairly similar (e.g., 21-30% of stream length in good condition; 31-33% in poor condition), one might wonder whether the three IBIs are classifying the same streams as either good or poor. And the answer to this is "sometimes." Of the stream length classified as in good condition with respect to fish, about 70% would also be classified as good using the macroinvertebrate IBI. Likewise, about 71% of stream length in good condition with respect to macroinvertebrates also exhibits good algal condition. Not surprisingly, the poorest association in IBI scores is between fish and algae; about 52% of stream length with good fish IBI scores also have good algal IBI scores. Assemblages that utilize habitat at different scales (like fish and algae) are expected to have more distinct responses to stressors.

Of the roughly 220,000 km of streams in the Mid-Atlantic region, roughly 107,000 km (48%) has one or more of the biotic assemblages in good condition, but only about 7,850 km (3.5%) would be classified as good by all three IBIs. There are 129,000 km of Mid-Atlantic streams (58% of the total) that are classified as poor using one or more of the assemblages; fewer than 4,350 km (2.0%) would be scored as poor using data from all three assemblages. The vast majority of stream length in the region exists in a middle ground, where one assemblage may be in good condition and the others in marginal or poor condition. In this middle ground, streams and rivers are experiencing different sorts of stress; those stressors that are present are affecting only one or two of the assemblages, and the different responses of the biotic assemblages produce differences in how we might view the ecological condition of the sites. Only by looking further into the relative extent of these stressors, and into how they differentially affect the biotic assemblages we use to assess ecological condition, can we begin to understand the different stories told by fish, macroinvertebrates and algae, and assess the overall condition of flowing waters in the Mid-Atlantic region.

STRESSORS IN MAIA FLOWING WATERS

In the previous section, the ecological condition of the flowing waters in the Mid-Atlantic region was described based on direct measurements of stream and river biota. Here we present our findings on the stressors to the streams/rivers of the Mid-Atlantic. These are based on direct measures of physical, chemical or biological characteristics of streams and their watersheds. They are stream and river attributes that can be directly or indirectly altered as a result of human activity or intervention in the stream system, and that have been known to have harmful effects on stream and river biota. We present this information in the belief that comparisons of stressors, like the ones we present here, will be useful to regional managers in determining where best to focus their limited resources for stream and river protection and restoration. Additional technical information on the potential stressors and their measurement can be found in the references listed in Appendix A.

We have two primary goals in assessing stressors in the flowing waters of the Mid-Atlantic. We hope to:

1. Estimate the relative extent of each stressor (i.e., the percentages of stream length having “poor” stressor condition), demonstrating which stressors are most common. Relative extent is one measure of each stressor’s relative importance.
2. Calculate each stressor’s relative risk to the biological assemblages we’ve used to assess ecological condition. Relative risk measures the association seen in our data between poor biological condition and poor stressor condition. It answers the question, “How much more likely is a given biological measure (e.g., a fish IBI) to indicate poor condition if a given stressor (e.g., riparian habitat) is also in poor condition?” We use relative risk as an indicator of the severity of stressor effects on biological assemblages.

For each stressor, a brief description of the nature of the measurements is provided, followed by the results. Wherever possible, we have used a similar strategy for assessing stressors as we have for biological measures—the distribution of values in a set of relatively undisturbed sites (reference sites) is used as a measure of what constitutes acceptable values for these stressors. This distribution of reference site scores is used to determine whether, and to what extent, the scores of other sites fall outside this distribution (more information on the reference site approach is given in Appendix A).

At the end of this section, we present the relative extent and relative risks of the stressors for the Mid-Atlantic as a whole, so that the reader can develop some appreciation of both the extent and the severity of individual stressors. As with the indicators of ecological condition, we also present the relative extent of stressors for each of the six ecological regions. Unfortunately (due to the constraints of small sample sizes) we cannot calculate relative risk on the scale of individual ecoregions.

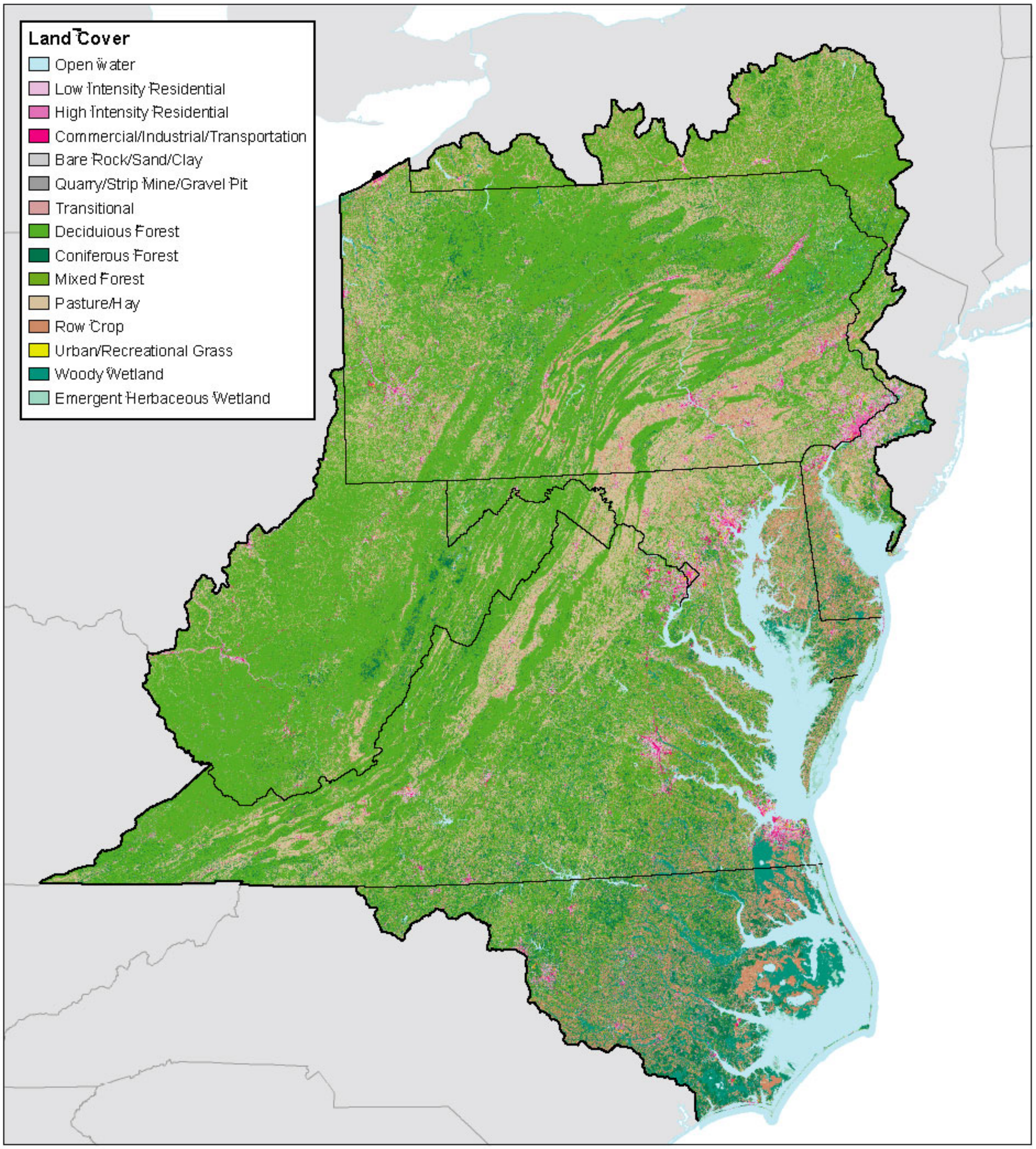

Figure 12. Land use and land cover in the Mid-Atlantic region, as determined from satellite imagery.

The heterogeneous nature of the land use and land cover in the Mid-Atlantic region is evident from satellite imagery (Figure 12). Agricultural areas, urban and suburban clusters, forests, mining sites, and other features are interwoven on the landscape, with many of these features indicating human activity. These human activities have the potential to alter stream and river quality and affect aquatic biota. The characteristics or stressors in Mid-Atlantic streams and their watersheds included in this report are:

(1) Stream/river acidification (from acid rain and mining),

(2) Other mining impacts,

(3) Nutrient runoff,

(4) In-stream habitat alteration (e.g., sedimentation, wood removal),

(5) Riparian habitat alteration,

(6) Non-native fish introductions.

ACIDIFICATION

Streams and rivers can become acidic through the effects of acid deposition (acid rain) or due to mine drainage (particularly from coal mining). The Mid-Atlantic region is unusual because it receives some of the highest rates of acid rain in the U.S., has geology that makes large areas within the region susceptible to acidification, and has a high incidence of coal mining.

Acid rain forms when the emissions from smokestacks and automobiles (particularly sulfur dioxide and nitrogen oxides) combine with moisture in the air, forming dilute solutions of sulfuric and nitric acid. Acid deposition can also occur in dry forms, like the particles that make up soot. When wet and dry deposition fall on sensitive watersheds, like those in the upland portions of the Mid-Atlantic, they can have deleterious effects on soils, vegetation and streams and rivers. In assessing acid rain's effects on flowing waters, we rely on a measure of the water's ability to buffer inputs of acids, called acid neutralizing capacity or ANC. When ANC values fall below zero, the water is considered acidic, and can be either directly or indirectly (e.g., by mobilizing toxic metals like aluminum) toxic to biota.

Acid mine drainage forms when water moves through mines and mine tailings, combining with sulfur-bearing minerals to form strong solutions of sulfuric acid, and mobilizing many toxic metals. As in the case of acid rain, we can assess the acidity of waters in mining areas by using their ANC values. Mine drainage also produces extremely high concentrations of sulfate—much higher than those found in acid rain. While sulfate is not directly toxic to biota, we use it as an indicator of mining's influence on streams and rivers. When ANC and sulfate are low, we can attribute acidity to acid rain. When ANC is low and sulfate is high, we can attribute acidity to acid mine drainage.

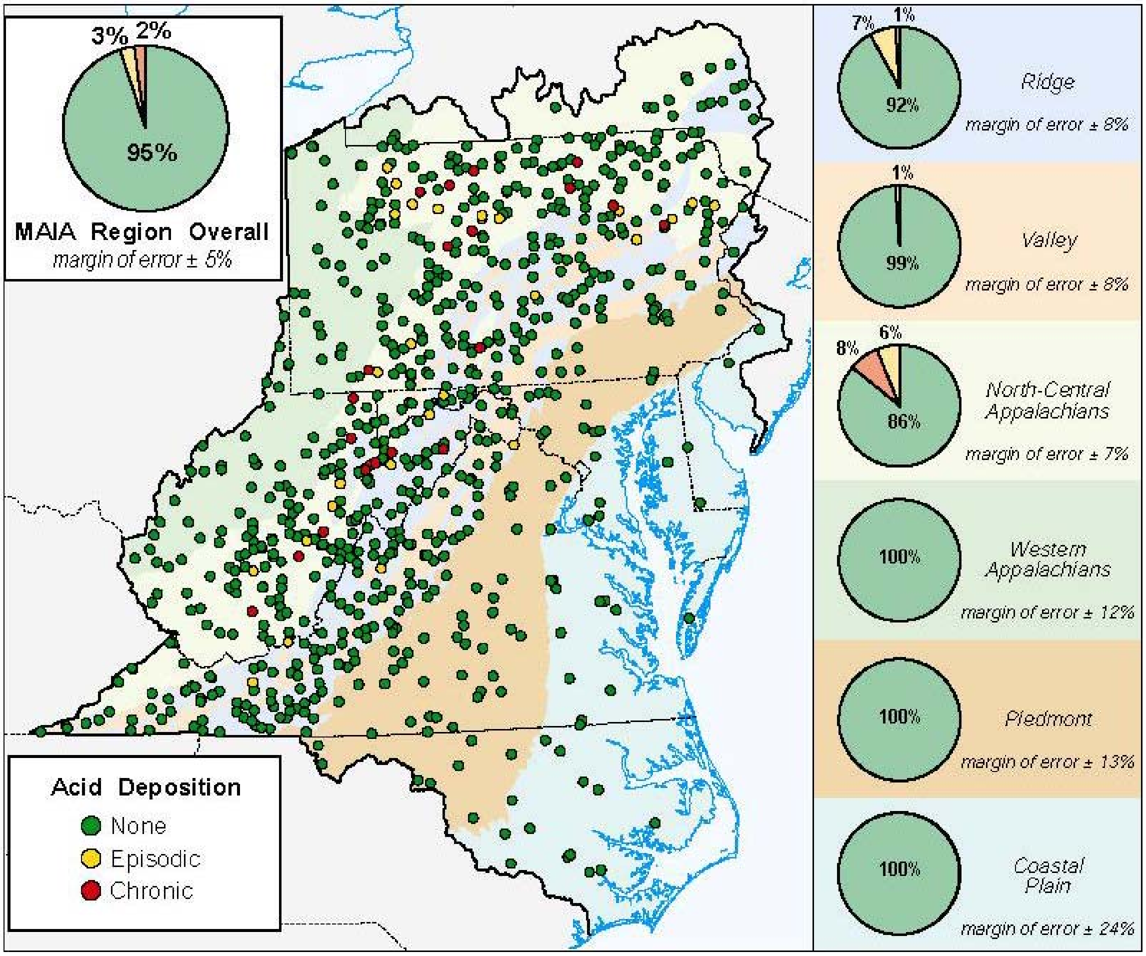

Figure 13. Extent of acid deposition effects on flowing waters of the Mid-Atlantic, and the proportion of the total stream length in unacidified, episodically acidified and chronically acidified categories. Roughly 5% of the region's stream length exhibits effects of acid deposition. Nearly all of the stream length affected by acid deposition in the Mid-Atlantic is in the North and Central Appalachian (14%) and Ridge (8%) ecoregions.

Streams and rivers may be acidic throughout the year (chronically acidic) or only for short periods (episodically acidic), such as when flows are high during storms or snowmelt. Both forms of acidity have deleterious effects on biota, including all of the biological assemblages we are using in this assessment. Data from streams sampled during spring and summer, like those in this Mid-Atlantic assessment, can be used to assess directly the incidence of chronic acidification. Across the region as a whole, just over 2% of the total stream length is chronically acidic (ANC≤0) due to acid rain. In order to estimate how this number would change if we considered both chronic and episodic acidity, we change the ANC threshold to 50 µeq/L—the National Acid Precipitation Assessment Program concluded in 1990 that streams with ANC values lower than 50 µeq/L are susceptible to episodic acidification, and may experience fish kills and changes to their macroinvertebrate communities during short-term pulses of acid rain runoff. When both chronic and episodic acidity are considered, we conclude that about 5% of the total stream length in the region is affected by acid rain (Figure 13).

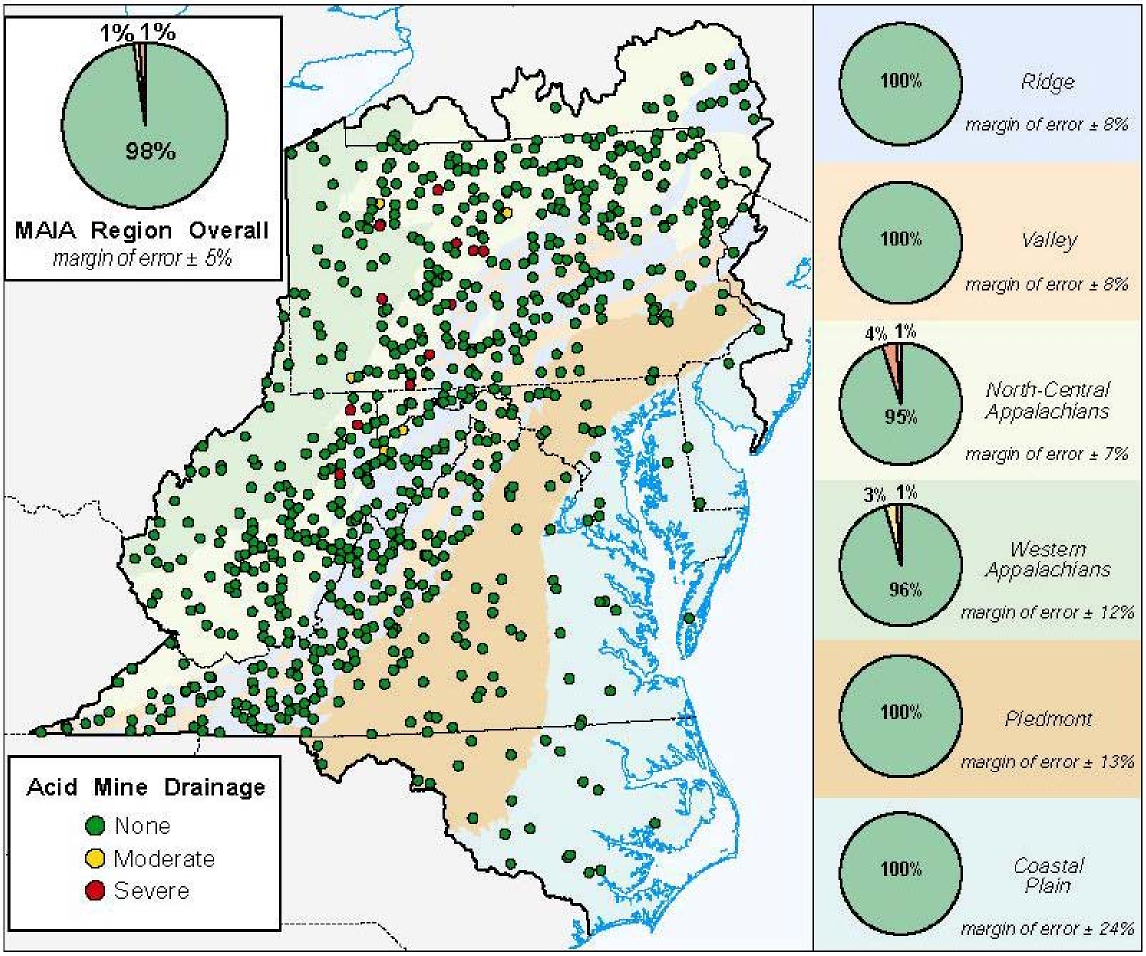

Figure 14. Extent of acid mine drainage in flowing waters of the Mid-Atlantic, and the proportion of the total stream length in unaffected, moderately affected, and severely affected categories. Acid mine drainage is not as common in the Mid-Atlantic as acid deposition effects, with about 2% of stream miles affected. All of the stream length affected by acid mine drainage in the Mid-Atlantic region is in the North and Central Appalachian (5%) and Western Appalachian (4%) ecoregions.

For problems such as acid rain and acid mine drainage, an ecoregion perspective is particularly appropriate. Ecoregion designations integrate similar geology, soils, watershed topography, climate and vegetation characteristics that help explain stream responses to certain types of stressors or pollution. Some ecoregions have streams that are much more susceptible to acid rain because they lack the limestone and other well-buffered bedrocks that help protect streams from acidic inputs. Due to these ecoregional differences, nearly all of the streams in the Mid-Atlantic affected by acid rain are in two ecoregions (Figure 13). About 8% of the stream length in the North and Central Appalachians is chronically acidic, and an additional 6% is affected by episodic acidification. Fewer streams are chronically acidic in the Ridge ecoregion (less than 1% of total stream length), but combined episodic and chronic acidification affect 7% of the total length. None of the other ecoregions has more than 0.5% of stream length affected by acid rain.

