United States
Environmental Protection
Agency

National Rivers and Streams Assessment

2008–2009

A Collaborative Survey

DRAFT

National Rivers and Streams Assessment 2008–2009

A Collaborative Survey

DRAFT

U.S. Environmental Protection Agency
Office of Wetlands, Oceans and Watersheds
Office of Research and Development
Washington, DC 20460

EPA/841/D-13/001

February 28, 2013

Table of Contents

Executive Summary xi

Key findings xi

Biological quality xi

Chemical stressors xii

Physical habitat stressors xiii

Human health indicators xiii

Change in stream condition xiii

Implications xiv

Chapter 1. Introduction 1

The nation’s rivers and streams 1

Some facts about large rivers 2

Smaller streams and rivers 3

The *Wadeable Streams Assessment* 4

Chapter 2. Design of the National Rivers and Streams Assessment 6

What area does the NRSA cover? 6

What regions are used to report NRSA results? 7

How were sampling sites chosen? 10

How were waters assessed? 12

Setting expectations 14

Chapter 3. Condition of the Nation’s Rivers and Streams 19

Background 19

Indicators of biological condition 19

Macroinvertebrate Multimetric Index 20

Findings for the Macroinvertebrate Multimetric Index 23

Macroinvertebrate Observed/Expected Ratio of Taxa Loss 23

Findings for O/E Taxa Loss 24

Table of Contents (Continued)

Fish Multimetric Index 25

Findings for the Fish Multimetric Index 25

Periphyton Multimetric Index 26

Findings for the Periphyton Multimetric Index 27

Aquatic indicators of stress 28

Chemical stressors 29

Physical habitat stressors 35

Ranking stressors: relative extent, relative risk, and attributable risk 40

Relative extent 41

Relative risk 42

Attributable risk 45

Chapter 4. Human Health Considerations in the Nation's Rivers and Streams ... 47

Background 47

Mercury in fish tissue 47

Findings for mercury in fish tissue 49

Pathogen indicators (enterococci) 50

Findings for enterococci 52

Chapter 5. Changes in Stream Condition 56

Findings for changes in stream condition 56

Chapter 6. Ecoregional Results 61

Introduction 61

Nationwide comparisons 63

Biological condition — Macroinvertebrate Multimetric Index 63

Nutrients – total phosphorus and nitrogen 64

Riparian vegetative cover 65

Enterococci 67

Northern Appalachians 67

Table of Contents (Continued)

Setting 68

Summary of NRSA findings, Northern Appalachians 68

Southern Appalachians 70

Setting 70

Summary of NRSA findings, Southern Appalachians 71

Coastal Plains 73

Setting 73

Summary of NRSA findings, Coastal Plains 74

Upper Midwest 75

Setting 75

Summary of NRSA findings, Upper Midwest 76

Temperate Plains 78

Setting 78

Summary of NRSA findings, Temperate Plains 79

Southern Plains 80

Setting 80

Summary of NRSA findings, Southern Plains 81

Northern Plains 83

Setting 83

Summary of NRSA findings, Northern Plains 83

Western Mountains 85

Setting 85

Summary of NRSA findings, Western Mountains 86

Xeric 88

Setting 88

Summary of NRSA findings..... 89

Table of Contents (Continued)

Chapter 7. Summary and Next Steps 91

Moving the science forward 93

Next steps 94

Glossary of Terms 100

Sources and References 102

General references 102

Stream and river sampling and laboratory methods 103

Probability designs 104

Ecological regions 104

Fish multimetric indices 105

Indices of biotic integrity 105

Observed/expected models 106

Periphyton 106

Physical habitat 107

Reference condition 108

Other EMAP assessments 108

Biological condition gradient/quality of reference sites 108

Relative risk 108

Nutrients 109

List of Abbreviations and Acronyms 110

Tables and Figures

Tables

Table 1. Length of river and streams represented in the NRSA, by ecoregion 10

Table 2. Indicators evaluated for the NRSA 14

Figures

Figure 1. Biological condition of the nation's rivers and streams, based on the Macroinvertebrate Multimetric Index xii

Figure 2. Average annual precipitation in the U.S. 6

Figure 3. Major NRSA climatic regions.. 8

Figure 4. Nine ecoregions surveyed for the NRSA 8

Figure 5. NRSA sample sites 11

Figure 6. Reach layout used for sampling in the NRSA 12

Figure 7. Biological condition of the nation's rivers and streams based on the - Macroinvertebrate Multimetric Index 23

Figure 8. Macroinvertebrate taxa loss in the nation's rivers and streams as measured - by the Observed/Expected Ratio of Taxa Loss 24

Figure 9. Condition of the fish assemblage in the nation's rivers and streams as - measured by the Fish Multimetric Index 26

Figure 10. Condition of periphyton assemblage in the nation's rivers and streams based - on the Periphyton Multimetric Index 28

Figure 11. Total phosphorus concentrations in the nation's rivers and streams 30

Figure 12. Total nitrogen concentrations in the nation's rivers and streams 31

Figure 13. Salinity conditions in the nation's rivers and streams 33

Figure 14. Acidification in the nation's rivers and streams 35

Figure 15. Excess streambed sediment in the nation's rivers and streams 37

Figure 16. In-stream habitat in the nation's rivers and streams 38

Figure 17. Riparian vegetative cover in the nation's rivers and streams 39

Figure 18. Riparian disturbance in the nation's rivers and streams 40

Figure 19. Relative extent of stressors in the nation's rivers and streams 41

Figure 20. Relative extent, relative risk, and attributable risk to macroinvertebrates - based on the Macroinvertebrate Multimetric Index 43

Tables and Figures (Continued)

Figure 21. Relative extent, relative risk, and attributable risk to fish based on the Fish Multimetric Index 44

Figure 22. Relative extent, relative risk, and attributable risk to periphyton based on - the Periphyton Multimetric Index 45

Figure 23. Human health fish tissue assessment for target and sampled populations of - the nation’s rivers 50

Figure 24. Percent of fish tissue target population sampled for mercury in fish tissue in - the three major climatic regions of the U.S. 50

Figure 25. Enterococci human health thresholds exceedance in the nation’s rivers and - streams 52

Figure 26. Mercury in fish tissue from urban sites 54

Figure 27. PFOS in fish tissue from urban sites 55

Figure 28. Change in macroinvertebrate condition and nutrients between 2004 and - 2008–2009, based on percent of length in good condition 58

Figure 29. Change in stream fish habitat, riparian vegetation cover, and riparian - disturbance between 2004 and 2008–2009 60

Figure 30. Ecoregional surveys for the NRSA 62

Figure 31. Biological condition in rivers and streams based on the Macroinvertebrate - Multimetric Index across the nine ecoregions 63

Figure 32. Total phosphorus levels in rivers and streams across the nine ecoregions 64

Figure 33. Total nitrogen levels in rivers and streams across the nine ecoregions 65

Figure 34. Riparian vegetative cover in rivers and streams across the nine ecoregions 66

Figure 35. Enterococci human health threshold exceedance in rivers and streams - across the nine ecoregions 67

Figure 36. NRSA survey results for the Northern Appalachians ecoregion 69

Figure 37. NRSA survey results for the Southern Appalachian ecoregion 72

Figure 38. NRSA survey results for the Coastal Plains ecoregion 74

Figure 39. NRSA survey results for the Upper Midwest ecoregion 77

Figure 40. NRSA survey results for the Temperate Plains ecoregion 79

Figure 41. NRSA survey results for the Southern Plains ecoregion 82

Figure 42. NRSA survey results for the Northern Plains ecoregion 84

Tables and Figures (Continued)

Figure 43. NRSA survey results for the Western Mountains ecoregion 87

Figure 44. NRSA survey results for the Xeric ecoregions 89

Figure 45. Map of about 1,200 probability sites in California sampled since 2000 using - compatible EMAP-style survey designs 96

Figure 46. Biological condition of perennial streams in the six major ecological regions - of California 97

Figure 47. Percentage of California stream length that exceeds severe and moderate - threshold values for various chemical and physical habitat stressor variables - in streams associated with each of three major land cover types 97

Figure 48. Relative risk of biological impairment associated with a series of habitat and - chemistry variables in southern California streams 98

Figure 49. The combination of probability and reference distributions provides - objective context for interpreting targeted monitoring data.................................... 98

Executive Summary

This *National Rivers and Streams Assessment 2008–2009: A Collaborative Survey* (NRSA) presents the results of an unprecedented sampling effort undertaken by the U.S. Environmental Protection Agency and its state and tribal partners. It provides information on the ecological condition of the nation's rivers and streams and the key stressors that affect them, both on a national and an ecoregional scale. It also discusses change in water quality conditions in streams sampled for an earlier study, the *Wadeable Streams Assessment* of 2004.

During the summers of 2008 and 2009, more than 85 field crews sampled 1,924 river and stream sites across the country. Using standardized field methods, they sampled waters as large as the Mississippi River and as small as mountain headwater streams. Sites were selected using a random sampling technique that uses a probability-based design. This design ensures that the results of the survey reflect the full variety of river and stream types and sizes across the U.S. To determine water quality conditions, sampling results were compared to conditions at least-disturbed (or reference) sites in different ecological regions.

The goals of the NRSA are to determine the extent to which rivers and streams support a healthy biological condition and the extent of major stressors that affect them. In addition, the survey supports a longer-term goal: to determine whether our rivers and streams are getting cleaner and how we might best invest in protecting and restoring them.

Key findings

Biological quality

Biological condition is the most comprehensive indicator of water body health: when the biology of a stream is healthy, the chemical and physical components of the stream are also typically in good condition. Twenty-one percent of the nation's river and stream length is in good biological condition, 23% is in fair condition, and 55% is in poor condition, based on a robust, commonly used index that combines different measures of the condition of aquatic benthic macroinvertebrates (aquatic insects and other creatures such as crayfish). Of the three major climatic regions (Eastern Highlands, Plains and Lowlands, and West) discussed in this report, the West is in the best biological condition, with 42% of river and stream length in good condition. In the Eastern Highlands, 17% of river and stream length is in good condition; in the Plains and Lowlands, 16% is rated in good condition (Figure 1).

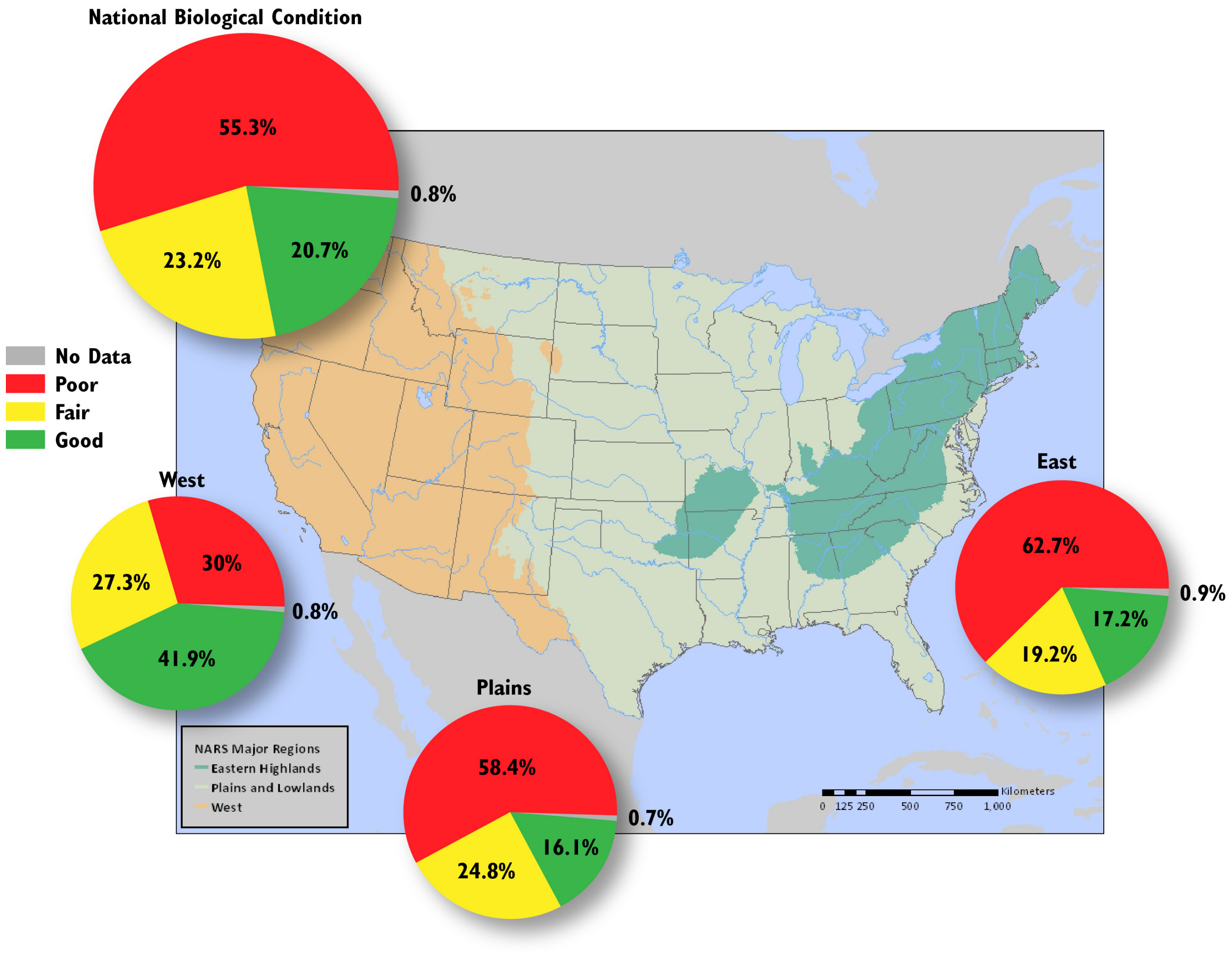

Figure 1. Biological condition of the nation's rivers and streams, based on the Macroinvertebrate Multimetric Index (EPA/NRSA).

Chemical stressors

Four chemical stressors were assessed: total phosphorus, total nitrogen, salinity, and acidification. Of these, phosphorus and nitrogen are by far the most widespread. Forty percent of the nation’s river and stream length has high levels of phosphorus and 28% has high levels of nitrogen. Poor biological condition (for macroinvertebrates) is 50% more likely in rivers and streams with high levels of phosphorus and 40% more likely in rivers and streams with high levels of nitrogen. Acidification, although a problem in less than 1% of U.S. river and stream length, has a significant impact on biological condition where it is found: poor biological condition is 50% more likely in waters affected by acidification.

Physical habitat stressors

Four indicators of physical habitat condition were assessed for the NRSA: excess streambed sediments, riparian vegetative cover (vegetation in the land corridor surrounding the river or stream), riparian disturbance (human activities near the river or stream), and in-stream fish habitat. Of these, poor riparian vegetative cover and high levels of riparian disturbance are the most widespread stressors, reported in 24% and 20% of the nation's river and stream length, respectively. However, excess levels of streambed sediments, reported in 15% of river and stream length, were found to have a somewhat greater impact on biological condition. Poor biological condition is 60% more likely in rivers and streams with excessive levels of streambed sediments.

Human health indicators

Two indicators that provide insight into potential risks to human health were assessed: mercury in fish tissue and enterococci (bacteria). Human health screening values for mercury in fish tissue are exceeded in 13,144 miles of U.S. river length (streams were not evaluated). In 9% of river and stream length, samples exceed an enterococci threshold level for protecting human health.

Change in stream condition

Compared to the findings of the 2004 WSA, some statistically significant changes are found in stream condition. Nationally, the amount of stream length in good quality for macroinvertebrate condition dropped from 27.4% in 2004 to 20.5%; this change appears driven in large part by a 13.3% decline in streams in good condition in the Plains and Lowlands climatic region. In addition, the percent of stream length in good condition for phosphorus dropped nationally from 52.8% to 34.2% and declined in all three major climatic regions. However, other indicators showed an increase in stream length in good condition: the percent of stream length in good condition for nitrogen rose from 46.6% in 2004 to 55.4%; percent of stream length with good in-stream fish habitat rose from 51.7% to 68.9%; and percent of stream length in good condition for riparian disturbance (i.e., with low levels of disturbance) rose from 22.7% to 34.8%. It is important to note that these are differences *for streams only,* between two points in time. Future surveys and more data are needed to discern trends and the reasons for those trends.

Implications

A picture of the condition of the nation's rivers and streams is emerging from this survey and its predecessor streams assessment. Our rivers and streams are under significant stress and more than half exhibit poor biological condition. Phosphorus, nitrogen, and streambed sediments in particular have widespread and severe impacts; reducing levels of these constituents will significantly improve the biological health of rivers and streams. This survey suggests the need to address the many sources of these stressors — including runoff from urban areas, agricultural practices, and wastewater — in order to ensure healthier waters for future generations.

Chapter 1. Introduction

The nation's rivers and streams

This report presents the findings of the *National Rivers and Streams Assessment 2008–2009: A Collaborative Survey*, the first statistically based survey of the condition of the nation's rivers and streams. The survey sampled a stunning range of waters: huge workhorse rivers that roll past our largest urban areas, tiny undisturbed creeks tucked away in national parks, and everything in between. This report also compares the condition of streams to those of an earlier study that focused on small streams (the *Wadeable Streams Assessment* or WSA) conducted by the U.S. Environmental Protection Agency and its partners in 2004.

Rivers and streams shape our landscape. They supply humans with drinking water, carry away our wastes and used water, irrigate our crops, power our cities with hydroelectricity, and offer us myriad recreational and commercial opportunities. They support fish and other aquatic life and provide shelter, food, and habitat for birds and wildlife of all types. They are the land's vast and interconnected circulatory system, carrying water, sediment, and organic material from the mountains to the sea. Clean and healthy rivers and streams greatly enhance the quality of our lives.

Over the centuries, we have radically changed most U.S. rivers and streams by interrupting their flows with dams and levees; straightening and modifying their channels for irrigation, navigation, or flood control; building our cities and developing our farmland in their watersheds and floodplains; withdrawing their water for our use; and discharging our waste materials into their flow. Our rivers and streams are also subject to other influences such as seasonal, annual, and climate-change-induced variations in precipitation and temperature, as well as changing cycles of erosion and deposition (e.g., during flooding or dam releases). To effectively manage, restore, and protect these rivers and streams, we must improve the information we need to make wise water quality decisions.

Some facts about large rivers

The nation's large rivers — the biggest of which are often referred to as the Great Rivers — are familiar to all of us, part of our American history and lore. Their contribution to our nation cannot be overestimated. Some examples of their power, breadth, and value:

- The Mississippi River is the largest in the U.S. by drainage area and discharge; its watershed (that is, the area it drains) is one of the largest in the world and covers 1.2 million square miles. At Lake Itasca, where the Mississippi begins, its average flow rate is 6 cubic feet per second. At New Orleans the average flow rate is 600,000 cubic feet per second. Agriculture is the dominant land use in the Mississippi River basin; 60% of all grain exported from the U.S. is shipped on the Mississippi River through the ports at its mouth.
- The Missouri River, known as the "Big Muddy," is the longest in the U.S., at about 2,540 miles, and drains one sixth of the country. It begins in the Rocky Mountains in Montana, flows east and south, and joins the Mississippi River north of St. Louis, Missouri. It was the "highway" used by Lewis and Clark and became an important route for trade and westward expansion in the 1800s. The Missouri has been extensively dammed for irrigation, hydroelectricity, and flood control, and its river basin is home to ten million people from 28 tribes, ten states, and a small part of Canada.
- The Delaware River is the longest undammed river east of the Mississippi, flowing for 330 miles from the confluence of the east and west branches in Hancock, New York, through Pennsylvania, New Jersey, and Delaware to the Atlantic Ocean. Its 13,539-square-mile watershed is only about 0.4% of the land area of the continental U.S., but it supplies water to 5% of the nation's population — over 15 million people — including residents of New York City and Philadelphia.
- The Columbia River Basin is the most hydroelectrically developed river system in the world. By volume, the Columbia is the fourth-largest river in the U.S., and it has the greatest flow of any North American river draining into the Pacific. More than 400 dams, including 11 on the Columbia mainstem and hundreds of others on tributaries in the watershed, generate more than 21 million kilowatts.
- The Colorado River flows across 1,450 miles of mountainous and desert terrain from the Rocky Mountains to the Gulf of California. It supplies water to over 25 million people in seven western states, two Mexican states, and 32 tribal communities; helps irrigate 3.5 million acres of farmland; and provides electricity for 30 million people. There are ten

major dams on the Colorado River — among them Hoover Dam — and 80 smaller diversions, making it one of the most controlled rivers in the world.

Smaller streams and rivers

At the other end of the spectrum from the nation’s large rivers are the small stream and river systems often referred to as “wadeable” because they are shallow enough to sample without a boat. About 90% of perennial (i.e., continuously flowing) stream and river miles in the U.S. are considered wadeable. These smaller streams are the ones we know best: they drain our neighborhoods and fields and flow past our campgrounds. They are also a critical part of the ecosystem, providing food and shelter to a broad array of aquatic organisms, birds, and wildlife.

Ecologists commonly define stream size according to the “Strahler stream order”; wadeable streams usually fall into the first - through fifth-order range. The life of a river begins in its headwaters, or first-order streams; as streams of a certain order join one another, their stream order increases.

Stream order affects a stream’s natural characteristics, including the biological communities — the plants and animals — that live in it. For example, first- and second-order streams are often quite clear and narrow and shaded by grasses, shrubs, and trees growing along their banks. The food base of these streams consists of terrestrial insects and leaves from stream bank plants, algae that attach to rocks and wood, aquatic insects adapted to shredding leaves and scraping algae, and small fish that feed on these organisms.

In contrast, rivers that are sixth-order and higher typically appear muddy because their large flow carries accumulated sediments downstream. They are wide, so the canopy cover along their banks shades only the river’s edge. The food base of wide rivers shifts away from the stream bank toward in-stream sources such as algae, small organisms that are drifting down stream, and eroded matter. The biological communities of mid-sized and large rivers are dominated by aquatic insects adapted to filtering and gathering fine organic particles and by larger fish that feed on plants, animals, and smaller fish.

Many streams, especially those in the arid West, do not flow year-round. These were not included in this survey because well-developed indicators to assess them are not yet available.

The *Wadeable Streams Assessment*

In 2004, EPA and its partners completed sampling for the first statistical survey of the condition of the nation's small, perennial streams. The survey's purpose was to establish a baseline of information on the condition of small streams and the extent of major environmental stressors that affect them. Through the efforts of state environmental and natural resource agencies, federal agencies, universities, and other organizations, more than 150 field biologists used standardized methods to collect environmental samples at 1,392 perennial stream locations. These sites were chosen using a statistical design to ensure that results represented the condition of *all* U.S. streams. The WSA resulted from this ground-breaking collaboration.

The WSA was implemented to help fill an information need identified over the years by a number of independent organizations, including the Government Accountability Office, the National Research Council, and the National Academy of Public Administration. In the early 2000s, these organizations noted that EPA and the states did not have a uniform, consistent approach to monitoring that supported water quality decision-making. They called for more efficient and cost-effective ways to understand the magnitude and extent of water quality problems, the causes of these problems, and practical ways to address them.

In response, EPA, states, tribes, academics, and other federal agencies began collaborating on a series of statistically based surveys called the National Aquatic Resource Surveys (NARS) to provide the public and decision-makers with improved, statistically valid environmental information. These surveys are nationally consistent and representative, use standardized field and laboratory protocols, and follow rigorous quality assurance protocols. The WSA was based on 15 years of EPA research and, like other surveys that followed, was designed to begin answering such short- and long-term questions as:

- What is the extent of waters that support a healthy biological condition, recreation, and fish consumption?

- How widespread are major stressors that affect water quality?
- Are we investing wisely in water resource restoration and protection?
- Are our waters getting cleaner?

Under the NARS program and since the publication of the WSA in 2006, EPA and its many partners have:

- Completed a survey of the nation's lakes, ponds, and reservoirs in 2007 (the *National Lakes Assessment*, EPA 841-R-09-001) and conducted field work in the 2012 summer sampling season for the next lakes assessment.
- Completed field work and lab analyses for the next *National Coastal Condition Report,* currently under development.
- Finished field sampling and embarked on the analysis and reporting stage of the first-ever *National Wetland Condition Assessment*.
- Developed this *National Rivers and Streams Assessment* and begun planning for the next rivers and streams field season in 2013–2014.

These accomplishments would not have been possible without collaboration and partnership among field biologists, taxonomists, statisticians, data analysts, project managers, quality control officers, and reviewers in state, tribal, and federal offices and universities across the country.

Why do we need consistent and statistically valid survey data on rivers and streams?

Under the Clean Water Act, states are expected to monitor and required to assess and report on the condition of the nation's waters, including the extent of waters that support the goals of the Act. However, methods of collecting and assessing data vary widely between states and change over time, making it difficult to compare this information from state to state, for the nation as a whole, or over time. State monitoring programs are generally designed to meet state-specific information needs, such as locating impaired waters that require additional pollution controls. They are not designed to answer national-level questions such as whether or not U.S. water quality is improving — one of the long-term goals of the National Aquatic Resource Surveys. These surveys are meant to complement the state-specific information and provide national and regional context to decision-makers.

Chapter 2. Design of the National Rivers and Streams Assessment

The NRSA is the first nationally consistent survey assessing the ecological condition of the full range of flowing waters in the conterminous U.S. (lower 48 states). The target population includes the Great Rivers (such as the Mississippi and the Missouri), small perennial streams, and urban and non-urban rivers. Run-of-the-river ponds and pools are included, along with tidally influenced streams and rivers up to the leading edge of dilute sea water.

The NRSA was designed to answer basic questions about the extent to which our rivers and streams support healthy biological conditions and how widespread their key stressors are. Over the longer term, as additional surveys in this series are completed, we will also learn whether our waters are getting cleaner over time, and whether our policy decisions to protect and restore them are effective or should be changed.

What area does the NRSA cover?

This report covers the conterminous U.S. — 3,007,436 square miles. Of this area, 73% is state or private land and the rest is federal or tribal land. Initial NRSA projects in Hawaii and Alaska are also underway.

State political boundaries offer few insights into the true nature of the features that affect our streams and rivers. The most fundamental trait that defines our waters is annual precipitation (see Figure 2). On either side of the 100th meridian that runs from west Texas through North Dakota, a sharp change occurs where precipitation falls plentifully to the east but sparsely to the west. (The high

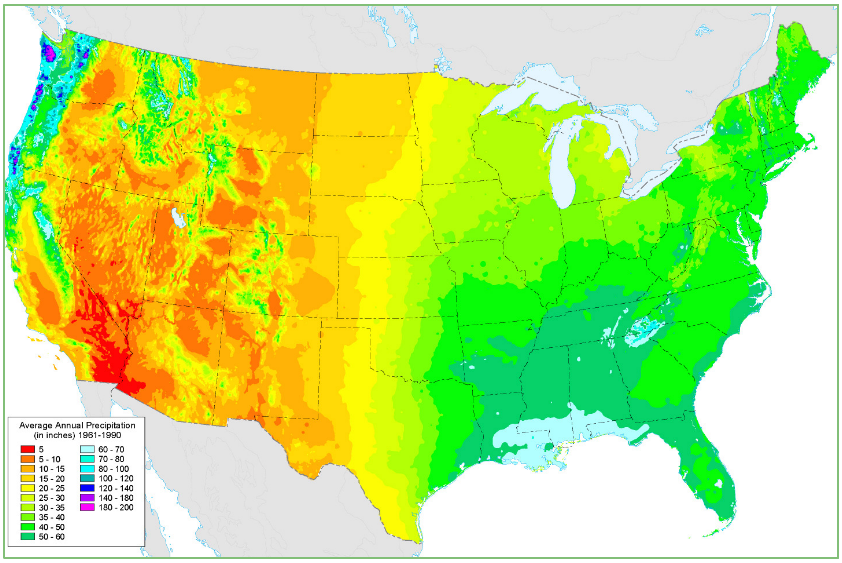

Figure 2. Average annual precipitation in the U.S. (NOAA).

mountains of the West and the Pacific coast are exceptions to the general scarcity of water in the West.) The east–west divide in moisture has shaped not only the character of these waters but also how we use them, how we value them, and even the legal system with which we manage their allocation. A second divide that defines the nature of our rivers and streams is the north–south gradient in temperature.

This huge area includes a wide diversity of landscapes, from the maple-beech-birch forests and coastal plains of the East, to the enormous agricultural plains and grasslands of the mid-continent, to the deserts and shrub lands of the Southwest, and to the giant mountain ranges of the Rocky Mountains, Sierra Nevadas, and Cascades in the west. The Appalachian Mountains, running from Maine to Alabama, cross state and climatic boundaries and separate the waters flowing to the Atlantic from those flowing to the Gulf of Mexico.

The establishment and spread of European colonies and the industrial revolution of the 18th century transformed our natural landscape as more people arrived and modified many of the features of our land and waters. Tens of thousands of dams, large and small, have altered the flow of virtually every major river and many smaller ones. The current and future condition of our waters will continue to be influenced by our population patterns and how we use all components of a watershed, including surface water, ground water, and the land itself.

What regions are used to report NRSA results?

The broadest scale unit for which results are reported in the NRSA is the continental U.S. itself. Next are three climatic regions corresponding to major climate and landform patterns: the West, Plains and Lowlands, and Eastern Highlands. The body of this report describes the results for these broader-scale reporting units.

The finest-scale reporting unit included in this report consists of nine ecological regions that further divide the climatic regions (Figure 4). The NRSA uses ecoregions to report results because the patterns of response to stress, and the stressors themselves, are often best understood in the context of these ecological regions.

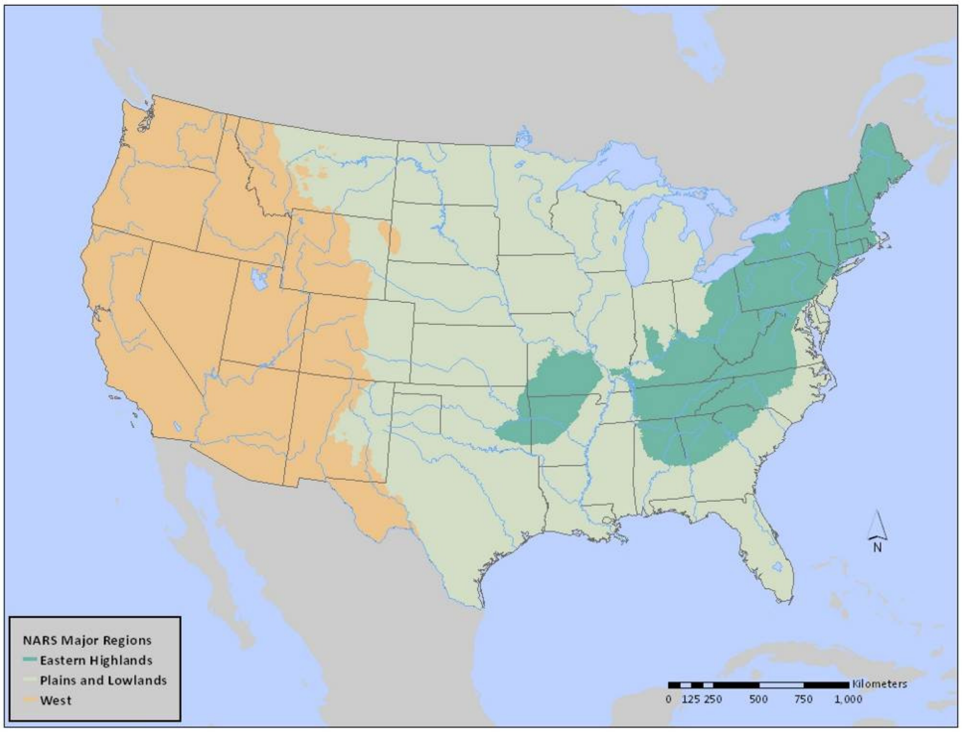

Figure 3. Major NRSA climatic regions (EPA/NRSA).

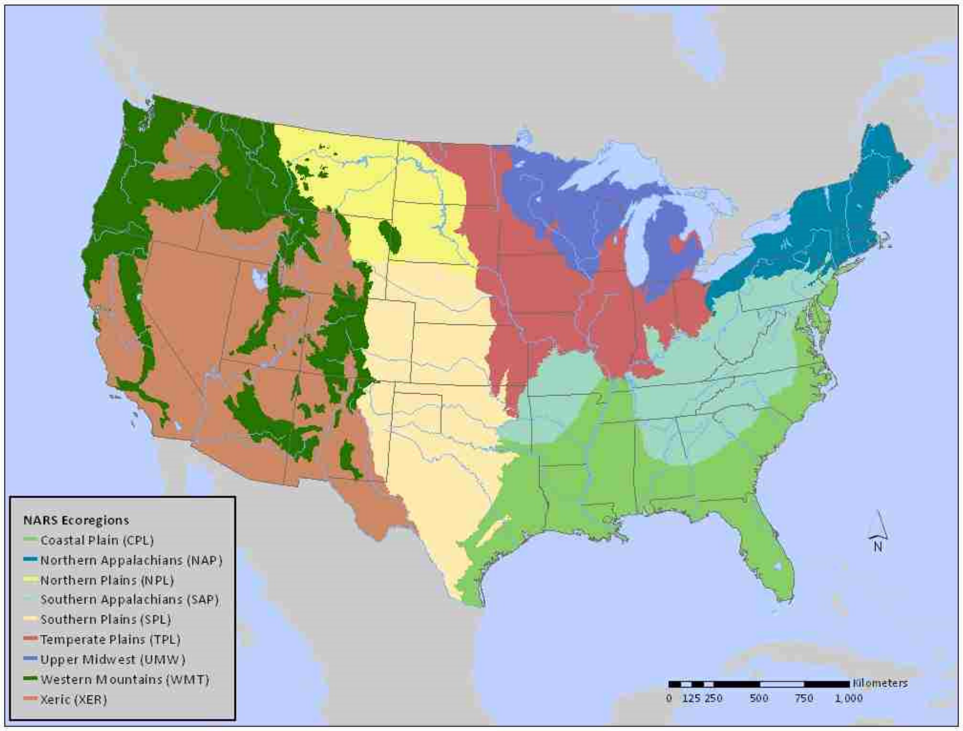

Figure 4. Nine ecoregions surveyed for the NRSA.