The extent of acid mine drainage is substantially less than acid deposition—only 2% of the stream length in the Mid-Atlantic is acidic due to mine drainage (Figure 14), with more than half of these streams exhibiting chronic acidity. All of the acid mine drainage streams are located in the Appalachian ecoregions where coal mining is common. In the North and Central Appalachians, just under 5% of stream length is affected by acid mine drainage; 4% of the stream length is severely and chronically acidic (Figure 14). The Western Appalachian ecoregion has acid mine effects in roughly 4% of its stream length.

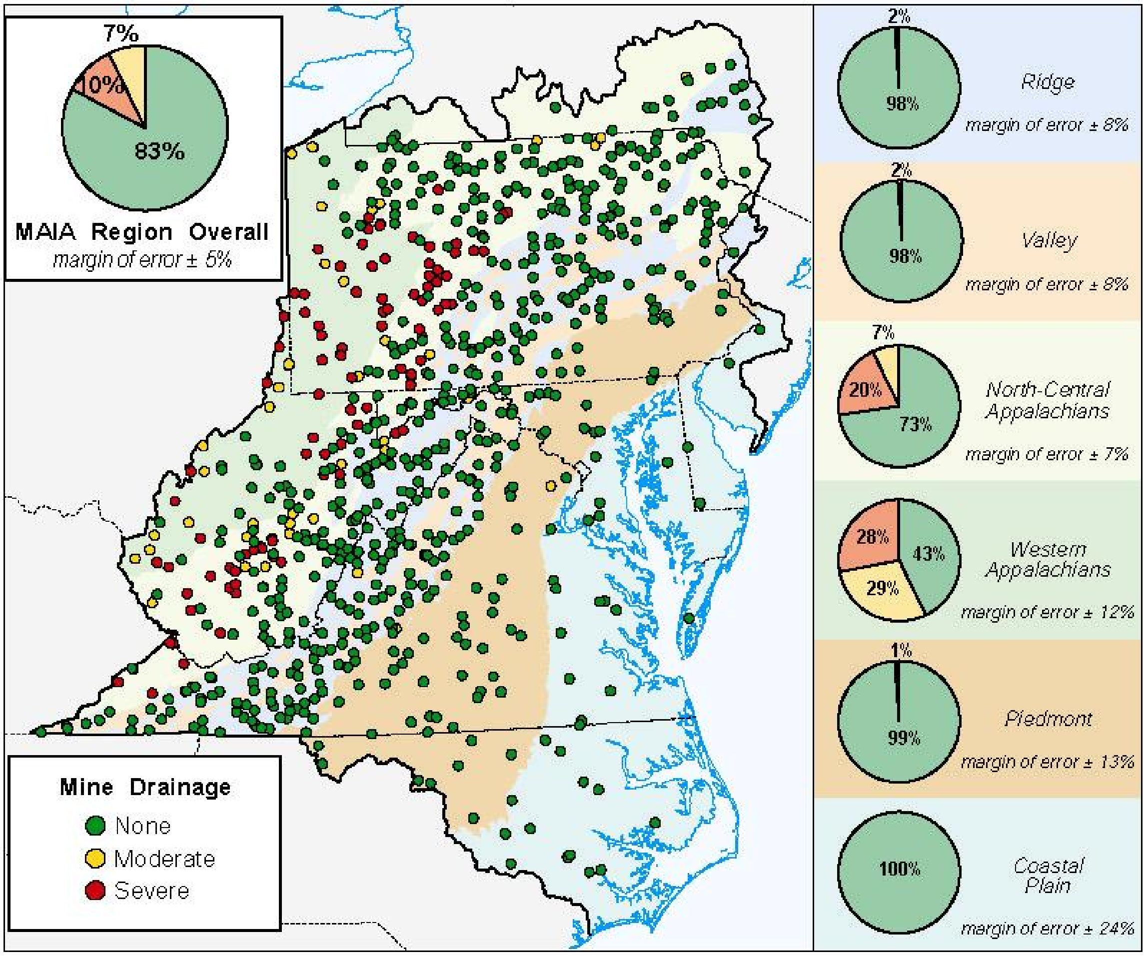

Figure 15. Extent of all mine drainage effects on flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to mining indicators. Roughly 17% of the region's stream length exhibits effects of mine drainage. Nearly all of the stream length affected by mine drainage in the Mid-Atlantic is in the North and Central Appalachian (27%) and Western Appalachian (57%) ecoregions.

In total, there are some 9,600 kilometers of Mid-Atlantic flowing waters that are acidic due to acid rain or susceptible to acid rain, and about 4,100 kilometers that are acidic due to mine drainage.

OTHER MINING EFFECTS

Streams that are acidic due to mine drainage are less common in the Mid-Atlantic than streams acidified by acid rain, but mine drainage effects extend far beyond acidification. Downstream effects of mines include export of fine sediments and toxic metal contamination (metals reside primarily in stream bottom sediments in non-acidic streams); these less well-known stresses can have pronounced effects on bottom-living organisms. Although only about 2% of stream miles in the Mid-Atlantic are acidic because of mine drainage, an additional 15% of the stream length is non-acidic, but degraded by mine drainage (Figure 15). About 10% of Mid-Atlantic stream miles would be considered severely affected by mine drainage (either acidic, or with extremely elevated concentrations of sulfate indicating a dominant source of water from mines).

Only small amounts of mine drainage effects are exhibited outside of the two coal-mining ecoregions (Figure 15). In the Piedmont and Ridge ecoregions, roughly 1-2% of stream length is affected by non-acidic mine drainage, due to having mines in the headwaters (the headwaters of several rivers in the Piedmont and Ridge ecoregions are in the coal-bearing regions to the East). In the Western Appalachians, where coal deposits are common, the majority of streams have at least moderate indicators of mine drainage effects (57% of total length); 28% of the stream length in this region would be considered severely affected. In the North and Central Appalachians, 27% of the total stream length has some signs of mining effects, with 20% of stream length having indicators of severe mine drainage affects.

NUTRIENT ENRICHMENT

The introduction of excessive nutrients (e.g., phosphorus and nitrogen) can affect streams directly, for example by increasing algal growth, or indirectly, by altering the quality and quantity of food for higher trophic levels like macroinvertebrates and fish. In extreme cases, nutrients can lead to levels of algal growth that deplete the oxygen in the water, choke out other forms of biota, and significantly alter the assemblages present. Common sources of nutrients include municipal sewage, runoff from septic fields, and agricultural fertilizers. Atmospheric deposition is an additional source of nitrogen (but a minor source of phosphorus), and may be important in areas that are otherwise unaffected by urban and agricultural land uses.

The growth of algae in fresh waters (lakes and streams) in the U.S. are considered to be primarily limited by the amounts of phosphorus present, and elevated phosphorus levels are therefore of special concern. In the Mid-Atlantic as a whole, phosphorus concentrations would be considered severely elevated in about 14% of stream length (Figure 16); more than 44% of stream length in the region has phosphorus levels we would classify as good.

Because of its direct link to agricultural land use, phosphorus is most commonly elevated in the ecoregions with higher percentages of agriculture—the Piedmont (29% of stream length with severely elevated phosphorus), Western Appalachian (16%) and Valley ecoregions (12%). The primarily forested areas of the Mid-Atlantic, the North and Central Appalachian and Ridge ecoregions, have a majority of their stream length (66% and 60%, respectively) in good condition with respect to phosphorus.

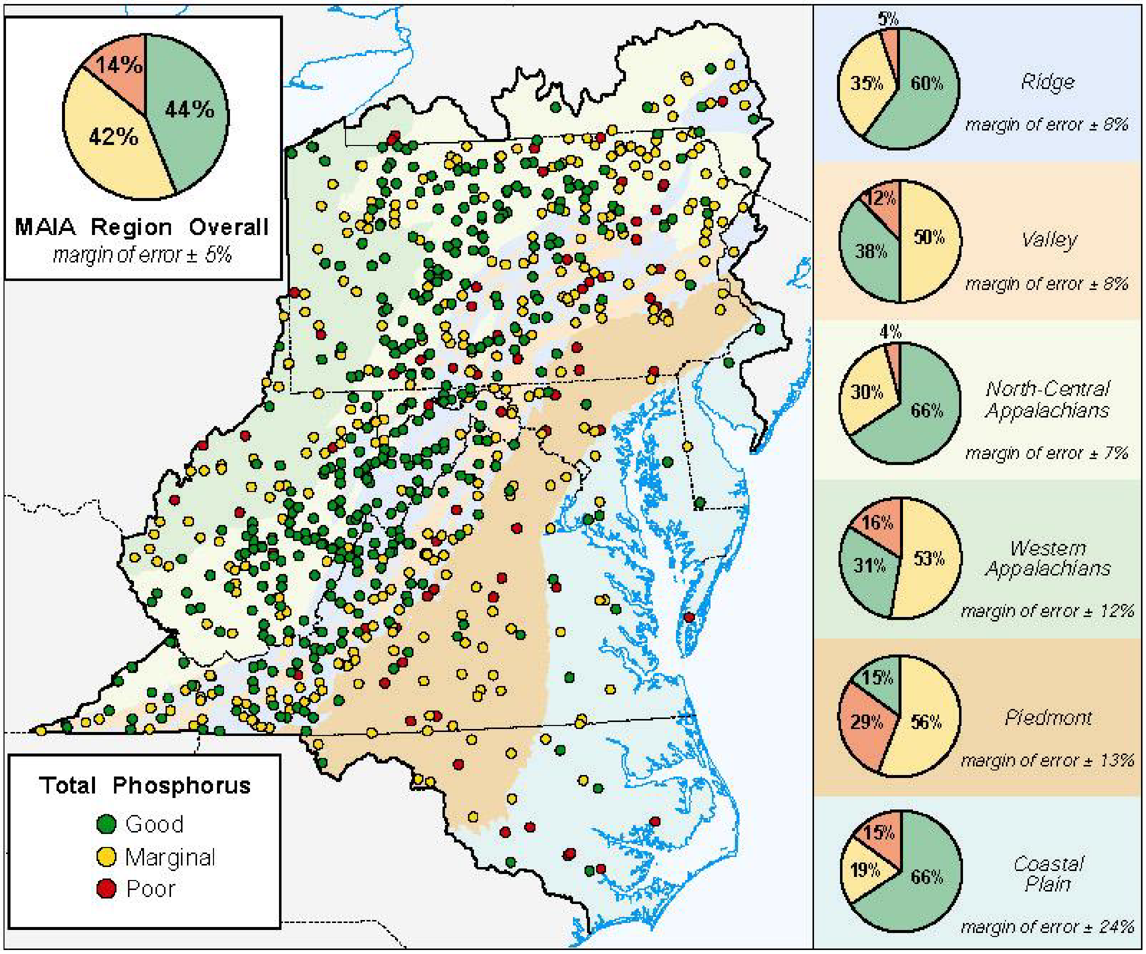

Figure 16. Extent of excess phosphorus concentrations in flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to this nutrient. Roughly 14% of the region's stream length exhibits excessive phosphorus concentrations. The Piedmont ecoregion has the highest proportion of streams (29%) with poor phosphorus concentrations.

Nitrogen is another nutrient that can stimulate plant growth, especially in the presence of high phosphorus concentrations. Like phosphorus, nitrogen is commonly found in agricultural fertilizers, but may also originate in acid rain (nitrogen deposition), animal manure, and sewage discharges. Overall, 17% of Mid-Atlantic stream length would be considered to be in poor condition with respect to nitrogen (Figure 17); more than 40% has good nitrogen levels.

Although both phosphorus and nitrogen result from fertilizer runoff, and other agricultural practices, additional sources of nitrogen lead to a different ecoregion distribution for this nutrient

(Figure 17). Nitrogen (either as nitrate or ammonium) can be a major component of atmospheric deposition, and results both from the combustion of fossil fuels (especially in vehicles) and the release of gaseous forms of nitrogen from confined animal feedlots. The Valley (39%) and Coastal Plain (25%) ecoregions exhibit the highest proportions of stream length with severely elevated nitrogen, while the forested ecoregions again have the highest proportions of streams with low nitrogen concentrations (Ridge ecoregion 63%, North and Central Appalachians 48%).

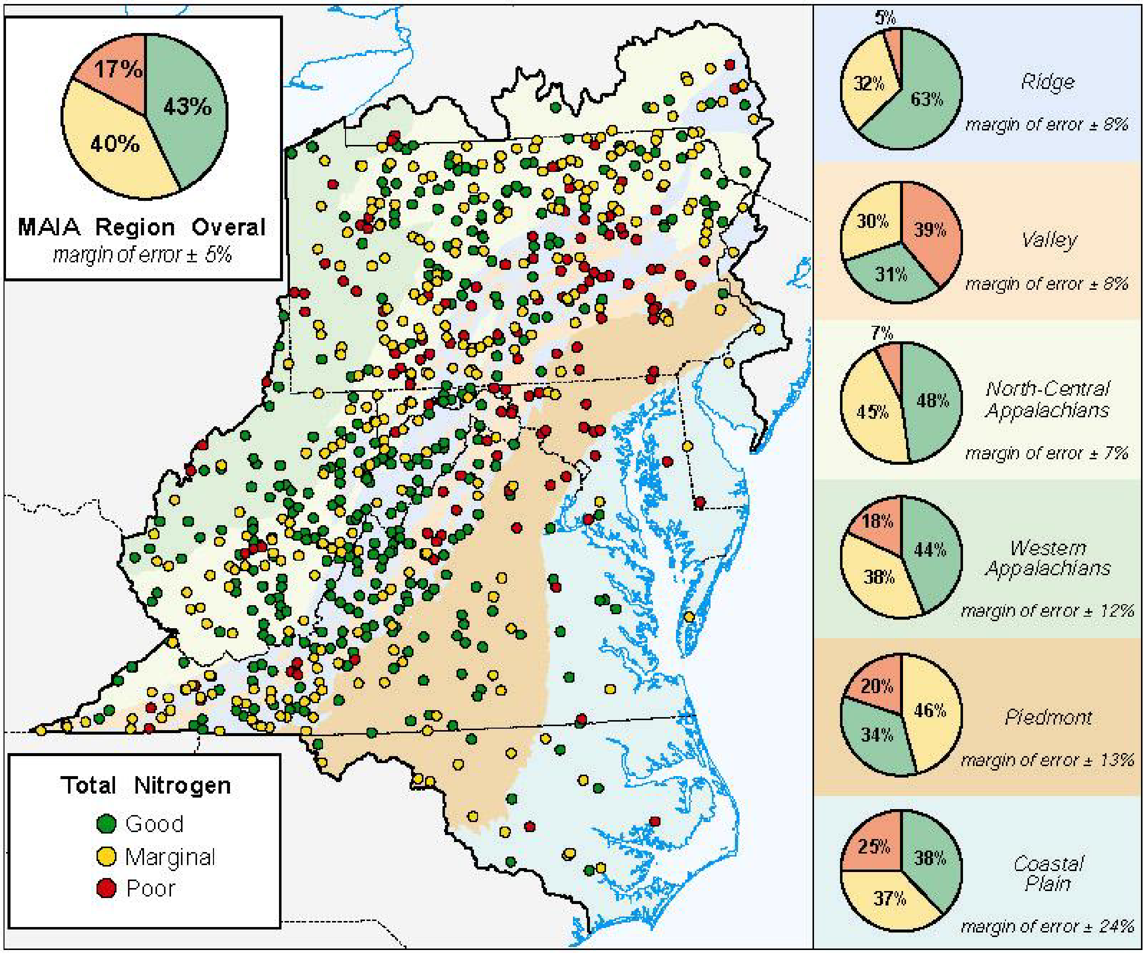

Figure 17. Extent of excess nitrogen concentrations in flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to this nutrient. Roughly 17% of the region's stream length exhibits excessive nitrogen. The Valley ecoregion has the highest proportion of streams (39%) with poor nitrogen concentrations.

IN-STREAM HABITAT

High quality habitat is an important and often overlooked ingredient for good stream condition. In the course of EMAP sampling, data were collected on many aspects of both riparian (near-stream) and in-stream habitat known to be important to biota. These quantitative measures of habit can be used to diagnose the possible causes of habitat degradation. We focus in this assessment on two characteristics of in-stream habitat (sedimentation and large woody material) that play important roles in establishing high quality habitat structure for fish, macroinvertebrates and algae.

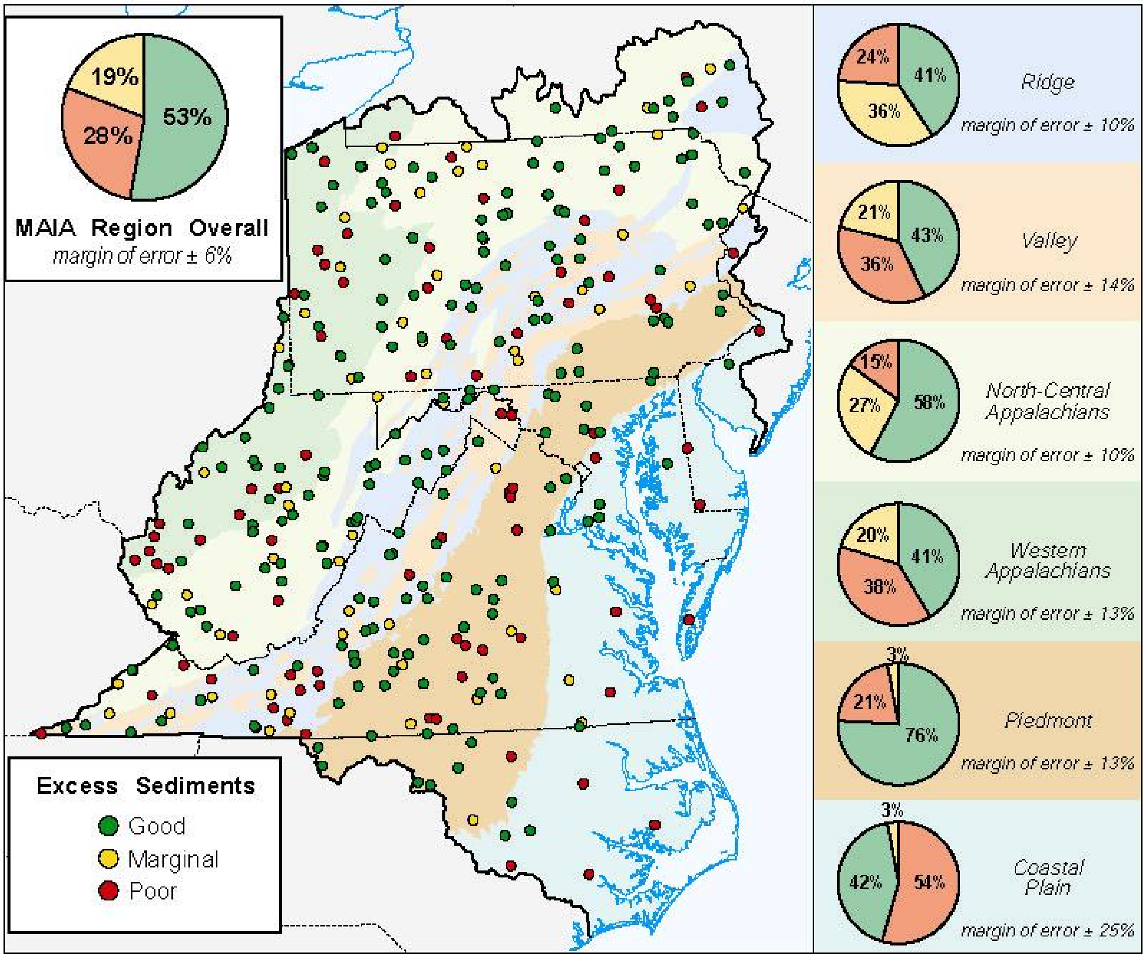

Figure 18. Extent of excess sedimentation in flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to fine sediments. Roughly 28% of the region's stream length exhibits amounts of fine sediment far in excess of expectations. The Coastal Plain ecoregion has the highest proportion of streams (54%) with excess fine sediments.

In order to assess stream sedimentation, we compared measurements of the amount of fine sediments on the bottom of each stream (sands and fines) with expectations based on each stream's ability to transport fine sediments downstream (a function of the slope, depth and complexity of the stream). Fine sediments in excess of expectations suggest that the supply of sediments from the watershed to the stream is greater than what the stream can naturally process. For the purposes of this assessment, we calculated the ratio of observed to expected sediment sizes for all streams, including reference sites, and used the distribution of ratios in the reference sites to define the ratio's natural variability. This is the same approach used for biological measures and the other stressors in this assessment—using a set of reference streams to define expectations for the least disturbed sites in each ecoregion (see Appendix A).

About 28% of the total stream length in the Mid-Atlantic has fine sediments far in excess of expectations (Figure 18), but more than half (53%) were within the expected range and would be considered to be in good condition. The Coastal Plain (54% in poor condition), Western Appalachian (38%) and Valley (36%) ecoregions had the highest proportions of stream length with excessive sediments (Figure 18). Somewhat surprisingly, the Piedmont ecoregion has the highest proportion of stream length (76%) with no excess sediment problems. Note that this does not mean that the Piedmont region had the lowest levels of fine sediment, only that the amount of fine sediments in most of these streams are within expectations.

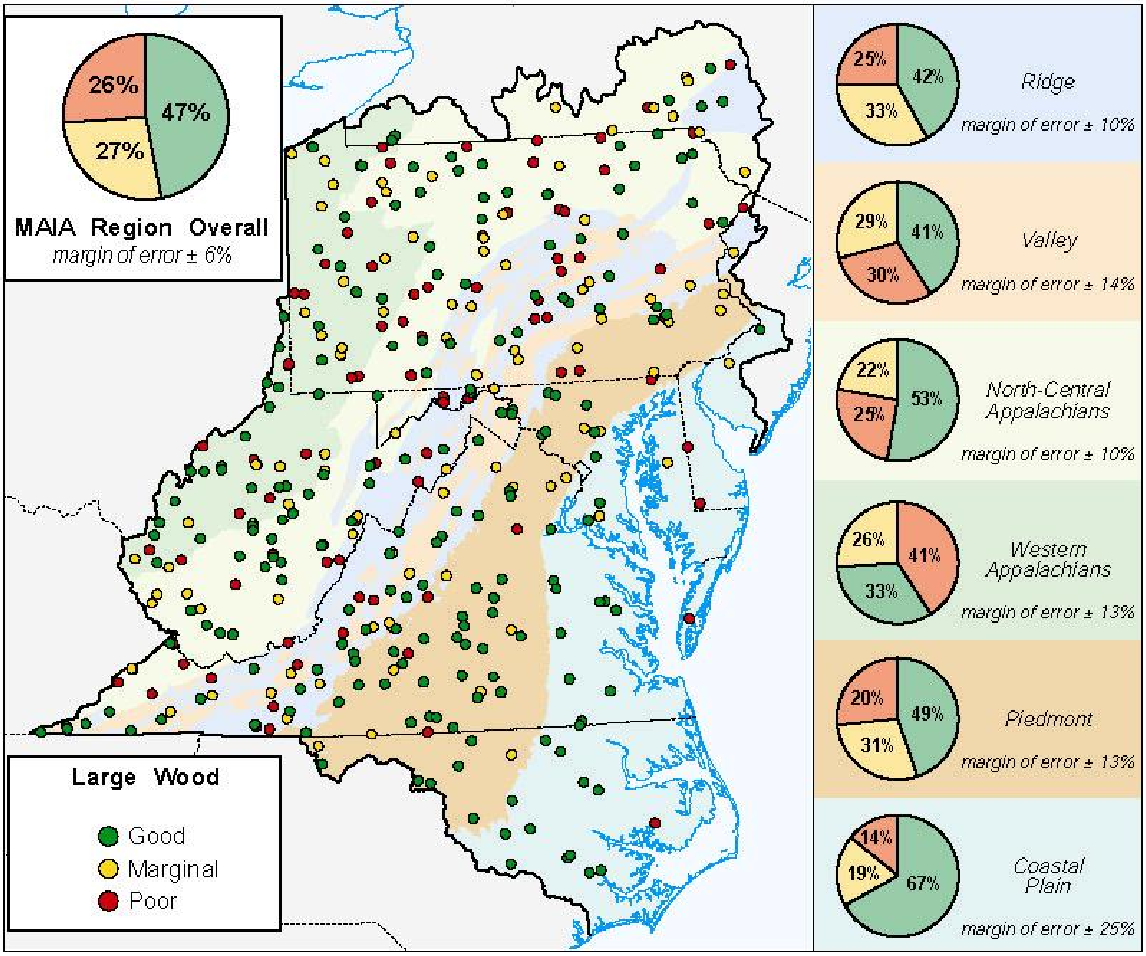

Figure 19. Extent of large wood in flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to in-stream wood. Roughly 26% of the region's stream length is completely devoid of large wood.

Another aspect of in-stream habitat that creates high quality habitat space for biota is the amount of large woody material. Downed and dead trees, falling into streams from nearby riparian areas, are widely recognized as crucial components of the complex habitats that typify streams with high biodiversity. The amounts of wood found in Mid-Atlantic streams are quite low compared to many other forested areas of the U.S., and may have historically been much higher. In assessing large wood, we compare present values only to those of the least disturbed sites in the region, and not to historical estimates. If historical amounts of wood were higher as is suspected, then an assessment using historical reference condition might well paint a different picture.

For the Mid-Atlantic as a whole, 26% of stream length was completely devoid of large wood (our definition of poor condition; see Appendix A), while 47% had amounts of wood similar to reference sites (Figure 19). The Coastal Plain ecoregion presents the best picture, with 67% of stream length in good condition, and only 14% in poor condition for wood (Figure 19). The Western Appalachian (41% of stream length in poor condition) and Valley (30%) ecoregions had the highest proportions of stream length with no large wood.

RIPARIAN HABITAT

Riparian (or streamside) vegetation provides shade to flowing waters (particularly small streams), maintaining cool water temperatures required by many fish species for reproduction, growth and survival. Riparian vegetation that washes or falls into the stream can be a source of food for stream organisms, especially macroinvertebrates. It also strengthens and stabilizes stream banks and helps to prevent silt and associated contaminants from entering the stream. In-stream large wood derived from riparian trees creates complex habitat and pools for stream fish and aquatic insects. Human beings alter riparian habitat in a variety of ways: clearing vegetation from the banks and riparian areas, logging or farming up to the stream edge, dumping litter or other wastes in riparian areas, building roads along and across streams, adding stabilizing structures (e.g., rip-rap) along banks, and building dams or other diversion structures in or near the stream channel.

We incorporated aspects of riparian vegetation cover, structural complexity, and the intensity of human disturbances into an index of Riparian Habitat Quality for use in this assessment. The index ranges from zero to one, with a value of one resulting from the combination of: (1) a multi-storied corridor of woody vegetation; (2) canopies that are closed (or nearly closed; and (3) riparian areas free of visible human disturbance (trash, roads fences, etc.). We calculated this index for all sites, and compared each site's score to the distribution found in reference sites.

Riparian habitat results for the Mid-Atlantic as a whole indicate that 23% of the total stream length had riparian areas in poor condition, while 57% had riparian habitat similar to that of reference sites (Figure 20). The Coastal Plain (26% of stream length in poor condition) and Western Appalachian (26%) ecoregions have the poorest riparian habitat (Figure 20). As was the case with excess sediments, the Piedmont ecoregion has somewhat surprisingly large proportion of stream length in good condition (77%). It may not be a coincidence that this region scored well for both in-stream and riparian habitat, as the two are closely linked. Good riparian habitat provides protection from excess sediment that might otherwise enter the stream, as well as supplying large woody material to streams (Figure 21). Upland areas of the Mid-Atlantic, the North and Central Appalachian and Ridge ecoregions, also have large proportions of stream length with good riparian condition (56% and 70%, respectively).

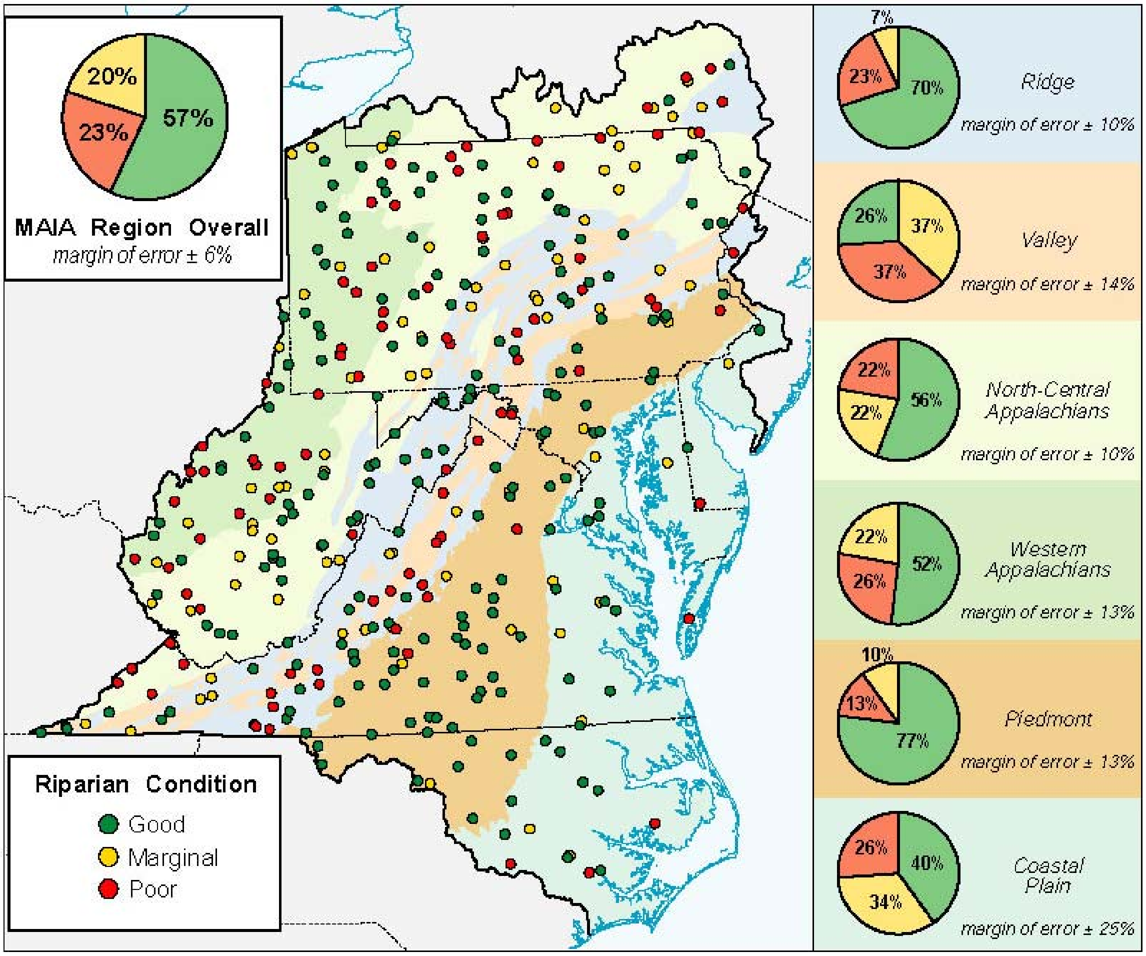

Figure 20. Extent of problems with riparian condition along flowing waters of the Mid-Atlantic, and the proportion of the total stream length in good, marginal and poor condition with respect to riparian areas. Roughly 23% of the region's stream length exhibits poor riparian condition. The Valley ecoregion has the highest proportion of stream length (37%) with poor riparian condition.

NON-NATIVE FISH

To some people a thriving rainbow trout stream indicates a successful fisheries management program. To others it suggests the introduction of a non-native, and potentially invasive, species—and a potential loss of biotic integrity and native biodiversity.

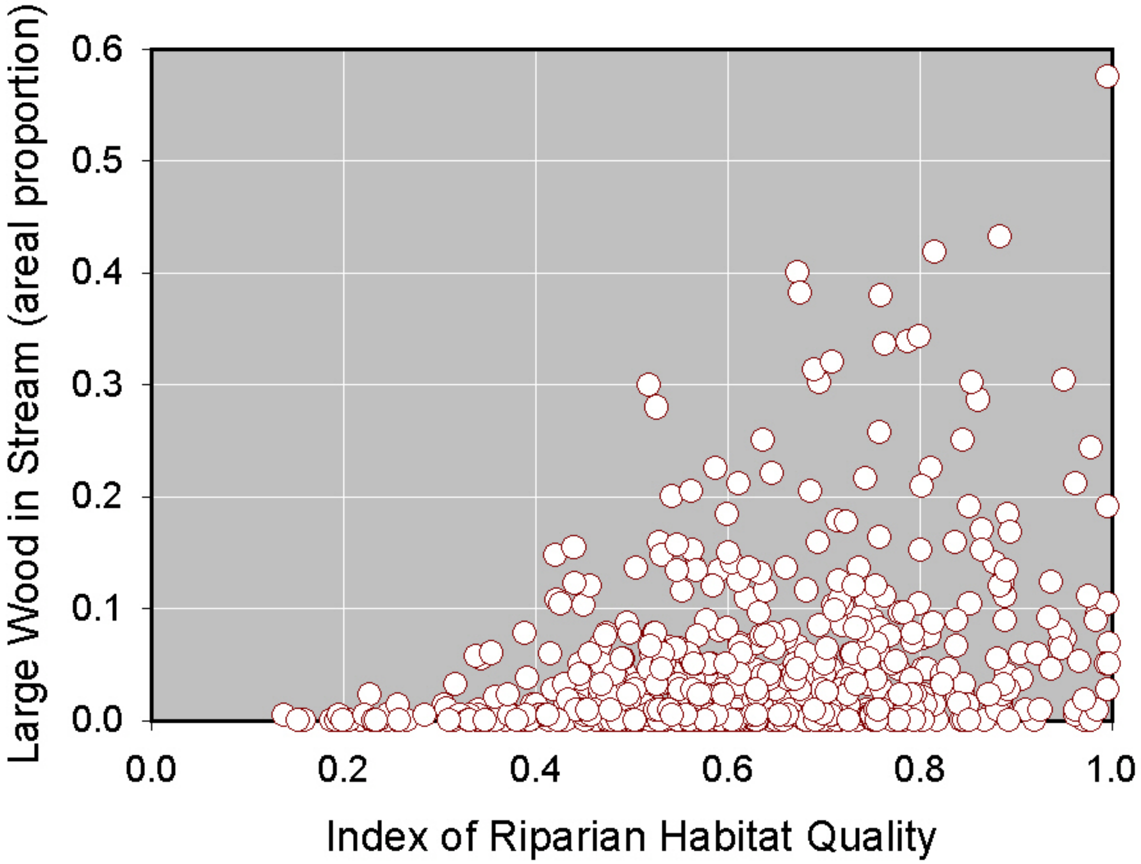

Figure 21. Relationship between Large Wood (an areal estimate of wood in stream) and Riparian Condition for 592 streams in the Mid-Atlantic. High riparian habitat quality can confer many benefits to streams and rivers, including the supply of wood to maintain complex in-stream habitat for biota.

Some states specifically recognize trout-stocked fisheries as a "designated use" for certain streams, yet many consider fish stocking of non-native species to be a potential stressor in the stream. Non-native fish do not necessarily imply poor stream condition, but non-native species have been known to replace native fish by direct predation or by out-competing them for available habitat, food, or both. In the Mid-Atlantic as a whole, 47% of the stream length has at least some non-native individuals (Figure 22). We don't attempt to identify classes of stream condition for non-native species (e.g., good, marginal or poor condition based on non-native fish species), because of the difficulty of setting expectations. The procedure we've used for all previous indicators (biology and stressors) involves deciding what an appropriate group of reference sites might be for that indicator, but this creates difficulties for a non-native species indicator. Many of the reference sites (nearly 65%) that we might use for a chemical or physical habitat indicator have at least some individuals of introduced species present. If we were using historical condition as a reference, then it might be reasonable to expect all streams to be free of non-native species, and any introduced species would be enough to classify a site as poor. But the difference between historical expectations (no non-natives) and current conditions (where 65% of reference sites have non-natives) is so great as to make setting expectations nearly impossible, especially given the differences in opinion about whether the presence of non-natives really represents a stress at all.

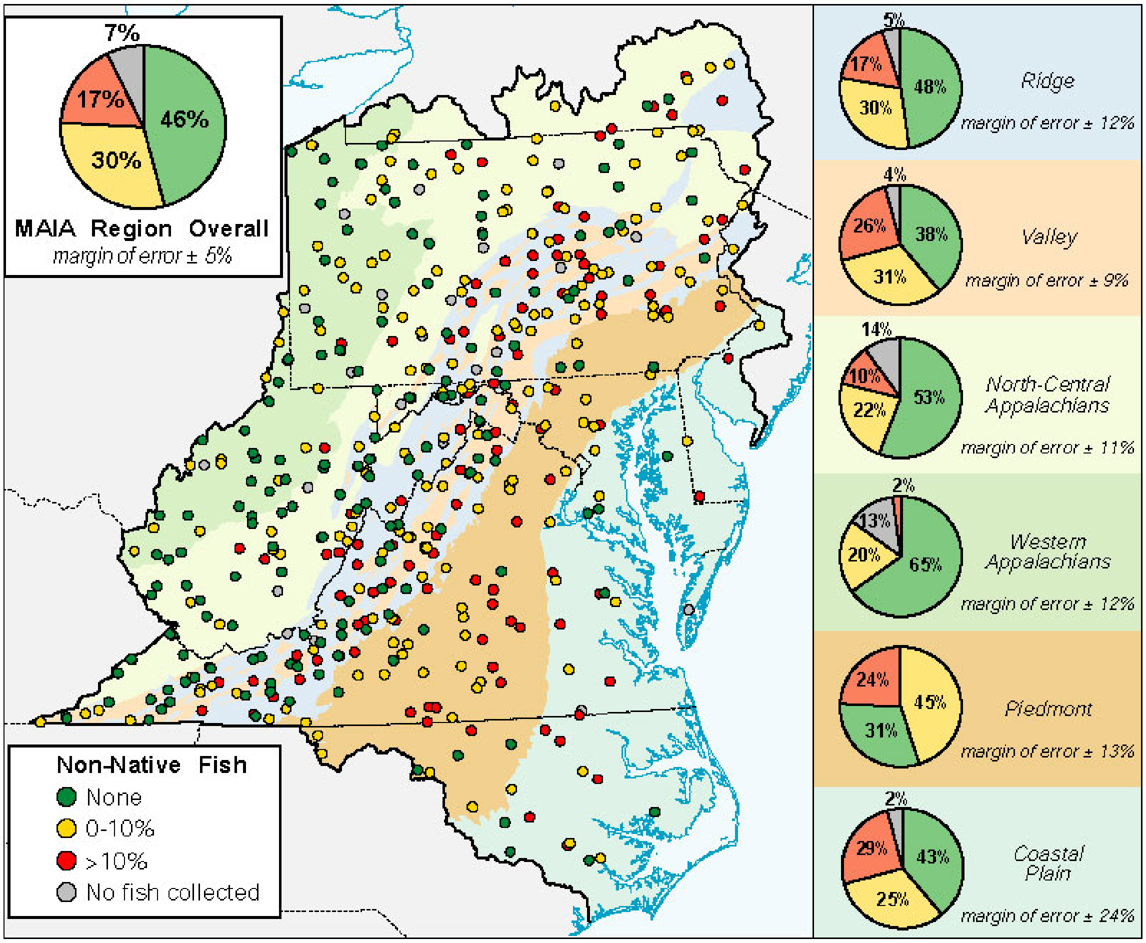

Figure 22. Percentage of Mid-Atlantic stream length with non-native fish species present. Approximately 47% of total stream length had non-native individuals present, while 46% did not. Roughly 7% of stream length is fishless. The Piedmont ecoregion has the highest proportion of stream length with introduced fish species (76%).