Typically, management practices aimed at preventing degradation or restoring water quality may apply to many flowing waters with similar problems throughout an ecoregion. Both the climatic regions and ecoregions used in this report are aggregations of ecoregions as described by Omernik in 1987. Ecoregion-specific results are included in Chapter 6 of this report.

- The *Eastern Highlands* climatic region is composed of the mountainous areas east of the Mississippi River. It is further divided into the Northern Appalachians ecoregion encompassing New England, New York, and northern Pennsylvania, and the Southern Appalachians ecoregion extending from Pennsylvania into Alabama, through the eastern portion of the Ohio Valley and including the Ozark Mountains.
- The *Plains and Lowlands* climatic region includes five of the NRSA ecoregions. The Coastal Plain includes the low gradient areas of the east and southeast. It contains the Atlantic and Gulf of Mexico coastal plains and the lowlands of the Mississippi delta, which extend from the Gulf northward through Memphis, Tennessee. The Upper Midwest is dominated by lakes and has little elevation gradient. The Temperate Plains is also known as the Corn Belt. The Northern and Southern Plains are better known as the Great Prairies. The Northern Plains includes the Dakotas, Montana, and northeast Wyoming. The Southern Plains encompasses Nebraska, Kansas, Colorado, Oklahoma, and Texas.
- The *Western* climatic region is defined by its Mountainous regions and the arid or Xeric region that includes both the true deserts and the arid lands of the Great Basin.

To get a statistically valid state picture of water quality conditions, some of the states participating in the NRSA opted for a finer state-scale resolution than the ecoregion scale by increasing the number of sites they sampled within their borders. While their data are included in the analyses described in this report, state-scale results are not presented. The states are preparing similar analyses that reflect their own water quality standards and regulations.

It should be noted that NRSA assessments and findings regarding the condition of waters nationally and in each ecoregion are not Clean Water Act section 303(d) impaired waters determinations. Such determinations are made by states on specific water body segments using applicable state water quality standards.

How were sampling sites chosen?

NRSA sampling locations were selected using a modern survey design approach. This approach, which is based on random selection, has been used in a variety of fields (e.g., health surveys, election polls, monthly labor estimates) to determine the status of populations or resources of interest using a representative sample of relatively few members or sites. This approach is especially cost-effective if the population is so numerous that all components cannot be sampled, or if it is not necessary to sample the entire resource in order to reach the desired level of precision.

As consumers of information, we have all become accustomed to seeing survey data reported in the news. Results in the NRSA have similar rigor in their ability to estimate the percent of stream miles, within a range of certainty, that are in good, fair, and poor condition.

In order to pick a random sample, one must first know the location of members of the population of interest. The NRSA design team used the EPA-USGS National Hydrography Dataset Plus (NHD-Plus), a comprehensive set of digital spatial data on surface waters at the 1:100,000 scale, to identify the locations of perennial streams. They also obtained information about stream order from the NHD-Plus. Table 1 shows the length of flowing waters in each of the nine ecological regions used for the NRSA.

Table 1. Length of river and streams represented in the NRSA, by ecoregion

Ecoregion	Miles of Rivers and Streams in NRSA
Northern Appalachians	119,094
Southern Appalachians	315,242
Coastal Plains	176,510
Upper Midwest	96,142
Temperate Plains	227,017
Southern Plains	36,594
Northern Plains	27,227
Western Mountains	150,975
Xeric	44,974

The 1,924 sites sampled for the NRSA were identified using a particular type of random sampling technique called a probability-based sample design. In such a design, every element in the population has a known probability of being selected for sampling. This important feature ensures that the results of the survey reflect the full range in character and variation among flowing waters across the U.S. Site selection rules included weighting to provide balance in the number of river and stream sites from each of the size classes. Site selection was also controlled for spatial distribution to make sure sample sites were distributed across the U.S. (see Figure 5). Among these randomly selected sample sites were 359 of the original 2004 WSA sites. These were revisited as part of the NRSA to examine whether conditions have changed.

When sites were selected for sampling, research teams conducted office evaluations and field reconnaissance to determine if the sites were accessible or if a river or stream labeled as perennial in NHD-Plus was, in fact, flowing during the sampling season. If a river or stream was not flowing or was determined to be inaccessible, it was dropped from the sampling effort and replaced with a perennial river or stream from a list of replacement sites within the random design.

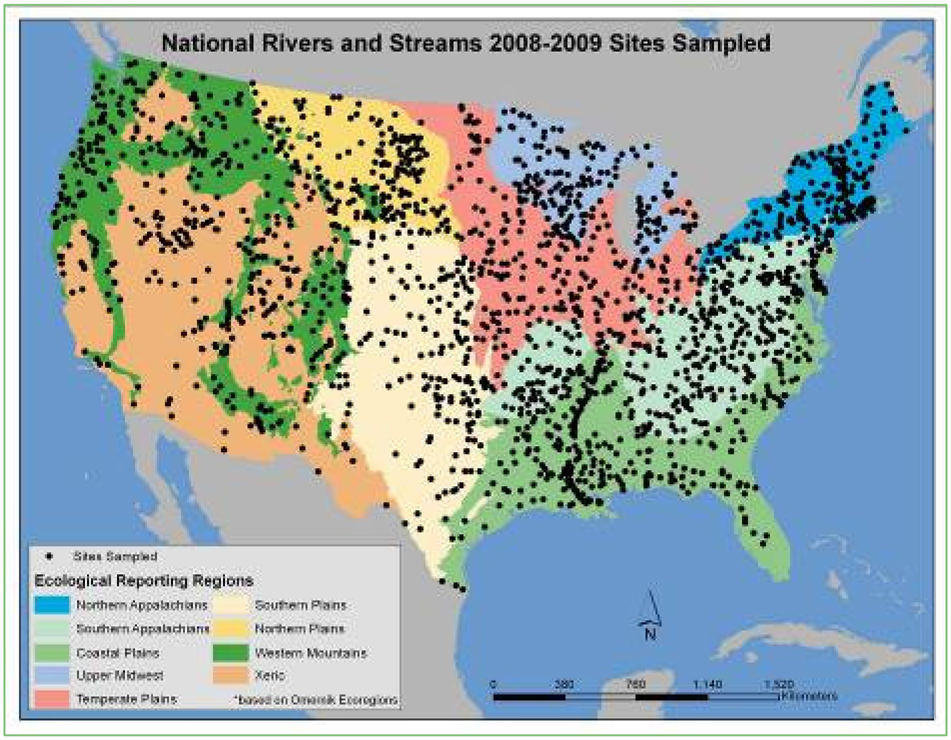

Figure 5. NRSA sample sites.

How were waters assessed?

During the summers of 2008 and 2009, more than 85 trained crews, composed primarily of state/tribal environmental agency, EPA, and contract staff, sampled river and stream sites across the U.S. using standardized field protocols. The field protocols were designed to collect data relevant to the ecological condition of stream resources and the key stressors affecting them. Each site was sampled by a three- or four-person field crew.

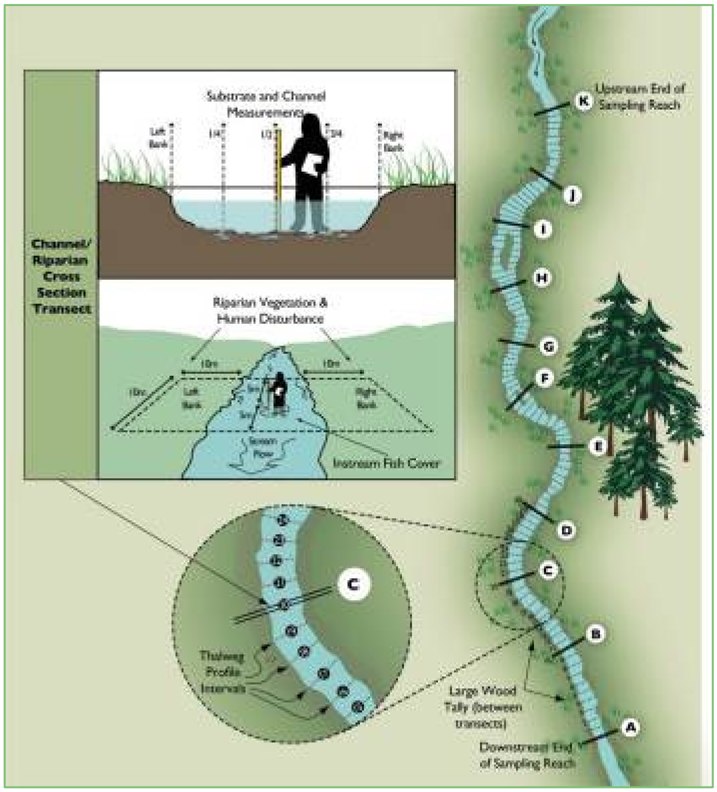

Figure 6. Reach layout used for sampling in the NRSA.

During each site visit, crews laid out the sample reach (i.e., stretch of river or stream) and the numerous transects to guide data collection (see Figure 6). Field crews collected water samples which were sent to a lab for basic chemical analysis, and collected biological samples from 11 transects or fixed paths along each stream reach which were sent to taxonomists for identification. Crews recorded extensive data on field forms and documented information about the physical characteristics of each stream and the riparian area adjacent to its banks. Each crew was audited and 10% of the sites were revisited as part of the quality assurance plan for the survey.

The use of standardized field and laboratory protocols for sampling across all 48 states included in the NRSA (including the pilots in Alaska and Hawaii) is a key feature of the survey. It allows the data to be combined to produce a nationally consistent assessment. This standardization is necessary: states, tribes, academics, and federal agencies use a wide range of methods to sample streams and rivers, and inconsistent results might have arisen if different methods were used in this survey. In fact, this nationwide sampling effort provided an opportunity to examine the comparability of different sample protocols by applying both the

NRSA method and various state or USGS methods to a subset of the sites. Crews collected physical, chemical, and biological data at all NRSA sites.

The NRSA uses fish, benthic macroinvertebrates (insects and other small animals such as snails and crayfish) and algae as biological indicators of ecological condition. It focuses on these three groups of organisms because they are each sensitive to different disturbances that result from human activities and therefore give us a measurement of the *biological integrity* of rivers and streams. Biological integrity has been defined as “the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region” (Karr and Dudley, 1981). Macroinvertebrates are included in almost every state and federal program monitoring rivers and streams, and are increasingly evaluated by volunteer water quality monitoring organizations. Water quality monitoring and management programs are also enhancing their understanding of biological integrity by adding other biological assemblages, including fish and algae.

The NRSA supplements information on the ecological condition of streams with measurements of key stressors that might negatively influence or affect stream condition. Stressors are the chemical, physical, and biological components of the ecosystem that have the potential to degrade biological integrity. Some of these are naturally occurring, some result only from human activities, but most come from both sources. The challenge is in understanding and effectively minimizing the pressures humans exert on aquatic systems through their use of the surrounding environment.

Examples of *chemical stressors* are excess nutrients (nitrogen and phosphorus), salinity, and acidification from acid deposition or mining. Most *physical stressors* — such as excess sedimentation, bank erosion, and loss of streamside trees and vegetation — are created when the physical habitat within the watershed of a stream network is altered. One of the key components of an ecological assessment is a measure of how common each stressor is in a region, and how severely it affects biotic integrity.

In addition to these stressors, the NRSA investigated *human health indicators,* specifically mercury levels in fish tissue and the fecal indicator enterococci.

Table 2 shows the key indicators evaluated for this report. NRSA scientists sampled for a number of other indicators as well; future reports will discuss these, but they are not included here due to technical and time considerations.

Table 2. Indicators evaluated for the NRSA

Biological Indicators	Chemical Indicators	Physical Indicators	Human Health Indicators
■ Benthic macroinvertebrates ■ Periphyton (algae) ■ Fish community	■ Phosphorus ■ Nitrogen ■ Salinity ■ Acidity	■ Streambed sediments ■ In-stream fish habitat ■ Riparian vegetative cover ■ Riparian disturbance	■ Enterococci (fecal indicator) ■ Mercury in fish tissue

Setting expectations

In order to interpret the data collected by the NRSA field crews and to assess current ecological condition, scientists need to compare the collected data to a benchmark — an estimate of what we would *expect* to find in a natural condition. Setting reasonable expectations for each of the indicators is one of the greatest challenges to an assessment of ecological condition. Should we take a historical perspective and try to compare current conditions to an estimate of pre-Columbian conditions, or to pre-industrial conditions, or to conditions at some other point in history? Or should we accept that some level of anthropogenic disturbance is a given, and simply use the best of today's conditions as the yardstick against which we compare everything else? These questions, and their answers, all relate to the concept of reference condition: what do we use as a reference, or yardstick, to assess today's condition?

Because it is difficult to estimate historical conditions for many indicators, the NRSA's benchmark is "least-disturbed condition": the best available physical, chemical, and biological habitat conditions given today's state of the landscape. Least-disturbed condition is defined based on data from sites selected according to a set of explicit screening criteria, used to define what is least-disturbed by human activities. These criteria vary from region to region to reflect the natural variability across the American landscape; for the NRSA, separate criteria were defined for each of the nine ecoregions. The screening criteria were developed with the goal of identifying the least amount of ambient human disturbance in each ecoregion. Reference criteria, in essence, describe the sites whose condition is "the best of what's left" in the U.S.

The NRSA compares a subset of the chemical and physical data collected at each site to the screening criteria to determine whether any given site is in least-disturbed condition for its ecoregion. The NRSA does not use data on the biological assemblages as a screening factor to select reference sites because that would have pre-judged expectations for biological condition. For each of the stressor indicators, the NRSA used a similar process (i.e., identifying least-disturbed sites according to specific criteria, but excluding the specific stressors themselves from the criteria identifying the sites).

The reference site approach is then used to set expectations. The range of conditions found in the reference sites for an ecoregion describes a distribution of values expected for least-disturbed condition. The benchmarks used to define distinct condition classes (e.g., good, fair, poor) based on the degree of disturbance are drawn from this reference condition.

The NRSA approach was to examine the range of values for an indicator in all of the reference sites in a region, and to use the fifth percentile of the reference distribution to separate the most disturbed sites from moderately disturbed sites. This means that stream miles in the most disturbed category are worse than 95% of the best sites used to define reference condition. Similarly, the 25th percentile was used to distinguish between moderately disturbed sites and least-disturbed sites: stream miles reported as least-disturbed are as good as 75% of the sites used to define reference condition.

Within the reference site population, there are two sources of variability:

- Natural variability — the wide range of habitat types naturally found within each ecoregion — creates a spread of reference sites representing those different habitats. Capturing natural variability in reference sites helps establish reference conditions that represent the range of natural environments in the ecoregions.
- Human activities have changed many areas in the U.S., with natural landscapes transformed by cities, suburban sprawl, agricultural development, and resource extraction. The extent of those disturbances varies across regions. Some regions have

reference sites in watersheds with little to no evidence of human impact, such as mountain streams or rivers in areas with very low population densities. Other regions have few sites that have not been influenced by human activities. The least-disturbed reference sites in these widely influenced regions display more variability in quality than those in areas with little human disturbance.

Variation within the reference distribution due to disturbance was addressed before benchmarks were set for the condition classes of good, fair, and poor. For regions where the reference sites exhibited a disturbance signal, the data analysis team accounted for this disturbance by shifting the mean of the distribution toward the less-disturbed reference sites.

NRSA partners supported this reference-condition-based approach, which is consistent with EPA guidance and state practice. Interested readers can find more detailed information about determining reference condition in the NRSA technical report, published online at www.epa.gov/aquaticsurveys.

Understanding biological condition

The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. It establishes many national goals to control pollution, including that water quality support healthy aquatic communities and provide for recreational uses like swimming and fishing wherever attainable. A primary goal of the NRSA is to develop a baseline understanding of the biological condition of our nation's streams.

One of the most meaningful ways to answer basic questions about water quality is to directly observe the communities of plants and animals that live in water bodies. Aquatic plants and animals are constantly exposed to various stressors. Therefore, they reflect not only current conditions, but also the cumulative impacts of stressors and changes in conditions over time.

Benthic macroinvertebrates (aquatic insects, crustaceans, worms, and mollusks that live in river and stream beds and in vegetation) are widely used to determine biological condition. These organisms can be found in all rivers and streams, even in the smallest streams that cannot support fish. Because they are relatively stationary and cannot escape pollution, macroinvertebrate communities integrate the effects of stressors over time (i.e., pollution-tolerant species will survive in degraded conditions, and pollution-intolerant species will die). These communities are also critically important to fish because most game and non-game species require a good supply of benthic macroinvertebrates as food. Biologists have been studying the health and composition of benthic macroinvertebrate communities in streams for decades. Biological condition is the most comprehensive indicator of water body health; when the biology of a stream is healthy, the chemical and physical components of the stream are also typically in good condition. In fact, several states have found that biological data frequently detect stream impairment where chemistry data do not.

Data on biological condition are invaluable for managing the nation's aquatic resources and ecosystems. Water quality managers can use these data to set protection and restoration goals, decide which indicators to monitor and how to interpret monitoring results, identify stresses to the water body and decide how they should be controlled, and assess and report on the effectiveness of management actions. Many specific state responsibilities under the Clean Water Act—such as determining the extent to which waters support aquatic life uses, evaluating cumulative impacts from polluted runoff, and determining the effectiveness of discharger permit controls—are tied directly to an understanding of biological condition.

Using multiple biological assemblages to determine biological condition

EPA's guidance on developing biological assessment and criteria programs recommends the use of multiple biological assemblages to determine biological condition. The term "multiple biological assemblages" simply refers to the three main categories of life found in a water body: plants (e.g., algae), macroinvertebrates, and vertebrates (e.g., fish). The purpose of examining multiple biological assemblages is to generate a broader perspective of the condition of the aquatic resource of interest.

Each assemblage plays a different role in the way that rivers and streams function. Algae and macroinvertebrates occur throughout all types and sizes of rivers and streams, whereas very small streams may be naturally devoid of fish. Algae are the base of the food chain and capture light and nutrients to generate energy. They are sensitive to changes in shading, turbidity, and increases or decreases in nutrient levels. Macroinvertebrates feed on algae and other organic material that enters the aquatic system from the surrounding watershed. Macroinvertebrates are also an important food source for many aquatic vertebrates such as fish, which in turn serve as an important food source for people and wildlife. Each of these groups of aquatic organisms is sensitive in its own way to different human-induced disturbances.

The NRSA uses benthic macroinvertebrates, fish, and algae as biological indicators of ecological condition. This is the first time three different biological assemblages have been evaluated for one national survey. For each of these assemblages, scientists calculated a series of metrics or individual measures and combined them into index scores. Results for each of these assemblages are presented in this report.

However, research is still underway to determine how the different assemblage indices can be accurately combined into one overall index. Therefore, the macroinvertebrate assemblage — and specifically the Macroinvertebrate Multimetric Index, or MMI — was selected to represent overall biological condition for purposes of this report. The Macroinvertebrate MMI integrates a broad variety of informative macroinvertebrate metrics into one overall result and provides a particularly strong picture of biological condition that is widely used by state water quality agencies to assess and report on their rivers and streams. It was also used as the primary indicator of biological condition in the 2004 WSA. Work is ongoing to explore methods for integrating different assemblage indices into one overall index for future reports in this series.

Chapter 3. Condition of the Nation’s Rivers and Streams

Background

The goal of the Clean Water Act is to restore and maintain the “chemical, physical, and biological integrity” of the nation’s waters. The NRSA examines these three aspects of water quality through a set of commonly used and widely accepted indicators. It does not include all aspects of aquatic ecosystem integrity or review all possible chemical, physical, or biological stressors known to affect water quality.

This chapter discusses the indicators of biological condition that were measured and analyzed for the NRSA, the chemical and physical aquatic indicators of stress, and a ranking of the relative importance of the stressors in affecting biological condition. Results for each indicator are shown for the nation’s rivers and streams and for the three major climatic regions (Eastern Highlands, Plains and Lowlands, and West). Chapter 4 presents the findings of the human health indicators, and Chapter 6 presents indicator results for each of the nine NRSA ecoregions. An analysis of the changes between this study and the 2004 WSA is presented in Chapter 5. It is important to keep in mind that the overall NRSA findings should not be compared directly to those of the WSA because of the difference in overall population surveyed (rivers and streams versus streams only).

Indicators of biological condition

Ecologists evaluate the biological condition of rivers and streams by analyzing key characteristics of the communities of organisms that live in them. These characteristics include the composition and relative abundance of related groups of organisms that represent a portion of the overall biological community. The NRSA focuses on three such key groups, known as *assemblages*: benthic macroinvertebrates (aquatic insects, crustaceans, worms, and mollusks that live at the bottom of rivers and streams); periphyton (algae that attach themselves to stream and river beds, plants, rocks, and woody debris); and fish. This is the first time three different biological assemblages were evaluated for one national statistical survey. The reason for evaluating three distinct groups is to secure as robust an understanding of the biological condition of rivers and streams as possible. This is because each assemblage plays a different role in the way that rivers and streams function. For example, algae are the base of the food chain and capture light and nutrients to generate energy. They are sensitive to changes in shade, turbidity, and nutrient levels. Macroinvertebrates feed on algae and other organic material and are also an important food source for many other aquatic animals, such as fish; in turn, fish serve as an important source of food for people and wildlife. Each of these groups of aquatic organisms is sensitive in its own way to human disturbances.

NRSA researchers collected samples of these organisms and sent them to laboratories for analysis, yielding data sets that provided the types and number of taxa (i.e., classifications or groupings of organisms) found at each site. These were then analyzed to assess the condition of each group of organisms, using well-established and tested indices. As a final step in interpreting this information, analysts developed a ranking system for the stressors that affect each of these biological assemblages.

Macroinvertebrate Multimetric Index

Macroinvertebrates are widely used as indicators of biological condition because they respond to human disturbance in known and predictable ways. Given their broad geographic distribution, abundance, ease of collection, and connection to fish and other aquatic animals (i.e., as a source of food), these organisms serve as excellent indicators of the biological quality of rivers and streams and of the human stressors that affect them.

The Macroinvertebrate Multimetric Index (MMI) is similar in concept to the Leading Economic Index in that the total index score is the sum of scores for a variety of individual measures (also known as metrics). To develop the Leading Economic Index, economists select metrics such as manufacturers’ new orders for consumer goods, building permits, money supply, and other aspects of the economy that reflect economic growth. Similarly, to determine the Macroinvertebrate MMI, ecologists selected six metrics indicative of different aspects of macroinvertebrate community structure:

- Taxonomic richness — the number of distinct taxa (family or genus) within different taxonomic groups of organisms, within a sample. A sample with many different families or genera, particularly within those groups that are sensitive to pollution, indicates least-disturbed physical habitat and water quality and an environment that is not stressed.

- Taxonomic composition — the proportional abundance of certain taxonomic groups within a sample. Certain taxonomic groups are indicative of either highly disturbed or least-disturbed conditions, so their proportions within a sample serve as good indicators of condition.

- Taxonomic diversity — the distribution of the number of taxa and the number of organisms among all the taxa groups. Healthy rivers and streams have many organisms from many different taxa groups; unhealthy streams are often dominated by a high abundance of organisms in a small number of taxa.

- Feeding groups — the distribution of macroinvertebrates by the strategies they use to capture and process food from their aquatic environment, such as filtering, scraping, grazing, or predation. As a river or stream degrades from its natural condition, the distribution of animals among the different feeding groups will change, reflecting changes in available food sources.

- Habits/habitats — the distribution of macroinvertebrates by how they move and where they live. A stream with a diversity of habitat types will support animals with diverse habits, such as burrowing under streambed sediments, clinging to rocks, swimming, and crawling. Unhealthy systems, such as those laden with silt, will have fewer habitat types and macroinvertebrate taxa with less diverse habits (e.g., will be dominated by burrowers).

- Pollution tolerance — the distribution of macroinvertebrates by the specific range of contamination they can tolerate. Highly sensitive taxa, or those with a low tolerance to pollution, are found only in rivers and streams with good water quality. Waters with poor quality will support more pollution-tolerant species.

The specific metrics chosen for each of these characteristics varied among the nine ecoregions used in the analysis. Each metric was scored and then combined to create an overall Macroinvertebrate MMI for each ecoregion. Analysts calculated a Macroinvertebrate MMI for each site, factored in the river or stream length represented by the site, and then generated an estimate of the river and stream length in a region, and nationally, with a given Macroinvertebrate MMI score.

Because it integrates a broad variety of informative macroinvertebrate metrics into one overall result, the Macroinvertebrate MMI provides a particularly strong picture of biological condition that is widely used by state water quality agencies to assess and report on their rivers and streams. It was also used as the primary indicator of biological condition in the 2004 WSA. For these reasons, and because it is not yet possible to integrate the indices for the three different biological assemblages (macroinvertebrates, fish, and periphyton) into one overall result, the Macroinvertebrate MMI serves as the key indicator of biological condition for the NRSA as well. Work is ongoing to explore methods for integrating different assemblage indices into one overall index for future reports in this series.

What are confidence intervals?

Confidence intervals (the small lines at the end of the bars in this report's charts) convey the level of certainty or confidence in the condition estimates presented in this report. For example, for the Macroinvertebrate MMI, the NRSA finds that 20.7% of the nation's river and stream length is in good condition, with a confidence interval of +/- 2.8 %; this means that there is a 95% certainty that the real value is between 17.9 % and 23.5 %. The confidence interval depends primarily on the number of sites sampled. As more rivers and streams are sampled, the confidence interval becomes narrower, meaning there is more confidence in the findings. When fewer rivers and streams are sampled, the confidence interval become broader, meaning there is less certainty. Figure 7 shows an example of this pattern, in which the confidence interval for the national results (the largest sample size) is narrowest, whereas the confidence intervals for the major regions, where a smaller number of streams were sampled, are generally broader. Ultimately the breadth of the confidence interval is a tradeoff between the need for increased certainty to support decisions and the money and resources dedicated to monitoring.

Findings for the Macroinvertebrate Multimetric Index

As illustrated in Figure 7, the Macroinvertebrate MMI results show that 21% of the nation's river and stream length (247,558 miles) is in good condition, 23% (276,796 miles) is in fair condition, and 55% (659,788 miles) is in poor condition compared to least-disturbed reference conditions. Of the three major climatic regions, the Eastern Highlands has the highest percentage of river and stream length in poor condition (63%, or 272,171 miles), followed by the Plains and Lowlands (58%, or 328,821 miles) and the West (30%, or 58,796 miles).

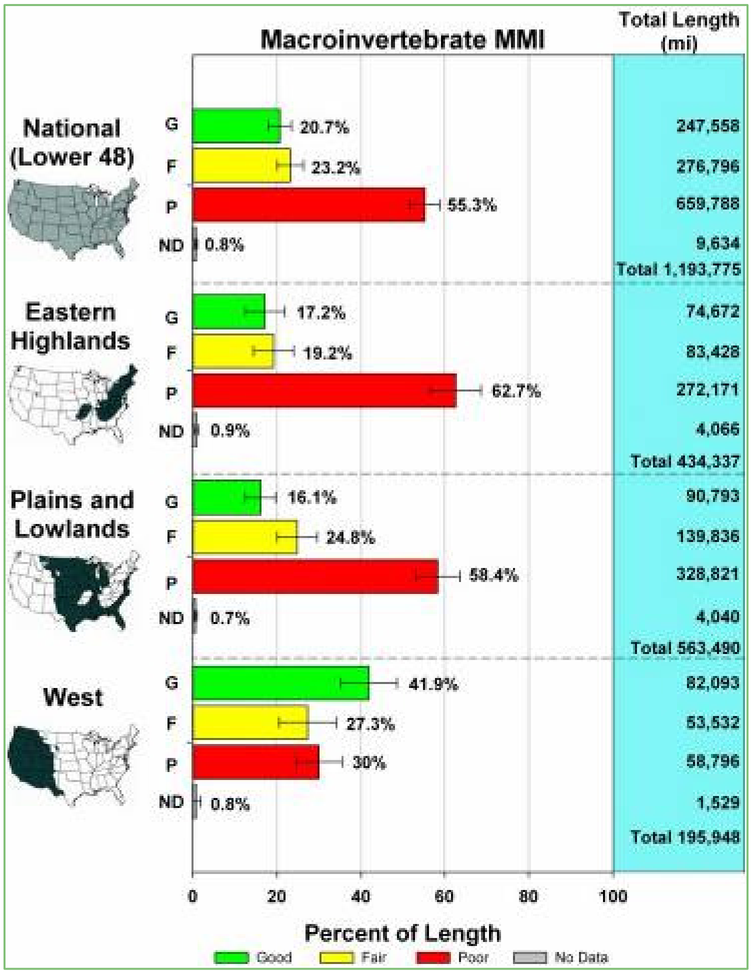

Figure 7. Biological condition of the nation's rivers and streams based on the Macroinvertebrate Multimetric Index. This index combines metrics of benthic community structure and function into a single index for each region.

Macroinvertebrate Observed/Expected Ratio of Taxa Loss

The Macroinvertebrate Observed/Expected Ratio of Taxa Loss (or O/E Taxa Loss) measures taxa that have been lost at a site. The taxa expected at individual sites (E) are predicted from a model developed from data collected at least-disturbed sites. By comparing the list of taxa observed (O) at a site with those expected to occur, the proportion of expected taxa that have been lost can be quantified as the ratio of O/E. O/E taxa loss models are calibrated for the specific natural conditions in each area for which they are used. For the NRSA, analysts developed three O/E taxa loss models to predict the extent of taxa loss in rivers and streams in the Eastern Highlands, Plains and Lowlands, and West.

O/E Taxa Loss values range from 0 (none of the expected taxa are present) to slightly greater than 1 (more taxa are present than expected). Each tenth of a point less than 1 represents a 10% loss of taxa at a site, so a score of 0.9 indicates that 90% of the expected taxa are present and 10% are missing. The quality of reference sites available for a region sets the bar for what is expected, so regions with lower-quality reference sites will have a lower bar. It is important to keep in mind that this indicator examines only one specific aspect of biological condition (biodiversity loss), while the Macroinvertebrate MMI discussed above combines multiple characteristics. Therefore, results are not expected to be the same.

Findings for O/E Taxa Loss

Findings for O/E Taxa Loss are presented in four categories: (1) less than 10% taxa loss, (2) 10%–20% taxa loss, (3) 20%–50% taxa loss, and (4) more than 50% taxa loss. As shown in Figure 8, 40% of U.S. stream length lost less than 10% of taxa; 14% lost 10%–20% of taxa; 29% lost 20%–50% of taxa; and 17% lost more than 50% of expected taxa.

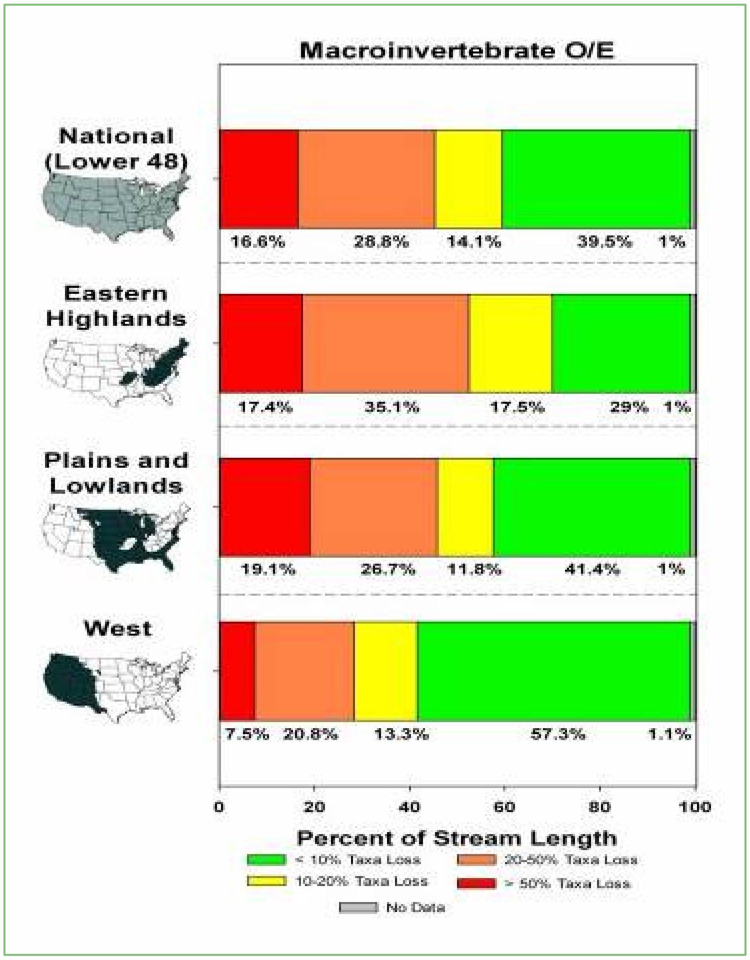

Figure 8. Macroinvertebrate taxa loss in the nation's rivers and streams as measured by the Observed/Expected Ratio of Taxa Loss. This indicator displays the loss of taxa compared to the reference sites for each region.