One convenient way to display information when thresholds between good, marginal and poor condition cannot be identified, is with a graph known as a cumulative frequency distribution or CDF. Figure 23 presents a CDF of the percentages of stream length that have different proportions of non-native individuals. At any point on the horizontal axis, one can read the proportion of stream length (or, more correctly in this case, the proportion of stream kilometers that have at least some fish) that meet or exceed that level. For example, we can estimate the proportion of stream length with 10% (or more) non-native individuals by reading the value on the vertical axis that corresponds to the 10% value on the horizontal axis. Similarly, the proportion of stream length dominated by non-natives (e.g., where more than half of the individuals are non-native species) would be about 3% (i.e., the difference between 100% and 97%, read from the graph). We include these values not as suggestions for identifying classes of impairment, but to demonstrate that the reader can form his or her own opinions of what constitutes a "non-native fish stressor" and estimate how much of the stream resource fits these criteria.

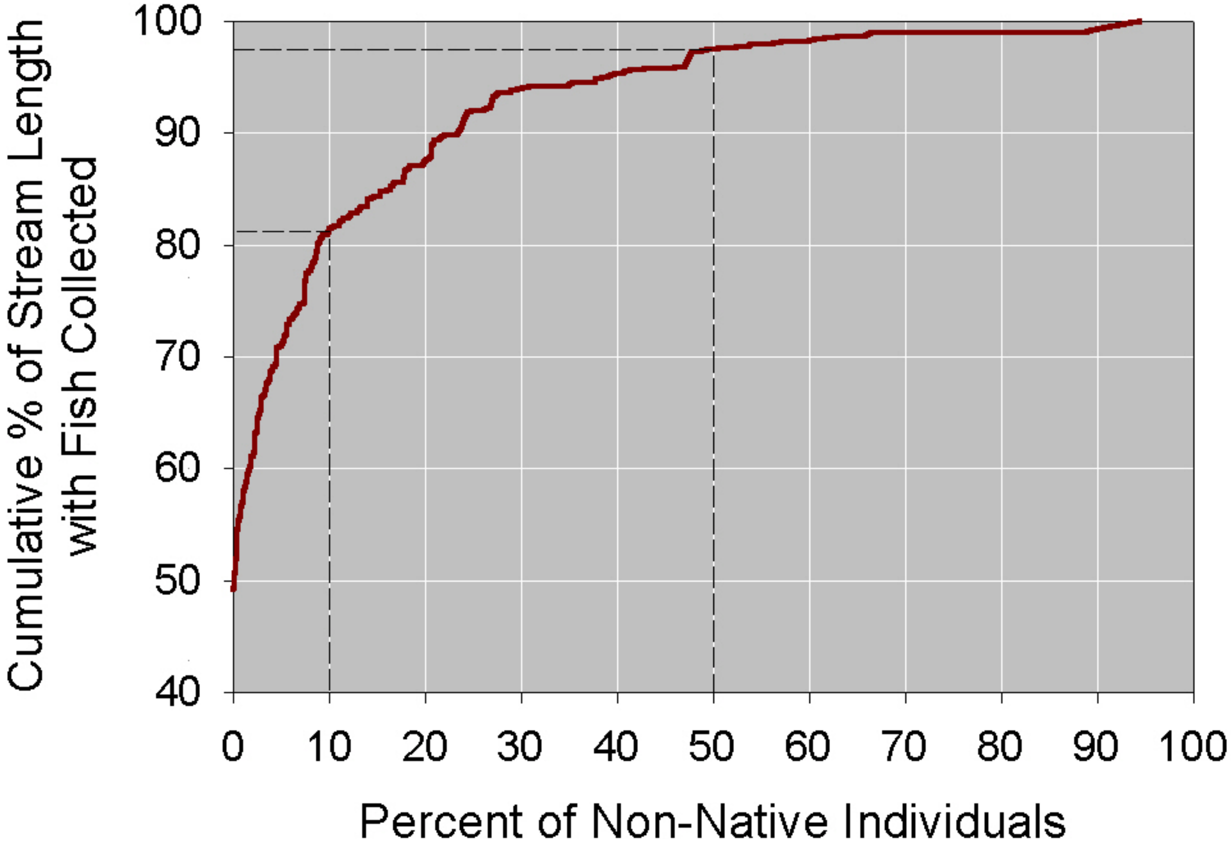

Figure 23. Cumulative frequency distribution for the percentage of non-native fish in flowing waters of the Mid-Atlantic. Approximately 50% of the stream miles where fish are found had no non-natives present. 18% had 10% (or more) non-natives, while about 3% of stream miles were dominated by non-natives (more than 50% of individuals).

Individual ecoregions exhibit large difference in the presence and absence of non-native fish species (Figure 22). The Piedmont (76% of stream length), Valley (69%) and Coastal Plain (68%) ecoregions have the highest proportions of stream length with non-native fish present. The Western Appalachian and North and Central Appalachian ecoregions have the highest proportions of streams where only native species were found (65% and 53% of stream length, respectively).

CONTAMINANTS IN FISH TISSUE

EPA has established criteria to protect both human beings and fish-eating wildlife from chemical contaminants that can be concentrated in fish tissue. For the MAIA study, fish tissue samples were collected and analyzed (whenever a sufficient number of fish were caught) for selected organic and metal contaminants. We report here on results for mercury and a combined index of organic contaminants. In general, these results are intended to indicate the exposure to wildlife from these chemicals, rather than the risks of human consumption. We analyzed whole fish, rather than fillets, and so our analyses included portions of fish not commonly consumed by human beings.

In order to place stream sites in condition classes, we used a wildlife criterion, based on American river otter (*Lontra canadensis*), of 0.1 micrograms per gram – a site where any fish species exceeded this concentration was considered to be in poor condition with respect to mercury (additional information on the mercury criterion can be found in Appendix A. For the MAIA region as a whole, 19% of the stream and river length had fish exceeding this criterion (Figure 24). An important caveat in interpreting this statistic is that 36% of the MAIA stream length either had no fish, or did not have sufficient fish to allow contaminant measurements. While it seems likely that some proportion of this 36% of stream length would also have had fish with elevated mercury, the exact proportion is not known. The highest proportions of stream length with elevated mercury in fish were found in the Piedmont (31%) and Coastal Plain (29%) ecoregions. The ecoregion with the fewest streams with elevated mercury was the Valley ecoregion (10% of stream length).

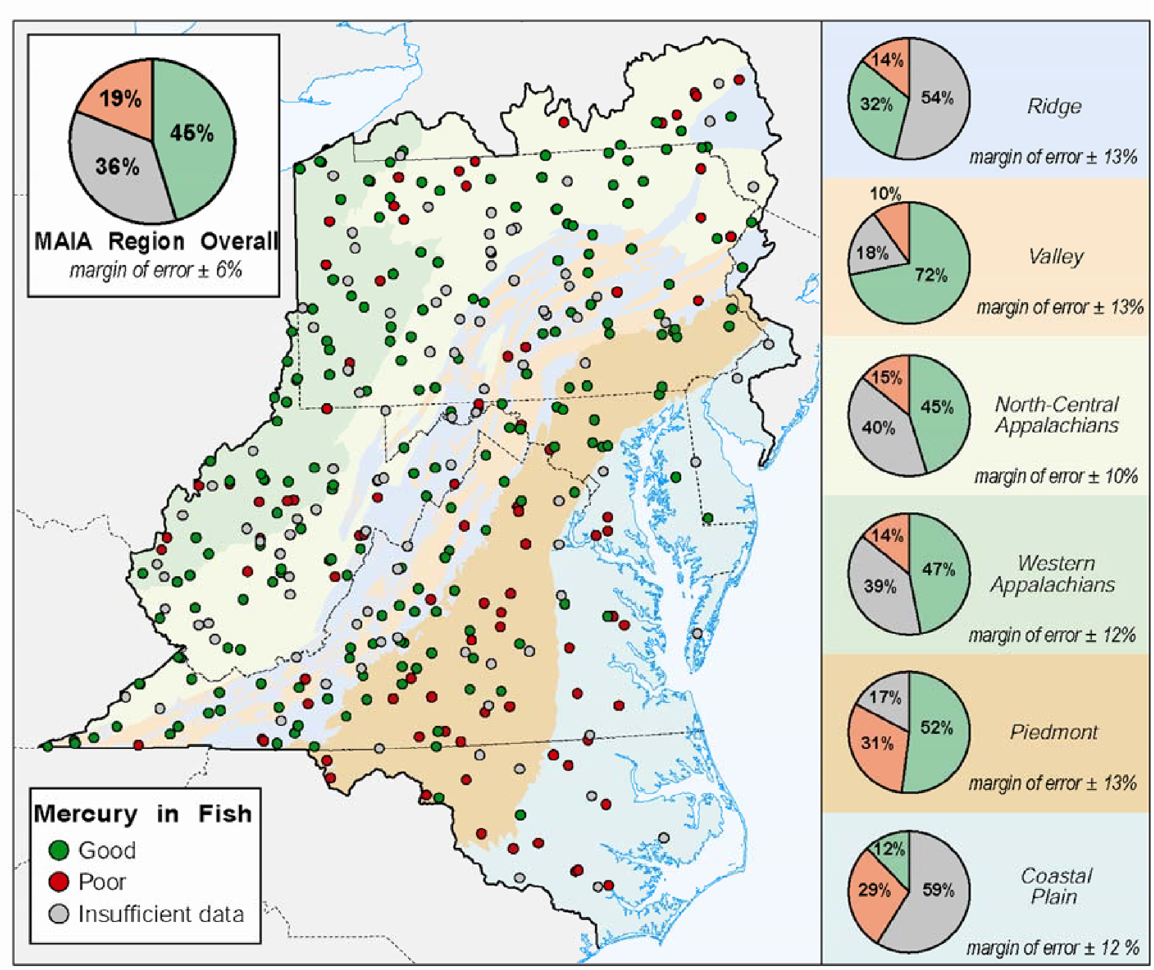

Figure 24. Percentage of Mid-Atlantic stream length with mercury concentrations in fish tissue that exceeded the criterion for American river otter. Approximately 19% of total stream length had elevated mercury concentrations present, while 46% did not. About 36% of the stream length either had no fish, or insufficient fish to allow contaminant analysis. The Piedmont and Coastal Plain ecoregions exhibited the highest proportions of stream length with fish mercury concentrations exceeding the 0.1 microgram per gram criterion (31% and 29%, respectively).

Fish tissue samples were also analyzed for several organic contaminants, including Chlordane, DDT and its metabolites, Dieldrin and Polychlorinated Biphenyls (PCBs). Most of these contaminants (with the exception of PCBs) are primarily from agricultural chemicals, and might be expected to be higher in ecoregions dominated by agriculture. We placed all streams where any fish species exceeded the American river otter criterion for any of these organic contaminants in the poor condition category (see Appendix A for additional information on the wildlife criteria used for these contaminants). Only 4% of the total stream and river length in MAIA contained fish that exceeded any of the organic contaminant criteria (Figure 25). As was the case for mercury, these results need to placed in context—about one-third (34%) of the MAIA stream length either contained no fish, or did not have sufficient fish to allow contaminant analysis, so the 4% estimate should probably be considered a lower bound on the true value. Unlike mercury, where the Valley ecoregion had a low proportion of stream length with elevated concentrations, organic contaminants are more likely to be found in the Valley (8% of stream length) than any other ecoregion. This most likely reflects the different sources for these two categories of contaminants—while the organic contaminants are primarily agricultural chemicals, mercury is thought to derive mostly from atmospheric precipitation.

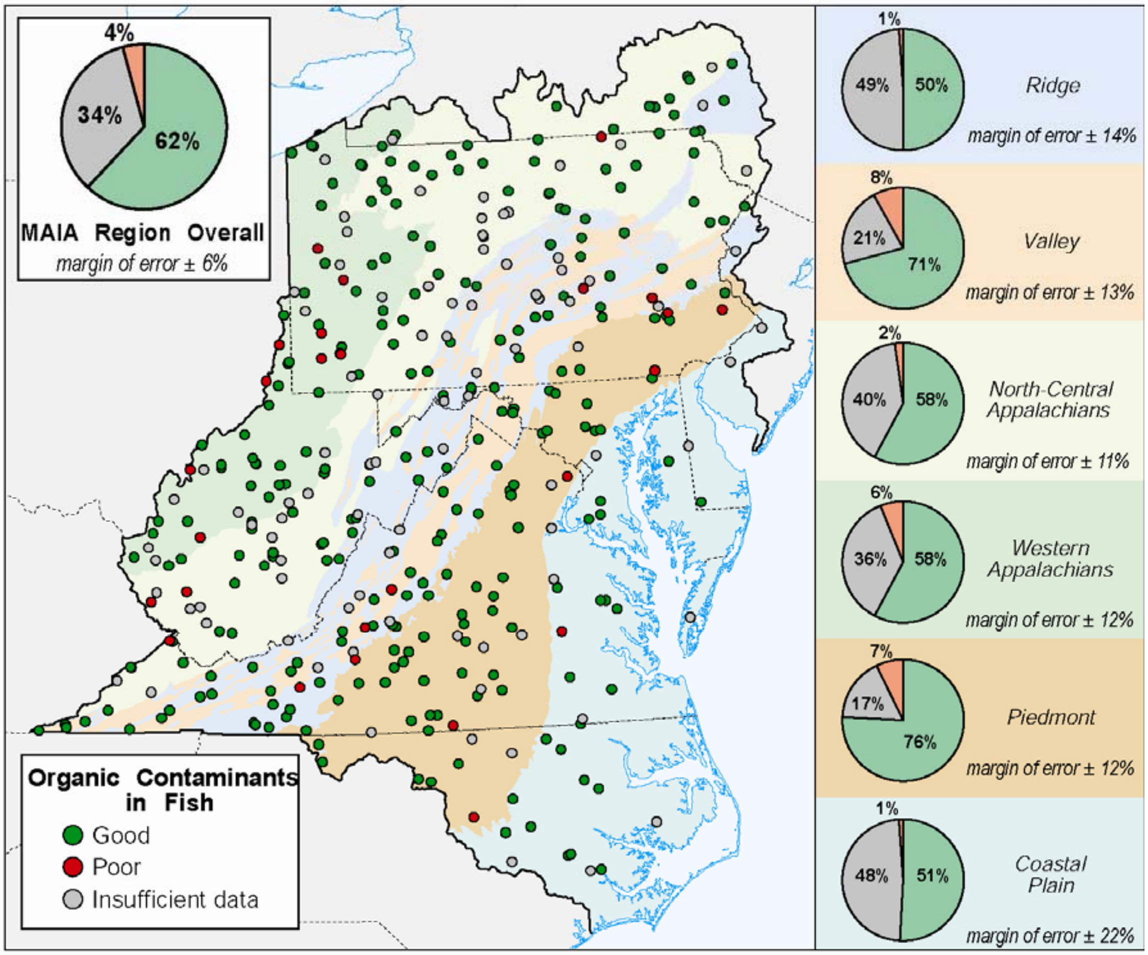

Figure 25. Percentage of Mid-Atlantic stream length with organic contaminant concentrations in fish tissue that exceeded the criterion for American river otter. Approximately 4% of total stream length had elevated concentrations of either Chlordane, DDT, Dieldrin or PCBs in fish. The Valley ecoregion exhibited the highest proportions of stream length with elevated organic contaminant concentrations (8%).

SUMMARY RANKING OF POTENTIAL STRESSORS

An important prerequisite to making wise policy and management decisions is understanding the relative magnitude or importance of current stressors. There are multiple ways that we might choose to define "relative importance" with stressors. One aspect to consider is how common each stressor is—i.e., what is the extent, in kilometers of stream, of each stressor and how does it compare to the other stressors? We might also want to consider the severity of each stressor—i.e., how much effect does each stressor have on biotic integrity, and is its effect greater or smaller than the effect of the other stressors? Ideally, we'd like to combine these two factors (extent and severity) into a single measure of relative importance. Currently we have no good method for producing this combined measure. For this reason we present separate rankings of the relative extent and the relative severity of stressors to flowing waters in the Mid-Atlantic.

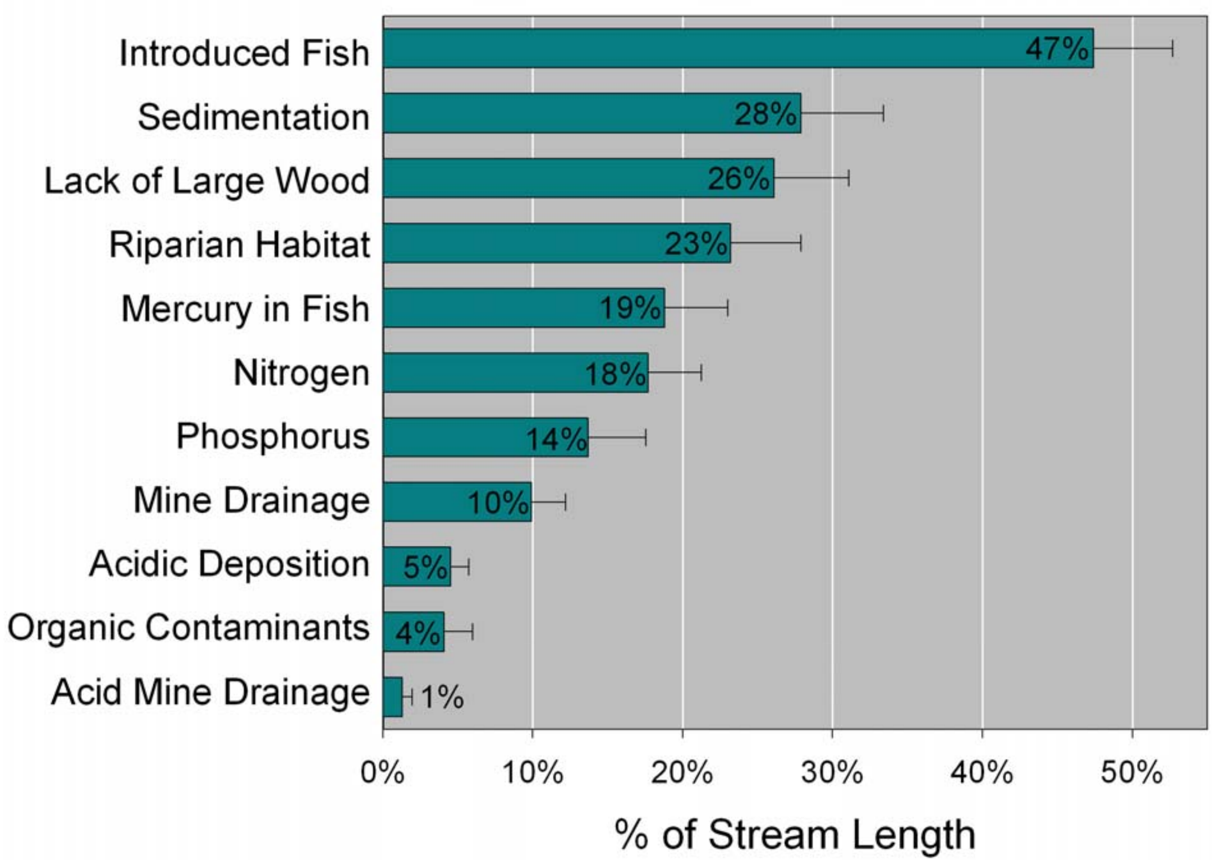

Figure 26. Relative extent of major stressors on stream condition in the Mid-Atlantic. Each bar represents the proportion of stream length in poor condition for that stressor, with 90% confidence intervals around each estimate. If introduced fish species are considered a stressor, then they are the most common stressor in the Mid-Atlantic. All of the physical habitat indicators also rank high in relative importance based on extent.

RELATIVE EXTENT

In Figure 26, stressors are ranked according to the proportion of stream/river length impaired (or in poor quality) with regard to each stressor indicator. The potential stressor that occurs in the highest proportion of flowing waters is non-native fish (47% of the stream length in the Mid-Atlantic had at least one non-native fish present). As discussed earlier in this report, many would not consider non-native fish (often game fish) to be a stressor; we list it here to highlight the broad extent of non-native fish in the region—indicating a potentially serious alteration of biological integrity—and leave it up to the reader to decide whether it should be considered a stressor in the same way as other stressors. The three next-most common stressors are elements of stream habitat: excess sediments (28% of stream length), absence of large woody debris (26%) and low riparian habitat quality (23% of stream miles). In terms of rank, the habitat stressors are followed by several chemical stressors (mercury, nutrients, acidity)—these are found less extensively in the Mid-Atlantic than habitat stressors. Elevated mercury in fish tissue (19% of stream length), excess nitrogen (18% of stream miles) and phosphorus (14%) are still very common, as are the effects of mine drainage (10% of stream length). The percentage of stream length affected by acid rain (5%), organic contaminants of fish tissue (4%), and acid mine drainage (1%) appear minor when compared to the other stressors, at least at the scale of the Mid-Atlantic as a whole. They are clearly of greater relative importance in selected ecoregions (Figures 13 and 14).

RELATIVE RISK

In order to address the question of severity of stressor effects, we borrow the concept of “relative risk” from medical epidemiology, because of the familiarity of the language it uses. We have all heard, for example, that we run a greater risk of developing heart disease if we have high cholesterol levels. Often such results are presented in terms of a relative risk ratio—e.g., the risk of developing heart disease is four times higher for a person with total cholesterol of 300 mg than for a person with 150 mg. total cholesterol.

In Figure 27 we present relative risk values for the biological and stressor data on streams in the Mid-Atlantic. Because different biological assemblages are expected to be affected by different stressors, relative risk is calculated separately for the fish IBI, the macroinvertebrate IBI and the algal IBI. In our case, relative risk is defined as the proportional increase in the likelihood of encountering a poor IBI score when a stressor's condition in the same stream is also classified as poor (see Appendix B for details of relative risk calculation). Not all relative risks are statistically significant, and so we focus this assessment on those that are.

In an assessment of relative risk based on cross-sectional survey data (as opposed to data from a controlled experiment) it is impossible to separate completely the effects of individual stressors that often occur together. For example, streams with high nitrogen concentrations often exhibit high phosphorus as well; non-acidic streams with mines in their catchments often have sediments far in excess of expectations. The analysis presented in Figure 27 treats the stressors as if they occur in isolation, even though we know they do not. We do not currently have an analytical technique to separate the effects of correlated stressors, other than to point out in the discussion where co-occurrence of stressors should be considered in the interpretation of the assessment.

One of the most important conclusions from the analysis in Figure 27 is that different biological assemblages appear to be affected by different stressors. We certainly expect this to be the case (it is the primary justification for including multiple assemblages in monitoring programs, and in assessments like the current one), but the results in Figure 27 are strong confirmation of this. The presence of non-native fish species is associated with poor fish assemblage integrity, but does not appear to affect either macroinvertebrates or algae. Excess sediments present a significantly elevated risk to both macroinvertebrate and algal assemblages, but not to fish. Acidic deposition and acid mine drainage put fish and macroinvertebrate assemblages at risk, but do not appear to increase the likelihood of finding algal assemblages in poor condition.

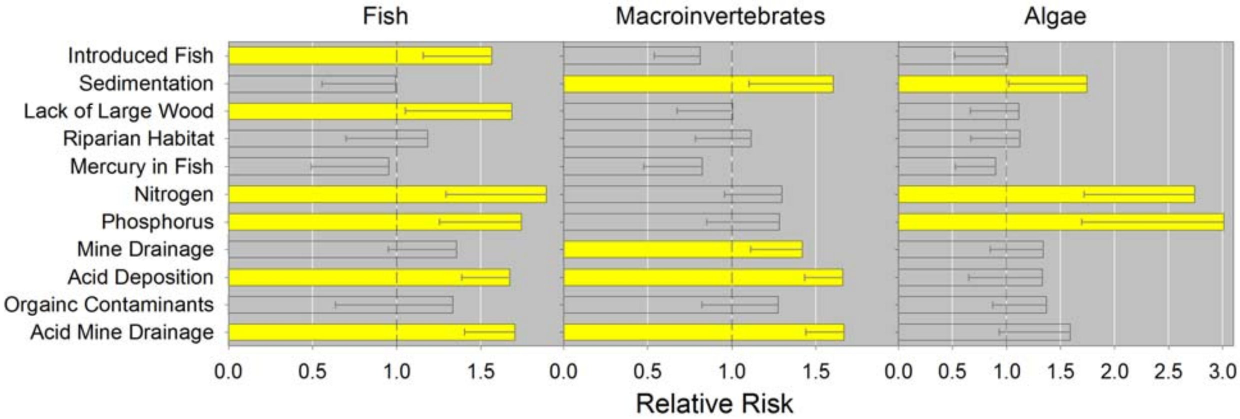

Figure 27. Relative risk values for associations between biotic integrity (for each assemblage) and stressor condition (for each assessed stressor). Length of bars is the increase in likelihood of encountering a poor ecological condition (based on biological indicators) when the stressor is also ranked as poor. For example, algal assemblages are roughly three times as likely to be in poor condition when phosphorus concentrations are also poor. Lines (with caps) within bars indicate one-sided lower 95% confidence intervals for estimated relative risk. A relative risk of 1.0 denotes "no stressor effect", and stressors with confidence intervals lying entirely above 1.0 are statistically significant (one-sided p<=0.05), as represented by yellow bars. Grey bars represent stressors for which we could not detect a significant effect.

The significant relative risks in Figure 27 give us an idea both of how severe each stressor’s effect on biotic integrity is, and which stressors we might want to focus on when a given assemblage is in poor ecological condition. Both algae and macroinvertebrates exhibit high relative risks for a mix of physical and chemical habitat indicators. For example, the stressors with significant relative risk values for algae are excess sediments and the two nutrients, phosphorus and nitrogen. Algal assemblages are 1.5 to 3 times more likely to be in poor condition when one (or more) of these stressors is elevated. As mentioned earlier, algae are expected to be directly effected by elevated nutrient concentrations, because they are the only primary producers among the biological indicators in this assessment. In fact, the relative risk of nutrient effects on algae are the highest ones observable in our data. Sediments, which have an obvious and deleterious scouring effect on attached algae, also appear to pose a significant risk to algal biotic integrity.

The greatest relative risks to macroinvertebrates are excess sedimentation, mine drainage (either acidic or non-acidic) and acidic deposition. Again, these quantitative results demonstrate what we expect qualitatively from macroinvertebrate assemblages—namely, that disturbances that alter the micro-habitats within streams, or affect pollution intolerant taxa, have significant effects on macroinvertebrate integrity. Most macroinvertebrate species occupy either the small spaces between coarse streams substrates like cobbles and gravels, or cling to hard surfaces exposed to stream currents—both micro-habitats are buried when excess fine sediments are present in a stream. Figure 27 illustrates both the direct risk we calculate from excess sediments, and the associated risk posed by non-acidic mine drainage, where excess sediments are likely to occur. The direct chemical effects of acidification, whether from acidic deposition or acid mine drainage, are also associated with elevated risks for macroinvertebrates.

In the case of fish assemblages, the significant stressors are a mix of chemical, physical and biological habitat indicators. The presence of non-native fish species, and the absence of large woody material, are both strongly associated with poor fish biotic integrity in our dataset. Acidity, whether from acidic deposition or acid mine drainage, is also strongly associated with poor fish assemblages, due to the well documented loss of sensitive taxa in acidic streams. Nitrogen and phosphorus are not expected to have direct effects on fish biotic integrity, but our data suggest significant relative risk values for these nutrients. We cannot determine from these data whether nitrogen and phosphorus are simply associated with other factors that have direct effects on fish (e.g., the many cumulative effects of agricultural landuse), or whether the other biotic alterations that occur in streams with high nutrients (increased algal growth, increased occurrence of low oxygen concentrations) have effects that reverberate up the trophic pyramid to affect fish.

The results in Figure 27 also illustrate that almost all of the stressors we measure have a significant effect on at least one biotic assemblage. The only exception to this is riparian habitat condition. Interestingly, riparian habitat is the only stressor indicator that does not result from direct, in-stream measurements. Previous research has shown that riparian habitat is related to many of the other stressors we measure in the streams—for example, good riparian condition is associated with nutrient removal from agricultural runoff, control of erosion (and therefore control of excess sediments) and the provision of dead wood to streams to support complex in-stream habitat (see Figure 21). The lack of response in our relative risk analysis may have more to do with the scale at which we assess riparian habitat (e.g., our measurements include only the riparian habitat along the study reach where biota are sampled—measurements made at the scale of the whole watershed, or along an entire stream network may capture more of the disturbance signal) than its lack of importance to ecological condition.

COMBINING EXTENT AND RELATIVE RISK

The most comprehensive assessment of the effect of stressors on biotic integrity comes from combining the relative extent (Figure 26) and relative risk (Figure 27) results—stressors that pose the greatest risk to individual biotic assemblages will be those that are both common (i.e., they rank high in terms of extent in Figure 26) and whose effects are potentially severe (i.e., exhibit high relative risk ratios in Figure 27). In order to evaluate these combined measures of stressor importance, we present the relative extent and relative risk results for each assemblage in a side-by-side comparison, below.

A quick examination of the combined fish results (Figure 28) suggests that both non-native species and the absence of large woody material in streams are highly important stressors to fish biotic integrity—both demonstrate significant relative risks, and both are found in more than 25% of Mid-Atlantic stream length. Elevated nutrient concentrations also appear to pose significant risk to fish assemblages, but are found less extensively (roughly 15% of stream length). And the effects of acidic deposition and acid mine drainage are severe when found (relative risk > 1.5), but are relatively rare in the Mid-Atlantic (less than 5% of stream length).

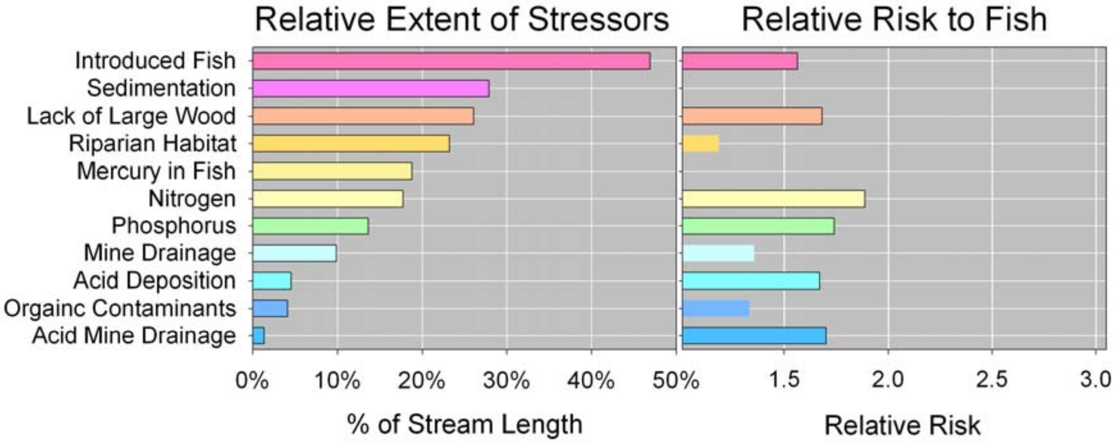

Figure 28. Comparison of relative extent (left panel) and relative risk to fish (right panel). All stressors with relative risk values greater than 1.5 are significant (see Figure 27) for fish; stressors with relative risk values less than one are not shown. Stressors that represent the greatest risk to fish assemblages are characterized by high values for both extent and relative risk (e.g., non-native fish).

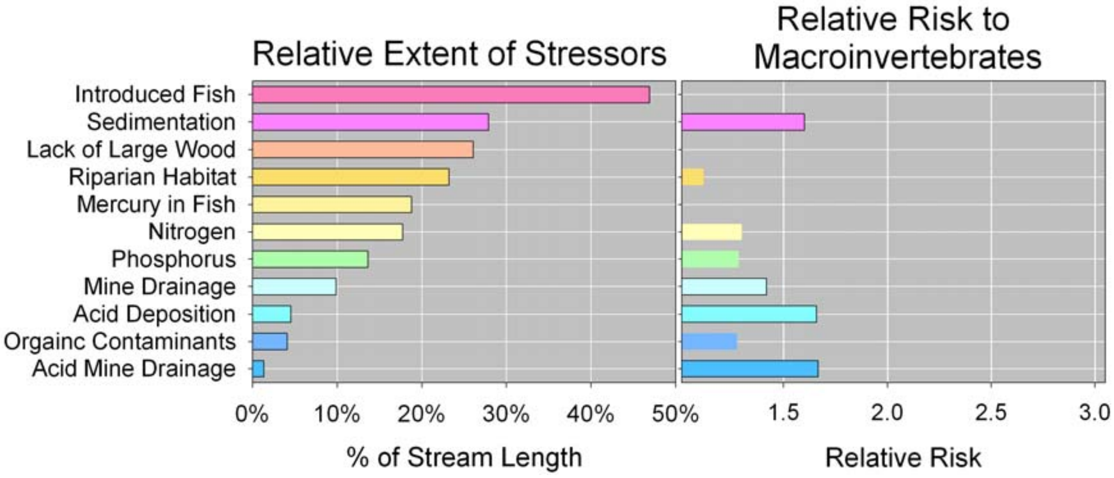

Figure 29. Comparison of relative extent (left panel) and relative risk to macroinvertebrate biotic integrity (right panel). All stressors with relative risk values greater than 1.4 are significant (see Figure 27) for macroinvertebrates; stressors with relative risk values less than one are not shown. Stressors that represent the greatest risk to macroinvertebrate assemblages are characterized by high values for both extent and relative risk (e.g., excess sediments).

In the case of macroinvertebrates (Figure 29), excess sediments are quite clearly the most important stressor—they are strongly and significantly associated with poor macroinvertebrate integrity, and are relatively common (ca. 28% of Mid-Atlantic stream length). As was the case with fish, acidic conditions can have a severe effect on macroinvertebrates when they occur (either from acidic deposition or acid mine drainage), but their relative extent is low (<5%) and are therefore of lower overall importance to regional macroinvertebrate integrity.

Elevated nutrient concentrations appear to be of the first importance (Figure 30) to algal assemblages—they exhibit the highest calculated relative risk ratios in our data, and are relatively common (roughly 15% of stream length). Excess sediments might be considered to be of nearly equivalent importance—the relative risk to algal biotic integrity is lower than that of nutrients, but they are nearly twice a common (ca. 28% of Mid-Atlantic stream length). No other stressor exhibited significant relative risk values for algae.

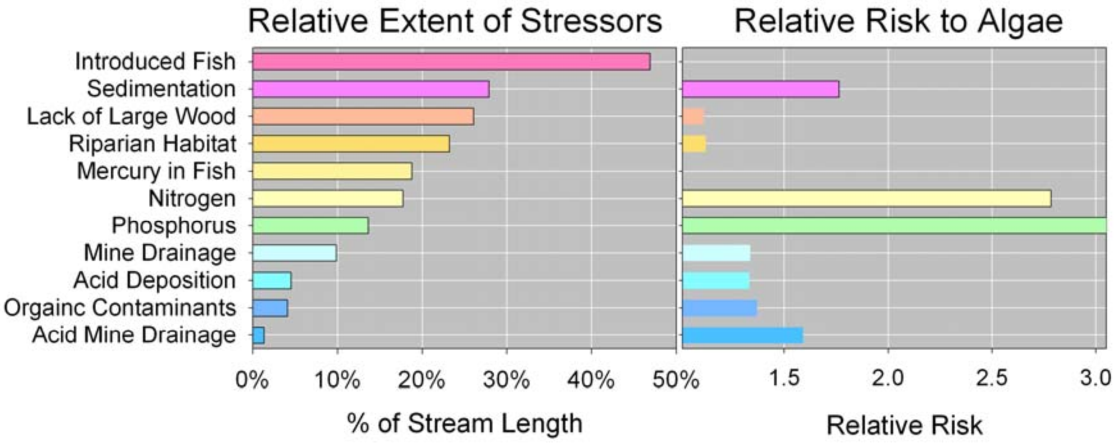

Figure 30. Comparison of relative extent (left panel) and relative risk to algal biotic integrity (right panel). All stressors with relative risk values greater than 1.6 are significant (see Figure 27) for algae. Stressors that represent the greatest risk to algal assemblages are characterized by high values for both extent and relative risk.

GEOGRAPHIC TARGETING

Throughout this assessment we have observed ecoregional differences in the condition of MAIA flowing waters—both in ecological condition and in the relative importance of stressors. It would be reasonable for land managers to ask, “Can we use these results to help guide (target) how we spend our resources? Are there sub-regions of the Mid-Atlantic that we should make a higher priority than others? Should we be tackling different problems in different areas?”