Of the three major regions, the West had the highest percentage of stream length with 10% or less taxa loss (57%) and the smallest percentage with more than 50% taxa loss (8%). The Plains and Lowlands and the Eastern Highlands had similar percentages of stream length with more than 50% taxa loss (19% and 17% respectively), although the Plains and Lowlands had a greater percentage of stream length in the good range with less than 10% taxa loss (41% versus 29% for the Eastern Highlands).

Fish Multimetric Index

Evaluating the variety and abundance of fish species (the fish *assemblage*) in streams and rivers has been integral to water monitoring and water quality management programs for many years. Fish are sensitive indicators of physical and chemical habitat degradation, environmental contamination, migration barriers, and overall ecosystem productivity. They need plants, insects, and small aquatic creatures to feed on; in-stream and streambank cover to shelter in; appropriate streambed substrate conditions for spawning; and overhanging vegetation to shade the water in which they live. They are affected by changes in temperature, dissolved oxygen, pH, and myriad other physical and chemical constituents in water. They are also long-lived, will move (if they can) to avoid pollutants or other stresses, and are economically, culturally, and recreationally valuable. Determining the health and wellbeing of the fish assemblage helps us evaluate the extent to which our waters are meeting the goals of the Clean Water Act.

For the NRSA, scientists developed a Fish MMI using an approach that estimates expected condition at individual sites. Separate indices were developed for each of the three major climatic regions. These indices were based on a variety of metrics including taxa richness, taxonomic composition, pollution tolerance, habitat and feeding groups, spawning habits (specifically, the percent of individuals that deposit eggs on or within the substrate in shallow waters), the number and percent of taxa that are migratory, and the percent of taxa that are native. Fish were collected using standard electrofishing methods, tallied, and identified in the field; except for those used for tissue analysis and as voucher specimens, they were then released alive.

Findings for the Fish Multimetric Index

As shown in Figure 9, the NRSA Fish MMI indicates that 37% of the nation’s river and stream length (or 440,129 miles) is in good condition for this indicator, 15% (174,676 miles) is in fair condition, and 36% (425,688 miles) is in poor condition compared to least-disturbed conditions.

The remaining 13% of river and stream length either is not assessed or, for various reasons, has insufficient data. Reasons why this percentage is relatively large include denials of fish collection permits by state, federal, or local authorities (often because of the possible presence of threatened or endangered species) and conditions and sites that were deemed to be unsafe or unsuitable for fish sampling.

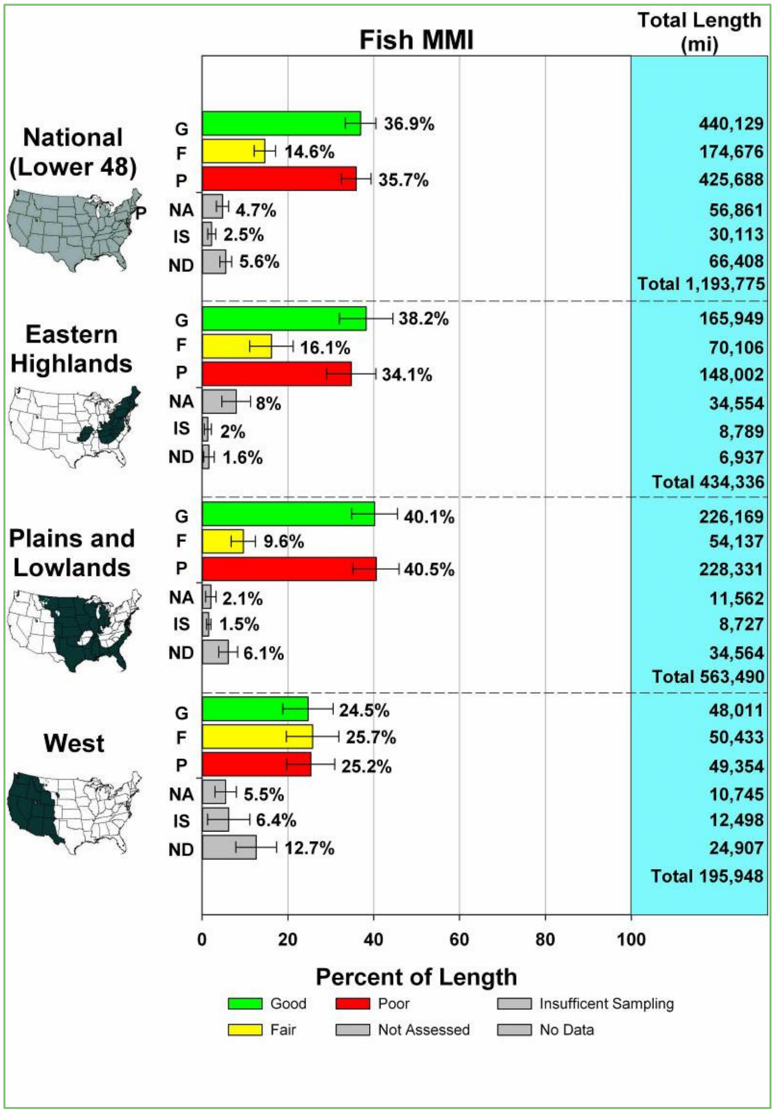

Figure 9. Condition of the fish assemblage in the nation's rivers and streams as measured by the Fish Multimetric Index (EPA/NRSA). The index combines metrics of fish assemblage structure and function into a single index for each region.

Results for the Eastern Highlands and Plains and Lowlands are similar for this index. The Plains and Lowlands region has the highest percentage of stream length in poor condition (41%, or 228,331 miles) and an almost equal percentage in good condition (40%, or 226,169 miles). For the Eastern Highlands, 35% of river and stream length (148,002 miles) ranks in poor condition and 38% (165,949 miles) ranks in good condition. In the West, on the other hand, good, fair, and poor rankings each apply to about 25% of river and stream length. Note that the West has the largest percentage of stream length that was either not assessed or had insufficient data.

Periphyton Multimetric Index

Periphyton, which are bottom-dwelling algae that attach themselves to stream and river beds, plants, rocks, and woody debris, are an important foundation of many river and stream food webs. They also stabilize substrates and serve as habitat for many other organisms. Because they are attached, they are affected by physical, chemical, and biological disturbances in the water body.

The most common types of periphyton, diatoms, are particularly useful ecological indicators because they are found in abundance in most river and stream ecosystems. Diatoms are algae with inorganic cell walls composed of silica. They grow as single cells but also form filaments or colonies. The great numbers of diatom species in rivers and streams provide multiple, sensitive indicators of environmental change and of the specific conditions of their habitat.

Analysts developed the Periphyton MMI for the NRSA using diatoms. Samples from the NRSA sample sites were identified and counted in the laboratory. The Periphyton MMI was developed based on 12 metrics related to sensitive-tolerant species, functional composition, and diversity composition:

- The proportion of sensitive-tolerant (diatom) taxa, which are metrics based on proportion of sensitive and tolerant taxa from specific families of diatoms relative to all taxa. These metrics included the proportion of all sensitive diatom taxa, the proportion of several individual sensitive taxa, as well as the proportion of two tolerant taxa.
- Functional metrics include the proportion of highly motile diatom individuals, stalked diatom individuals, and planktonic diatom, relative to all diatom taxa.
- Diversity metrics include the proportion of diatom taxa relative to the number of individual diatoms counted, Shannon diversity of diatoms, and number of diatom families per individual diatoms counted.

Findings for the Periphyton Multimetric Index

Based on the Periphyton MMI, 42% of the nation's river and stream length, or 497,738 miles, is rated in good condition compared to least-disturbed conditions, 14% (169,392miles) is rated in fair condition, and 43% (507,007 miles) is rated in poor condition (Figure 10). Of the three major climatic regions, the Eastern Highlands has by far the largest percentage of river and stream miles in poor condition for this index (64%, or 277,761 miles). The West follows with 39% (75,875 miles); for the Plains and Lowlands, 27% (153,371 miles) are rated poor compared to least-disturbed condition.

Aquatic indicators of stress

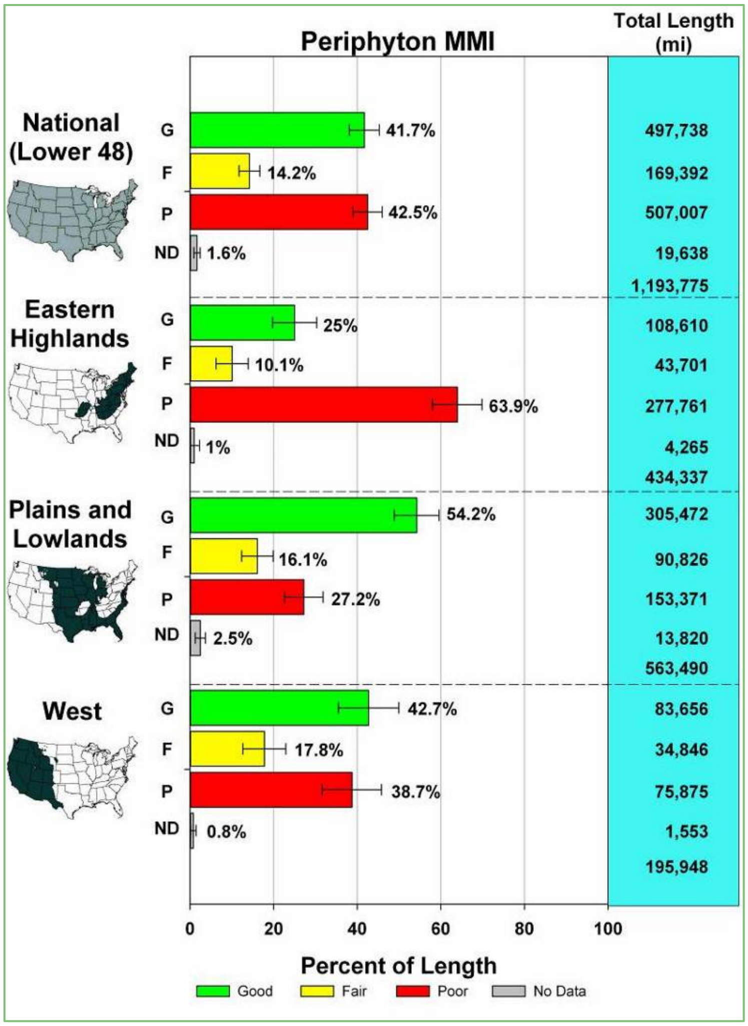

Figure 10. Condition of periphyton assemblage in the nation's rivers and streams based on the Periphyton Multimetric Index (EPA/NRSA). This index combines metrics of periphyton pollution sensitivity and taxa diversity.

In the aquatic environment, a stressor can be anything that could adversely affect the community of organisms that resides there. For the NRSA, a set of chemical and physical stressor indicators were selected because they are widespread, of potential concern, and can be measured. These indicators of stress were not intended to be all-inclusive. Some important stressors were not included in the survey due to technical or cost constraints. Several others — primarily more leading-edge indicators or more complex analytes — were sampled but are still undergoing analysis and are not included in this report. EPA and its partners will be reporting on these stressors in supplemental technical documents or in peer-reviewed journals.

NRSA indicators are based on direct measures of stress in the river or stream or in its adjacent riparian areas. This report does not track the origins of these stressors, which can come from a wide variety of human activities, natural sources, and land uses. A summary of the national and regional results for chemical and physical stressors are shown in Figures 11 through 18. See the “Ranking Stressors” section below for a discussion of the severity of impacts from individual stressors and the benefits that would be derived if those stressors were reduced or eliminated. The purpose of these NRSA analyses is to help rank the different threats posed by stressors to our water resources, and assist in setting priorities for management actions.

Chemical stressors

Four chemical stressors were assessed as indicators in the NRSA: total phosphorus, total nitrogen, salinity, and acidification. These stressors were selected because of national or regional concerns about the extent to which they might be affecting the quality of the biological communities in rivers and streams, and to allow comparison of findings with the 2004 WSA. Scientists developed thresholds for interpreting the data for these indicators from a set of least-disturbed reference sites for each of the nine NRSA ecoregions, as described in Chapter 2. These thresholds are the same as those used for the WSA.

Total phosphorus

Phosphorus is an essential nutrient in the environment and a common component of fertilizers. Because of the naturally low concentrations of phosphorus in most rivers and streams, even small increases can adversely affect water quality and biological condition. High concentrations in rivers and streams may be associated with poor agricultural practices, runoff from urban areas and lawns, leaking septic systems, or discharges from sewage treatment plants. Too much phosphorus can lead to increased growth of algae and large aquatic plants; decaying algae and plants reduce dissolved oxygen levels and water clarity, interfere with swimming, and reduce aesthetic enjoyment of our waters. High levels of phosphorus can also lead to algae blooms that can produce toxins harmful to human and animal health. Natural variability in phosphorus concentrations is reflected in the regional thresholds for high, medium, and low levels, which are based on least-disturbed reference sites for each of the nine NRSA ecoregions.

Findings for total phosphorus

Approximately 34% (407,225 miles) of the nation's river and stream miles are in good condition for phosphorus compared to least-disturbed reference conditions, 26% (308,177 miles) are in fair condition, and 40% (475,598 miles) are in poor condition (Figure 11). Of the three major climatic regions, the Eastern Highlands has the greatest proportion of river and stream length in poor condition based on phosphorus levels (48%, or 208,435 miles).

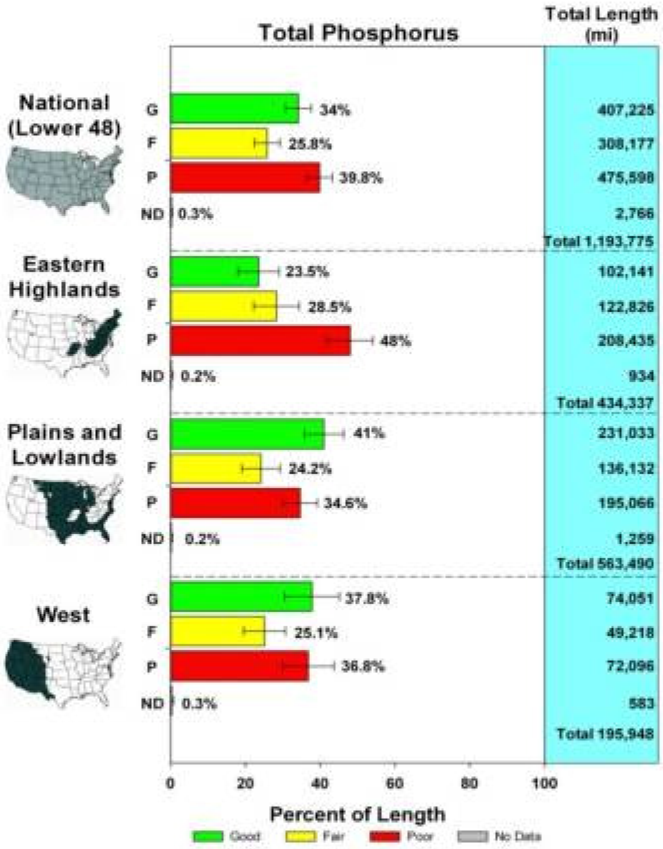

Figure 11. Total phosphorus concentrations in the nation's rivers and streams (EPA/NRSA). Percent of river and stream length in good, fair, and poor, condition based on phosphorus concentrations compared to least-disturbed regional reference sites.

Total nitrogen

Nitrogen is an essential nutrient that, at high concentrations, can stimulate excess growth of algae and large aquatic plants when phosphorus levels are also high. Common sources of excess nitrogen include fertilizers, wastewater, animal wastes, and atmospheric deposition. Low dissolved oxygen levels, algae blooms, and degraded habitat conditions for benthic macroinvertebrates and other aquatic life can result from high nitrogen concentrations.

Findings for total nitrogen

About 55% (660,168 miles) of the nation’s river and stream miles are in good condition for nitrogen compared to least-disturbed reference conditions (Figure 12). About 17% (201,517 miles) are rated fair for nitrogen, and 28% (329,314 miles) are rated poor. Unlike the findings for phosphorus, however, the findings for the Plains and Lowlands show the greatest proportion of river and stream length with high concentrations of nitrogen (32%, or 182,824 miles), followed by the Eastern Highlands (24%, or 103,128 miles) and the West (22%, or 43,362 miles).

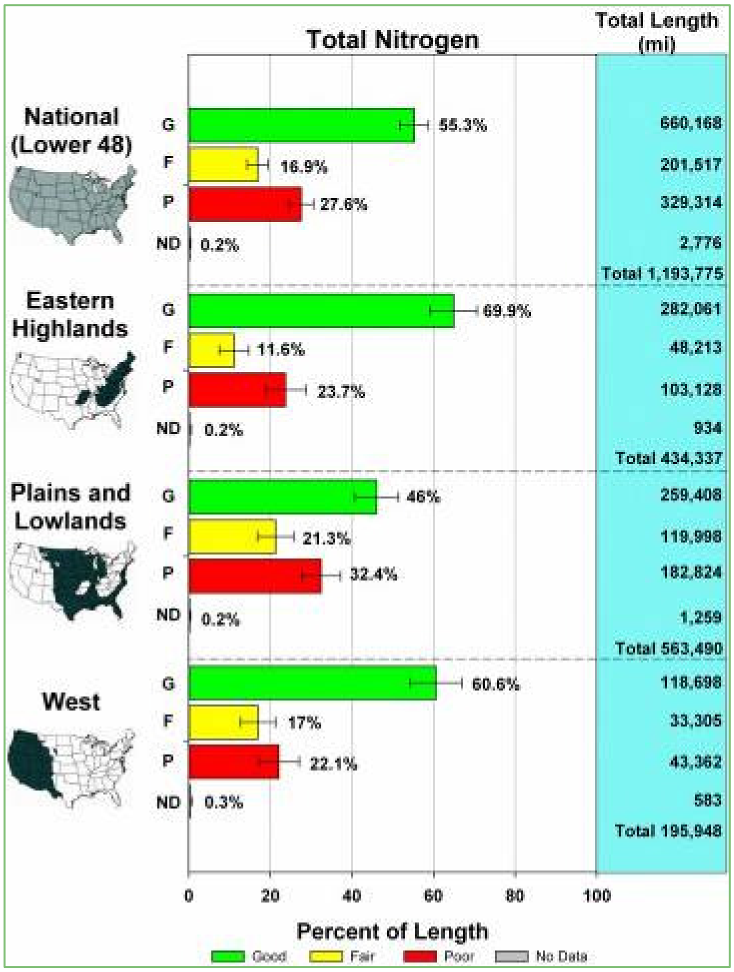

Figure 12. Total nitrogen concentrations in the nation's rivers and streams (EPA/NRSA). Percent of river and stream length in good, fair, or poor condition for nitrogen compared to least-disturbed regional reference sites.

Nutrients and eutrophication in rivers and streams

Eutrophication is a condition that results from high levels of nutrients in a water body and is characterized by excessive plant growth. Although eutrophication is a natural process, human activities can accelerate it by increasing the rate at which nutrients and organic substances enter waters from surrounding watersheds. Agricultural and urban runoff, leaking septic systems, sewage discharges, eroded stream banks, and similar sources can increase the flow of nutrients and organic substances into rivers and streams, and subsequently into downstream lakes and estuaries. These substances can over-stimulate the growth of algae and aquatic plants, creating eutrophic conditions that interfere with recreation and the health and diversity of insects, fish, and other aquatic organisms.

Nutrient enrichment due to human activities has long been recognized as one of the leading problems facing our lakes, reservoirs, and estuaries. It has also been more recently recognized as a contributing factor to river and stream degradation. Nutrient over-enrichment of rivers and streams is a problem because of the negative impacts on aquatic life, adverse health effects on humans and domestic animals, aesthetic and recreational use impairment, and excessive nutrient input into downstream water bodies.

Excess nutrients can lead to excessive growth of phytoplankton (free-floating algae) in slow-moving rivers, periphyton (algae attached to the substrate) in shallow streams, and macrophytes (aquatic plants large enough to be visible to the naked eye) in all waters. Unsightly filamentous algae can impair the aesthetic enjoyment of rivers and streams. In more extreme situations, excessive growth of aquatic plants can slow water flow in flat streams and canals, interfere with swimming, snag fishing lures, and clog water intake screens.

Nutrient enrichment in streams has also been demonstrated to affect animal communities. For example, declines in invertebrate community structure have been correlated directly with increases in phosphorus concentration. High concentrations of nitrogen in the form of ammonia (NH_3) are known to be toxic to aquatic animals. Excessive levels of algae have also been shown to be damaging to invertebrates. Finally, fish and invertebrates will experience growth problems and can even die if either oxygen is depleted or pH increases are severe; both of these conditions are symptomatic of eutrophication.

As a river or stream system becomes more enriched by nutrients, different species of algae may spread and species composition can shift. However, unless such species shifts cause clearly demonstrable symptoms of poor water quality — such as fish kills, toxic algae, or very long streamers of filamentous algae — the general public is unlikely to be aware of a potential ecological concern.

Salinity

Salts can be toxic to freshwater plants and animals and can make water unsafe for drinking, irrigation, and livestock watering. Excess salinity can occur in areas where evaporation is high and made worse by repeated use of water for irrigation or water withdrawals; where road de-icers are applied; and in mining, oil drilling, and wastewater discharges. Conductivity (a measure of water’s ability to pass an electrical current) was used as a measure of salinity for this study.

Findings for salinity

Salinity is not a problem in 87% of the nation’s river and stream miles (or 1,030,381 miles). About 10%, or 117,423 miles, are rated fair for salinity, and 4% (42,336 miles) are rated poor compared least-disturbed sites in the nine NRSA ecoregions (Figure 13). All three major climatic regions have about 3%–4% of stream length rated poor for salinity. However, the Eastern Highlands region has a higher percentage of waters rated fair (14%, or 62,283 miles), compared to 7% (41,401 miles) for the Plains and Lowlands and 7% (13,738 miles) for the West.

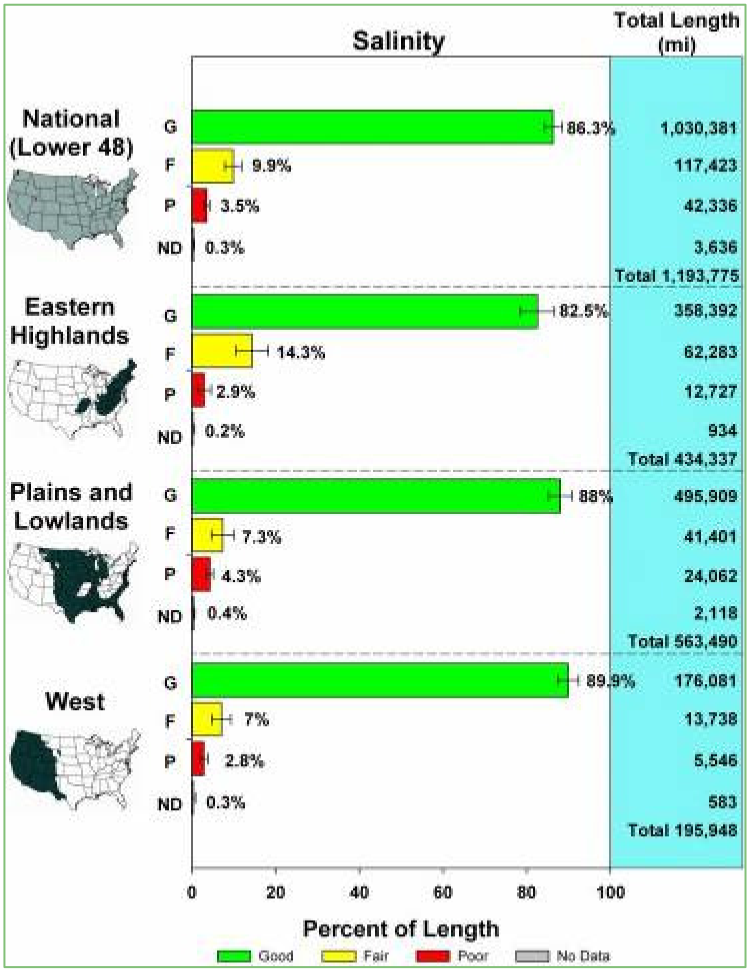

Figure 13. Salinity conditions in the nation's rivers and streams (EPA/NRSA). Thresholds are based on conditions of least-disturbed regional reference sites. Indicator based on electrical conductivity.

Acidification

Streams and rivers can become acidic because of acid deposition (acid rain), or acid mine drainage, particularly from coal mining. These problems tend to be focused in a few geographic areas. Streams and rivers can also be acidic because of natural conditions, such as high levels of dissolved organic compounds. Some fish and macroinvertebrates are acid-sensitive and can only tolerate small changes in acidity. Acidification can also indirectly affect aquatic life by releasing toxic metals such as aluminum from soils into the water.

The NRSA identifies the extent to which flowing waters are not acidic, are naturally acidic (similar to reference conditions), and are acidic because of anthropogenic sources. This last category includes rivers and streams that are acidic due to chronic or episodic acid deposition, or because of mine drainage.

Acid deposition forms when smokestack and auto emissions (primarily sulfur dioxide and nitrogen oxides) combine with moisture in the air to form dilute solutions of sulfuric acid and nitric acid. It can also occur in dry form, such as the particles that make up soot. Acid deposition on sensitive watersheds can have damaging effects on soils, vegetation, and aquatic systems. To assess the effect of acid deposition on flowing waters, the NRSA relied on a measure of water's ability to buffer inputs of acids, called acid-neutralizing capacity (ANC). When ANC values fall below zero, water is considered acidic and can be either directly or indirectly toxic to aquatic life. When ANC is between 0 and 25 milliequivalents, the water is considered sensitive to episodic acidification during rainfall events. These threshold values were determined based on values derived from the National Acid Precipitation Assessment Program.

Acid mine drainage occurs when water moves through mines and mine tailings, combining with sulfur released from certain minerals to form strong solutions of sulfuric acid and mobilizing toxic metals. The acidity of waters in mining areas can also be assessed by using ANC values. However, since mine drainage also produces very high concentrations of sulfate, sulfate serves as an indicator of the influence of mines on streams and rivers. Thus when ANC values and sulfate values are low, acidity can be attributed to acid rain; when ANC values are low and sulfate values are high, acidity can be attributed to acid mine drainage.

Findings for acidification

Figure 14 shows that the vast majority of U.S. rivers and streams (99%, or 1,178,614 miles) are not affected by acidification. Anthropogenic sources in the remaining waters include acid deposition (0.1%, or 1,245 miles of river and stream length), mine drainage (0.2%, or 2,902 miles) and episodic acidity due to high runoff events (0.2%, or 2,825 miles). About 0.3% (5,233 miles) of river and stream length is affected by acidity from natural sources. In the Eastern Highlands region, acid mine drainage affects 0.6% (2,391 miles) of river and stream length and acid deposition affects 0.3% (1,425 miles). In the Plains and Lowlands region, 0.5% of river and stream length, or 2,825 miles, is affected by episodic acidity.

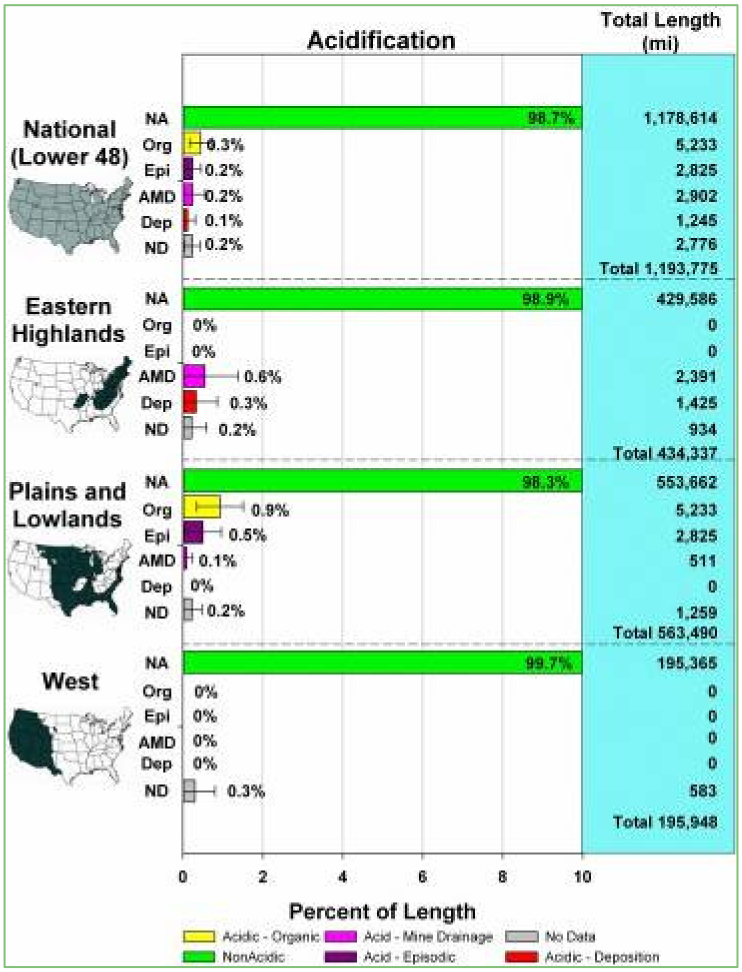

Figure 14. Acidification in the nation's rivers and streams (EPA/NRSA).

Physical habitat stressors

Many human activities such as construction, agriculture, removal of vegetation near streams, land development, and spread of impervious surfaces (such as roads and parking lots) stress the physical condition of rivers and streams and, consequently, stress fish and other aquatic organisms. The NRSA focuses on four indicators of physical habitat conditions in rivers and streams: excess streambed sediments, in-stream fish habitat, riparian (streamside) vegetation, and riparian disturbance.

Excess streambed sediments

The size and shape of natural stream and river channels and the size of the particles that make up their beds reflect the interplay between sediment inputs and the flow of water. Human uses of the landscape, such as agriculture, construction, and urbanization, can increase the amount of fine sediments entering streams and rivers. The same types of land uses can also change the amount and timing of water runoff into channels, especially when they increase the amount of impervious land surfaces. Typically these hydrologic alterations increase the frequency of high-magnitude floods, and channels can respond by down-cutting (incising), eroding their banks, and washing away important aquatic habitat. The most common response to increased fine sediment inputs is a shift to a channel formed of finer, more unstable particles as these sediments are transported downstream. These excess fine sediments can fill in the habitat spaces between stream cobbles and rocks where many aquatic organisms live or breed.

For the NRSA, scientists measured the ratio between the particle size of observed sediments to the size of sediments each river or stream can move or scour during its flood stage, based on measures of the size, slope, and other physical characteristics of the stream channel. This ratio, also known as relative bed stability (RBS), differs naturally among regions depending on characteristics such as geology, topography, hydrology, natural vegetation, and natural disturbance history. Very high RBS, indicating channels with beds that are substantially more stable than expected (e.g., evidence of hardening after prolonged scouring or reduced fine sediment supply, concrete-lined channels) was not assessed by the NRSA as it is difficult to determine the role of human alteration in stream coarsening on a national scale. In this report, the NRSA addresses bed sediment conditions at the low end of RBS, indicating lower-than-expected streambed stability, or higher excess sedimentation, resulting from high inputs of fine sediments or increases in stormflows.

Findings for excess streambed sediments

About 55% (654,401 miles) of the nation’s river and stream length has streambed sediment characteristics in good condition compared to regional reference conditions (Figure 15). Streambed sediment characteristics are rated fair in 30% (351,696 miles) of river and stream length and poor in 15% (177,493 miles). For this indicator, a slightly higher percentage of rivers and streams in the West are rated in poor condition (18%, or 34,539 miles) than in the Eastern Highlands (15%, or 63,111 miles) or the Plains and Lowlands (14%, or 79,844 miles).