With the wealth of data collected by the MAHA and MAIA projects, we can begin to provide answers to some of these questions. Within each ecoregion, the condition of the three different biological assemblages, and the relative importance of different stressors, can be used to guide stream protection and restoration goals. In this section, we provide very short summaries of the condition assessments for each Mid-Atlantic ecoregion, and speculate briefly on what the results might imply to managers. This comparative look at the results of an ecological assessment might be termed “geographic targeting.”

COASTAL PLAIN

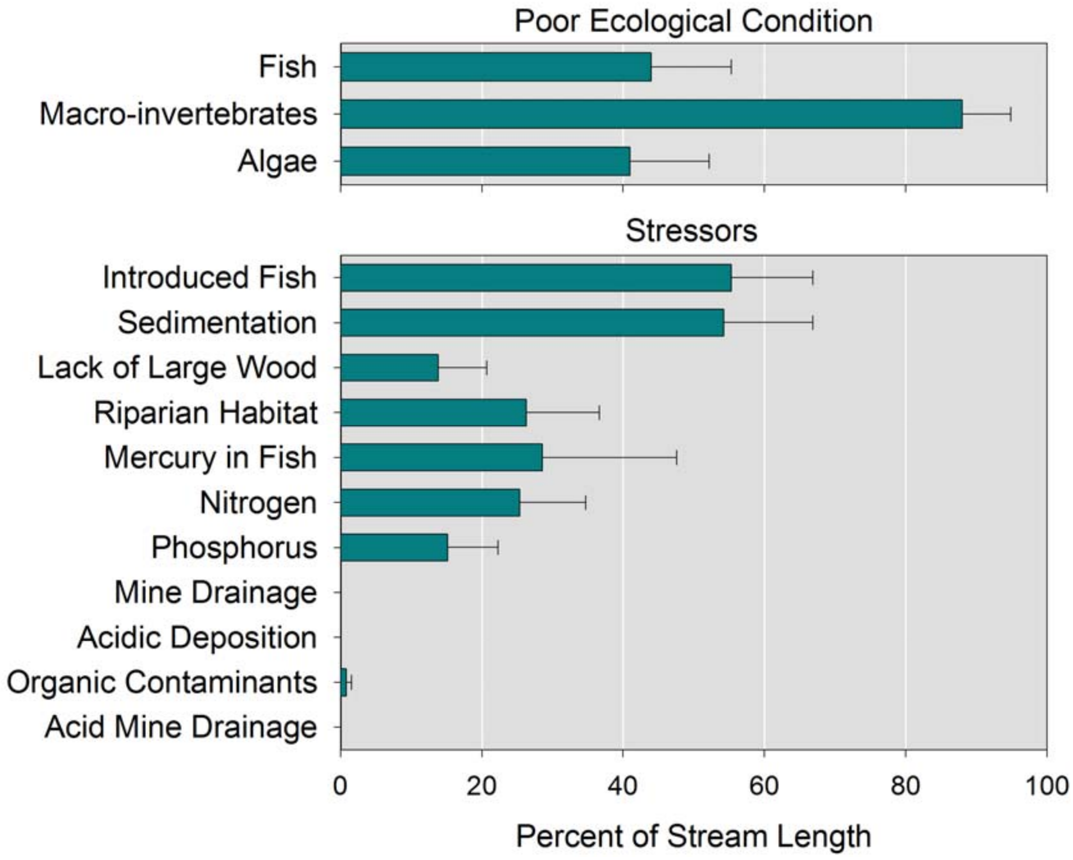

Figure 31. Summary of Coastal Plain ecoregion condition.

Perhaps the most striking result for the Coastal Plain ecoregion is the large proportion of stream length in poor condition for macroinvertebrates. Although stream managers might be tempted to focus on macroinvertebrates (or, more specifically, on the stressors that are known to degrade their condition), it is important to recognize that all three biological assemblages are more commonly found in poor condition in the Coastal Plain than in the Mid-Atlantic as a whole—88% vs. 41% for macroinvertebrates, 43% vs. 31% for fish, and 41% vs. 33% for algae.

This region has the highest proportion (relative to other ecoregions) of stream length with severe sedimentation, and the relative risk assessment (previous section) suggests strongly that macroinvertebrates (as well as algae) are strongly affected by excess fine sediments. If stream and watershed managers in the Coastal Plain were to focus on the single environmental problem with the largest probability of improving biotic integrity, then controlling sediment inputs might be a wise choice.

The Coastal Plain also exhibits a very large proportion of stream miles with non-native fish species present. While non-native fish species are difficult to eradicate once they become established, measures to limit further introductions and dispersal might help prevent further degradation of the biotic integrity of fish assemblages in this ecoregion.

PIEDMONT

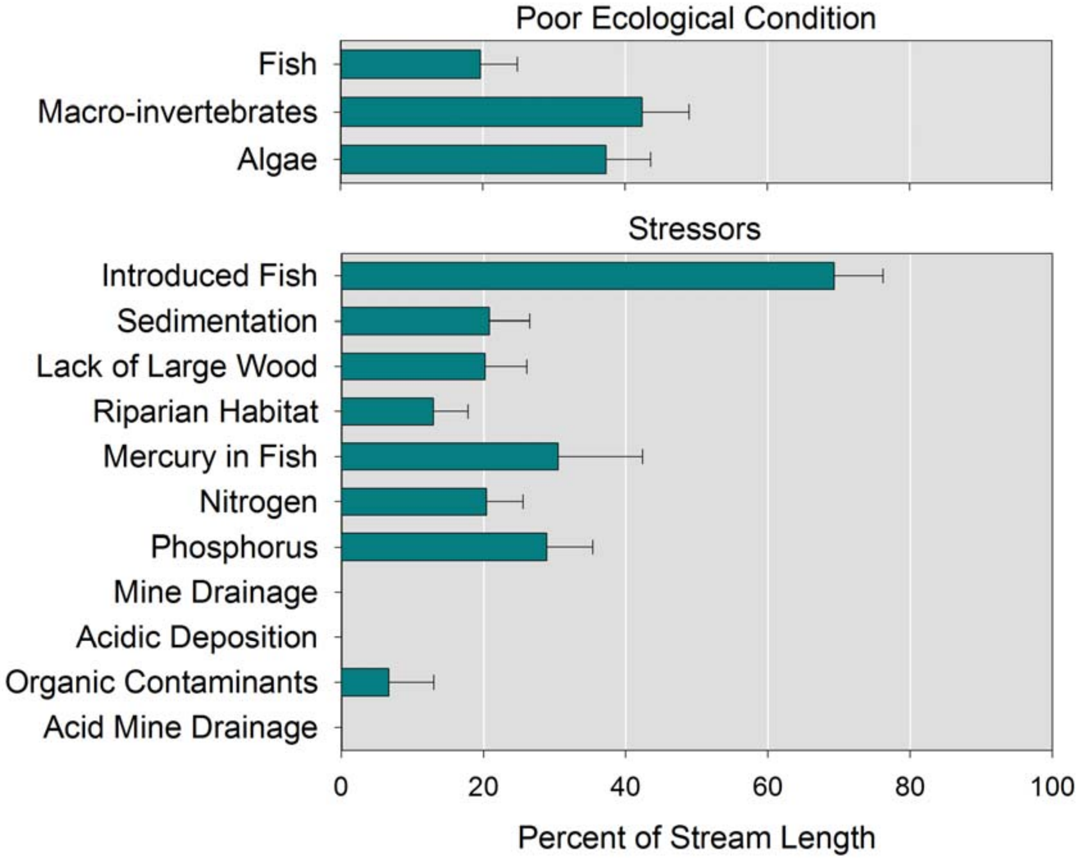

Figure 32. Summary of Piedmont ecoregion condition.

Like the Coastal Plain, the Piedmont ecoregion has a larger proportion of stream length in poor condition for macroinvertebrates than for any other biological assemblage. But unlike the Coastal Plain, the Piedmont does not have an obvious stressor to focus on—no single stressor known to affect macroinvertebrates (sedimentation, acidity) is particularly prevalent.

The Piedmont is instead characterized by a relatively even ranking of the most common stressors (all of the habitat stressors and both of the nutrient stressors are found in 15% to 30% of stream length), and the largest proportion of stream length with non-native fish (nearly 70%). Excessive concentrations of both nitrogen and phosphorus are found in a larger proportion of streams in this ecoregion than in the Mid-Atlantic as a whole, while the habitat stressors are uncommon relative to the larger region. Even though nutrients rank relatively low in the Mid-Atlantic stressor hierarchy (Figure 26), a focus on them in the Piedmont might be warranted. Interestingly, algae are the only assemblage in the Piedmont where the proportion of streams in poor condition is substantially higher than in the Mid-Atlantic as a whole. Our relative risk analysis suggests that high nutrient concentrations pose a significant risk to algal biotic integrity, and high proportions of poor stream condition for both algae and nutrients in the Piedmont certainly suggest that a focus on nutrients would be beneficial in improving streams in the region.

VALLEYS

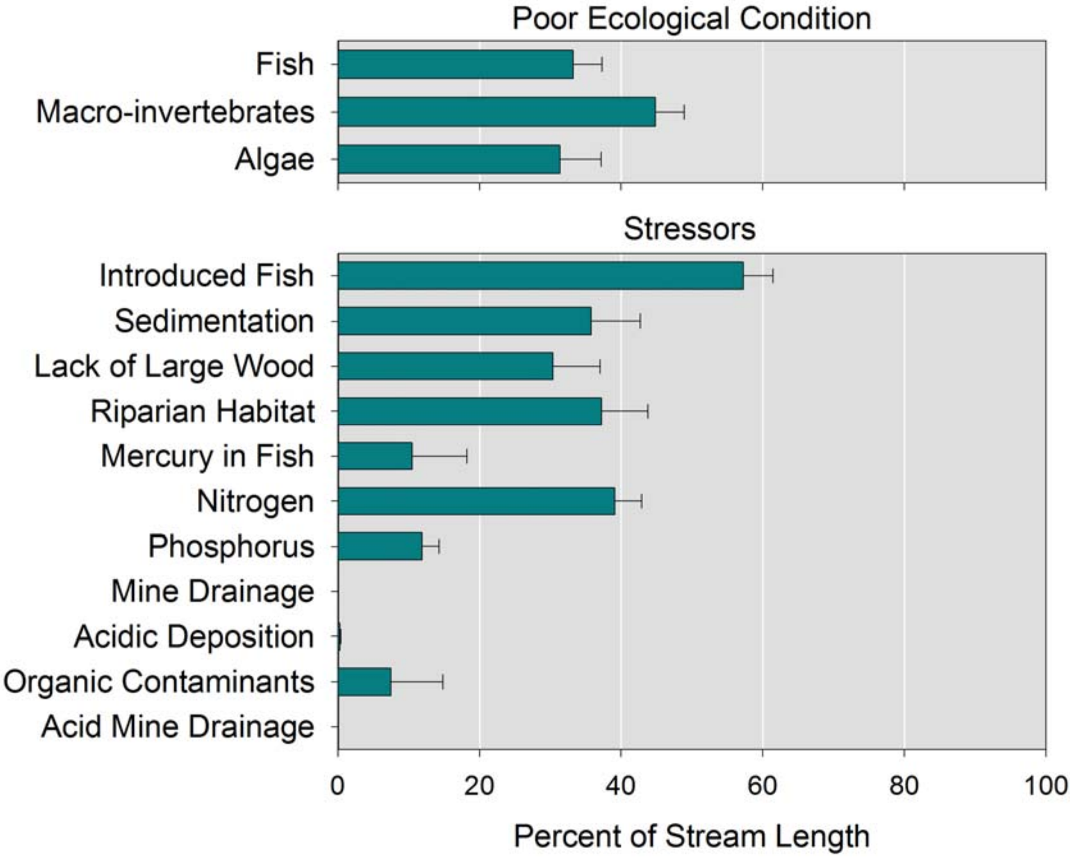

Figure 33. Summary of Valley ecoregion condition.

In common with both of the other lowland ecoregions (the Coastal Plain and Piedmont) the Valley ecoregion has a larger proportion of stream length in poor condition for macroinvertebrates than for any other biological assemblage, although poor condition is found in all three assemblages in a slightly larger proportion of streams in the Valley ecoregion than in the Mid-Atlantic as a whole—45% vs. 41% for macroinvertebrates, 33% vs. 31% for fish, and 34 % vs. 33% for algae.

Like the Piedmont, the Valley ecoregion is characterized by a relatively even ranking of the most common stressors (all of the habitat stressors, as well as nitrogen, are found in 25% to 40% of stream length), but all have greater extents here than in the Piedmont. There has been substantial monitoring and research work to show that intact riparian areas can help prevent nitrogen runoff (largely from agricultural fertilizers) from reaching streams. Protecting and restoring riparian areas in the Valley ecoregion could well lead to improvements in all of the most common stressors in the region—controlling sediment and nitrogen inputs, and providing additional large woody material to streams deficient in wood. Managers might well look at the summary in Figure 33 and conclude that focusing their restoration and remediation resources on improving riparian condition could provide the single biggest improvement in stream condition.

RIDGES

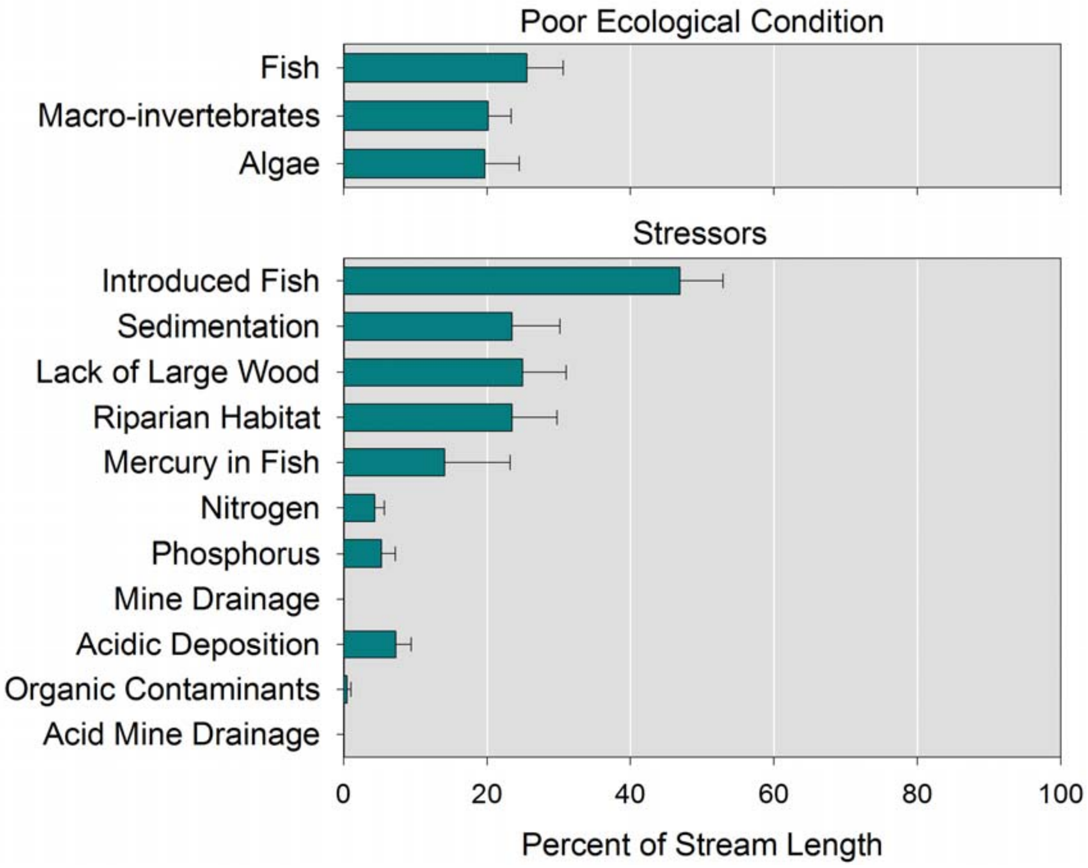

Figure 34. Summary of Ridge ecoregion condition.

The Ridge ecoregion might be considered to be in the best condition of any Mid-Atlantic ecoregion. All three biological assemblages are found in poor condition in less than 25% of stream length—well below the region-wide proportion for the Mid-Atlantic as a whole. It is easier to decide what ***not*** to focus on in this ecoregion than to identify an obvious target for restoration resources. Nutrients, for example, are a problem in 4-5% of stream length, and are probably best managed on a site-specific basis, rather than through a region-wide effort.

As one of the few ecoregions where the proportion of stream length with poor fish assemblages is higher than the proportion of macroinvertebrate and algal assemblages, focusing on those stressors that represent the greatest relative risk to fish would make sense. Reducing the extent of non-native fish, for example, may be a cost effective strategy for improving fish assemblages.

Alternatively, regional managers might look at the relatively high biotic integrity in this ecoregion, and conclude that efforts to conserve remaining areas of good ecological condition should focus on this ecoregion.

NORTH AND CENTRAL APPALACHIANS

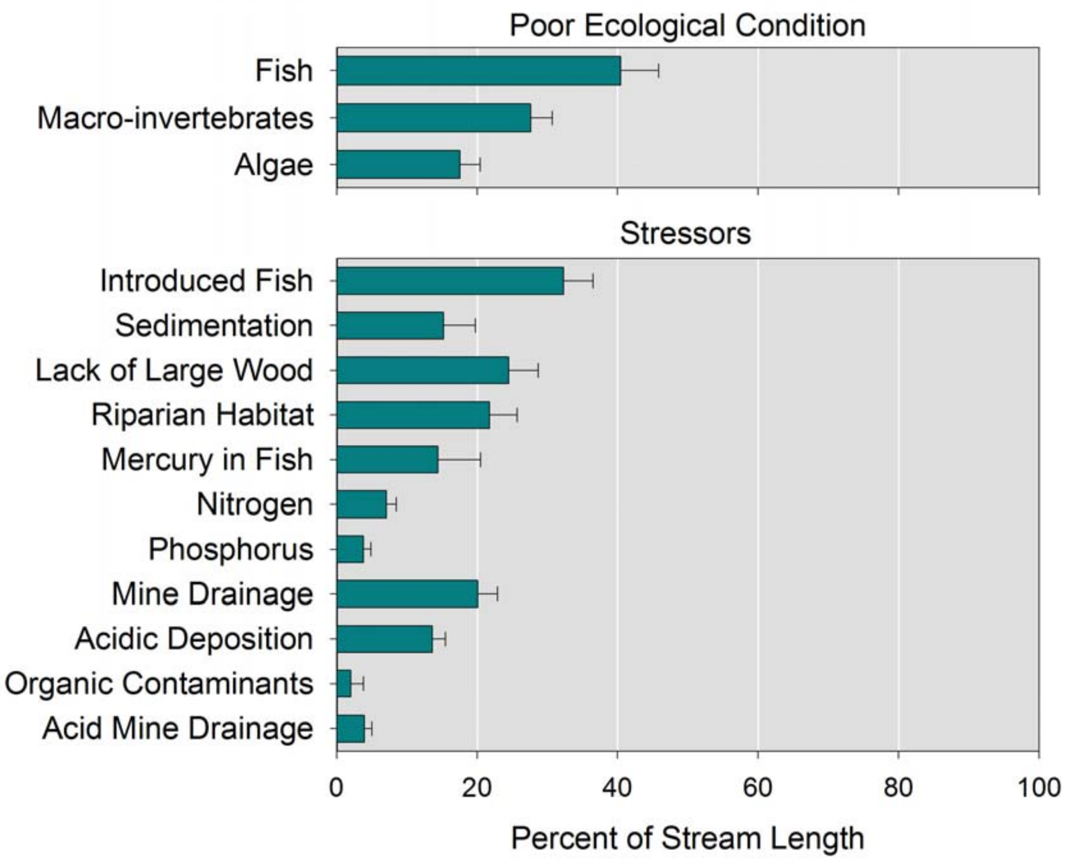

Figure 35. Summary of North and Central Appalachian ecoregion condition.