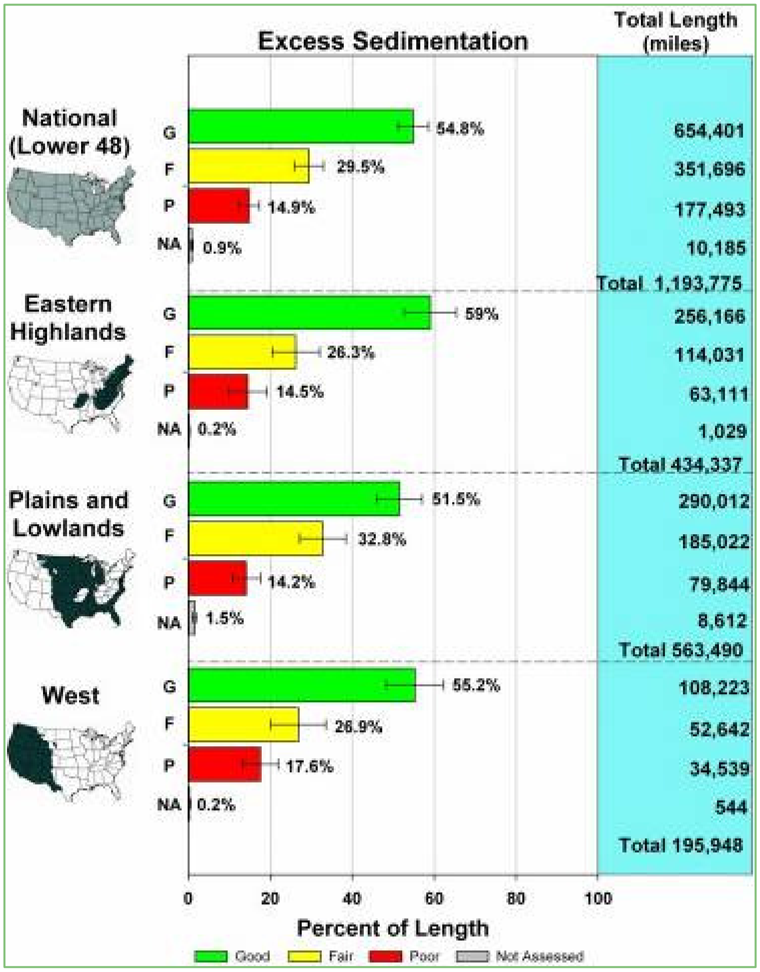

Figure 15. Excess streambed sediment in the nation's rivers and streams (EPA/NRSA).

In-stream fish habitat

The healthiest and most diverse communities of fish and macroinvertebrates are found in rivers and streams that have complex and varied forms of habitat, such as boulders, undercut banks, tree roots, and logs within the stream banks. Human use of rivers and streams and their adjacent riparian areas often results in the removal or loss of much of this habitat, which in turn affects the biological condition of the stream. The NRSA uses a habitat complexity measure that sums the amount of in-stream fish habitat and concealment features such as undercut banks, boulders, large pieces of wood, brush, and cover from overhanging vegetation within the water body and its banks. Because this measure differs naturally within and among ecoregions, low in-stream fish habitat complexity was assessed by comparison with expected values at least-disturbed sites adjusted for factors such as geography and climate within ecoregions.

Findings for in-stream fish habitat

Compared to least-disturbed reference condition, 68% (816,510 miles) of the nation’s river and stream length is in good condition for in-stream fish habitat, 20% (239,627 miles) is in fair condition, and 11% (136,675 miles) is in poor condition (Figure 16). Of the major climatic regions, the highest proportion of river and stream length in poor condition for in-stream habitat is in the Plains and Lowlands, where 15% (84,889 miles) of river and stream length is rated poor. In the West, 10% (18,786 miles) of river and stream length is rated poor, as is 8% (32,999 miles) in the Eastern Highlands region.

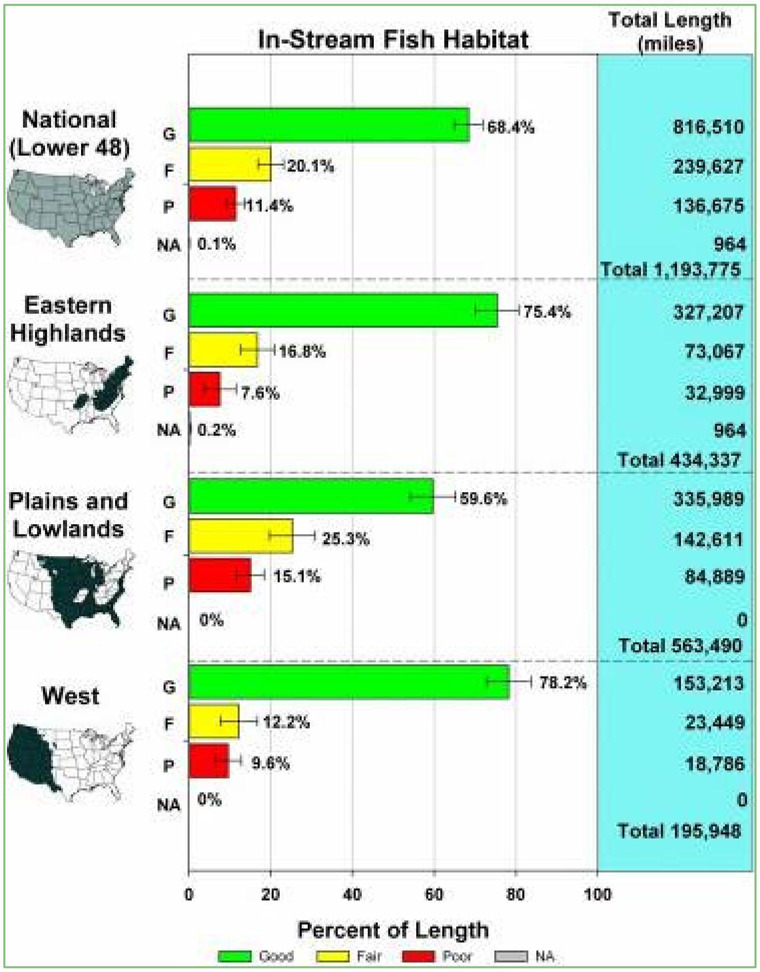

Figure 16. In-stream habitat in the nation's rivers and streams (EPA/NRSA).

Riparian vegetative cover

A river or stream can be buffered from the effects of human disturbance in the watershed by varied, multi-layered vegetation in the land corridor that surrounds it. Healthy, intact vegetative cover in these riparian areas can help reduce nutrient and sediment runoff from the surrounding landscape, prevent streambank erosion, provide shade to reduce water temperature, and provide leaf litter and large wood (such as branches and logs) to serve as food, shelter, and habitat for aquatic organisms. The NRSA uses a measure of riparian vegetative cover that sums the amount of cover provided by three layers of riparian vegetation: the ground layer, woody shrubs, and canopy trees. Because the amount and complexity of riparian vegetation differs naturally within and among ecoregions, lower-than-expected riparian vegetative cover was assessed by comparison with expected values at least-disturbed sites estimated within ecoregions.

Findings for riparian vegetative cover

Over half of the nation’s river and stream length (56%, or 669,687 miles) is in good condition for riparian vegetative cover compared to least-disturbed regional reference conditions. Another 20% (240,376 miles) is in fair condition, and 24% (283,712 miles) is in poor condition. The Eastern Highlands has the highest proportion of rivers and streams with poor riparian vegetative cover (27%, or 116,534 miles), followed by the Plains and Lowlands (23%, or 130,820 miles) and the West (19%, or 36,359 miles) (Figure 17).

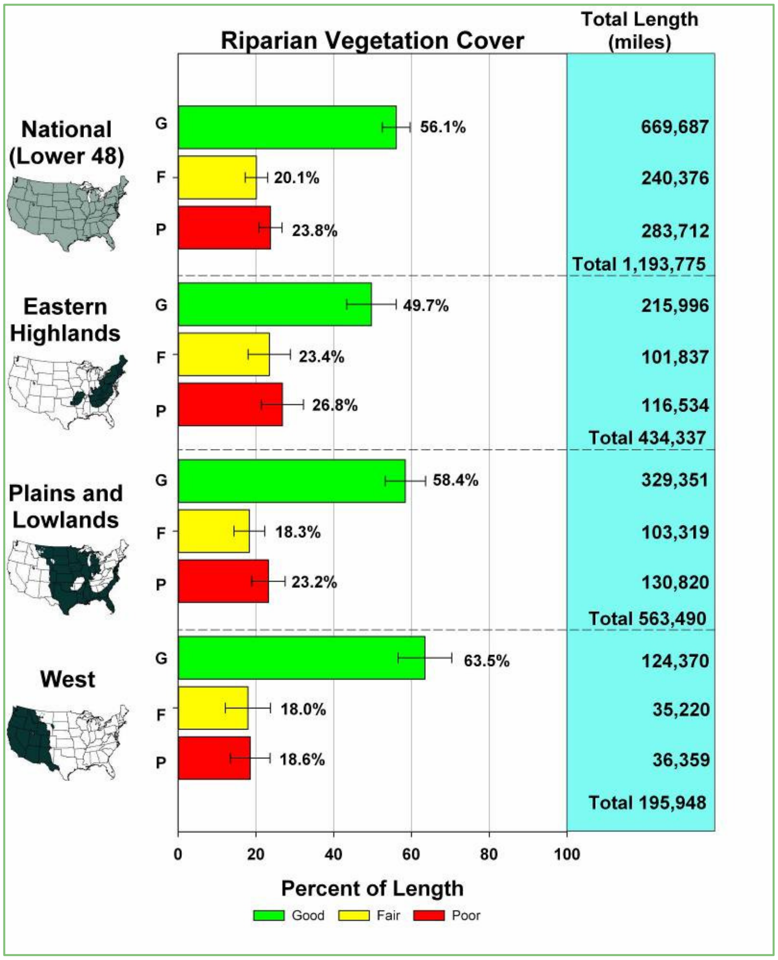

Figure 17. Riparian vegetative cover in the nation's rivers and streams (EPA/NRSA).

Riparian disturbance

The closer harmful human activities are to a river or stream, the more impact they will have on it. The NRSA uses a direct measure of riparian human disturbance that tallies 11 specific forms of human activities and their proximity to the river or stream in 22 riparian plots along the water body. Examples of human disturbance include roads, pavement and cleared lots, buildings, pastures and rangeland, row crops, dams, and logging or mining operations. The same disturbance criteria were applied to define high, medium, and low riparian disturbance in streams and rivers nationwide. For example, a river or stream scored medium if one type of human influence was noted in at least one-third of the riparian plots, and scored high if one or more types of disturbance were observed at all of the plots.

Findings for riparian disturbance

Thirty-four percent (411,035 miles) of the nation's river and stream length had low levels of riparian disturbance and scored as good for this indicator, 46% (543,374 miles) had medium levels of disturbance and were rated as fair, and 20% (239,366 miles) had high levels of disturbance and were rated poor for this indicator. The most widespread types of riparian disturbance were roads, pastures and rangeland, and buildings. Compared to the other physical stressors discussed above, a much greater proportion of U.S. river and stream length was rated as fair (with medium levels of riparian disturbance) and a significantly lower percentage of river and stream length was rated as good. The three major climatic regions had similar proportions of river and stream length in the good/fair/poor categories, although the West had the highest proportion of stream length rated as poor for riparian disturbance (24%, or 47,510 miles) and the lowest proportion rated as good (29%, or 56,995 miles) (Figure 18).

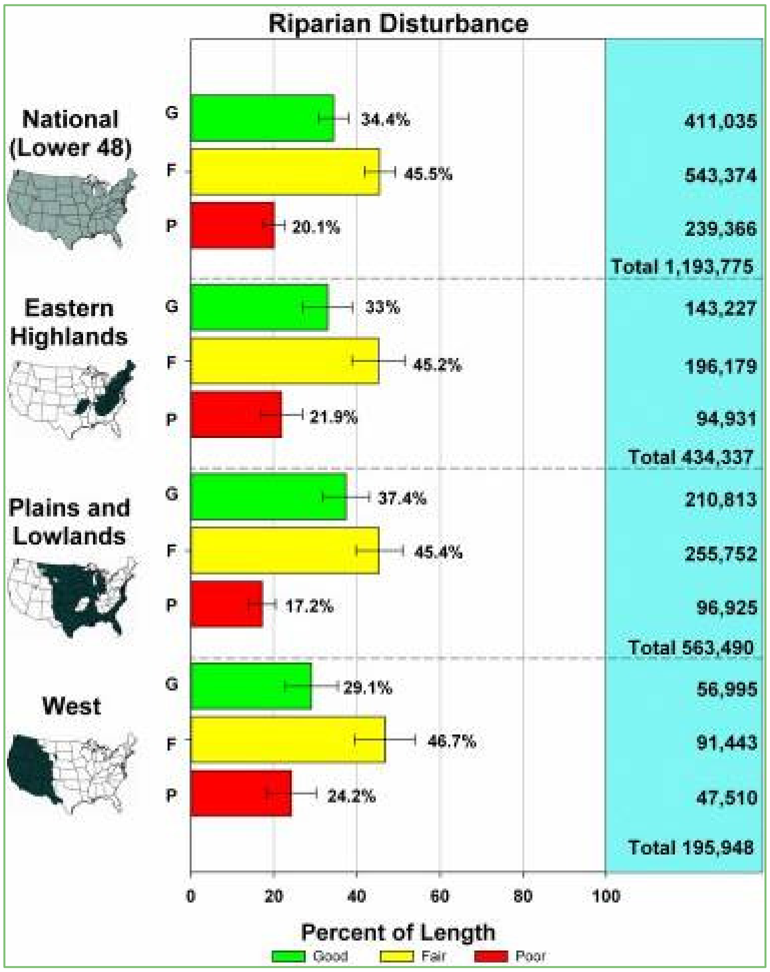

Figure 18. Riparian disturbance in the nation's rivers and streams (EPA/NRSA).

Ranking stressors: relative extent, relative risk, and attributable risk

One of the key roles of the NRSA, and of all assessments in this series, is to provide perspective on key stressors affecting the biological condition of our waters. This includes estimating the benefits that would be derived if those stressors were reduced or eliminated.

For the NRSA, analysts use three approaches to assess the influence of stressors on the ecological condition of the nation's rivers and streams. The first, *relative extent,* looks at how extensive any particular stressor is (e.g., how many miles of rivers and streams have excess phosphorus concentrations). The stressor discussions earlier in this chapter are based on relative extent. The second approach, *relative risk,* examines the severity of the impact from an individual stressor when it is found at high levels (e.g., how much more likely poor biological conditions are when phosphorus levels are high). To assess how ecological conditions may change when a stressor is reduced or removed requires taking both of these perspectives into consideration; this leads to the third approach, *attributable risk.* Attributable risk is derived by combining the first two risk values into a single number that estimates the expected improvement in biological conditions if that stressor is eliminated.

Throughout this section, stressors are assessed and reported on independently and as such do not sum to 100%. Most rivers and streams are likely to experience multiple stressors simultaneously, which can result in cumulative effects not accounted for in this analysis.

Relative extent

It is important for water resource managers to take into account how extensive a stressor is when setting priority actions at the national, regional, and state scale. Stressors that can be found in all geographic areas but are not pervasive do not have high relative extent.

Nationally, the most widespread stressors measured as part of the NRSA are phosphorus and nitrogen (Figure 19). Phosphorus levels are high compared to least-disturbed conditions in 40% of river and stream length; nitrogen is found at high levels in 28% of river and stream length.

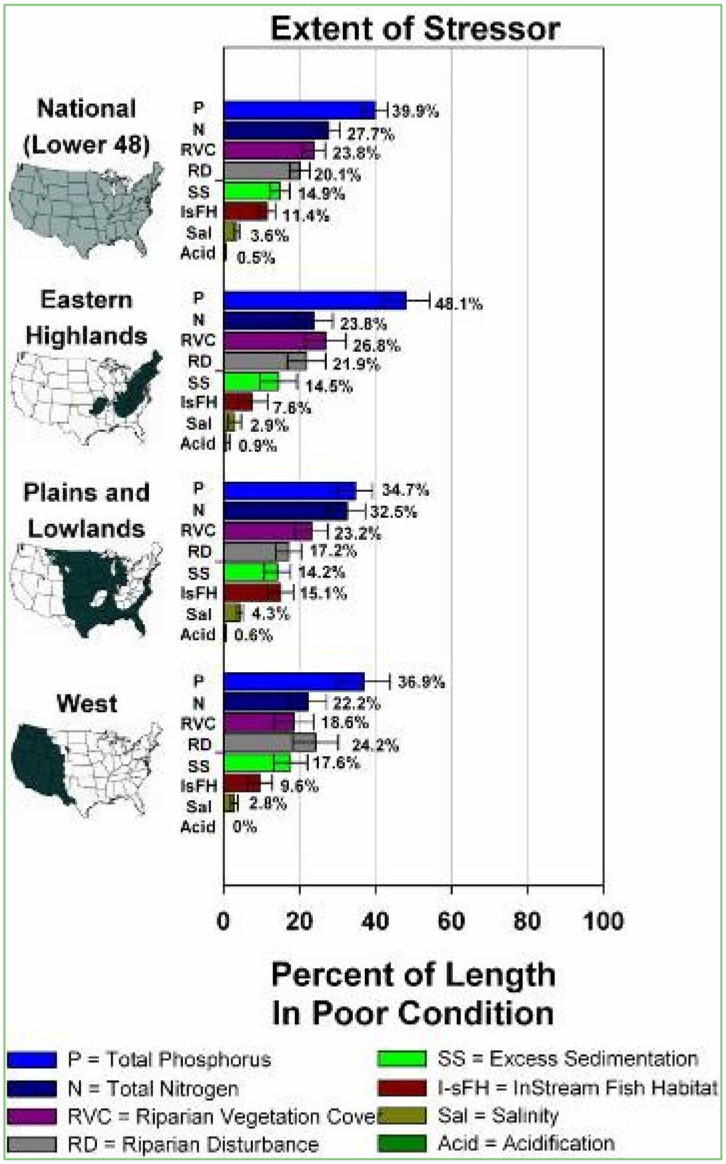

Figure 19. Relative extent of stressors in the nation's rivers and streams (EPA/NRSA).

Riparian vegetative cover is rated poor in 24% of river and stream length, and riparian disturbance is rated at high levels in 20%. With a few exceptions, the extent of these stressors shows a similar pattern across the three major climatic regions.

Relative risk

Relative risk is a way to examine the severity of the impact of a stressor when it occurs. Relative risk is used frequently in the human health field. For example, a person who smokes is 15 to 30 times more likely to get lung cancer or die of lung cancer than a person who does not.[1] Similarly, scientists can examine the likelihood of finding poor biological conditions in a river or stream when phosphorus concentrations are high, relative to the likelihood of poor biological conditions when phosphorus concentrations are low. When these two likelihoods are quantified, their ratio is called the relative risk. A relative risk value of 1 means that you are just as likely to find poor biological conditions when the stressor is high as when it is low — in essence, no demonstrable effect. A relative risk of 1.5, however, means that you are 50% more likely to find poor biological conditions when a stressor is high.

Results of the relative risk analyses for NRSA are presented in the middle panels of Figures 20 through 22. Relative risk differs for macroinvertebrates, fish, and periphyton. For macroinvertebrates nationally, the relative risks are largest for total phosphorus, excess sedimentation, and acidification, all in the range of 1.5. In other words, when these stressors occur in excess levels, streams and rivers are 50% more likely to have poor macroinvertebrate communities than when these stressors are low. The relative risks posed by the various stressors differ in the three major climatic regions, with the West showing the most sensitivity to all the stressors compared to the other regions. In the West, macroinvertebrate communities are 200%–300% more likely to be in poor condition when stressors are at excessive levels compared to when they are at normal levels.

---

[1] Centers for Disease Control. Lung cancer: Risk factors. http://www.cdc.gov/cancer/lung/basic_info/risk_factors.htm (accessed November 7, 2012).

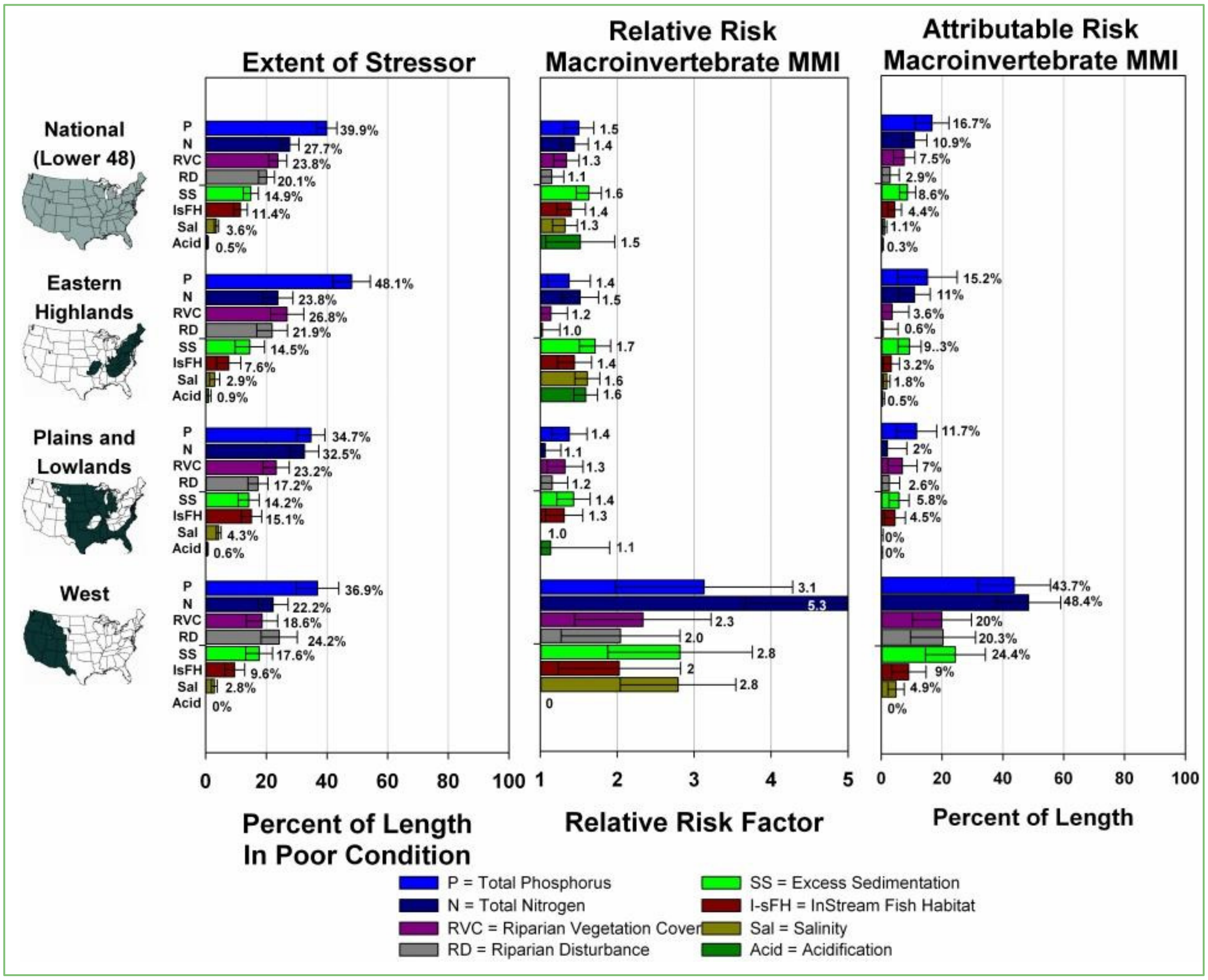

Figure 20. Relative extent, relative risk, and attributable risk to macroinvertebrates based on the Macroinvertebrate Multimetric Index (EPA/NRSA).

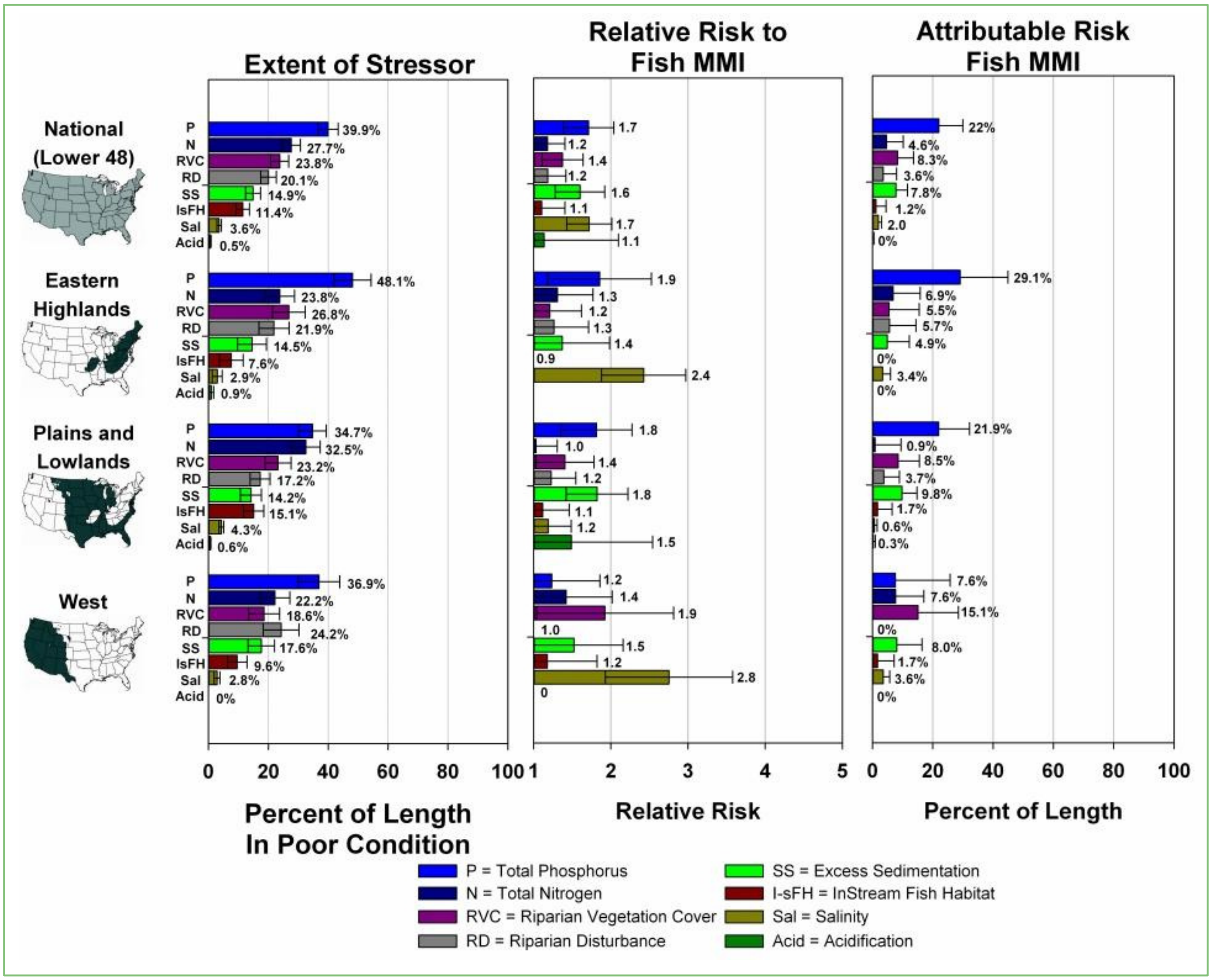

Figure 21. Relative extent, relative risk, and attributable risk to fish based on the Fish Multimetric Index (EPA/NRSA).

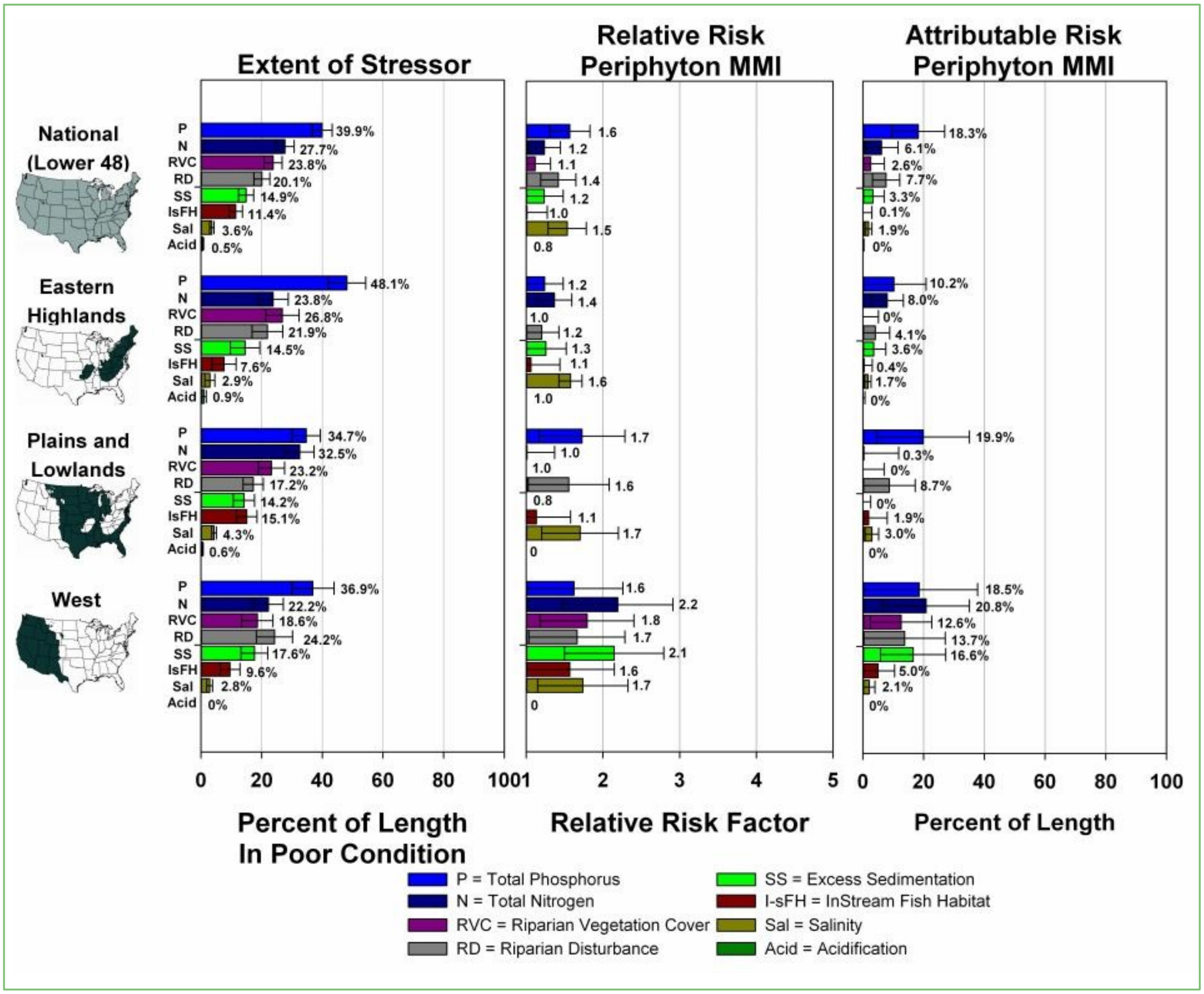

Figure 22. Relative extent, relative risk, and attributable risk to periphyton based on the Periphyton Multimetric Index (EPA/NRSA).

Previous studies in the mid-Atlantic Highlands and in the western U.S. provided some evidence of very different patterns of relative risk for macroinvertebrates, fish, and periphyton. The NRSA results are inconclusive on this. The relative risk values are consistently low for macroinvertebrates, both nationally and in the Eastern Highlands and Plains and Lowlands. For periphyton, relative risk scores are consistently high for salinity and variable by region for the other stressors. The relative risk values for fish are somewhat variable across the three regions.

Attributable risk

Attributable risk represents the magnitude or importance of a potential stressor and can be used to help rank and set priorities for policymakers and managers. Attributable risk is derived by combining relative extent and relative risk into a single number for purposes of ranking (see third panels of Figures 20 through 22). Conceptually, attributable risk provides an estimate of the proportion of poor biological conditions that could be reduced if high levels of a particular stressor were eliminated. This risk number is presented in terms of the percent of length that could be improved.

For example, as noted above, phosphorus occurs at excess levels in 40% of river and stream length. Rivers and streams are 50% more likely to have poor conditions for macroinvertebrates when phosphorus is high (relative risk of 1.5). Relative extent and relative risk combined result in an attributable risk level of about 17%. That is, if phosphorus levels were reduced, one might expect to see 17% of river and stream length improve to good conditions for macroinvertebrates. For periphyton, the attributable risk for phosphorus is 18%; for fish, it is 22%. In the West, where relative risks are large, the amount of improvement in river and stream length to good biological condition is correspondingly large.

Some stressors can have fairly large relative risk but small attributable risk (regardless of biological community) because the relative extent of this problem is small. For example, national relative risk levels for salinity are between 1.3 (for macroinvertebrates) and 1.7 (for fish), yet excess salinity occurs in only 4% of river and stream length nationally. Therefore, the resulting attributable risk levels are small.

Chapter 4. Human Health Considerations in the Nation's Rivers and Streams

Background

In addition to physical, chemical, and biological indicators of the condition of the nation's rivers and streams, the NRSA includes two indicators that provide insight into potential risks to human health: mercury in fish tissue, and the pathogen indicator enterococci.

Most human exposure to mercury is through the consumption of fish. When pregnant women, nursing mothers, and women who might become pregnant eat fish with mercury concentrations above specified thresholds for human protection, this poses a neurodevelopmental health risk to fetuses, babies, and young children. States issue consumption advisories for specific fish species and water bodies when state or local sampling results indicate elevated mercury concentrations. More information on fishing advisories is available from local health agencies and water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/index.cfm.

Enterococci are indicators of the presence of fecal material in water and, therefore, of the possible presence of disease-causing bacteria, viruses, and protozoa. These pathogens can sicken swimmers and others who use rivers and streams for recreation or eat raw shellfish or fish.

Mercury in fish tissue and enterococci were not evaluated for the 2004 WSA. These results are not intended to represent the full range of pollutants in rivers and streams that might adversely affect human health.

Mercury in fish tissue

Mercury is widely distributed in the environment, due to both natural processes and human activities. It enters the atmosphere from the natural degassing of the earth's crust (e.g., from volcanic action) and from some industrial sources such as coal-burning power plants and hazardous waste incineration. Once in the atmosphere, it can circulate widely and be deposited on land and water through rain and snow.

Microorganisms in water convert inorganic mercury to a toxic form of organic mercury called methylmercury. Methylmercury accumulates in fish, primarily in muscle tissue. Nearly all fish contain traces of mercury, and the amount of mercury measured in fish tissue usually increases with fish age and size. It also varies among fish species — those that prey on other fish typically accumulate higher concentrations of mercury than those that eat insects or other aquatic organisms. Measuring mercury levels in fish is critical because about 80% of all fish consumption advisories currently in effect involve mercury. Human health effects can include damage to the immune and nervous systems; developing embryos are particularly at risk.

For the NRSA, field sampling teams applied consistent methods to collect fish from 542 randomly selected river segments (fifth-order or larger) distributed across the lower 48 states. These 542 sites are a subset of the total sites sampled for the NRSA. The teams also collected additional fish at about 10% of the sites to evaluate field sampling variability. Each sample was a composite, consisting of multiple adult fish of the same species and similar size. Field teams selected fish species that people commonly eat, including largemouth and smallmouth bass, walleye, and various trout and catfish species. Fish fillet contaminant levels were then compared to EPA's human health screening values.

EPA analyzed the NRSA fish tissue samples for total mercury in addition to other contaminants. Following EPA guidance, scientists made the conservative assumption that all mercury is present in fish tissue as methylmercury. The human health screening value used to interpret mercury concentrations in fillet tissue is 0.3 milligrams of methylmercury per kilogram of tissue (wet weight) or 300 parts per billion, which is EPA's tissue-based water quality criterion for methylmercury. This threshold represents the concentration that, if exceeded, can be harmful to human health.

For a wide variety of additional chemicals (including selenium, pesticides, polychlorinated biphenyls (PCBs), and other contaminants of emerging concern), analyses are still underway and will be presented in future publications.

Findings for mercury in fish tissue

The human health fish tissue indicator focused on fifth-order and larger rivers. This sub-population contains 106,247 river miles, which represents 9% of the total NRSA river and stream miles associated with all flowing waters (1,193,755 miles). The NRSA limited the target population to fifth-order and larger rivers both because of resource constraints and the need to focus the assessment on waters that would likely support a population of fish of the size that are typically sought for human consumption. Given that levels of mercury in fish tissue vary but tend to increase with size and trophic level, this focus was intended to address both fish taken for subsistence and for sportfishing and produce assessment results that could be comparable across all the waters sampled. The sampled population is the portion of the target sub-population for which we can determine whether mercury levels were above or below the human-health-based screening value. The sampled population, 49% of the target sub-population, consists of 51,544 river miles. Mercury levels in the other 51% of the target sub-population (54,703 river miles) cannot be assessed because sites could not be sampled due to a variety of factors, including inability to obtain permits, lack of suitable fish, insufficient time to collect fish samples, and denial of access to sites.

All fillet samples analyzed for the NRSA contain quantifiable levels of mercury. Fish tissue results indicate that 13,144 river miles have concentrations above the 300 parts per billion human-health-based water quality criterion for mercury; 38,400 river miles do not. Figure 23 summarizes the target and sampled populations for the fish tissue indicator.

In the Eastern Highlands, 3,419 river miles exceed the human health screening value for mercury in fish tissue and 11,200 miles do not. In the Plains and Lowlands, the screening value is exceeded in 7,424 river miles and not exceeded in 22,315 miles. In the West, 2,301 miles exceed the screening value and 4,885 miles do not exceed it. Particularly in the West and the Plains and Lowlands, a high percentage of river length was not sampled for mercury in fish tissue. Results from the sampled sites cannot be extrapolated to these unassessed waters. Figure 24 shows the percent of rivers and streams in each of the three ecoregions that were sampled for mercury in fish tissue.

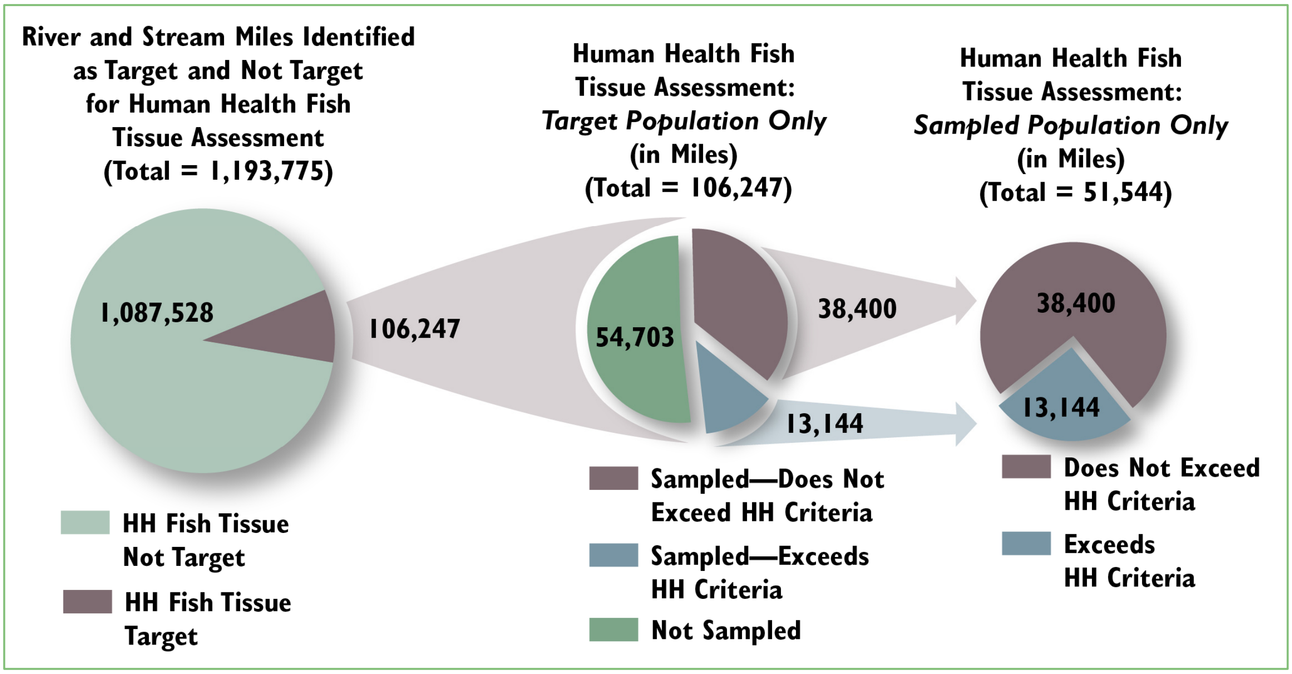

Figure 23. Human health fish tissue assessment for target (middle graphic) and sampled populations (right graphic) of the nation's rivers (EPA/NRSA). The fish tissue *target population* (106,247 miles of fifth order and larger rivers) is a subset of the overall NRSA population for all other indictors. No assessment can be made for the 54,703 miles of the target population that were not sampled, and the fish tissue target population assessment cannot be extrapolated to the entire rivers and streams target population. The fish tissue *sampled population* assessment (right graphic, 51,544 miles) cannot be extrapolated to either the entire rivers and streams target population, or the fish tissue target population.

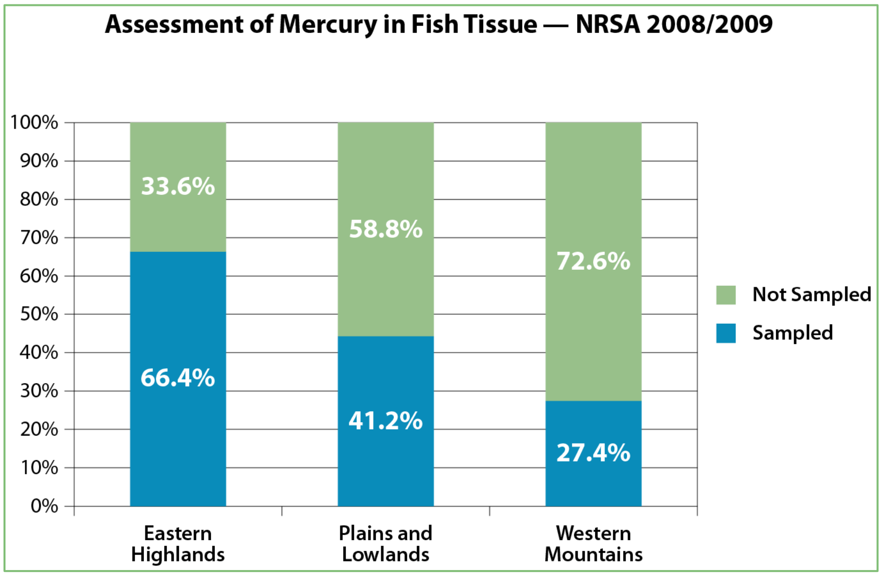

Figure 24. Percent of fish tissue target population sampled for mercury in fish tissue in the three major climatic regions of the U.S. (EPA/NRSA).

Pathogen indicators (enterococci)

Enterococci are bacteria that live in the intestinal tracts of warm-blooded animals, including humans, and therefore indicate possible contamination of streams and rivers by fecal waste. Enterococci are typically not considered harmful to humans, but their presence in the environment may indicate that other disease-causing agents such as viruses, bacteria, and protozoa may also be present. Epidemiological studies conducted at beaches affected by human sources of fecal contamination have established a relationship between the density of enterococci in ambient waters and the elevated incidence of gastrointestinal illness in swimmers. Other potential health effects can include diseases of the skin, eyes, ears, and respiratory tract. Eating fish or shellfish harvested from waters with fecal contamination can also result in human illness. Significant economic losses can occur due to beach closures, swimming and boating bans, and closures of fishing and shellfishing areas due to fecal contamination.

Sources of fecal indicator bacteria such as enterococci include wastewater treatment plant effluent, leaking septic systems, stormwater runoff, sewage discharged or dumped from recreational boats, domestic animal and wildlife waste, improper land application of manure or sewage, and runoff from manure storage areas, pastures, rangelands, and feedlots. There are also natural, non-fecal sources of fecal indicator bacteria, including plants, sand, soil, and sediments, that contribute to a certain background level in ambient waters and vary based on local environmental and meteorological conditions. In some situations, background levels of fecal indicator bacteria can be high and not necessarily related to the occurrence of fecal contamination or human health risks. Watershed-scale sanitary investigations can provide important context to fecal bacteria monitoring results.

For the NRSA, water samples were analyzed using a process known as quantitative polymerase chain reaction, or qPCR, a methodology that facilitates the detection of DNA sequences unique to these bacteria. Analysts compared the NRSA results to a new EPA qPCR threshold for protecting human health in ambient waters designated for swimming (1,280 calibrator cell equivalents per 100 milliliter).

Findings for enterococci

About 85% (1,009,897 miles) of the nation’s river and stream length are in good condition for enterococci (i.e., samples do not exceed the threshold level). About 9% (105,970 miles) are in poor condition, with samples that exceed the threshold level. Nearly 7% of river and stream length is not assessed for enterococci or has no data. Of the three major climatic regions, the Eastern Highlands has the highest percentage of stream length exceeding the threshold (12%, or 49,836 miles), followed by the Plains and Lowlands (9%, or 51,013 miles). In the West, only 3% (8,121 miles) of stream length exceed the threshold for enterococci (Figure 25).

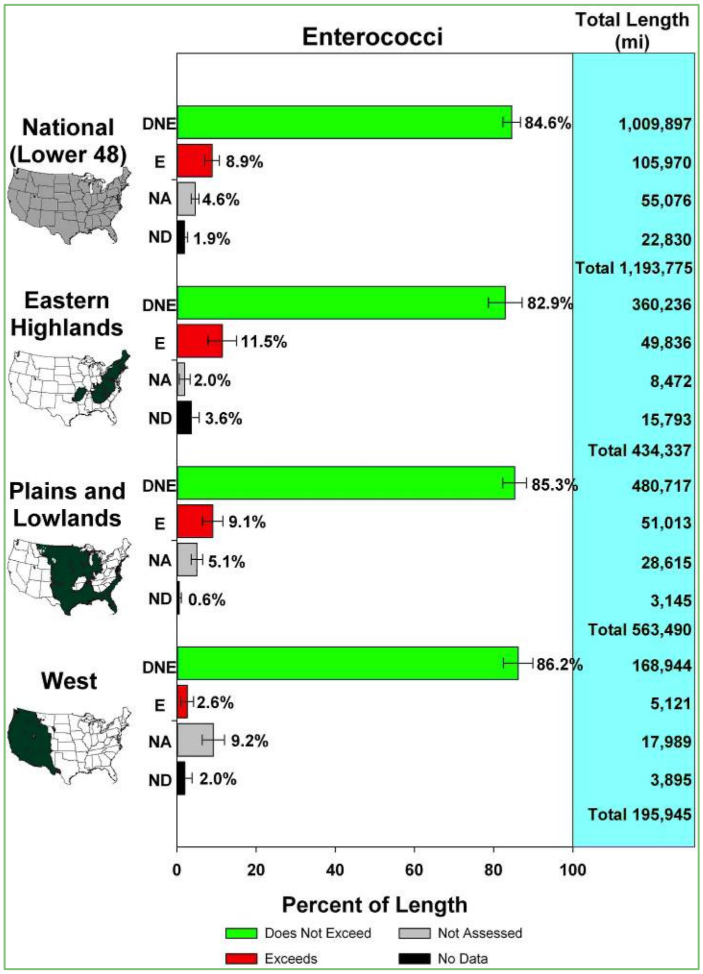

Figure 25. Enterococci human health thresholds exceedance in the nation's rivers and streams (EPA/NRSA). Percent of rivers and streams length exceeding or not exceeding EPA human health thresholds for enterococci.

Urban rivers

Cities share one key characteristic: they are comparatively small areas full of people, buildings, and businesses. The urban rivers that flow through and near them can serve as vital economic resources, often providing drinking water and recreational opportunities, boosting tourism, and improving the quality of city life. However, urban rivers also take on large, concentrated amounts of pollution from a variety of sources, including industrial discharges, mobile sources (e.g., cars/trucks), residential and commercial wastewater, trash, and polluted stormwater runoff from urban landscapes. As urban populations often share centralized water sources, this pollution creates public and environmental health hazards like lowered drinking water quality, water bodies that are not safe to swim in, and fish that aren't safe to eat. NRSA fish tissue sampling offered an opportunity to target these important waters to determine if a wide range of toxic substances were of concern.

To assist researchers in evaluating urban water quality, EPA identified each site selected for NRSA as either urban or non-urban. Urban waters were defined by intersecting a modified version of the Census Bureau national urban boundary geographic information system (GIS) coverage with the NHD-Plus. This essentially gave EPA a way to identify whether selected river and stream sites were within areas identified as contiguous census block groups and urban clusters meeting Census Bureau minimum population density requirements of at least 2,500 people.

From the 1,924 sites sampled for the NRSA, a subset of 164 urban river sites across the country were sampled for additional data analysis. Fish tissue samples at these locations were analyzed for chemicals of emerging concern, including perfluorinated compounds (PFCs) and synthetic musks, in addition to contaminants, such as mercury, PCBs, polybrominated diphenyl ethers (PBDEs), and organochlorine pesticides. Results for mercury and one PFC, perfluorooctane sulfonate (PFOS), are presented below; complete analysis and reporting on the remaining fish tissue analytical results for organic compounds will follow in a separate report. Additionally, comparisons between urban and non-urban waters will be examined in the future.

Urban rivers: findings for mercury

Mercury is widely distributed in the environment through natural processes and through industrial activities, such as fossil fuel (e.g., coal) combustion and hazardous waste incineration. These activities release mercury into the atmosphere where it can be transported for long distances before being deposited in water or on land. Once mercury is deposited in water, certain microorganisms can change it into methylmercury, a highly toxic form that builds up in fish, shellfish, and animals that eat fish. Fish and shellfish are the main sources of human exposure to methylmercury. The levels of methylmercury in fish and shellfish depend on several factors, including what they eat, how long they live, and how high they are in the food chain.

Mercury is widely found at detectable levels in fish tissue, and the amount of mercury measured in fish tissue usually increases with fish age and size. Fish tissue samples from 44 of the 163 urban sites assessed for mercury (or 26.9%) exceed the EPA fish-tissue-based human health water quality mercury criterion of 300 parts per billion (ppb) (see Figure 26). This represents 2,970 miles of the 11,002 assessed urban river miles.

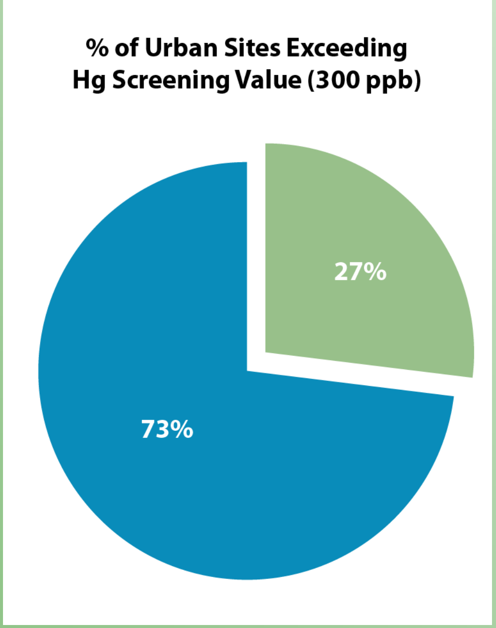

Figure 26. Mercury in fish tissue from urban sites.

Urban rivers: findings for perfluorooctane sulfonate

PFCs are artificial chemicals that persist in the environment and have been used for decades to make products that resist heat, oil, stains, grease, and water. They are used in many industrial applications and are found in stain-resistant fabrics, nonstick cookware, and some types of food packaging. One type of PFC, perfluorooctane sulfonate or PFOS, can accumulate to levels of concern in fish and wildlife.

PFOS was the most commonly detected PFC in the fish tissue samples. Fish tissue samples from 19 of the 162 urban sites assessed for PFCs contained PFOS above the one-meal-per-week Minnesota advisory value of 40 ppb. This represents 11.6% of the 11,002 assessed urban river miles, or 1,276 river miles (Figure 27). EPA is currently re-assessing the risk of PFOS to human health and expects to have a peer-reviewed reference dose for PFOS in 2013.

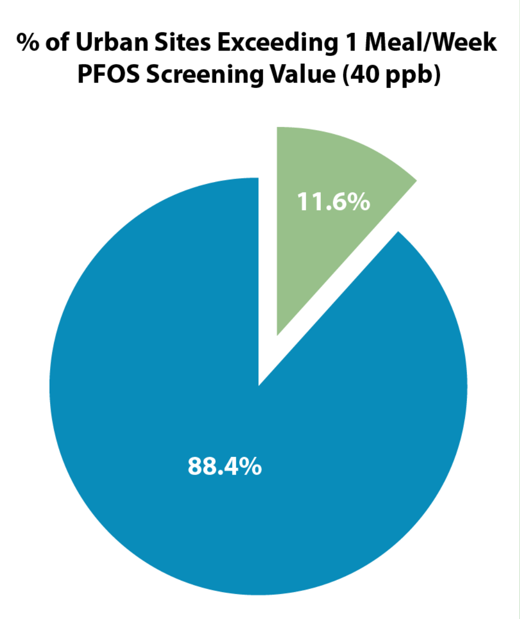

Figure 27. PFOS in fish tissue from urban sites.

Elevated mercury levels in fish are the leading cause of fish consumption advisories in the U.S. Urban river results showed that mercury concentrations occurred above the 300 ppb human health screening value at about a quarter of the assessed urban river miles. These results demonstrate the pervasive nature of mercury deposition in watersheds of the U.S. and mercury's subsequent accumulation in fish. PFCs are recognized as contaminants of emerging concern because they are toxic, ubiquitous, and persistent in the environment. Measured levels of PFOS in the fish tissue samples exceeded the one-meal-per-week screening value of 40 ppb at nearly 12% of the assessed urban river miles. To date, three states have issued fish consumption advisories based on elevated concentrations of PFOS in fish.

Chapter 5. Changes in Stream Condition

Among the long-term goals of the National Aquatic Resource Surveys is detecting trends in both the condition of our aquatic resources and in the stressors that affect them. Policymakers need this information in order to evaluate whether policy decisions have been effective or whether a different approach is necessary to achieve important water quality goals. Trends can be tracked either at the individual water body scale or at the larger population scale.

Typically, researchers and site managers are interested in changes at individual sites, while many policymakers are more driven by changes and trends in groups or populations. Both types of approaches are relevant to policy-making and complement each other in evaluating trends and causes This is analogous to human health considerations: for example, you and your doctor are interested in whether you are gaining or losing weight, but national health experts and the health policy debate will be driven more by whether there is an increase or decrease in the percentage of people in the U.S. who are gaining or losing weight.

To detect trends in the condition of rivers and streams, more years of data will be necessary. However, comparison of the “wadeable streams” portion of the NRSA with the 2004 WSA provides a preliminary assessment of *change* in conditions in *wadeable streams* only, between the two surveys. A change is not the same as a trend: it simply identifies the difference between two points in time.

Some of the changes found in streams between 2004 and 2008–2009 are statistically significant, and some are not. More data and additional analyses are necessary to fully understand what these changes are telling us.

Findings for changes in stream condition

Comparing the WSA results to the NRSA’s wadeable stream results provides an initial look at changes for six of the survey indicators — the Macroinvertebrate MMI, total phosphorus, total nitrogen, in-stream fish habitat, riparian vegetative cover, and riparian disturbance. Some indicators were not included in the change analysis because they had not been evaluated in the WSA or because protocols were modified for the later study. The same evaluation thresholds were used for both studies. It is important to remember that results from the WSA cannot be compared to results in other chapters of this report because the NRSA evaluates both rivers and streams, not just streams.

The figures below show the percent of stream length in good condition for a given indicator for the WSA in 2004 and the NRSA in 2008–2009. When the difference in the two estimates is statistically significant, it is noted with a red star. A detailed statistical analysis of the difference between surveys and the statistical confidence in that difference was performed and underlies the presentation of the results below. It should be noted that the WSA condition class percentages differ slightly from those in the WSA report to allow comparison between the target populations of wadeable streams across the country. Minor adjustments were made to the WSA percentages to be comparable to the NRSA design.

In Figure 28, results for the macroinvertebrate community indicator and nutrient indicators (phosphorus and nitrogen) are shown for the nation and the three major climatic regions. Nationally, the percent of stream length in good macroinvertebrate condition dropped from 27.4% in 2004 to 20.5% in 2008–2009. This difference is statistically significant for the nation and may be driven by a 13.3% decline in streams in good condition in the Plains and Lowlands. For the Eastern Highlands, the values also decline but the difference is not statistically significant. There is no difference in macroinvertebrate condition for streams in the West.

A consistent, statistically significant drop is evident in the percentage of stream length in good condition for phosphorus. Nationally, 52.8% of stream length was in good condition for phosphorus in 2004, compared to 34.2% in 2008–2009. This pattern occurred in each of the three major climatic regions, with the largest change (a decline of 22.5%) in the Plains and Lowlands.

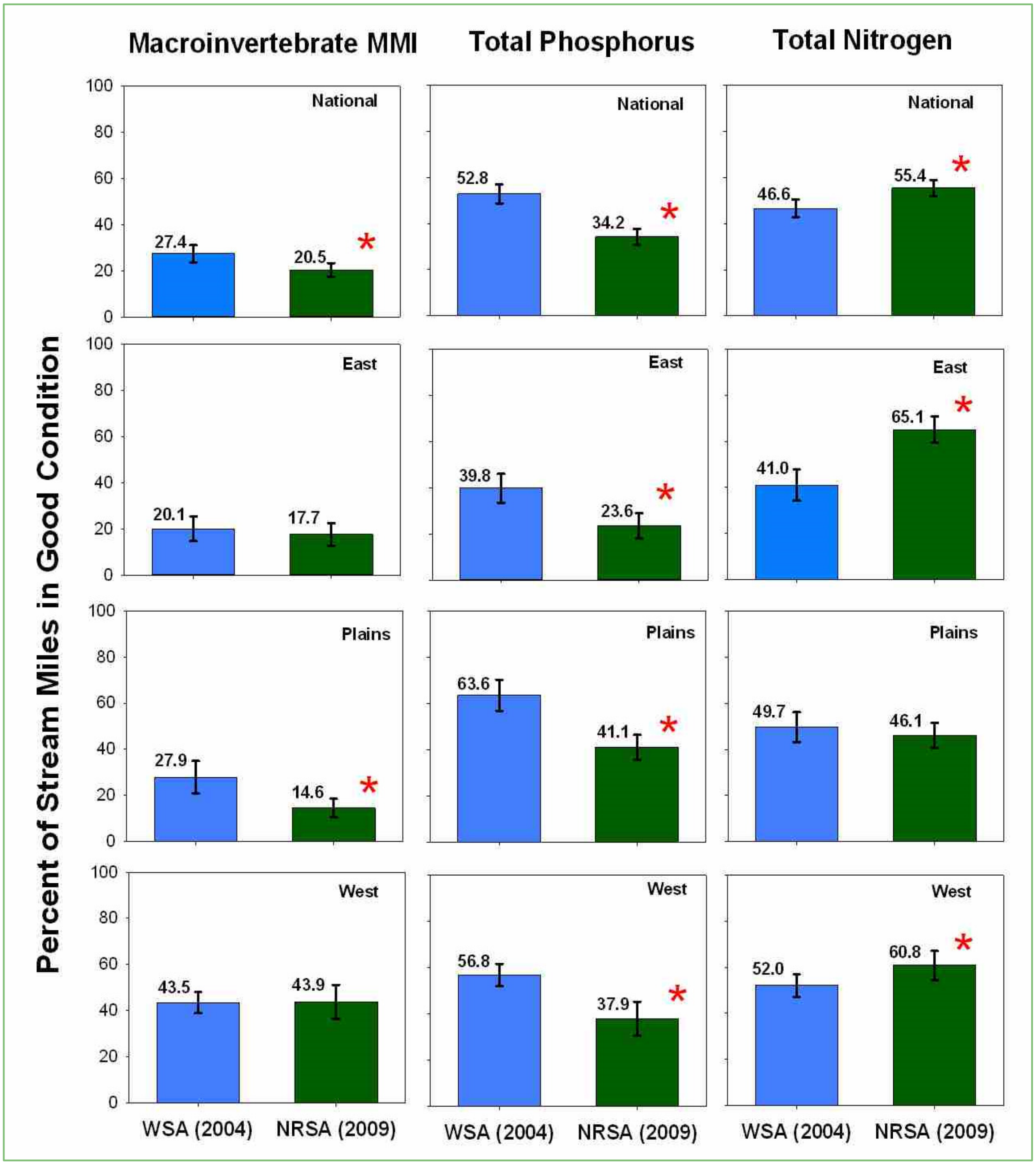

Figure 28. Change in macroinvertebrate condition and nutrients between 2004 and 2008–2009, based on percent of length in good condition; red stars indicate statistically significant change (EPA/NRSA). Note: WSA condition class percentages differ slightly from those in the WSA report to allow comparison between the target populations of wadeable streams across the country. Minor adjustments were made to the WSA percentages to be comparable to the NRSA design.

On the other hand, the percentage of stream length in good condition for nitrogen has risen nationally, from 46.6% in 2004 to 55.4% in 2008–2009. Increases occurred in the Eastern Highlands and the West, with each of those improvements being statistically significant. In the Plains and Lowlands, there was a slight decline in the percent of stream length in good condition but it is not statistically significant.

Figure 29 presents change results for three of the habitat indicators: in-stream fish habitat, riparian vegetation cover, and riparian disturbance. The percent of stream length with good in-stream fish habitat rose nationally and in each of the three regions. Nationally and in the West, the percent of stream length in good condition for riparian vegetation cover also rose, with no statistically significant changes in the Eastern Highlands or Plains and Lowlands. The percent of stream length with low levels of riparian disturbance also showed statistically significant increases nationally, in the Eastern Highlands, and in the Plains and Lowlands.

The fact that the differences noted above are statistically significant does not automatically mean they are the result of human activities. Already, analysts have examined the relationships between the change in nutrients and in natural phenomena such as precipitation, stream flow, and drought, but they have found no reasons to explain the differences. Additional work is underway to examine relationships to other signals of natural phenomena and to signals of human activity. EPA and the U.S. Geological Survey (USGS) are also examining how long-term trend data from USGS sites might help provide context for the changes seen between the WSA and the NRSA. Trends in water quality will emerge over time as more surveys are completed, and our understanding of the reasons for the trends will advance.

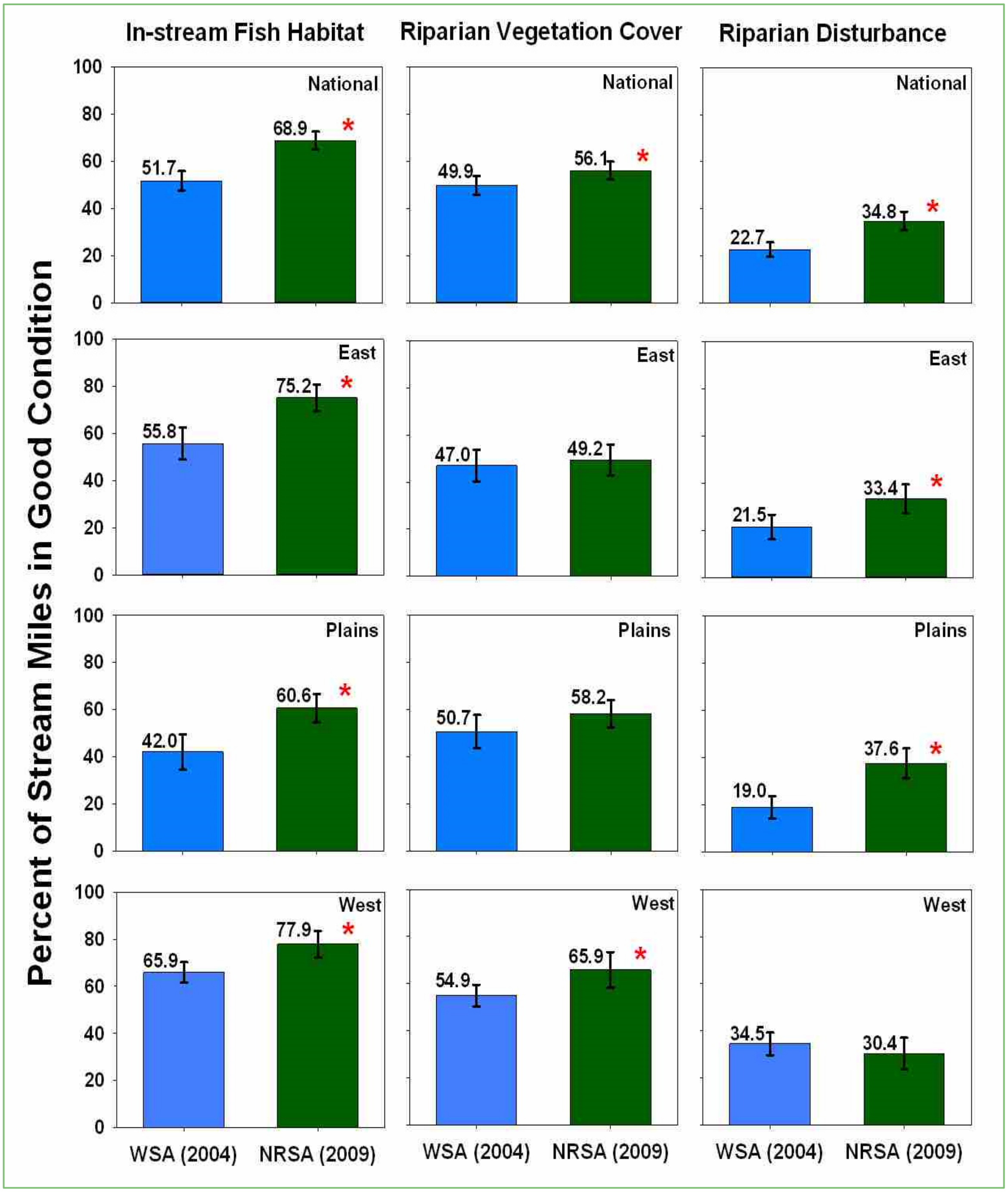

Figure 29. Change in stream fish habitat, riparian vegetation cover, and riparian disturbance between 2004 and 2008–2009, based on percent of stream length in good condition; red stars indicate statistically significant change (EPA/NRSA). Note: WSA condition class percentages differ slightly from those in the WSA report to allow comparison between the target populations of wadeable streams across the country. Minor adjustments were made to the WSA percentages to be comparable to the NRSA design.