The North and Central Appalachians, like the Ridge ecoregion, are in relatively good condition compared to the Mid-Atlantic as a whole (Figure 35). Only fish assemblages are found in poor condition in a larger proportion of stream length here (40%) than in the entire region (31%).

Relatively rare problems with sedimentation and nutrients might well be responsible for the small proportion of algal assemblages found in poor condition. But mine drainage and acidic deposition, both of which put fish and macroinvertebrate assemblages at risk (Figure 27), are more extensive in the North and Central Appalachians than in the rest of the Mid-Atlantic (with the exception of mine drainage in the Western Appalachians, below). The combined effects of acidification and (non-acidic) mine drainage could well explain the large proportion of stream length with poor fish IBI scores in the region. These two problems are likely to occur in different places (acid deposition effects are found in otherwise pristine upland watersheds; non-acidic mine drainage problems, like the transport of coal fines, are found in lower elevation watersheds with mines in their headwaters).

WESTERN APPALACHIANS

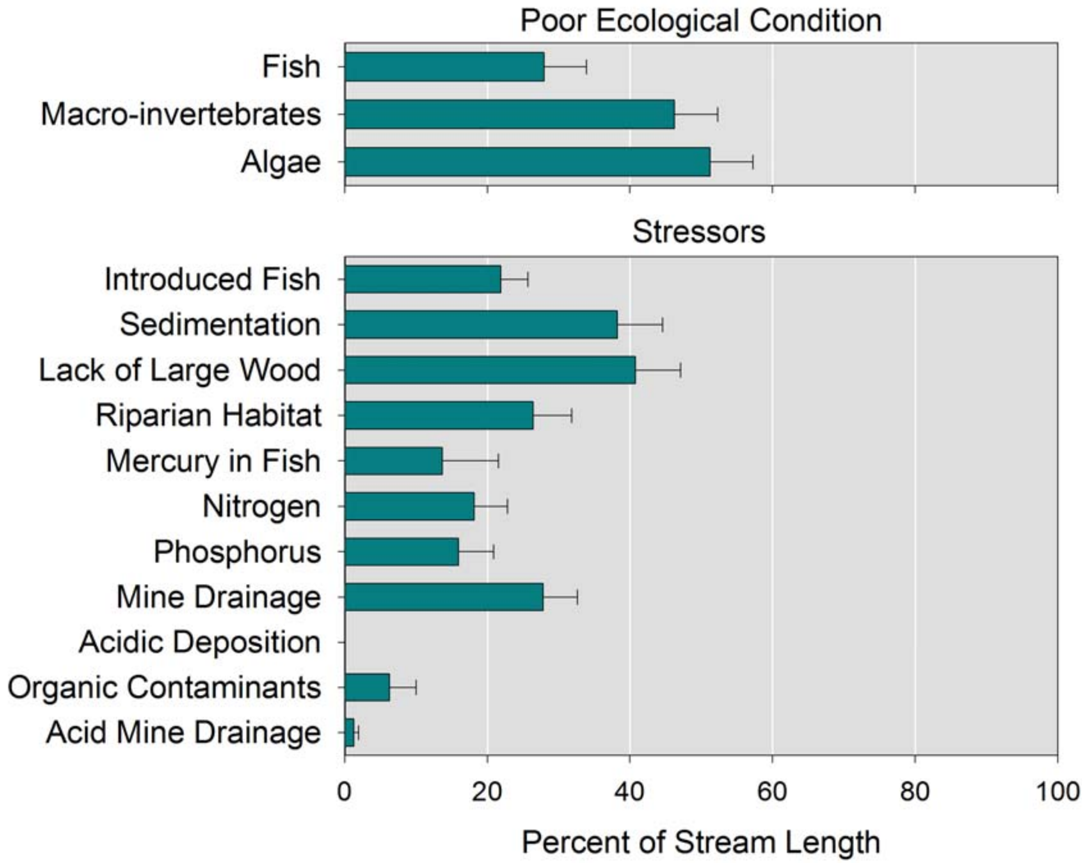

Figure 36. Summary of Western Appalachian ecoregion condition.

The Western Appalachian ecoregion has high proportions of stream length in poor condition for nearly all of the common stressors (Figure 36). But the results here are not all bad news—fish assemblages in this ecoregion are in poor condition in a smaller proportion of streams than in the Mid-Atlantic as a whole, and the extent of non-native fish species is lower than for any other ecoregion. Problems with biotic integrity are more common in the macroinvertebrate and algal assemblages in the Western Appalachians, and this allows managers to focus on the stressors likely to affect those assemblages.

Perhaps the most obvious stressor to focus on in this ecoregion is excess sedimentation. Because it puts both macroinvertebrate and algal biotic integrity at risk (Figure 27), and is a likely side effect of non-acidic mine drainage, sedimentation may be a reasonable target for future stream management actions. The extent of acid mine drainage in this heavily-mined region is quite low—perhaps as a result of control measures to control metals and acidity—but additional measures to control the input and movement of sediments from coal mining operations in Western Appalachian streams (e.g., improving riparian areas, also commonly degraded in the region) could well lead to improved biotic integrity.

CONCLUSIONS AND FURTHER DIRECTIONS

For more than a decade, numerous organizations have decried the lack of useful information available for producing a report card on the nation's environment. There have been two recent efforts, the Heinz Center's *State of the Nation's Ecosystems* report and EPA's own *Draft Report on the Environment* (see Appendix C) to produce a national report card. Both reports conclude that, in order to produce a true assessment of the nation's environment, monitoring efforts must be focused on collecting comparable indicators, based on consistent field protocols, and implement a sample survey design that produces a representative set of sample sites. This *MAIA State of the Flowing Waters Assessment*, and the research/monitoring program that produced its data, provides a regional-scale template for how a national report card might one day be created.

For a report card to be effective, the information it provides must be used to make decisions and to set future directions. An effective report card should fulfill two objectives. First, it should describe whether there is a problem, how big the problem is, and whether the problem is geographically localized or widely distributed. Second, it should give some clues about what needs to be changed in order to improve ecological condition. Our MAIA assessment has discussed both aspects.

Are there problems in the Mid-Atlantic region? We have used biological indices, based on fish, macroinvertebrate and algal assemblages, to answer this question. The information can be viewed from two perspectives: what is going well (i.e., how much of the resource is in good condition) and what is not going well (i.e., how much of the resource is in poor condition). Regardless of which assemblage is examined, the Mid-Atlantic region appears to be in trouble. For none of the three assemblages is more than 30% of the stream resource classified in good condition, and more than 30% of the resource is consistently assessed as in poor condition:

Assemblage	Percent of Stream Resource in:		
	Good Condition	Marginal Condition	Poor Condition
Fish	21	42	31
Macroinvertebrates	26	33	41
Algae	30	37	33

Historically, we have focused primarily on streams in either good or poor condition, but perhaps a third strategy is to concentrate our attention on the proportion of stream resource in the marginal category. Following the traditional medical concept of triage, we could focus on trying to prevent streams and rivers from slipping into the poor category, by focusing our attention on those that are now considered marginal. As the table above suggests, a large proportion of the resource falls into this category.

PROTECTION VS. RESTORATION

Are problems in the Mid-Atlantic region localized or widely distributed? Are there subregions in good condition that should be targets for protection efforts? Are there subregions in particularly poor condition that would be targets for restoration? Based on a protection strategy, the Ridge ecoregion and the North Central Appalachian ecoregion would be targets Figure 37). Each of these regions had over 40% of the flowing waters in good condition for at least one of the three biological assemblages.

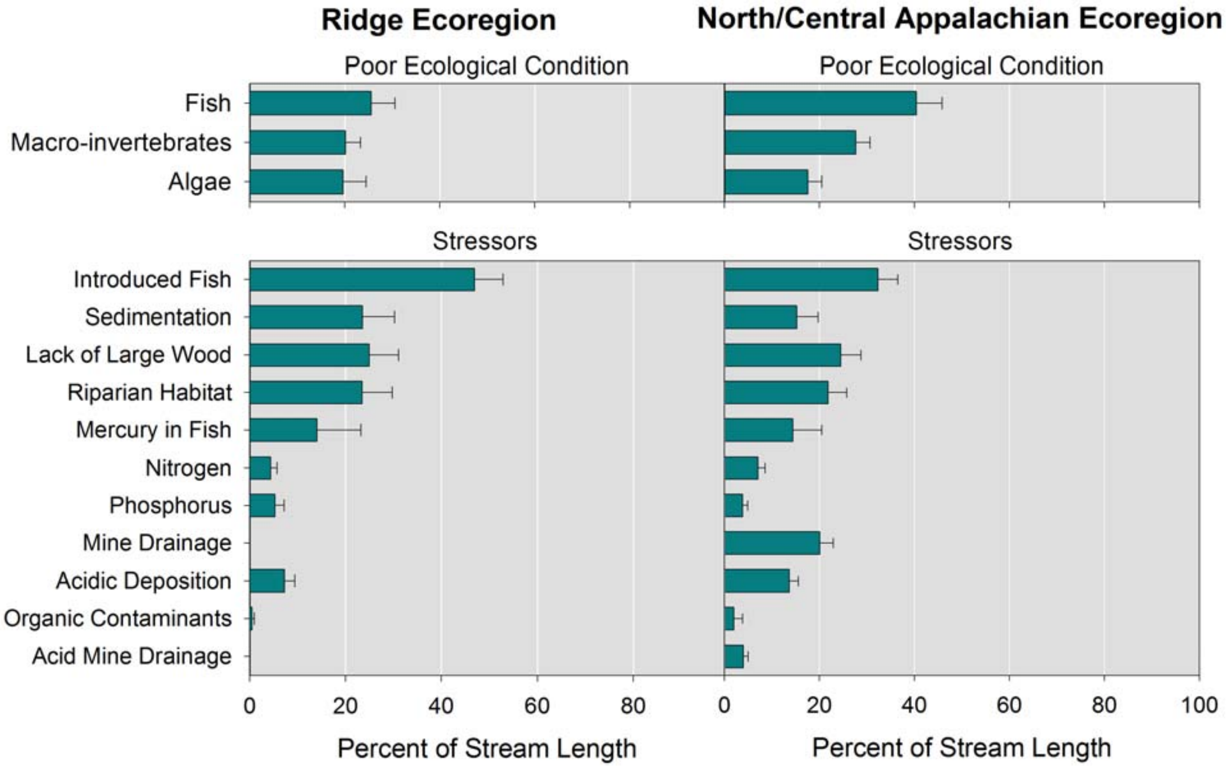

Figure 37. Combined results for two subregions that could be targeted for protection efforts—The Ridge and North/Central Appalachian ecoregions.

If one uses a restoration strategy, and focuses on the subregions in the poorest condition, the Valley, Western Appalachian, Piedmont and Coastal Plain ecoregions could all be targeted. Each of these ecoregions has over 40% of the stream/river resource in poor condition for at least one biological assemblage. Notice that these two strategies are mutually exclusive—no ecoregion would be identified for both protection and restoration. Four out of six ecoregions are identified by the restoration strategy, which is a not particularly helpful finding if our objective is to focus the restoration effort, but it certainly does reinforce the idea that, overall, Mid-Atlantic flowing waters are in trouble. If more stringent criteria are use—at least two of the three biological assemblages must show greater than 40% of the stream resource in poor condition—then only two subregions emerge as high priorities: the Coastal Plain and Western Appalachian ecoregions (Figure 38). These more stringent criteria yield a more focused geographic target for restoration efforts.

With what sorts of stressors are the Mid-Atlantics problems associated? Our analyses indicate that excess sedimentation, increased nutrients, non-native fish species, and the absence of large woody material in streams all pose significant relative risks, and are among the most prevalent stressors throughout the region. Within the Coastal Plain, one of the two regions on the potential priority list for restoration, several stressors should be considered: non-native fish, excess sedimentation, and increased nutrients all represent significant relative risks and are found extensively throughout the ecoregion. Within the Western Appalachian ecoregion, both excess sediment and lack of large wood are widespread stressors associated with significant relative risks. Mine drainage, while posing a somewhat lower relative risk, certainly is widespread within the Western Appalachian ecoregion.

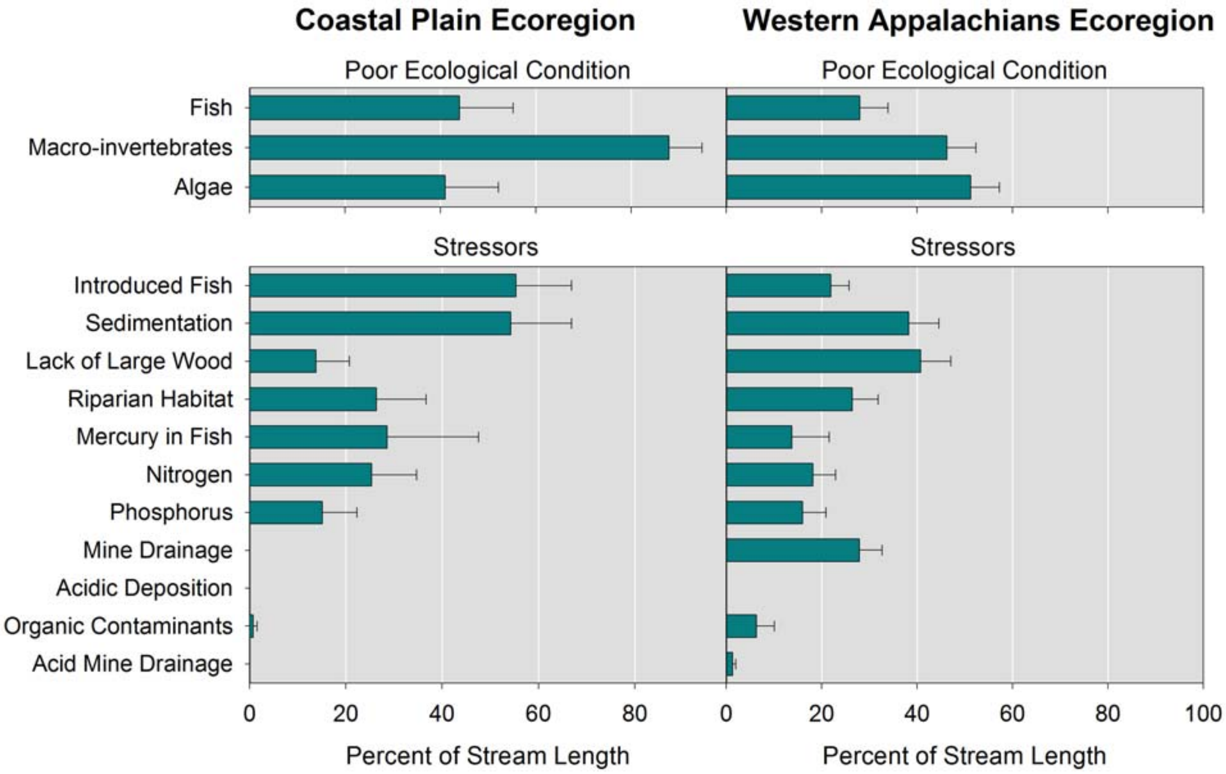

Figure 38. Combined results for two subregions that could be targeted for restoration efforts—the Coastal Plain and Western Appalachian ecoregions.

The simple conclusions reached here are based on the kind of unbiased assessment that probability monitoring can provide. Any environmental protection and restoration efforts are likely to use these results as only one factor, among many, in making decisions on how to move forward. Other considerations will include socio-economic and political factors, as well as extensive public input on priorities. But all of these other factors can be more effectively considered if environmental managers and the public are well informed about the state of the environment—educated evaluation, based on unbiased scientific assessment, should be a key ingredient in making sound environmental and economic decisions. Because of their importance, similar environmental reports should become high priority precursors to the making of effective environmental policies and decisions. We hope that the approach demonstrated here will help guide the design of such future regional and national assessments.

APPENDIX A: THRESHOLDS

Perhaps the most critical step in creating the kind of assessment presented in this report is the setting of thresholds—how do we decide, in the most scientifically justifiable way, which sites to place in Good, Marginal and Poor classes? As scientists, our role is to avoid being judgmental, and letting our own opinions influence the labels we place on individual sites or regions. We need an approach that relies entirely on data, not opinion, and lets the data "answer the questions" about condition classes.

Throughout this report we use what is known as the "reference site approach" to identify criteria. For nearly every variable (biological index, chemical concentration, or habitat index) we identify a set of reference sites, and use the distribution of variable values for this set of sites to define what "good" looks like. The only departures from this approach are for chemical variables (like acid neutralizing capacity) whose values have special meaning—e.g., any ANC value less than zero defines the class "acidic" chemically, and doesn't require any further classification.

We feel strongly that circular thinking, a common problem in any discussion of reference condition, should be avoided at all costs. The most common way that circularity finds its way in to the science or reference condition is through the use of biological data to identify reference sites that are then used in interpreting the same biological data. This approach essentially asks, "based on the biology, which are the best sites?", and then uses data from those "best" sites to answer the question, "for the set of reference sites identified, how would I characterize the biology?" For this reason, we choose to define "reference" differently for each index or variable we want to classify, always avoiding the use of the variable itself (or elements of it, if the variable is an index) to define reference condition. For example, if we want to classify scores for our fish Index of Biotic Integrity, we need to avoid using any fish data to define which sites are in reference condition.

The details of how we define "reference", as well as how we chose to use the reference distribution to set thresholds, and how we incorporate potential ecoregional differences, are presented below for each indicator used in this report. For each indicator where a reference site approach is appropriate, we first identified the independent criteria that could be used to determine reference condition, then examined the range of index or variable values that were found in all of the sites meeting those criteria. Each of these exercises produced a distribution like the one shown in Figure A-1. Once this distribution was established, we consistently used the 25th percentile value to set the lower limit on "Good" condition. The 1st percentile was used as the threshold below which values were deemed "Poor." Values between the 1st and 25th percentiles were classified as "Marginal". In this hypothetical example, higher scores indicate better condition—if an indicator worked in reverse (e.g., for phosphorus and nitrogen, higher values indicate excess nutrients), we used the 75th and 99th percentile values in an exactly analogous way to define the classes.

There is nothing magical about our choice of the 1st and 25th (or 99th and 75th) percentiles. EMAP data allow us to set these thresholds anywhere within the distribution . We chose to be consistent among all of the indicators we assess, and to use these thresholds because they have some understandable statistical meaning. Sites we classify as in "Poor" condition for any given indicator have a greater than 99% probability of being outside of (or more extreme than) our reference distribution. Sites classified as “Good” have a 75% probability of being within the reference distribution. Many other thresholds are possible, and are in fact in use in other programs. The 25th percentile is quite commonly used as a line separating “Good” from “Marginal.” Some bioassessments use the 5th, or even the 10th, percentile as a threshold to define “Poor” condition, often invoking the argument that our knowledge of what constitutes “reference” is imperfect and we are bound to include some sites in the reference distribution that are not truly the least disturbed in a region. For this reason, it can be argued, it is reasonable for some of the reference sites to have scores that we would label as “Poor.” This is an issue that will continue to be debated, but thus far there is no scientific consensus. We have chosen to use a conservative estimate of the Marginal/Poor threshold because of its statistical power to define what we mean by “Poor.”