Chapter 6. Ecoregional Results

Introduction

Ecoregions are geographic areas that display similar environmental characteristics, such as climate, vegetation, type of soil, and geology. EPA has defined ecoregions at various scales, from a continental scale (Level I) to fine scales that divide the land into smaller ecosystem units (Levels III or IV). This chapter will focus on NRSA results for the nine U.S. Level III ecoregions aggregated for use in the National Aquatic Resource Surveys. These nine ecoregions, shown in Figure 30, are:

- Northern Appalachians
- Southern Appalachians
- Coastal Plains
- Upper Midwest
- Temperate Plains
- Southern Plains
- Northern Plains
- Western Mountains
- Xeric

Ecoregions are designed to be used in environmental assessments, for setting water quality and biological criteria, and to set management goals for pollution control. This is because it is important to assess water bodies in their own ecological setting. For example, the rivers in the mountainous, cold-to-temperate Northern Appalachians will have many similar characteristics; they run through steep, rocky channels over glacial sediments, and are influenced by annual precipitation totals of 35 to 60 inches. These rivers will differ significantly from those in the dry plains, tablelands, and low mountains of the Xeric ecoregion, which drain erodible sedimentary rock and are subject to flash floods in a climate where precipitation ranges from 2 to 40 inches and average temperatures are much higher.

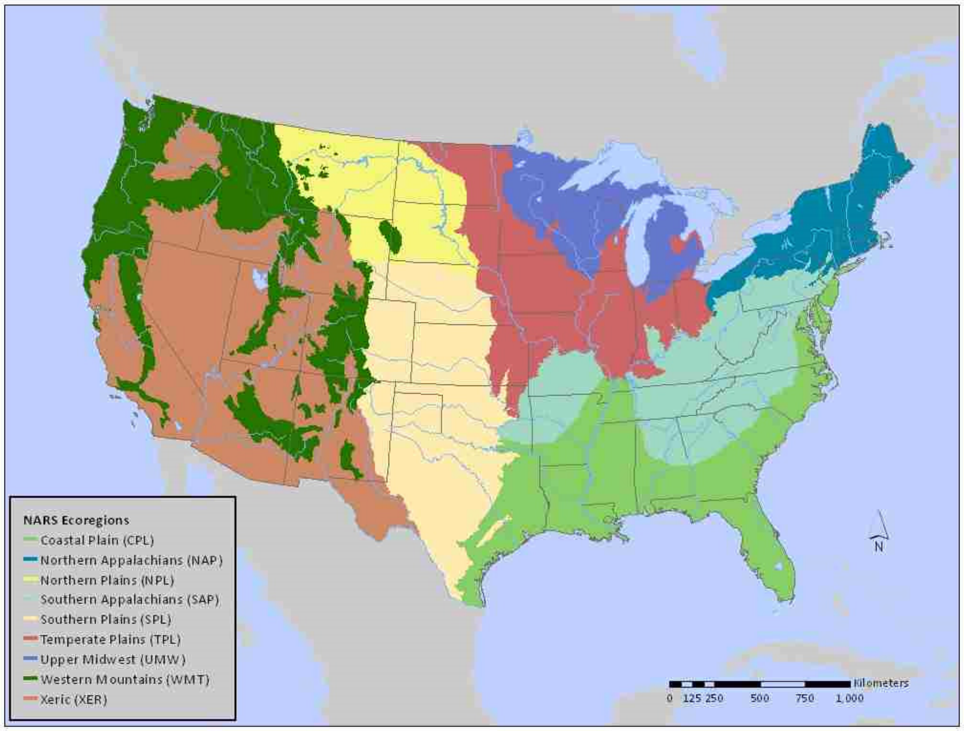

Figure 30. Ecoregional surveys for the NRSA (EPA/NRSA).

For purposes of the NRSA, least-disturbed reference sites in each ecoregion were used to set benchmarks for good, fair, and poor condition in that ecoregion, and reflect the variability within the ecoregion (see Chapter 2 and the NRSA Technical Report for more information on this approach). This allows sites in one ecoregion to be compared to the reference waters in that ecoregion. Because of this, it also allows results for one ecoregion to be compared to results for another.

This chapter provides nationwide comparisons of key NRSA results for the nine ecological regions. It then describes each ecoregion in more detail, providing background information and describing NRSA results for the length of rivers and streams throughout the ecoregion. These results should not be extrapolated to an individual state or water body within the ecoregion because the study was not intended or designed to characterize conditions at these finer scales. This information also cannot be compared to the ecoregional results presented in the earlier WSA, which presented results only for streams. See Chapter 5 for the assessment of change for wadeable streams only between the WSA and the NRSA. A number of states implemented randomized designs at the state scale to characterize the condition of rivers and streams throughout their state, but these assessments are not described here.

Nationwide comparisons

The three most widespread stressors to rivers and streams — phosphorus, nitrogen, and riparian vegetative cover — are depicted by ecoregion in the following maps, along with summaries of macroinvertebrate condition and enterococci levels. These maps provide an overview of how conditions vary across the nation, and in some cases illustrate distinct ecoregional patterns.

Biological condition — Macroinvertebrate Multimetric Index

The proportion of rivers and streams in poor biological condition based on the Macroinvertebrate MMI ranges from 26% in the Western Mountains ecoregion to 71% in the Coastal Plains ecoregion (Figure 31). A clear pattern is evident: the easternmost ecoregions

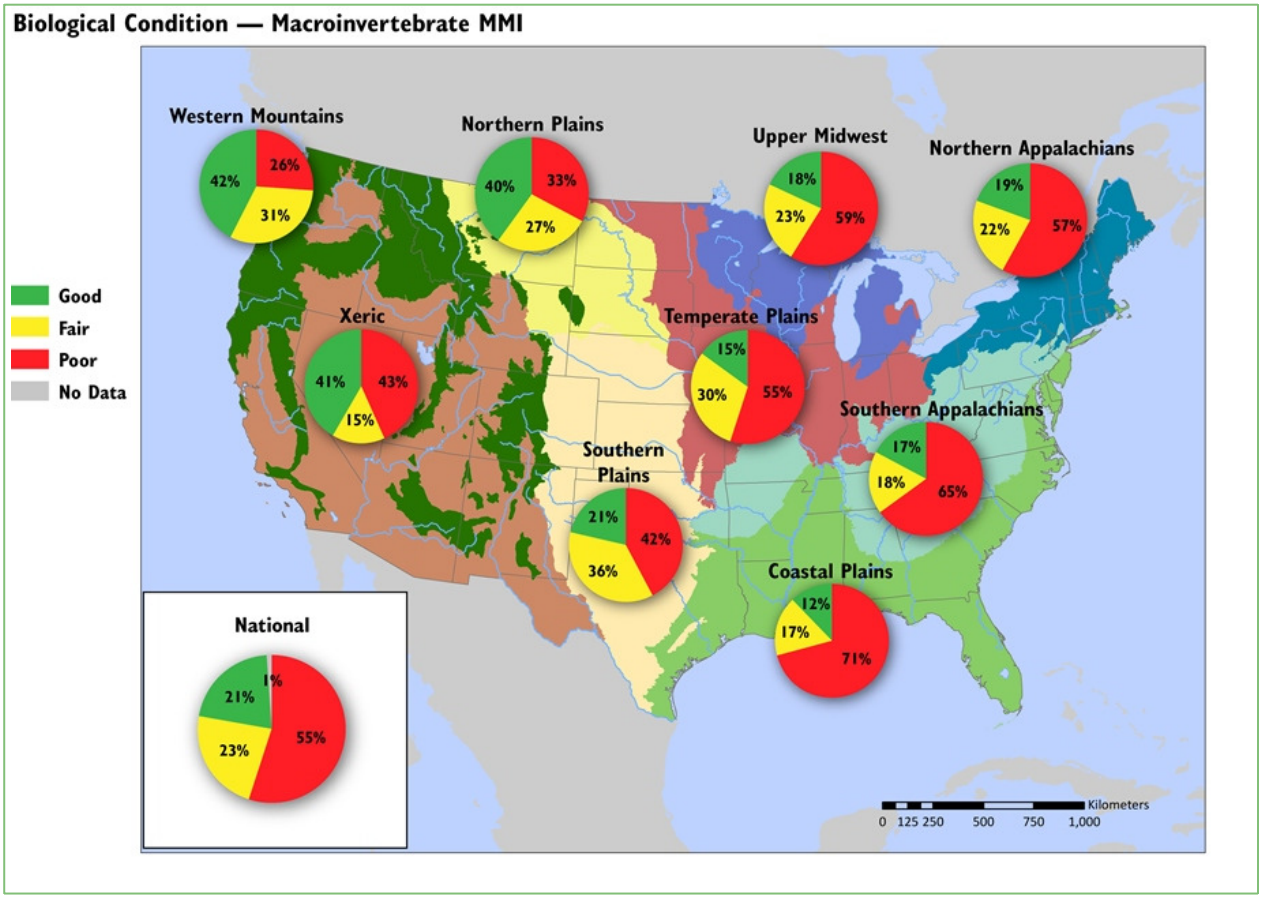

Figure 31. Biological condition in rivers and streams based on the Macroinvertebrate Multimetric Index across the nine ecoregions (EPA/NRSA). Percents may not add up to 100% due to rounding.

(generally east of the Mississippi River) have a higher proportion of rivers and streams scoring in poor biological condition than those in the western U.S. In the east, the percent of river and stream miles in poor biological condition ranges from 55% to 71%. In the western ecoregions, the percent in poor condition ranges from 26% to 43%.

Nutrients – total phosphorus and nitrogen

The nutrients phosphorus and nitrogen are the most widespread stressors of those assessed in the NRSA. Figure 32 shows that in six of the nine ecoregions, phosphorus levels are consistently rated poor (i.e., high) in about a third or more of river and stream miles. In two more ecoregions — the Northern Plains and the Northern Appalachians — the proportion of miles rated poor is much higher (84% and 71%, respectively). Only in the Southern Plains ecoregion are half the river and stream miles rated good and only 23% rated poor for phosphorus levels.

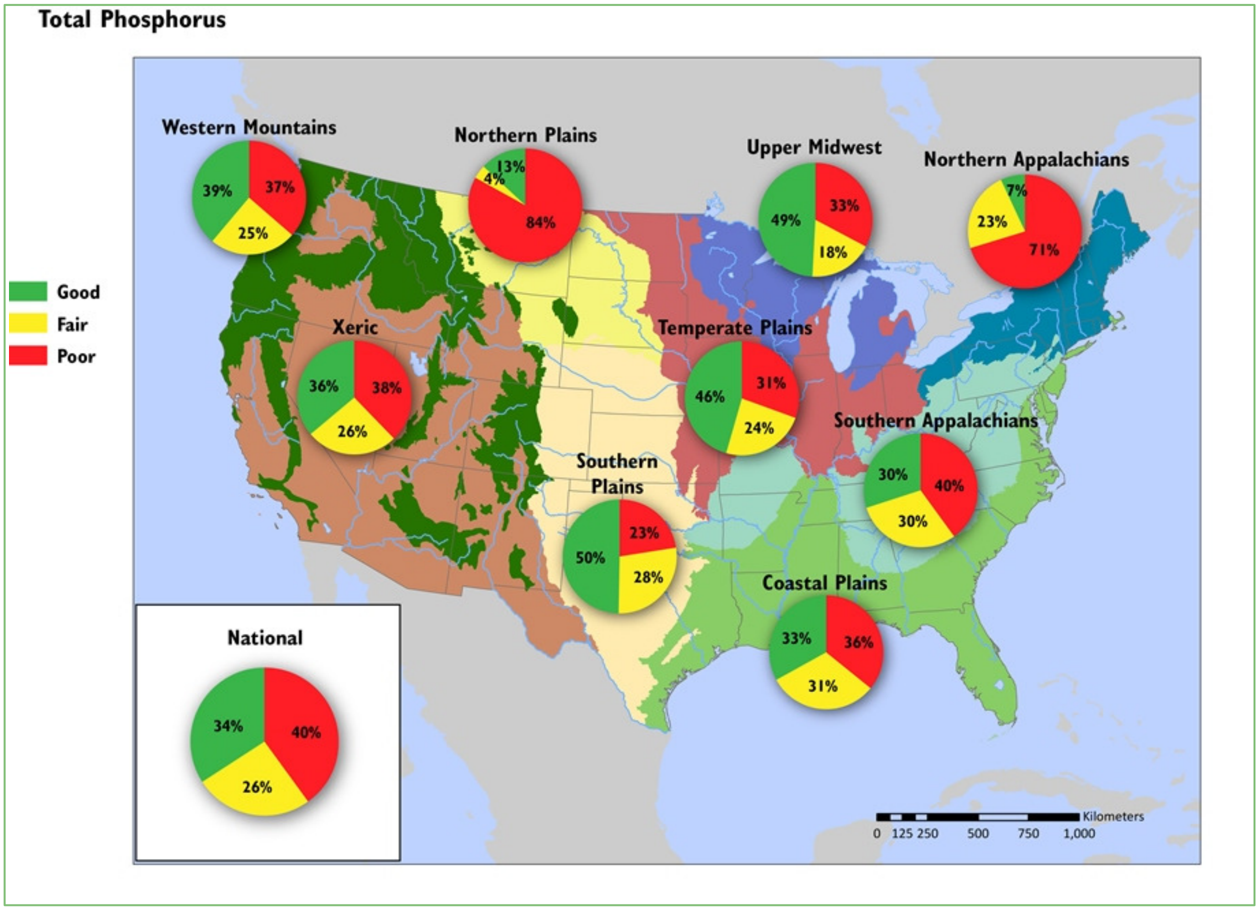

Figure 32. Total phosphorus levels in rivers and streams across the nine ecoregions (EPA/NRSA). Percents may not add up to 100% due to rounding.

The national picture shows less widespread impacts for nitrogen in many ecoregions (Figure 33). The ecoregions with the highest proportion of miles in poor condition for nitrogen are the Northern Plains (60% rated poor), the Temperate Plains (58% rated poor), the Northern Appalachians (42% rated poor), and the Xeric (36% rated poor). Five ecoregions (Coastal Plains, Southern Plains, Southern Appalachians, Western Mountains, and Upper Midwest) have between 7% and 21% of river and stream miles rated poor for nitrogen.

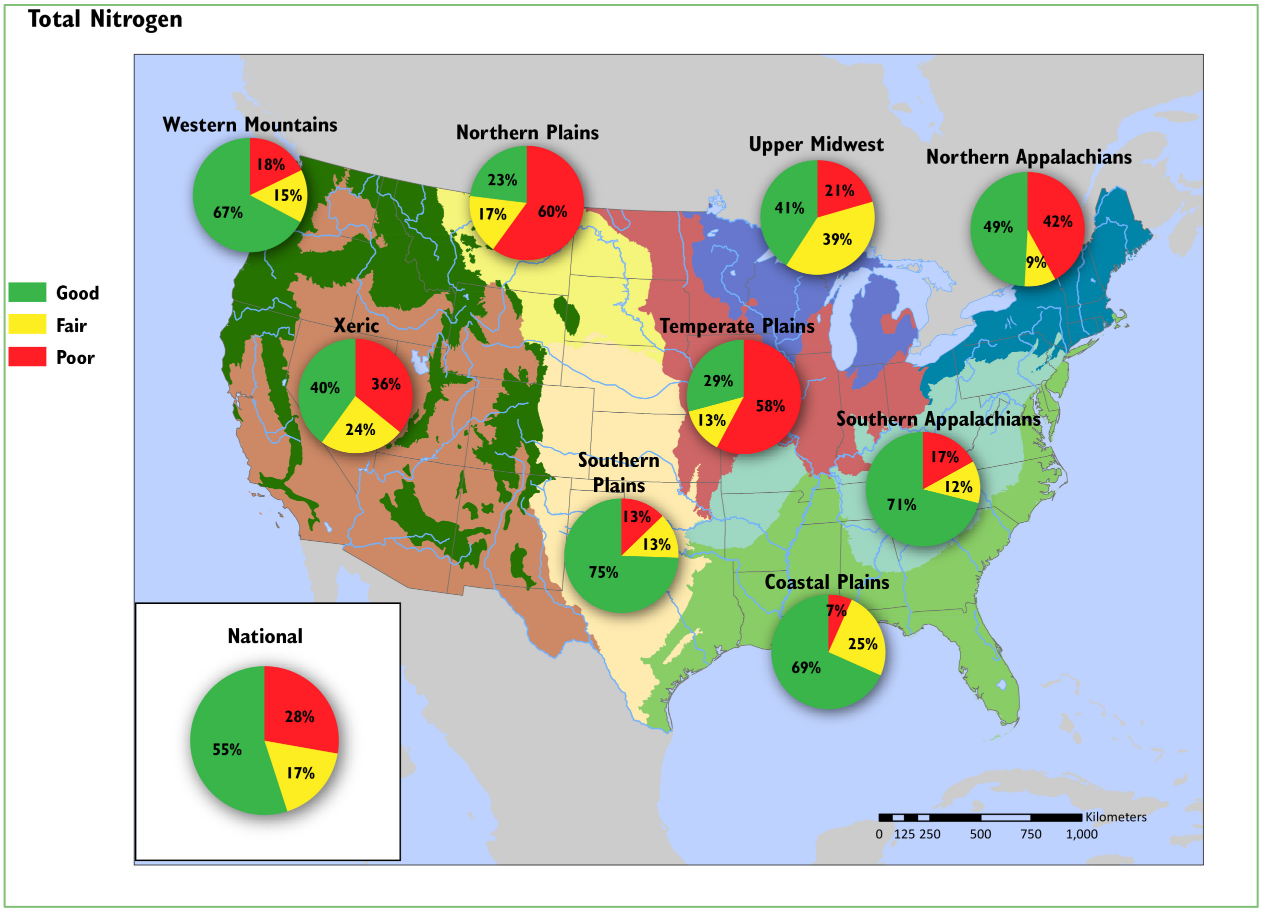

Figure 33. Total nitrogen levels in rivers and streams across the nine ecoregions (EPA/NRSA). Percents may not add up to 100% due to rounding.

Riparian vegetative cover

One ecoregion — the Northern Plains — stands out as having the highest percentage of river and stream miles in poor condition for riparian vegetative cover, at 59% (Figure 34). The next highest is the Xeric ecoregion, at 37% of river and stream miles rated poor. In the remaining seven ecoregions, between 13% and 29% of river and stream miles are rated poor for riparian vegetative cover.

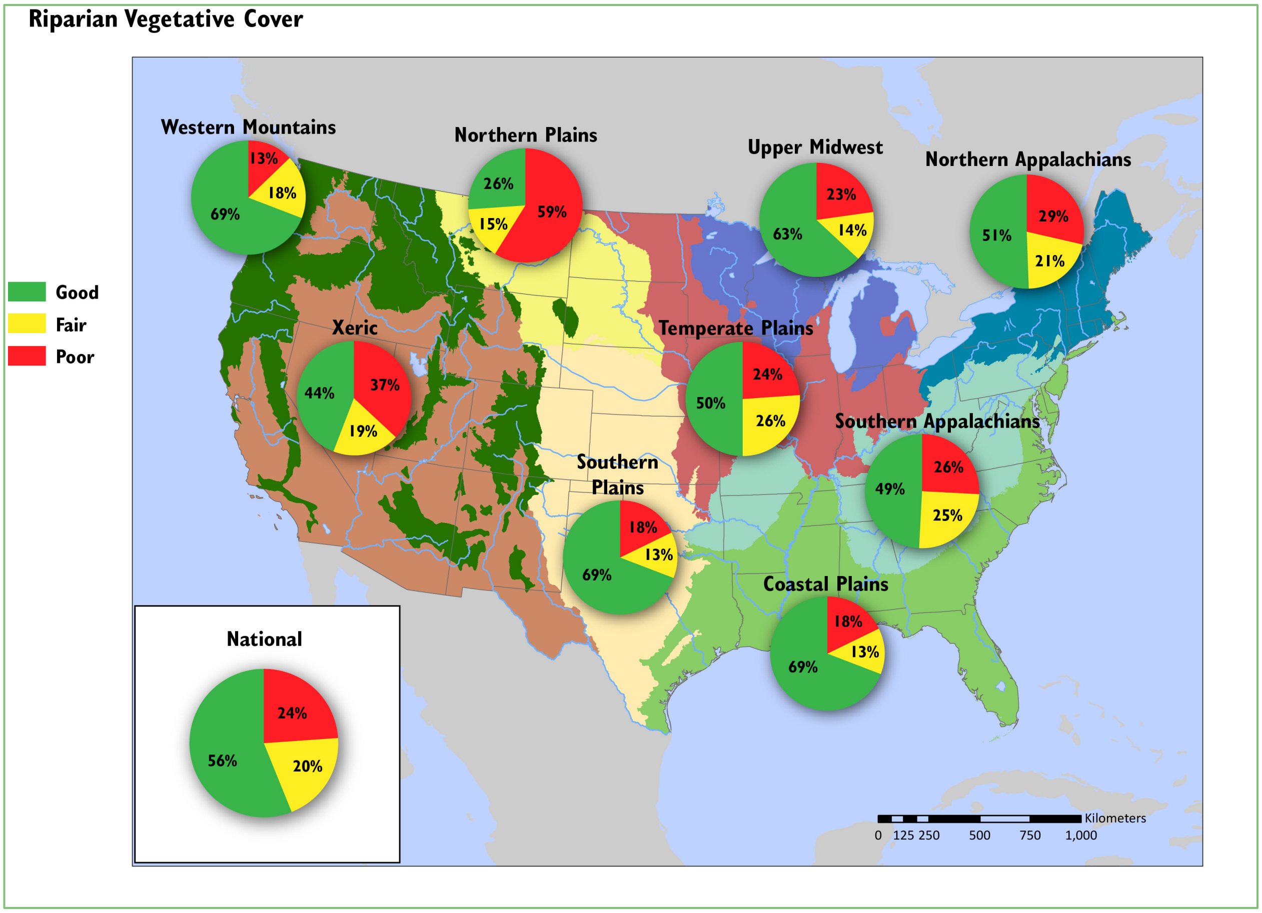

Figure 34. Riparian vegetative cover in rivers and streams across the nine ecoregions (EPA/NRSA). Percents may not add up to 100% due to rounding.

Enterococci

In six of the nine ecoregions, less than a tenth of river and stream miles exceed thresholds protective of human health for enterococci bacteria (Figure 35). Of the three remaining ecoregions, the Southern Appalachians has 14% of river and stream miles exceeding thresholds, the Southern Plains has 13%, and the Central Plains has 11%.

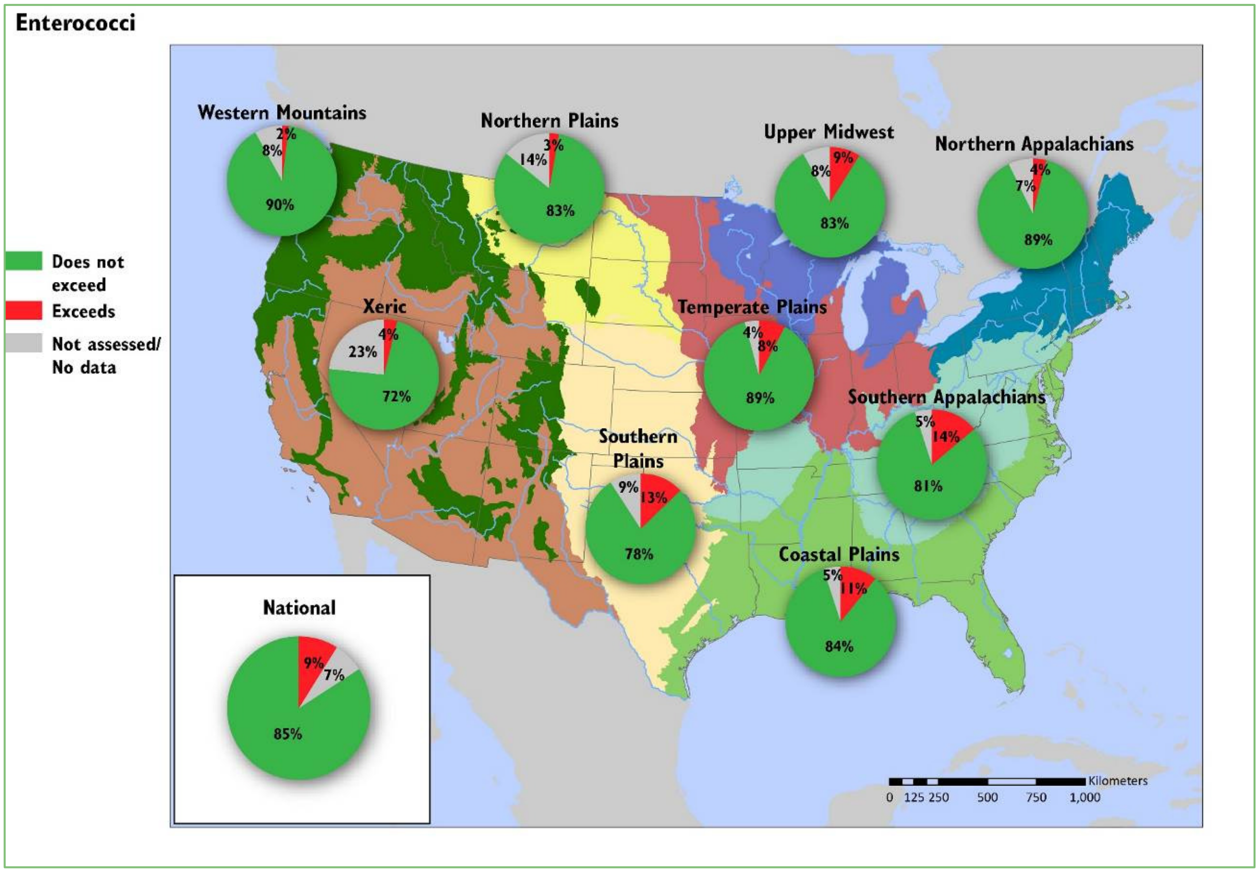

Figure 35. Enterococci human health threshold exceedance in rivers and streams across the nine ecoregions (EPA/NRSA). Percents may not add up to 100% due to rounding.

Northern Appalachians

Setting

The Northern Appalachians ecoregion covers all of the New England states, most of New York, the northern half of Pennsylvania, and northeastern Ohio. Included in the ecoregion are New York's Adirondack and Catskill Mountains and Pennsylvania's Allegheny National Forest. Major river systems include the St. Lawrence, Allegheny, Penobscot, Connecticut, and Hudson rivers. The total river and stream length represented in the NRSA for the Northern Appalachians ecoregion is 119,094 miles.

Forests in this ecoregion were extensively cleared in the 18th and 19th centuries. Current fish stocks are lower than at the time of European contact, but the coastal rivers of the Northern Appalachians ecoregion still have a wide variety of fish including shad, alewife, salmon, and sturgeon that are born in fresh water, move to the sea for most of their lives, and then return to fresh water to spawn. Major manufacturing, chemical, steel, and power production occur in the large metropolitan areas around New York City, Connecticut, and Massachusetts. It is common for treated wastewater effluent to account for much of the stream flow downstream from major urban areas.

This ecoregion is generally hilly, with some intermixed plains and mountain ranges. River channels in the glaciated uplands of the northern parts of the ecoregion are steep and rocky, and flow over glacial sediments. The climate is cold to temperate, with mean annual temperatures ranging from 39° to 48°F. Annual precipitation totals range from 35 to 60 inches. The Northern Appalachians ecoregion covers some 139,424 square miles of land (4.6% of the continental U.S.), with about 4,722 square miles of land under federal ownership. Based on satellite images from the 2006 National Land Cover Dataset, the distribution of land cover in this ecoregion is 61% forested, 15% planted/cultivated, and 9% developed; various other types of land cover (such as wetlands or scrubland) constitute the remaining 15% of the ecoregion.

Summary of NRSA findings, Northern Appalachians

A total of 206 NRSA sites were sampled to characterize the condition of rivers and streams in the Northern Appalachians ecoregion. Figure 36 shows an overview of the findings.

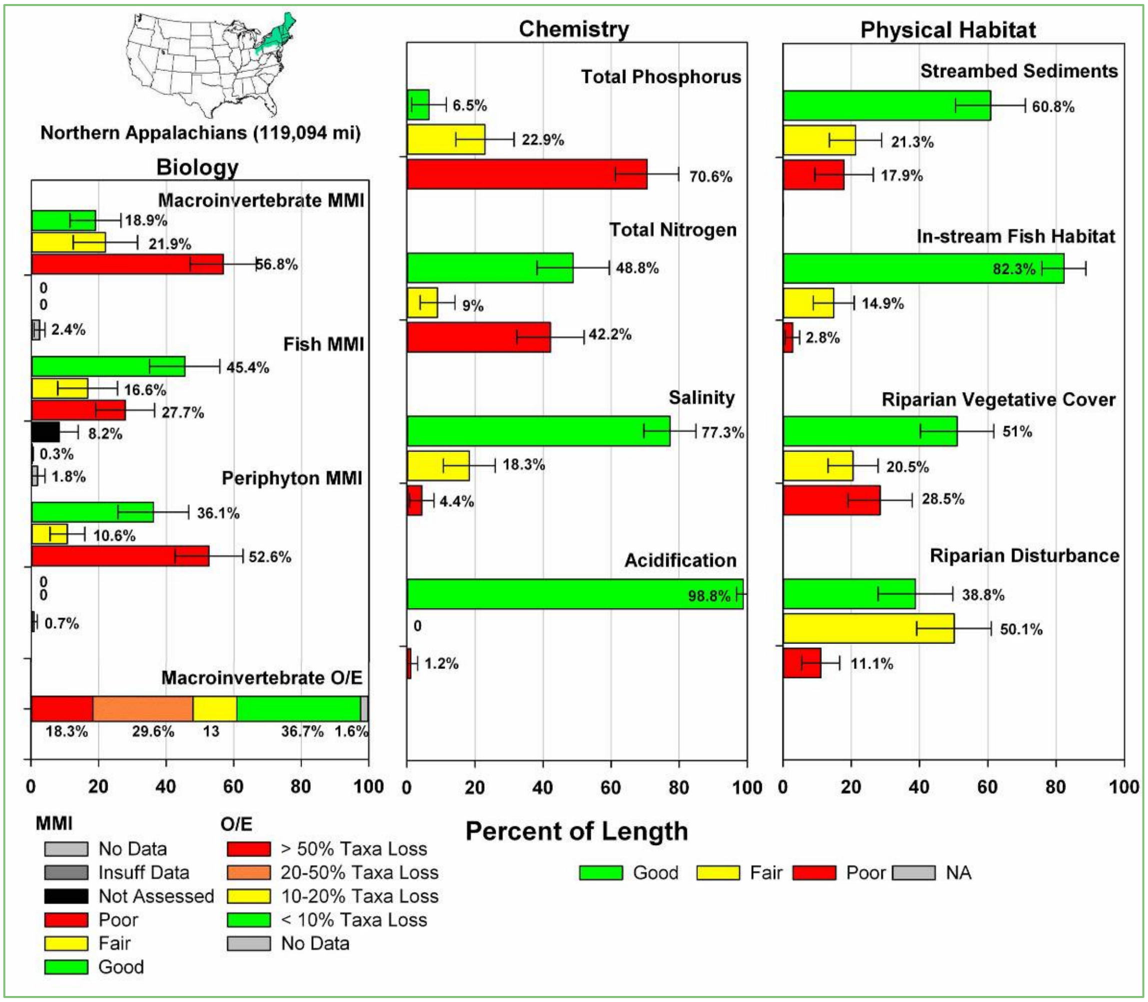

Figure 36. NRSA survey results for the Northern Appalachians ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

Biological condition

The Macroinvertebrate MMI shows that 57% of the river and stream length in the Northern Appalachians ecoregion is in poor condition, 22% is in fair condition, and 19% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 18% of river and stream length has lost more than 50% of taxa expected to occur, and 30% has lost between 20% and 50% of taxa.

The Periphyton MMI shows 53% percent of river and stream length in poor condition for periphyton, while for fish, 28% of river and stream length in this ecoregion is determined to be in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Northern Appalachians ecoregion are phosphorus, nitrogen, riparian vegetative cover, streambed sediments, and riparian disturbance. Compared to least-disturbed conditions for this ecoregion:

- Phosphorus is at high levels in 71% of river and stream length, medium levels in 23%, and low levels in 7%.
- Nitrogen is at high levels in 42% of river and stream length, medium levels in 9%, and low levels in 49%.
- Riparian vegetative cover is rated poor in 29% of river and stream length, fair in 21%, and good in 51%.
- Streambed sediments are rated poor in 18% of river and stream length, fair in 21%, and good in 61%.
- Riparian disturbance is at high levels in 11% of river and stream length, medium levels in 50%, and low levels in 39%.

Southern Appalachians

Setting

The Southern Appalachians ecoregion stretches over 10 states, from northeastern Alabama to central Pennsylvania, and includes the interior highlands of the Ozark Plateau and the Ouachita Mountains in Arkansas, Missouri, and Oklahoma. The topography of this ecoregion is mostly hills and low mountains, with some wide valleys and irregular plains. Its land area covers about 321,900 square miles (10.7% of the continental U.S.), with about 42,210 square miles in federal ownership. Many significant public lands, including the Great Smoky Mountains National Park, the George Washington and Monongahela National Forests, and Shenandoah National Park, are located within this ecoregion.

The Southern Appalachians ecoregion has some of the greatest aquatic animal diversity of any area of North America, especially for species of amphibians, fishes, mollusks, aquatic insects, and crayfishes. Some areas, such as the Great Smoky Mountains National Park, continue to protect exceptional stands of old-growth forest riparian systems. Nevertheless, the effects of habitat fragmentation, urbanization, agriculture, channelization, diversion, mining, and impoundments have altered many rivers and streams in this ecoregion.

Rivers in this ecoregion flow mostly over bedrock and other resistant rock types, with steep channels and short meander lengths. A number of major rivers originate here, including the Susquehanna, James, and Potomac, along with feeders into the Ohio and Mississippi River systems such as the Greenbrier River in West Virginia. The total river and stream length represented in the NRSA for the Southern Appalachians ecoregion is 315,242 miles. It is considered temperate wet, with annual precipitation of about 40 to 80 inches and mean annual temperature ranging from 55° to 65°F. Based on satellite images in the 2006 National Land Cover Dataset, land cover in this ecoregion is 60% forested, 23% cultivated, and 9% developed; the remaining 8% is in various other types of land cover.

Summary of NRSA findings, Southern Appalachians

A total of 316 NRSA sites were sampled to characterize the condition of rivers and streams in the Southern Appalachians ecoregion. An overview of the findings is shown in Figure 37.

Biological condition

The Macroinvertebrate MMI shows that 65% of the river and stream length in the Southern Appalachians ecoregion is in poor condition; an additional 18% is in fair condition, and 17% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 17% of river and stream length has lost more than 50% of taxa expected to occur, and 37% has lost between 20% and 50% of taxa.

The Periphyton MMI shows 68% percent of river and stream length in poor condition for periphyton, while for fish, 37% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Southern Appalachians ecoregion are phosphorus, riparian vegetative cover, riparian disturbance, nitrogen, and streambed sediments. Compared to least-disturbed conditions for this ecoregion:

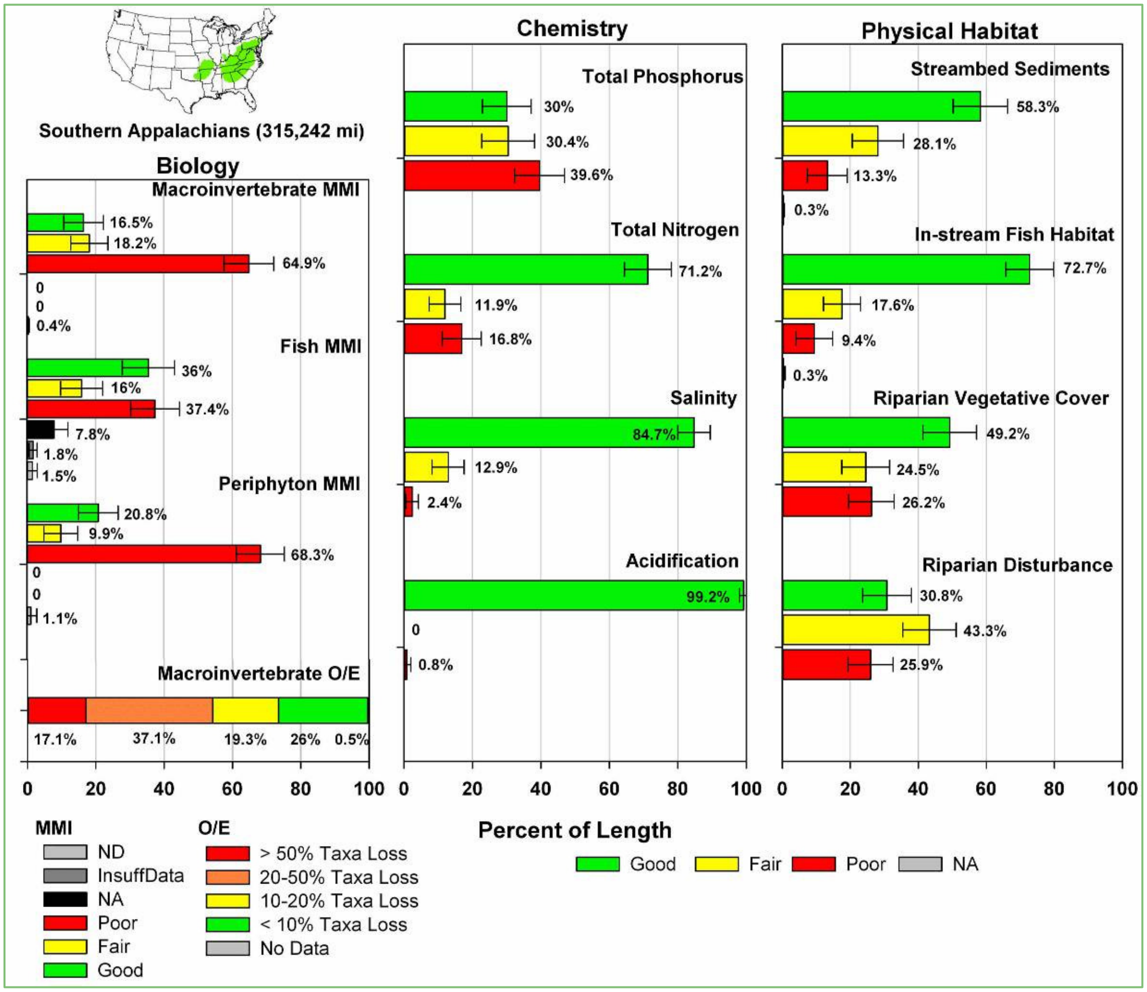

Figure 37. NRSA survey results for the Southern Appalachian ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

- Phosphorus is at high levels in 40% of river and stream length, medium levels in 30%, and low levels in 30%.
- Riparian vegetative cover is in poor condition in 26% of river and stream length, fair in 25%, and good in 49%.
- Riparian disturbance is at high levels in 26% of river and stream length, medium levels in 43%, and low levels in 31%.
- Nitrogen is at high levels in 17% of river and stream length, medium levels in 12%, and low levels in 71%.
- Streambed sediments are rated poor in 13% of river and stream length, fair in 28%, and good in 58%.

Coastal Plains

Setting

The Coastal Plains ecoregion covers all of Florida, eastern Texas, and the Atlantic seaboard from Florida to New Jersey. It includes the Mississippi Delta and Gulf Coast, and ranges north along the Mississippi River to the Ohio River. The total land area of this ecoregion is about 395,000 square miles, or 13.2% of the continental U.S. Of this, 25,890 square miles, or 6.6%, is in federal ownership. River systems within or intersecting the Coastal Plains ecoregion include the Mississippi, Suwannee, Savannah, Potomac, Delaware, Susquehanna, James, Sabine, Brazos, and Guadalupe.

River habitats in the Coastal Plains ecoregion have high species richness and the greatest number of endemic species of aquatic organisms in North America. These include fish, aquatic insects, and mollusks, as well as unique species such as paddlefish, American alligators, and giant aquatic salamanders. However, it is estimated that about 18% of the aquatic species in this ecoregion are threatened or endangered. Historically, this ecoregion had extensive bottomlands that flooded for several months; these areas are now widely channelized and confined by levees. Acid mine drainage, urban runoff, air pollution, sedimentation, and the introduction of non-native species have affected riparian habitats and native aquatic fauna.

In general, rivers in the Coastal Plains meander broadly across flat plains created by river deposition and form complex wetland topographies, with natural levees, back swamps, and oxbow lakes. Typically, they drain densely vegetated watersheds; well-developed soils and moderate rains and subsurface flows keep suspended sediment levels in the rivers relatively low. An exception is the Mississippi River, which carries large sediment loads from dry lands in the central and western portion of its drainage area. The total river and stream length represented in the NRSA for the Coastal Plains ecoregion is 176,510 miles.

The topography of this ecoregion is mostly flat plains, barrier islands, many wetlands, and about 50 important estuary systems that lie along its coastal margins. The climate is temperate wet to subtropical, with average annual temperatures ranging from 50° to 80°F and annual precipitation ranging from 30 to 79 inches. Based on satellite images in the 2006 National Land

Cover Dataset, the distribution of land cover in this ecoregion is 28% forested, 26% cultivated, 21% wetlands, 9% developed, and the remainder in various other types of land cover.

Summary of NRSA findings, Coastal Plains

A total of 308 NRSA sites were sampled to characterize the condition of rivers and streams in the Coastal Plains ecoregion. An overview of the findings is shown in Figure 38.

Biological condition

The Macroinvertebrate MMI shows that 71% of river and stream length in the Coastal Plains ecoregion is in poor condition compared to least-disturbed conditions, 17% is in fair condition, and 12% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 19% of river and stream length has lost more than 50% of the taxa expected to occur, and 44% of river

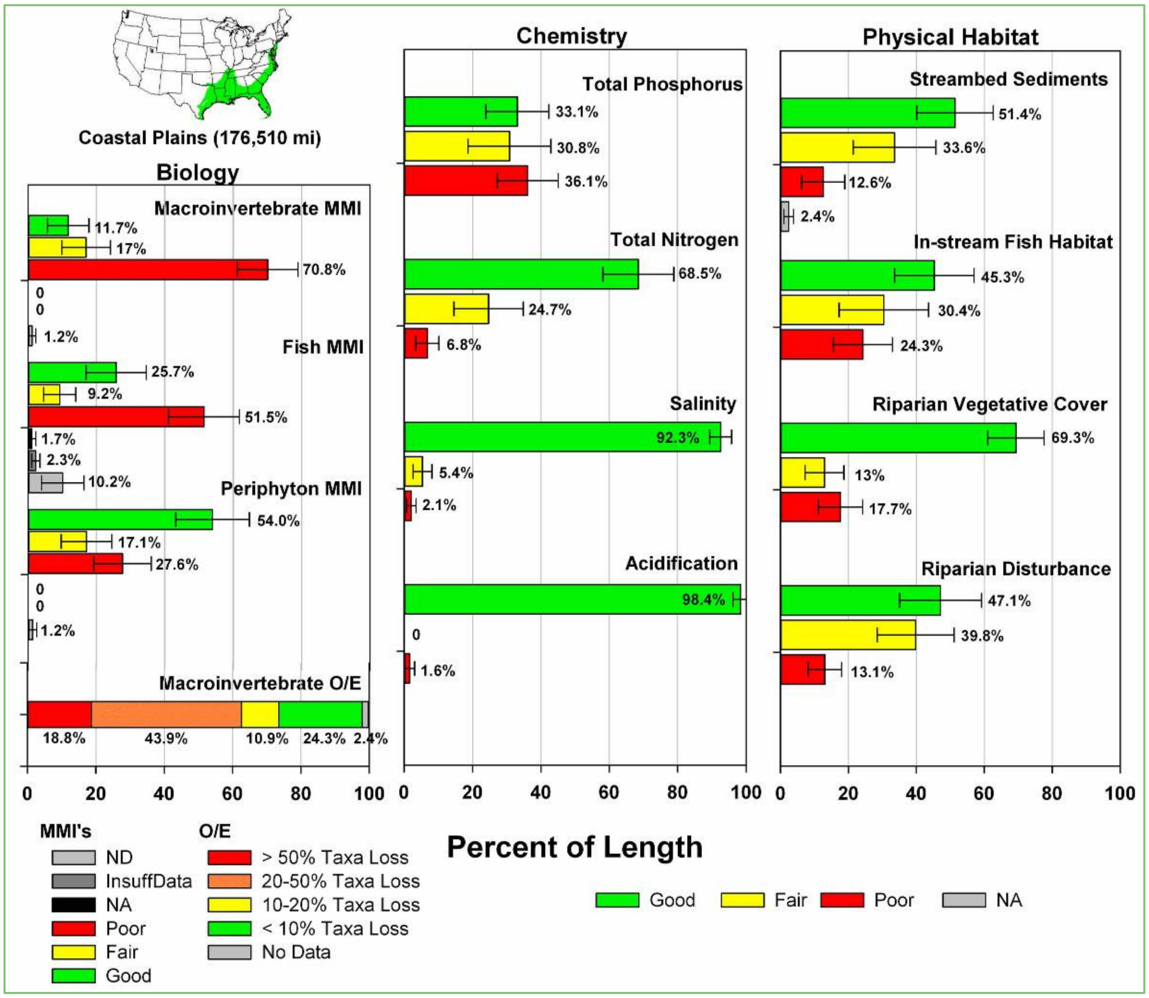

Figure 38. NRSA survey results for the Coastal Plains ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

and stream length has lost between 20% and 50% of taxa.

The Fish MMI also shows a large percentage of river and stream length (52%) in poor condition for fish, while for periphyton, 28% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Coastal Plains ecoregion are phosphorus, in-stream fish habitat, riparian vegetative cover, riparian disturbance, and streambed sediments. Compared to least-disturbed conditions for this ecoregion:

- Phosphorus is at high levels in 36% of river and stream length, medium levels in 31%, and low levels in 33%.
- In-stream fish habitat is in poor condition in 24% of river and stream length, fair in 30%, and good in 45% of river and stream length.
- Riparian vegetative cover is in poor condition in 18% of river and stream length, fair in 13%, and good in 69%.
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 13% of river and stream length, fair in 40%, and good in 47%.
- Streambed sediments are rated poor in 13% of river and stream length, fair in 34%, and good in 51%.

Upper Midwest

Setting

The Upper Midwest ecoregion covers most of Minnesota's northern half and southeastern area, two-thirds of Wisconsin, and almost all of Michigan, extending about 160,374 square miles or 5.3% of the continental U.S. National and state forests and federal lands account for about 25,000 square miles, or 15.5% of the area. The river systems in this ecoregion empty into portions of the Great Lakes regional watershed and the upper Mississippi River watershed. Major river systems include the upper Mississippi River in Minnesota and Wisconsin; the Wisconsin, Chippewa, and St. Croix rivers in Wisconsin; and the Menominee and Escanaba rivers in Michigan. Other important water bodies include Lakes Superior, Michigan, Huron, and Erie.

Virtually all of the virgin forest in this ecoregion was cleared in the 19th and early 20th centuries, and rivers and streams were greatly affected by logging. The Great Lakes aquatic systems are subject to increasing impact from invasive animal and plant species including the zebra mussel, round goby, river ruffe, spiny water flea, and Eurasian watermilfoil. Major manufacturing and chemical, steel, and power production occur in the large metropolitan areas of the Upper Midwest ecoregion.

Streams in the Upper Midwest ecoregion typically drain relatively small catchments and empty directly into the Great Lakes or Upper Mississippi River. These streams generally have steep gradients, but their topography and soils tend to slow runoff and sustain flow throughout the year. The total river and stream length represented in the NRSA for the Upper Midwest ecoregion is 96,142 miles.

The glaciated terrain of this ecoregion typically consists of plains with some hills. Lakes, rivers, and wetlands predominate in most areas. The climate is characterized by cold winters and relatively short summers, with mean annual temperatures ranging from 34° to 54°F and annual precipitation in the 20- to 47-inch range. Based on satellite images in the 2006 National Land Cover Dataset, the distribution of land cover in this ecoregion is 36% forested, 27% cultivated, 20% wetlands, and the remainder in various other types of land cover.

Summary of NRSA findings, Upper Midwest

A total of 161 NRSA sites were sampled to characterize the condition of rivers and streams in the Upper Midwest ecoregion. An overview of the findings is shown in Figure 39.

Biological condition

The Macroinvertebrate MMI shows that 59% of river and stream length in the Upper Midwest ecoregion is in poor condition compared to least-disturbed conditions, 23% is in fair condition, and 18% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that

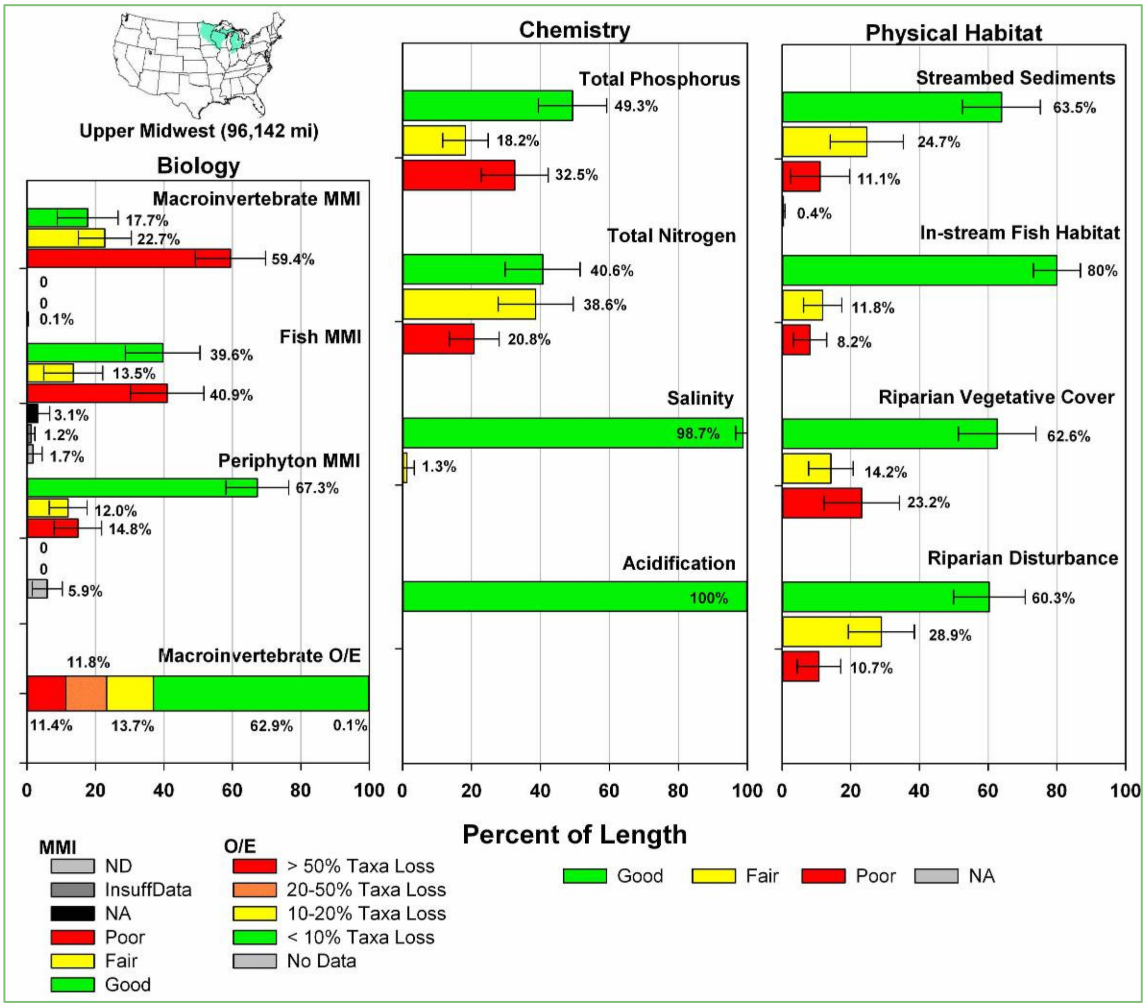

Figure 39. NRSA survey results for the Upper Midwest ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

11% of river and stream length has lost more than 50% of the taxa expected to occur, and 12% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 41% of river and stream length in poor condition for fish; for periphyton, only 15% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Upper Midwest ecoregion are phosphorus, riparian vegetative cover, and nitrogen. Compared to least-disturbed conditions for this ecoregion:

- Phosphorus is at high levels in 33% of river and stream length, medium levels in 18%, and low levels in 50% of stream length.
- Riparian vegetative cover is rated in poor condition in 23% of stream length, fair in 14%, and good in 63% of river and stream length.
- Nitrogen is at high levels in 21% of river and stream length, medium levels in 39%, and low levels in 41%.
- Streambed sediments and riparian disturbance are both rated poor in 11% of river and stream length.

Temperate Plains

Setting

The Temperate Plains ecoregion includes Iowa; the eastern Dakotas; western Minnesota; portions of Missouri, Kansas, and Nebraska; and the flat lands of western Ohio, central Indiana, Illinois, and southeastern Wisconsin. This ecoregion covers about 342,200 square miles, or 11.4%, of the continental U.S., with approximately 7,900 square miles under federal ownership. Many of the rivers in this ecoregion drain into the Upper Mississippi Ohio, and Great Lakes watersheds.

Much of this ecoregion is now primarily arable cultivated land, including field crops such as corn, wheat, and alfalfa as well as hog and cattle production. Crops and grazing have reduced natural riparian vegetative cover, increased sediment yield, and introduced pesticides and herbicides. Rivers have many species of fish, including minnows, darters, killifishes, catfishes, suckers, sunfishes, and black bass.

Rivers and streams in the tall grass prairie start from prairie potholes and springs and may be ephemeral (flowing for a short time after snowmelt or rainfall). Rivers carry large volumes of fine sediments and tend to be turbid, wide, and shallow. The total river and stream length represented in the NRSA for the Temperate Plains ecoregion is 227,017 miles.

The terrain of this ecoregion consists of smooth plains and many small lakes and wetlands. The climate is temperate, with cold winters, hot and humid summers, and mean temperatures ranging from 36° to 55°F. Annual precipitation ranges from 16 to 43 inches. Based on satellite images in the 2006 National Land Cover Dataset, the distribution of land cover in this ecoregion is 69% cultivated, 10% forested, 9% developed, and the remainder in other types of land cover.

Summary of NRSA findings, Temperate Plains

A total of 193 NRSA sites were sampled to characterize the condition of rivers and streams in the Temperate Plains ecoregion. An overview of the findings is shown in Figure 40.

Biological condition

The Macroinvertebrate MMI shows that 55% of river and stream length in the Temperate Plains ecoregion is in poor condition compared to least-disturbed conditions, 30% is in fair condition, and 15% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that

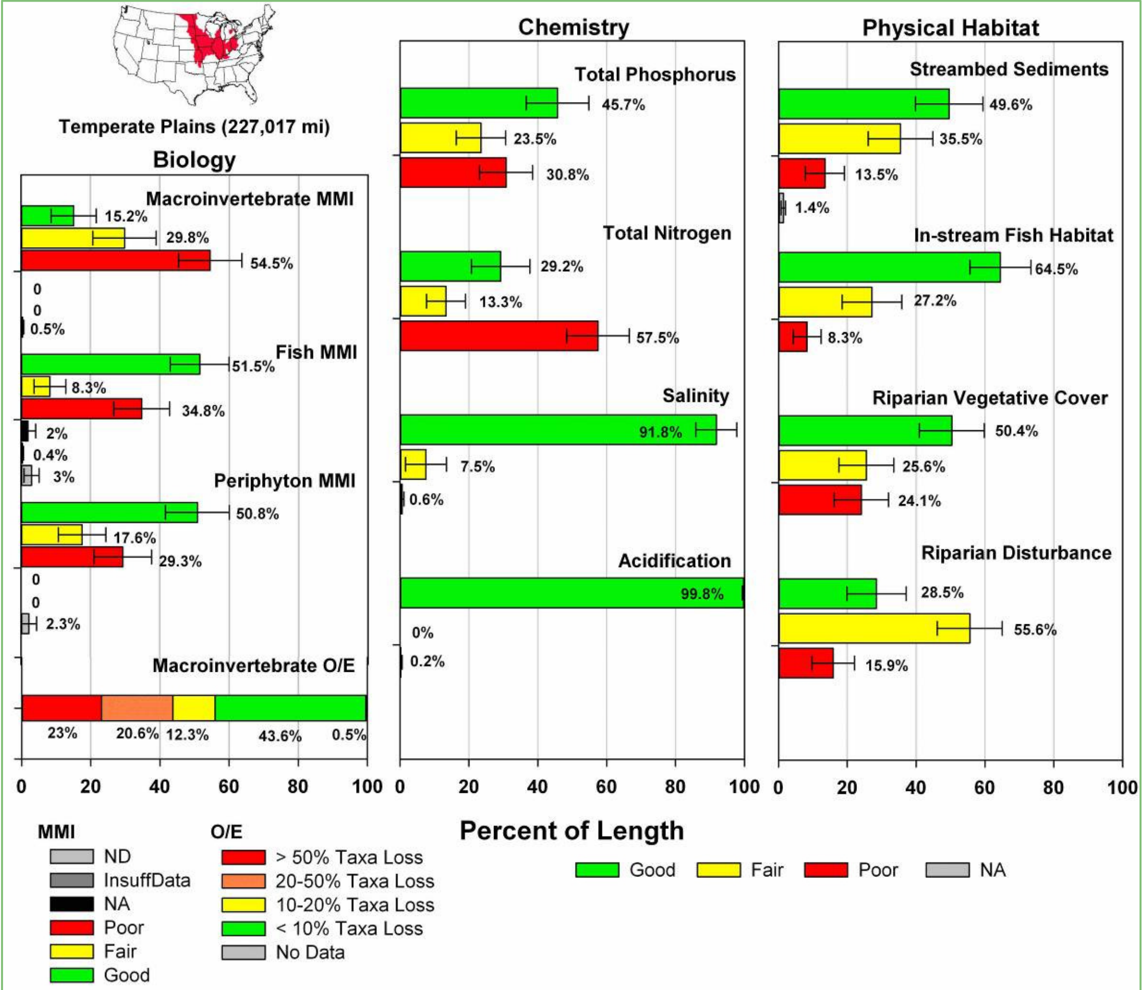

Figure 40. NRSA survey results for the Temperate Plains ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

23% of river and stream length has lost more than 50% of the taxa expected to occur, and 21% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 35% of river and stream length in poor condition for fish; for periphyton, 29% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Temperate Plains ecoregion are nitrogen, phosphorus, riparian vegetative cover, riparian disturbance, and streambed sediments. Compared to least-disturbed conditions for this ecoregion:

- Nitrogen is at high levels in 58% of river and stream length, medium levels in 13%, and low levels in 29%.
- Phosphorus is at high levels in 31% of river and stream length, medium levels in 24%, and low levels in 46%.
- Riparian vegetative cover is rated as poor in 24% of river and stream length, fair in 26%, and good in 50%.
- Riparian disturbance is at high levels in 16% of river and stream length, medium levels in 56%, and low levels in 29%.
- Streambed sediments are rated poor in 14% of river and stream length, fair in 36%, and good in 50%.

Southern Plains

Setting

The Southern Plains ecoregion covers about 405,000 square miles (13.5% of the continental U.S.) and includes central and northern Texas; most of western Kansas and Oklahoma; and portions of Nebraska, Colorado, and New Mexico. The Arkansas, Platte, White, Red, and Rio Grande rivers flow through this ecoregion, and most of the Ogallala aquifer (one of the world's largest water table aquifers which supplies irrigation and drinking water to eight states) lies underneath it. Federal land ownership in this ecoregion totals about 11,980 square miles, or about 3% of the total.

The terrain is a mix of smooth and irregular plains interspersed with tablelands and low hills. The Great Prairie grasslands, which once covered much of the Southern Plains ecoregion, are the most altered and endangered large ecosystem in the U.S. About 90% of the original tall grass prairie was replaced by other vegetation; agriculture and livestock grazing and production are prevalent. Agriculture is, in fact, an important economic activity in this ecoregion, and includes sorghum, wheat, corn, sunflower, bean, and cotton production. Livestock production and processing is also prevalent. This ecoregion also contains a sizable portion of U.S. petroleum and natural gas production in Oklahoma, Kansas, and Texas. The total river and stream length represented in the NRSA for the Southern Plains ecoregion is 36,594 miles.

Based on satellite images in the 2006 National Land Cover Dataset, the land in this ecoregion is 62% grassland/shrub, 27% cultivated, 5% forested, and the remainder in other types of land cover. The climate in this ecoregion is dry temperate, with mean annual temperatures ranging from 45° to 79°F. Annual precipitation is between 10 and 30 inches.

Summary of NRSA findings, Southern Plains

A total of 166 NRSA sites were sampled to characterize the condition of rivers and streams in the Southern Plains ecoregion. An overview of the findings is shown in Figure 41.

Biological condition

The Macroinvertebrate MMI shows that 42% of river and stream length in the Southern Plains ecoregion is in poor condition compared to least-disturbed conditions, 36% is in fair condition, and 21% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 23% of river and stream length has lost more than 50% of the taxa expected to occur, and 28% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 31% of river and stream length in poor condition for fish. Forty-three percent of river and stream length is in poor condition for periphyton.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Southern Plains ecoregion are riparian disturbance, streambed sediments, phosphorus, riparian

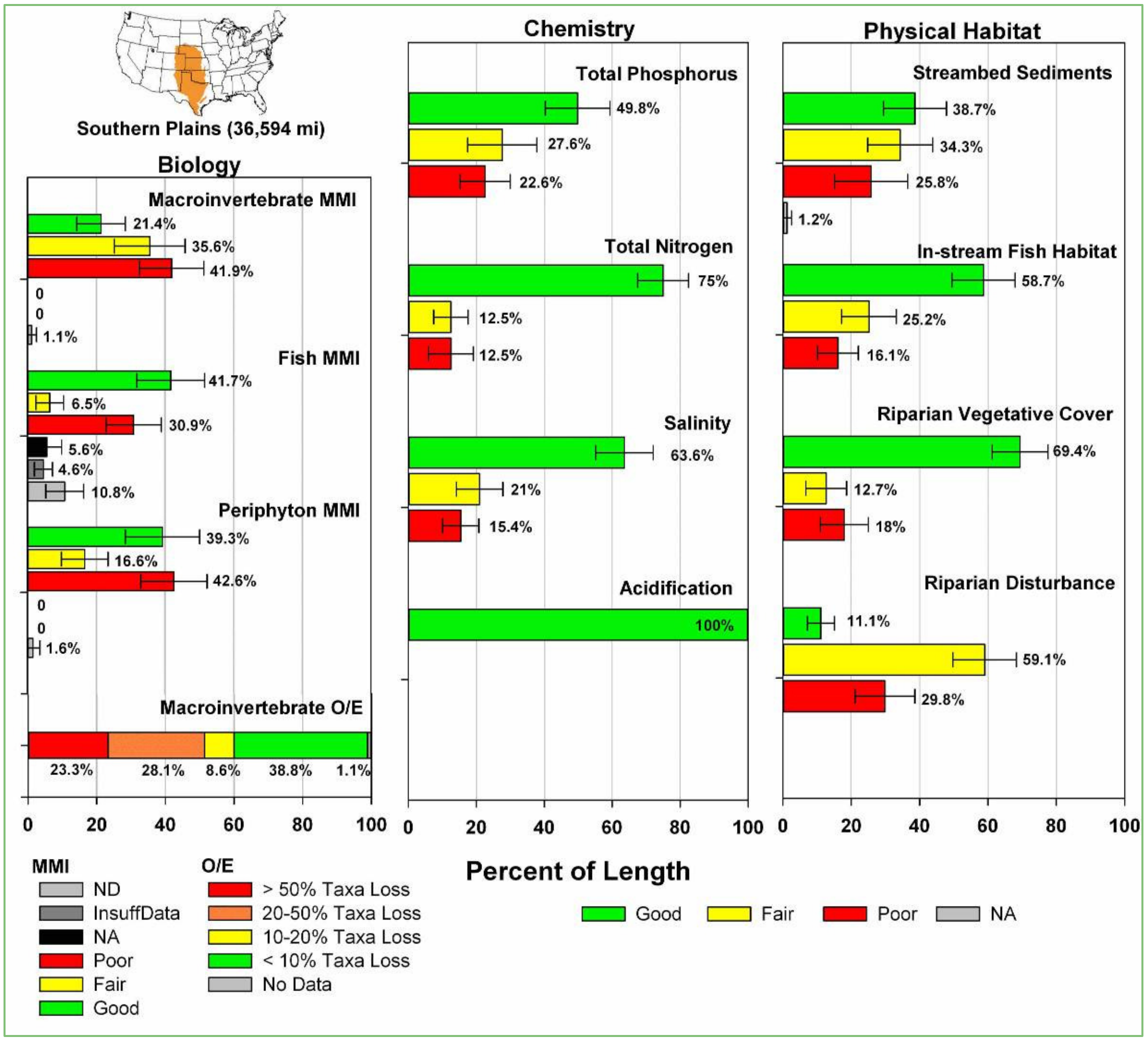

Figure 41. NRSA survey results for the Southern Plains ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

vegetative cover, and in-stream fish habitat. Compared to least-disturbed conditions for this ecoregion:

- Riparian disturbance is rated at high levels in 30% of river and stream length, medium levels in 59%, and good levels in only 11% of river and stream length.
- Streambed sediments are rated poor in 26% of river and stream length, fair in 34%, and good in 39%.
- Phosphorus is at high levels in 23% of river and stream length, medium levels in 28%, and low levels in 50%.
- Riparian vegetative cover is rated in poor condition in 18% of river and stream length, fair in 13%, and good in 70%.

- In-stream habitat is rated poor in 16% of river and stream length, fair in 25%, and good in 59%.
- Salinity, though not a widespread stressor nationally or in most other ecoregions, is rated poor in 15% of river and stream length in the Southern Plains ecoregion.

Northern Plains

Setting

The Northern Plains ecoregion covers approximately 205,084 square miles, or 6.8% of the continental U.S. It includes the western Dakotas, Montana east of the Rocky Mountains, northeast Wyoming, and a small section of northern Nebraska. This ecoregion is the heart of the Missouri River system and is almost exclusively within the Missouri River's watershed. Federal lands account for 52,660 square miles, or nearly 26% of the total area.

Human economic activity in this ecoregion is primarily agriculture, including cattle and sheep grazing and cropland. Coal mining occurs in the North Dakota, Montana, and Wyoming portions of the ecoregion, and petroleum and natural gas production are growing.

This ecoregion's terrain is irregular plains interspersed with tablelands and low hills. The Great Prairie grasslands were once an important feature of this ecoregion, but have largely been replaced by other vegetation or land uses, particularly cropland. The total river and stream length represented in the NRSA for the Northern Plains ecoregion is 27,227 miles.