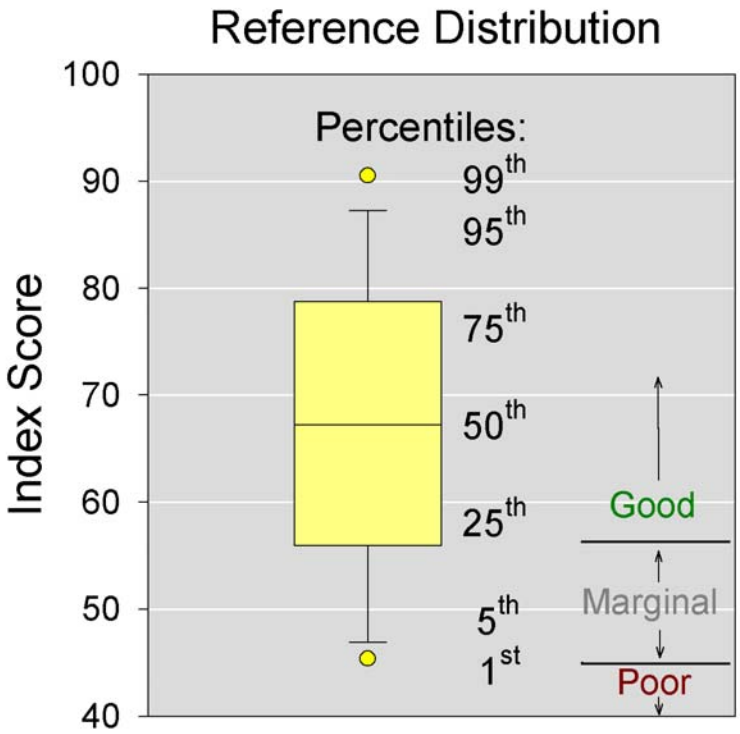

Figure A-1. Example of the range of scores in reference sites (for a hypothetical indicator or index), and percentile values of the reference distribution. In this assessment, we use the 25th percentile as threshold between Good and Marginal condition, and the 1st percentile as the line between Marginal and Poor condition.

MACROINVERTEBRATE INDEX OF BIOTIC INTEGRITY

IBI construction: We modified an Index of Biotic Integrity developed for the Mid-Atlantic Highlands by Klemm et al. (2003), for use in the Mid-Atlantic region as a whole. We examined the Klemm et al. metrics for responsiveness across the region, and eliminated one (*Plecoptera* richness) because it does not respond well to human disturbances as Mid-Atlantic streams become very large. The remaining metrics were re-scored and the final IBI divided into classes according to the reference distribution. As in Klemm et al., different metric scoring criteria were developed for pool-dominated streams and riffle-dominated streams. One major concern in developing a Mid-Atlantic IBI for macroinvertebrates was finding metrics that were responsive both in the uplands and in the Coastal Plain. Our final list of metrics is very closely aligned with those of an IBI developed specifically for the Coastal Plain by Maxted et al. (1999).

Reference definition: We used the process described by Waite et al. (2000) for the Mid-Atlantic Highlands, to define reference sites for macroinvertebrates. The chemical and physical variables used to identify candidate reference included ANC (non-acidic sites only), sulfate (sites with no effects of mine drainage), phosphorus and nitrogen (no excess nutrients), chloride (high chloride sites excluded—chloride is an indicator of general watershed disturbance), and overall habitat quality (based on Rapid Bioassessment Protocol [RBP] measures of habitat).

Thresholds: Based on the reference distribution, the classification thresholds for the MAIA macroinvertebrate IBI were:

Classes	Macroinvertebrate IBI Thresholds
Good Condition	$62.25 \leq \text{IBI} \leq 100$
Marginal Condition	$41 \leq \text{IBI} < 62.25$
Poor Condition	$0 \leq \text{IBI} < 41$

ALGAL INDEX OF BIOTIC INTEGRITY

IBI construction: We developed a new Index of Biotic Integrity based on the periphyton data collected in the MAHA and MAIA projects, using the same concepts as described for the macroinvertebrate IBI, including separate scoring of metrics for riffle-dominated and pool-dominated streams.

Reference definition: We used the process described by Waite et al. (2000) to define reference sites for algae. The chemical and physical variables used to identify candidate reference included ANC (non-acidic sites only), sulfate (sites with no effects of mine drainage), phosphorus and nitrogen (no excess nutrients), chloride (high chloride sites excluded—chloride is an indicator of general watershed disturbance), and overall habitat quality (based on Rapid Bioassessment Protocol [RBP] measures of habitat).

Thresholds: Based on the reference distribution, the classification thresholds for the MAIA algal IBI were:

Classes	Algal IBI Thresholds
Good Condition	$58 \leq \text{IBI} \leq 100$
Marginal Condition	$24.5 \leq \text{IBI} < 58$
Poor Condition	$0 \leq \text{IBI} < 24.5$

FISH INDEX OF BIOTIC INTEGRITY

IBI construction: We constructed four separate indices for use in the Mid-Atlantic, in order to deal with known differences in fish distributions across ecoregions and stream sizes. Details of IBI construction for the upland stream IBI can be found in the paper by McCormick et al. (2001) listed in Appendix C.

Reference definition: We used a number of chemical and physical variables to identify candidate reference sites in our data, including ANC (non-acidic sites only), sulfate (sites with no effects of mine drainage), phosphorus and nitrogen (no excess nutrients), chloride (high chloride sites excluded—chloride is an indicator of general watershed disturbance), human use of land in the watershed (e.g., urban, agricultural), road density in the watershed, riparian condition, and sedimentation. Specific criteria for these variables varied according to ecoregions, in an attempt to include some least-disturbed reference sites from each ecoregion. Despite our best efforts, the number of reference sites in regions like the Coastal Plain was very small (5), and our confidence that these truly represent reference condition was very low.

Thresholds: We varied the thresholds for groups of ecoregions, based on whether their reference distributions differed. For some ecoregions, the number of reference sites was very small (making our reference distributions highly uncertain), and we used the distribution of IBI scores in degraded sites (i.e., those with extreme values for several of the variables used in defining reference sites) to help set thresholds between Marginal and Poor condition (i.e., so that most reference sites score “Good” and most degraded sites score “Poor”).

IBI Threshold for:	Upland Streams	Upland Rivers	Piedmont and Valley Rivers	Coastal Plain Streams and Rivers
Good Condition	59 ≤ IBI ≤ 100	76 ≤ IBI ≤ 100	56 ≤ IBI ≤ 100	60 ≤ IBI ≤ 100
Marginal Condition	32 ≤ IBI < 59	40 ≤ IBI < 76	37 ≤ IBI < 56	40 ≤ IBI < 60
Poor Condition	0 ≤ IBI < 32	0 ≤ IBI < 40	0 ≤ IBI < 37	0 ≤ IBI < 40

MINE DRAINAGE

Index construction: We used the published protocols discussed in the papers by Herlihy et al. (1990) and Baker et al. (1991) (both listed in Appendix C) to separate mine drainage effects from acid deposition effects in the Appalachian Plateau ecoregions. We extended these protocols to other ecoregions in the Mid-Atlantic by examining concentrations of sulfate and ANC in sites with known mines in their watersheds.

Thresholds: For the coal mining ecoregions (North and Central Appalachians and Western Appalachians), sulfate concentrations greater than 400 µeq/L were used to indicate moderate mining effects; concentrations over 1,000 µeq/L indicated severe mining effects. Outside of the coal mining regions, we used 1,000 µeq/L of sulfate as the threshold between no effect and moderate effect, and 5,000 µeq/L as the threshold for severe mining effects. Differing thresholds of sulfate reflect the different strength of mining signals in each ecoregion—streams draining watersheds free of mining activity always have sulfate concentrations ≤ 400 µeq/L in the Western and North/Central Appalachians, while in other ecoregions streams with sulfate as high as 1,000 µeq/L occur in non-mining areas.

ACID MINE DRAINAGE

Index construction: We used ANC values to determine whether sites identified as having Mine Drainage (above) were also acidic.

Thresholds: Sites first identified as either moderately or severely affected by mine drainage were further classified by their ANC values: sites with ANC ≤ 0 were classified as severely affected by acid mine drainage; those with 0 < ANC ≤ 50 µeq/L were classified as having moderate acid mine drainage.

ACID DEPOSITION

Index construction: We used ANC values for sites that had no indicators of mine drainage (see above) to determine their status with respect to acid rain.

Thresholds: Sites unaffected by mine drainage were further classified by their ANC values: sites with ANC ≤ 0 were classified as chronically acidic; those with $0 < \text{ANC} \leq 50$ μeq/L were classified as being episodically acidic.

PHOSPHORUS

Index construction: We used measured values of total phosphorus as indicators of nutrient enrichment in streams.

Reference definition: Reference sites were identified as those with less than 10% non-natural land cover in their watersheds. Sites with more than 10% combined landuse classified as urban, agricultural or mining were eliminated from the candidate reference list. A total of 317 sites met these criteria, but none were in the Coastal Plain. Because we were unable to determine whether phosphorus thresholds that were appropriate for the rest of the Mid-Atlantic were appropriate for the Coastal Plain, we used a separate approach for this ecoregion. We used published EPA criteria (as used for the Mid-Atlantic Highlands—see U.S. EPA 2000 report in Appendix C) for phosphorus in the Coastal Plain.

Thresholds (concentrations in μg/L):

Phosphorus Threshold for:	Non-Coastal Plain Ecoregions	Coastal Plain Ecoregion
Good Condition	$0 \leq$ Total Phosphorus < 14	$0 \leq$ Total Phosphorus ≤ 50
Marginal Condition	$14 \leq$ Total Phosphorus < 63	$50 \leq$ Total Phosphorus < 100
Poor Condition	Total Phosphorus ≥ 63	Total Phosphorus ≥ 100

NITROGEN

Index construction: We used measured values of total nitrogen as indicators of nutrient enrichment in streams.

Reference definition: Reference sites were identified as those with less than 10% non-natural land cover in their watersheds. Sites with more than 10% combined landuse classified as urban, agricultural or mining were eliminated from the candidate reference list. A total of

317 sites met these criteria, but none were in the Coastal Plain. Because we were unable to determine whether nitrogen thresholds that were appropriate for the rest of the Mid-Atlantic were appropriate for the Coastal Plain, we used a separate approach for this ecoregion. Criteria developed for the Mid-Atlantic Highlands Report (see U.S. EPA 2000 in Appendix C) were used in the Coastal Plain—the thresholds for phosphorus listed above for the Coastal Plain were multiplied by 15 (the ratio of nitrogen to phosphorus in algae) to create nitrogen criteria for this ecoregion.

Nitrogen Thresholds (concentrations in µg/L):

Nitrogen Threshold for:	Non-Coastal Plain Ecoregions	Coastal Plain Ecoregion
Good Condition	Total Nitrogen < 425	Total Nitrogen ≤ 750
Marginal Condition	425 ≤ Total Nitrogen < 1200	750 ≤ Total Nitrogen < 1500
Poor Condition	Total Nitrogen ≥ 1200	Total Nitrogen ≥ 1500

EXCESS SEDIMENT

Index construction: We used the "Relative Bed Stability Index" of Kaufmann et al. (1999) as an indicator of excess fine sediments in streams. This index compares the observed mean substrate size to each stream's expected substrate size, based on stream bed shear stress during bank-full stage (calculated from stream size, slope, channel complexity, large wood and bed armoring). Values of the sediment index range from negative to positive, with theoretical expectations near values of zero.

Reference definition: Reference sites were identified as those meeting the same chemical criteria as for the macroinvertebrate and algal indices, in addition to having good riparian condition (see below). A total of 42 sites met these criteria. Because the Piedmont and Coastal Plain ecoregions have much lower gradient streams than the regions for which Kaufmann's bed stability index was developed, we were particularly concerned about defining expectations for these ecoregions. Unfortunately, there were insufficient numbers of reference sites in the Piedmont or Coastal Plain to determine whether thresholds needed to be determined separately for these low-gradient ecoregions. Rather than apply an inappropriate threshold, we chose to use the reference sites to set criteria for higher gradient ecoregions, and best professional judgment to set criteria for the Piedmont and Coastal Plain.

Sediment Thresholds:

Sediment Threshold for:	**Non-Piedmont and Non-Coastal Plain Ecoregions**	**Piedmont and Coastal Plain Ecoregions**
Good Condition	Index ≥ -0.3	Index ≥ -1.5
Marginal Condition	-0.9 ≤ Index < -0.3	-2.0 ≤ Index < -1.5
Poor Condition	Index ≤ -0.9	Index ≤ -2.0

LARGE WOODY MATERIAL

Index construction: We used areal estimates of wood in streams, collected according to the EMAP stream and river protocols (see Lazorchak et al. references in Appendix C), as indicators of large wood in streams. These estimates are calculated as the proportion of the area of the wetted stream channel covered by wood, and vary from 0 to 1. Details of the calculation of the index are covered in Kaufmann (1999).

Reference definition: Reference sites were identified as those with less than 10% non-natural land cover in their watersheds, and with excellent riparian habitat (see below—we used a riparian habitat index value of 0.8 or greater to identify excellent riparian habitat). A total of 50 sites met these criteria.

Large Wood Thresholds (units are proportion of wetted stream area):

Classes	**Area of Large Wood (ALW) Thresholds**
Good Condition	2.2% < ALW ≤ 100%
Marginal Condition	0% < ALW ≤ 2.2%
Poor Condition	ALW = 0%

RIPARIAN HABITAT CONDITION

Index construction: We used the riparian habitat condition index described by Kaufmann et al. (1999) as an indicator of the riparian condition of Mid-Atlantic flowing waters. This index combines quantitative measures of the complexity of riparian vegetation (i.e., presence of multiple layers of trees and shrubs), canopy cover, and visible human disturbances in the riparian area. The index is unit-less and ranges from 0 to 1.

Reference definition: Reference sites were identified as those meeting the same chemical criteria as for the macroinvertebrate and algal indices, in addition to expected amounts of fine sediments (Bed Stability Index > -1; see discussion above), and little or no direct human disturbance in the riparian area. A total of 31 sites met these criteria.

Riparian Habitat Index Thresholds:

Classes	Riparian Habitat Index Thresholds
Good Condition	Index > 0.61
Marginal Condition	$0.5 \leq \text{Index} \leq 0.61$
Poor Condition	Index < 0.5

CONTAMINANTS IN FISH

Index construction: Composite fish samples collected at each site (where possible); the goal was to collect common species found throughout the MAIA region, and that are likely to be abundant in a majority of streams. Crews attempted to collect two contaminant samples from each stream reach: (1) a primary target species (species whose adults are small, such as minnows, sculpins and darters); and (2) a secondary target species (species with large adults, such as suckers, bass, trout, sunfish and carp). Details of sampling and sample handling can be found in the MAIA field manual (Lazorchak et al. 1998). Mercury and organic contaminant concentrations were measured in homogenized whole fish collected by these methods.

Reference definition: Reference sites were not used in setting contaminant thresholds. We instead used published threshold values based on wildlife risk from Lazorchak et al. (2003). These thresholds were calculated specifically for the Mid-Atlantic region, based on toxicity studies of commonly occurring wildlife species that rely almost exclusively on fish for their diets. We chose to use the values for American River otter (see table below). Stream and river sites were classified into one of three classes:

1. No fish collected (or no fish present)
2. Neither primary nor secondary target species exceeds American River otter criterion (“good” condition)
3. One or both fish samples (primary and secondary) exceeds American River criterion for one or more contaminants (“poor” condition)

Thresholds: Wildlife criteria values for mercury and organic contaminants (reproduced from Lazorchak et al. (2003); concentrations in µg/g of fish):

Contaminant	Detection Limits	Wildlife values (µg/g of fish)		
		Otter	Mink	Kingfisher
Mercury	0.025	0.10	0.07	0.03
Chlordane	0.002	1.14	0.83	0.005
DDT and metabolites	0.002	0.49	0.36	0.02
Dieldrin	0.002	0.03	0.02	0.36
PCBs	0.002	0.18	0.13	0.44

APPENDIX B: CALCULATING RELATIVE RISK

DEFINITION AND EXAMPLE CALCULATION

We define relative risk as the ratio of two probabilities:

$$\frac{\Pr(\mathit{Poor\ IBI\ score, given\ Poor\ Stressor\ Score})}{\Pr(\mathit{Poor\ IBI\ Score, given\ Good\ Stressor\ Score})}$$

where the numerator and denominator are conditional probabilities of a poor IBI score under poor (numerator) vs. good (denominator) stressor conditions.

As an example we calculate the relative risk of excess sediments for macroinvertebrates. We begin by collecting together all sample sites having the same combinations of good and poor condition for macroinvertebrate IBI and for sedimentation.

Number of Sites		*Sediment Condition*	
		Good	***Poor***
Macroinvertebrate Condition	***Good***	78	8
	Poor	50	55

Next, we estimate the total number of stream kilometers in each of the table's classes, by summing the sampling weights for all of the sites in each class.

Estimated stream length (km)		*Sediment Condition*	
		Good	***Poor***
Macroinvertebrate Condition	***Good***	22697.5	3934.1
	Poor	27446.3	27678.7

The next step is to express the stream lengths as percentages of the total. The sum of stream weights across all four classes is 81756.6 km. Only a small percentage of streams have Good IBI when Sediment is Poor.

% of Stream Length		*Sediment Condition*		
		Good	***Poor***	
Macroinvertebrate Condition	***Good***	27.8%	4.8%	
	Poor	33.5%	33.9%	
	Sum	61.3%	38.7%	Total: 100%

Now, we estimate the probability, or “risk”, of a poor IBI, for poor sediment sites only, as being equal to 33.9/38.7 = 0.876. Likewise, the risk of a poor IBI in streams with good sediment conditions is given by 33.5/61.3 = 0.546. Comparison of these two risks shows that a poor IBI has a greater risk of occurring when sediment conditions are poor (risk = 0.876) then when sediment conditions are good (risk = 0.546).

The **relative risk** ratio expresses this relationship in a single number, the ratio of the poor-stressor IBI risk to the good-stressor IBI risk—that is, the relative risk = 0.876/0.546 = 1.60.

The way we interpret this number in this assessment is that a poor IBI is 1.60 times more likely to occur when sediment conditions are poor than when they are good.

CONFIDENCE INTERVALS FOR RELATIVE RISK

We used large-sample approximations to construct confidence intervals for relative risk (RR). Large-sample distributions for estimated RR are better approximated using the log transformation to produce symmetry about the null value of 1.0, and to ensure that confidence bounds remain within the domain of the estimated parameter (see Lachin reference in Appendix C). Given an estimate of the standard error for the estimated log(RR), percentiles of the standard normal distribution were then used to construct a conventional large-sample confidence interval for log(RR). Finally, interval endpoints were back-transformed to give the corresponding confidence interval for RR.

To estimate the standard error of log(RR), we used a Taylor linearization method (see Sarndal et al. reference in Appendix C), which accounts for the unequal inclusion probabilities of the MAIA sampling design.

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