Based on satellite images in the 2006 National Land Cover Dataset, the land in this ecoregion is 68% grassland/shrub, 23% cultivated, 3% forested, and the remainder in other types of land cover. The climate in this ecoregion is dry and characterized by short, hot summers and long, cold winters. Temperatures average 36° to 46°F, and annual precipitation totals range from 10 to 25 inches. High winds are an important climatic factor in this ecoregion, which is also subject to periodic intense droughts and frosts.

Summary of NRSA findings, Northern Plains

A total of 175 NRSA sites were sampled to characterize the condition of rivers and streams in the Northern Plains ecoregion. An overview of the findings is shown in Figure 42.

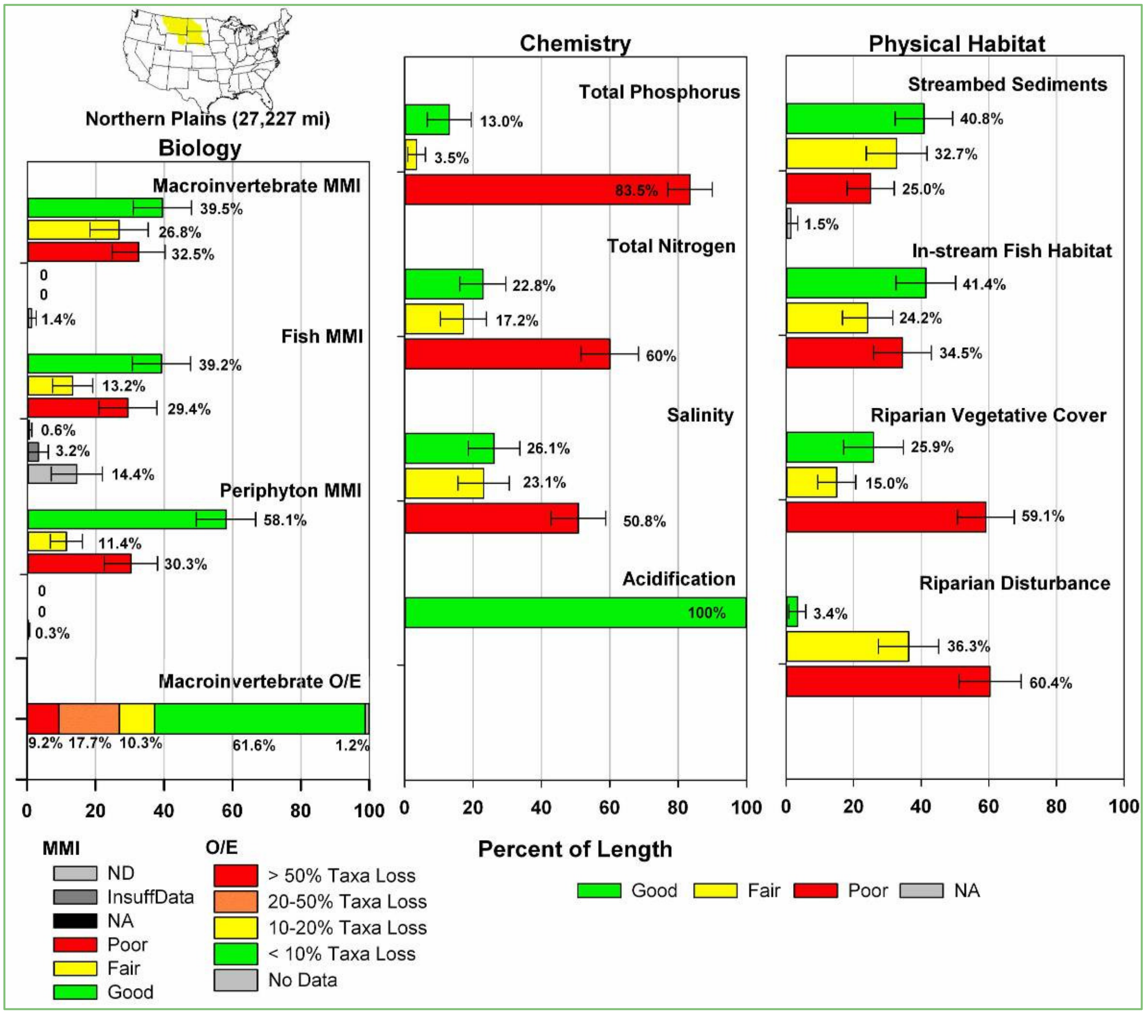

Figure 42. NRSA survey results for the Northern Plains ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

Biological condition

The Macroinvertebrate MMI shows that 33% of river and stream length in the Northern Plains ecoregion is in poor condition compared to least-disturbed conditions, 27% is in fair condition, and 40% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 9% of river and stream length has lost more than 50% of the taxa expected to occur, and 18% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 29% of river and stream length in poor condition for fish; for periphyton, 30% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Northern Plains ecoregion are phosphorus, riparian disturbance, nitrogen, riparian vegetative cover, and salinity. Compared to least-disturbed conditions for this ecoregion:

- Phosphorus is at high levels in 84% of river and stream length, medium levels in 4%, and low levels in 13%.
- Riparian disturbance is rated high in 60% of river and stream length, medium in 36%, and low in 3%.
- Nitrogen is at high levels in 60% of river and stream length, medium levels in 17%, and low levels in 23%.
- Riparian vegetative cover is rated poor in 59% of river and stream length, fair in 15%, and good in 26%.
- Salinity is a widespread stressor in the Northern Plains and is found at high levels in 51% of river and stream length, at medium levels in 23%, and at low levels in 26% of river and stream length.

Western Mountains

Setting

The Western Mountain ecoregion includes the Cascade, Sierra Nevada, and Pacific Coast ranges in the coastal states; the Gila Mountains in the southwestern states; and the Bitterroot and Rocky Mountains in the northern and central mountain states. The headwaters and upper reaches of the Columbia, Sacramento, Missouri, and Colorado River systems all occur in this ecoregion. This ecoregion covers about 397,832 square miles, with about 297,900 square miles, or 74.8%, classified as federal land.

The terrain of the Western Mountains ecoregion is characterized by extensive mountains and plateaus separated by wide valleys and lowlands. Coastal mountains are transected by many fjords and glacial valleys, are bordered by coastal plains, and include important estuaries along the margins of the ocean. Soils are mainly nutrient-poor forest soils. Rivers drain dense forested catchments and contain large amounts of woody debris that provide habitat diversity and stability. Rivers reaching the Pacific Ocean historically had large runs of salmon and trout, although many of these populations have been reduced by the effects of dams, flow regulation, overfishing, and introduced species. Smaller rivers generally start as steep mountain streams with staircase-like channels, steps, and plunge pools, with riffles and pools appearing as slope decreases. Upper river reaches experience debris flows and landslides when shallow soils become saturated by rainfall or snowmelt. The total river and stream length represented in the NRSA for the Western Mountains ecoregion is 150,975 miles.

Based on satellite images in the 2006 National Land Cover Dataset, the land in this ecoregion is 55% forested, 36% shrub/scrub and grassland, and the remainder in other types of land cover. The climate is sub-arid to arid and mild in southern lower valleys, and humid and cold at higher elevations. The wettest climates of North America occur in the marine coastal rain forests of this ecoregion. Mean annual temperatures range from 32° to 55°F, and annual precipitation ranges from 16 to 240 inches.

Summary of NRSA findings, Western Mountains

A total of 210 NRSA sites were sampled to characterize the condition of rivers and streams in the Western Mountains ecoregion. An overview of the findings is shown in Figure 43.

Biological condition

The Macroinvertebrate MMI shows that 26% of river and stream length in the Western Mountains ecoregion is in poor condition compared to least-disturbed conditions, 31% is in fair condition, and 42% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 6% of river and stream length has lost more than 50% of the taxa expected to occur, and 18% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 21% of river and stream length in poor condition for fish, while for periphyton, 36% of river and stream length is in poor condition.

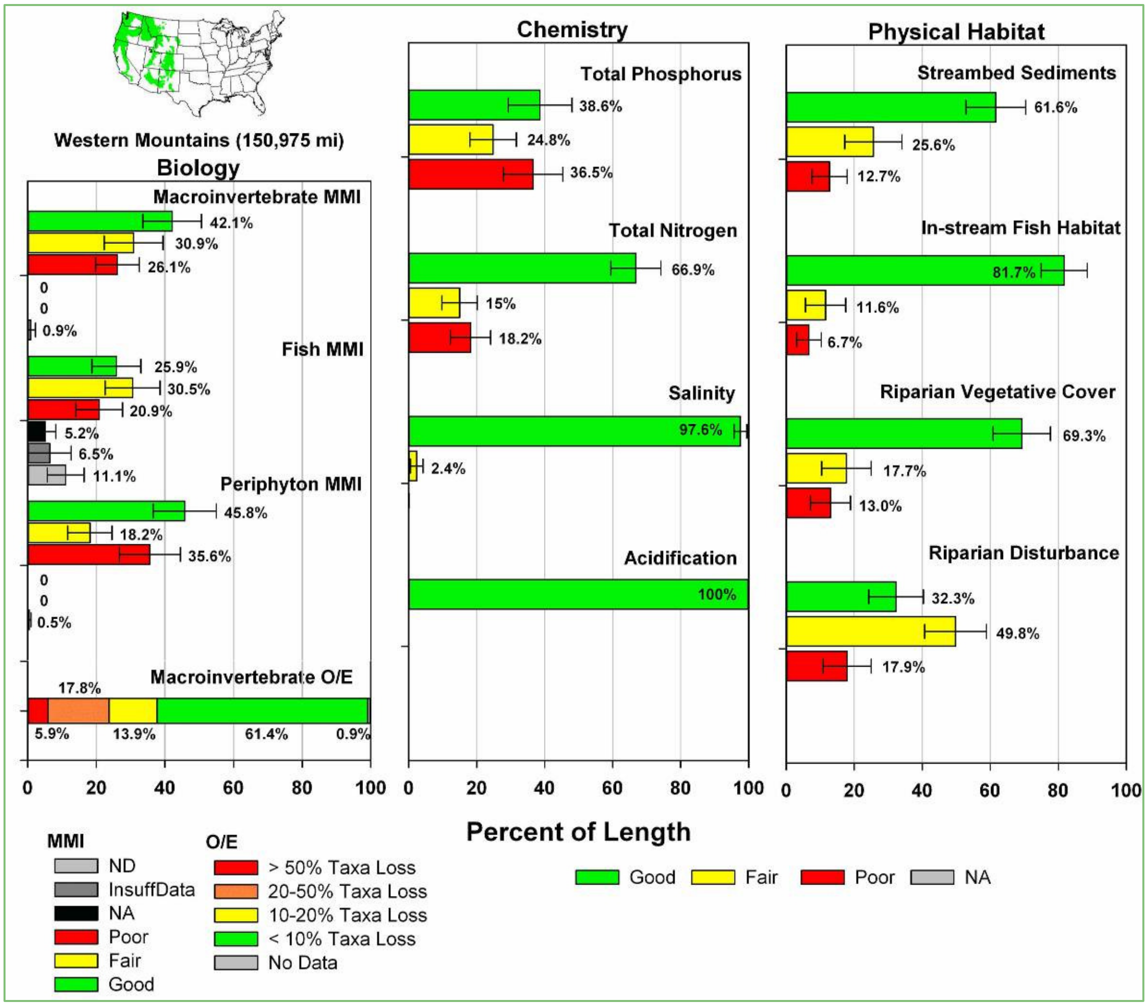

Figure 43. NRSA survey results for the Western Mountains ecoregion (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Western Mountains ecoregion are phosphorus, nitrogen, riparian disturbance, riparian vegetative cover and streambed sediments. Compared to least-disturbed conditions for this ecoregion:

- Phosphorus is at high levels in 37% of river and stream length, medium levels in 25%, and low levels in 39%.
- Nitrogen is at high levels in 18% of river and stream length, medium levels in 15%, and low levels in 67%.
- Riparian disturbance is rated high in 18% of river and stream length, medium in 50%, and low in 32%.

- Riparian vegetative cover is rated poor in 13% of river and stream length, fair in 18%, and good in 69%.
- Similarly, streambed sediments are rated poor in 13% of river and stream length, fair in 26%, and good in 62%.

Xeric

Setting

The Xeric ecoregion covers the largest area of all NRSA aggregate ecoregions and includes the most total land under federal ownership. It covers portions of 11 western states and all of Nevada, for a total of about 636,583 square miles, or 21% of the continental U.S. Around 453,000 square miles, or 71% of the land, is classified as federal lands, including the Grand Canyon National Park, Big Bend National Park, and the Hanford Nuclear Reservation.

The terrain of the Xeric ecoregion is composed of a mix of physiographic features, including plains with hills and low mountains, high-relief tablelands, piedmont, high mountains, and intermountain basins and valleys. The ecoregion includes the flat to rolling topography of the Columbia/Snake River Plateau; the Great Basin; Death Valley; and the canyons, cliffs, buttes, and mesas of the Colorado Plateau. Its relatively limited surface water supply contributes to the Upper and Lower Colorado, Great Basin, California, Rio Grande, and Pacific Northwest regional watersheds. Large rivers flow all year, are supplied by snowmelt, and peak in early summer. Small rivers are mostly ephemeral. Rivers are often subject to rapid change due to flash floods and debris flows. In southern areas of the ecoregion, internal drainages often end in saline lakes or desert basins without reaching the ocean (e.g., Utah's Great Salt Lake).

Rivers in this ecoregion create a riparian habitat oasis for plants and animals. Many fish are endemic and have evolved to cope with warm, turbid waters. Many are threatened or endangered due to flow regulations from dams, water withdrawals, and introduced non-native species. The total river and stream length represented in the NRSA for the Xeric ecoregion is 44,974 miles.

Based on satellite images in the 2006 National Land Cover Dataset, the land in this ecoregion is 77% shrub/scrub and grassland, 8% cultivated, 7% forested, and the remainder in various types of land cover. The climate in this ecoregion varies widely from warm and dry to temperate, with mean annual temperatures ranging from 32° to 75°F and annual precipitation in the 2- to 40-inch range.

Summary of NRSA findings

A total of 189 NRSA sites were sampled to characterize the condition of rivers and streams in the Xeric ecoregion. An overview of the findings is shown in Figure 44.

Biological condition

The Macroinvertebrate MMI shows that 43% of river and stream length in the Xeric ecoregion is in poor condition compared to least-disturbed conditions, 15% is in fair condition,

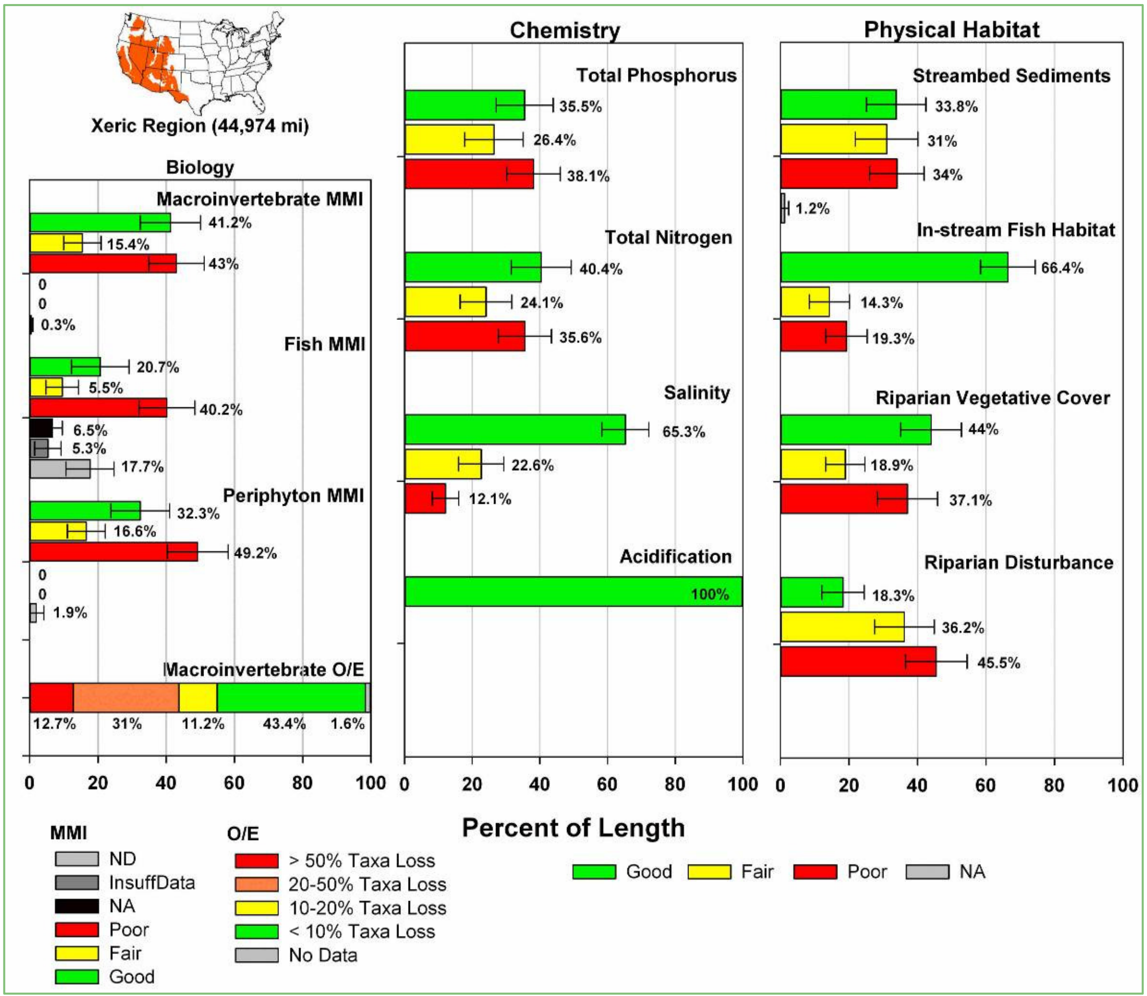

Figure 44. NRSA survey results for the Xeric ecoregions (EPA/NRSA). Bars show the percentage of river and stream length within a condition class for a given indicator. Percents may not add up to 100% due to rounding.

and 41% is in good condition. The Macroinvertebrate O/E Taxa Loss results show that 13% of river and stream length has lost more than 50% of the taxa expected to occur, and 31% of river and stream length has lost between 20% and 50% of taxa.

The Fish MMI shows 40% of river and stream length in poor condition for fish; for periphyton, 50% of river and stream length is in poor condition.

Indicators of stress

Of the indicators of stress measured for the NRSA, the most widespread in the Xeric ecoregion are riparian disturbance, riparian vegetative cover, phosphorus, nitrogen, and streambed sediments. Compared to least-disturbed conditions for this ecoregion:

- Riparian disturbance is rated high in 46% of river and stream length, medium in 36%, and low in 18%.
- Riparian vegetative cover is in poor condition in 37% of river and stream length, fair condition in 19%, and good condition in 44%.
- Phosphorus is at high levels in 38% of river and stream length, medium levels in 26%, and low levels in 36%.
- Nitrogen is at high levels in 36% of river and stream length, medium levels in 24%, and low levels in 40%.
- Streambed sediments are rated poor in 34% of river and stream length, fair in 31%, and good in 34%.

Chapter 7. Summary and Next Steps

This first *National Rivers and Streams Assessment* was an unprecedented sampling and analytical effort by EPA and its state and tribal partners. Over two summers, 85 field crews sampled nearly 2,000 sites along the nation's wide-ranging rivers and streams. Twenty-two separate field training sessions were held to prepare for this survey. The efforts of the field crews yielded over 25,000 samples shipped to laboratories across the country. For example, over the course of the survey, 3,300 benthic macroinvertebrate samples (each sample with hundreds of individual preserved macroinvertebrates) were shipped to eight laboratories for sorting, identification, and analysis. Seventeen different indicators were sampled or evaluated at the NRSA sites. Ten million bits of data were collected in field and analyzed in laboratories. These data from the NRSA are available at www.epa.gov/aquaticsurveys.

Overall, the NRSA finds that biological communities in our rivers and streams are being heavily affected and degraded across the country. More than half of the nation's river and stream length is in poor condition, based on an index that combines different measures of the condition of aquatic benthic macroinvertebrates. The eastern and mid-western ecoregions tend to have the most waters in poor biological condition, with the percentage of rivers and streams rated poor ranging from 55% to 71%. In the west (including the Northern and Southern Plains ecoregions), the percentage of rivers and streams in poor biological condition ranges from 26% to 42%.

Of the four chemical stressors assessed, phosphorus and nitrogen are the most widespread. Biological communities are 50% more likely to be in poor condition when phosphorus levels are high and 40% more likely to be in poor condition when nitrogen levels are high. Phosphorus is the most widespread stressor in six of the nine ecoregions, and nitrogen is the most widespread in one ecoregion. Analysis of the NRSA data suggest that if phosphorus levels were reduced in areas where levels are currently high, we might see 17% of the nation's river and stream length improve to good conditions for macroinvertebrates.

Of the four physical habitat stressors assessed in the NRSA, poor riparian vegetative cover and high levels of riparian disturbance are reported in 24% and 20% of the nation's river and stream length respectively, and are the most widespread. Riparian disturbance is the most widespread stressor in two of the nine ecoregions. However, excess streambed sediments have a somewhat greater impact on biological condition. Poor biological condition is 60% more likely in rivers and streams with excessive levels of streambed sediments. Nearly 9% of river and stream length in poor biological condition might improve to good conditions for macroinvertebrates if excess levels of streambed sediments were reduced or eliminated.

The NRSA also includes two indicators that provide insight into potential risks to human health. It finds that in 9% of the nation's river and stream length, levels of enterococci bacteria exceed threshold levels for protecting human health. Additionally, the NRSA is able to report that over 13,000 miles of rivers have mercury levels in fish tissue that exceed human health screening values.

As we continue to implement these surveys over time, an important element of the NRSA is the ability to track changes in the condition of our rivers and streams. This report provides a first glimpse of that capability by examining the differences between stream conditions as reported in 2004 and wadeable systems assessed as part of the NRSA. Several NRSA indicators show statistically significant change compared to the 2004 WSA. An increase in stream length in good condition is evident for nitrogen, in-stream fish habitat, riparian disturbance, and riparian vegetation; however, there is also a decrease in stream length in good condition for phosphorus and overall biological condition as measured by the macroinvertebrate index. These findings of change apply only to streams and are only identifying differences between two points in time; they should not be interpreted as trends in water quality conditions. Reasons for the changes have not been determined although work continues in evaluating possible human or natural explanations. Future assessments of the nation's rivers and streams will be able to provide more robust trend assessments as additional years of data become available and as our understanding of the relationship between human activity, natural phenomena, and environmental change mature.

The survey's finding that more than half of river and stream length is in poor biological condition and that excess nutrients and poor habitat are widespread contributors to poor condition supports continued management attention to these problems at the national, regional, state, and watershed scales. Management actions should be focused not only on improving those areas where biological conditions are poor, nutrient levels are high, and habitat conditions are already degraded, but on protecting those areas that are still in good condition.

Moving the science forward

Many of the contributions of the NRSA go beyond the findings discussed in this report. Scientists developed new methods of sampling and assessing important water indicators such as streambed sediments; data were collected on leading-edge indicators that will be analyzed and reported separately; and state and tribal partners gained — and shared — new expertise in state-of-the-art field monitoring methods and probability-based surveys.

EPA scientists and collaborators are continuing to move the science forward to assess the core indicators that are part of the NRSA. Many of these efforts are focused on new ways to assess the benthic macroinvertebrate community using a method similar to the one used for the fish assemblage and periphyton assemblage indicators. This advanced approach uses a modeling technique — called random forest modeling — to improve the establishment of reference condition and our ability to assess the condition of biological communities. NRSA scientists will publish supplemental benthic analysis using the random forest model and set the stage for incorporating this procedure into the next NRSA report.

NRSA scientists are also working toward developing assessment and reporting methods that will more fully integrate the three biological indicators into one to evaluate the overall condition of rivers and streams. Transferring NRSA methods and technology to state and tribal programs is another key aspect of moving the science forward.

As additional data continue to come back from laboratories, they will be analyzed and published as NRSA supplemental reports. For example, many analytes that were included in the fish tissue analysis are still waiting for final laboratory analysis. These include pesticide data, PCBs, and chemicals of emerging concern such as pharmaceuticals. In urban rivers, crews also collected water samples to look at the presence and amount of chemicals of emerging concern.

EPA included several leading-edge indicators as part of the NRSA. These indicators were selected to address emerging issues and developments in aquatic sciences and were included to support innovative research within the EPA. For example, the EPA Office of Research and Development led an effort to study microbial sediment enzyme activity (or sediment enzymes), an indicator that focuses on nutrient concentration within the streambed sediment. The work to collect and analyze sediment enzymes is helping EPA and our partners better understand nutrient limiting factors within the stream or river channel that affect the biological community. The result may prove to be a sensitive indicator that can help us implement the most effective management action to address nutrient pollution. A number of peer-reviewed journal articles focus on the technical aspects of the analysis and assessment of this innovative indicator.

Next steps

As this report was being written, planning was already underway for the 2013–2014 *National Rivers and Streams Assessment*. EPA and its state and tribal partners have taken stock of the lessons learned from the 2008–2009 survey as well as from other National Aquatic Resource Surveys; they have met to discuss possible changes in indicators, methods, reference sites, logistics, and analytical approaches; sites for the 2013–2014 sampling seasons have been selected; and manuals for field and laboratory methods and quality assurance are being updated and prepared. Supplemental reports based on these 2008–2009 findings will be issued as assessments are completed. These supplemental reports will be made available on the National Aquatic Resource Surveys main website at www.epa.gov/aquaticsurveys.

EPA, states, tribes, and other federal partners expect to continue to produce national water quality assessments on a regular cycle under the National Aquatic Resource Surveys program. A new national coastal assessment report will be released in 2013 based on field sampling that took place in 2010. A first-ever national wetlands condition assessment, based on field sampling in 2011, is also scheduled for 2013. A second national lakes assessment is planned for 2014 based on sampling during the summer of 2012.

As these national assessments continue, many states are developing and conducting their own state-scale probability surveys of their rivers and streams, lakes, and coastal waters. EPA will continue to explore ways to best support states as they sample, analyze, and report on their waters using these surveys. For example, EPA is working to build and refine tools states can use to assess survey data at different scales and is exploring options for providing direct technical support. As a first step, EPA will make available the statistical codes that were used to develop the MMIs and thresholds for assessment. EPA is also piloting in-person training on the statistical tools and methods that were used in the National Lakes Assessment. Modifications and refinements will be made to this pilot effort to train states and tribes for the NRSA and other NARS programs.

This survey would not have been possible without the assistance and collaboration of hundreds of scientists working for state, federal, and tribal agencies and universities across the country. These scientists helped plan and design the survey, select sites and indicators, develop and improve monitoring methods, train crew members, conduct sampling, track samples, screen and analyze results, and review and write up the findings. Working together on future surveys, and on state-scale surveys of similar design, EPA and its partners will continue developing a high quality baseline of information on rivers and streams that can be used to evaluate our progress in protecting and restoring them.

California uses the NARS approach to enhance monitoring capacity

Introduction

One of the strengths of the NARS program has been its ability to transfer significant technical advances in monitoring approaches and techniques to states and tribes. Partnerships with states and tribes were designed to help build local capacity to take advantage of the new tools that NARS was developing.

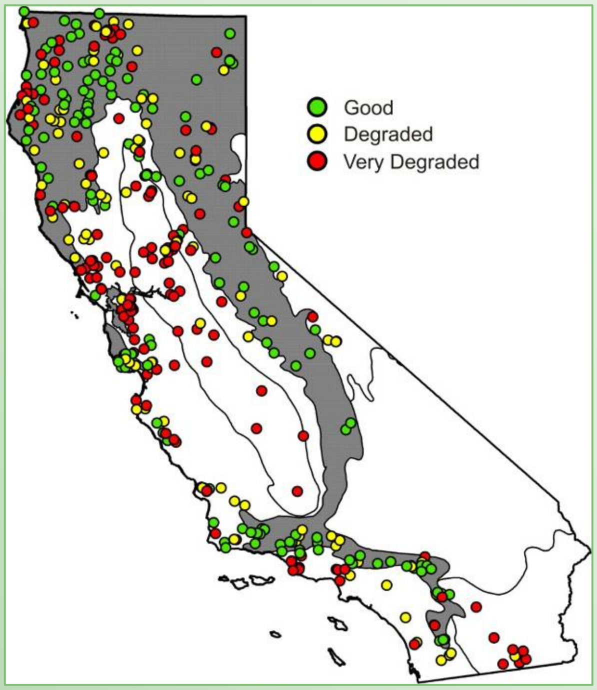

Figure 45. Map of about 1,200 probability sites in California sampled since 2000 using compatible EMAP-style survey designs.

Over the last 12 years, California has embraced this technical and partnership approach. First participating in the EPA Environmental Monitoring and Assessment Program (EMAP) Western pilot to monitor streams and rivers, California used what it learned to produce a thriving program that is transforming the way water quality monitoring is conducted and data are evaluated throughout the state. Since 2000, California has leveraged about 250 EMAP/NRSA sites into a probability dataset of over 1,200 sites (Figure 45). The list of data applications and opportunities for partnerships keeps growing every year.

Regional assessments and land use assessments

The high density of sites in California supports the development of regional assessments and analyses (e.g., of stressor extent and risk) that are more relevant to the scale at which policy and management decisions are made (Figure 46). California also added the ability to produce summaries for major land cover classes such as forested, agricultural, or urban land (Figure 47). This was the first attempt to use a probability survey to produce land-use-specific assessments. Knowing the probability-derived distribution of stressors and indicators in urban, agricultural, and forested landscapes gives managers context for interpreting the results of monitoring done in these types of landscapes.

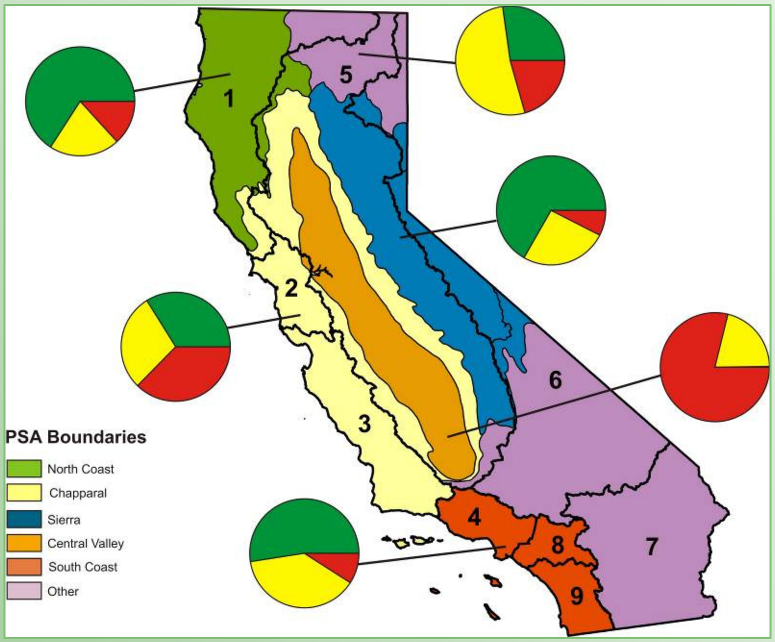

Figure 46. Biological condition of perennial streams in the six major ecological regions of California. (Green = good biological condition, yellow = altered biological condition, and red = very altered biological condition.)

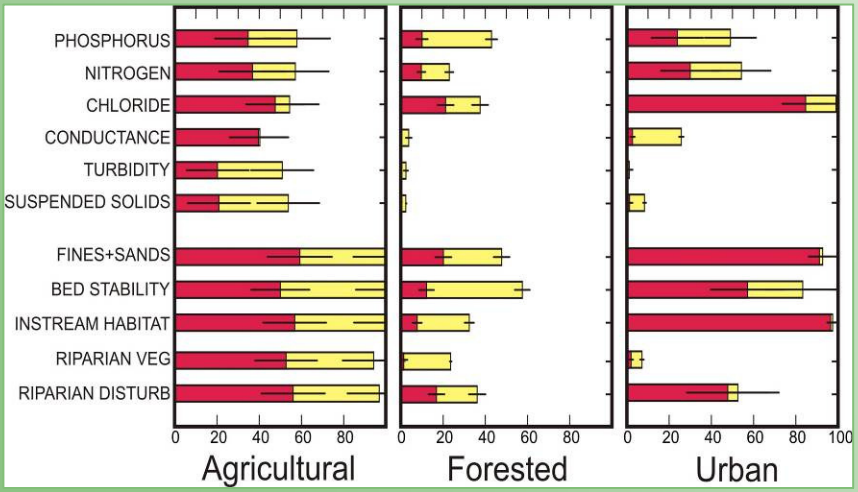

Figure 47. Percentage of California stream length that exceeds severe (red) and moderate (yellow) threshold values for various chemical and physical habitat stressor variables in streams associated with each of three major land cover types.

Beyond condition assessments

Exploring stressor–condition relationships

CA measures a large suite of water chemistry and in-stream and riparian habitat parameters in addition to ecological condition indicators such as benthic invertebrates and algae. Site-specific information is supplemented with over a hundred layers of GIS data that look across the site, watershed and region. This provides a dataset that can be used to explore stressor–condition relationships for a wide variety of objectives (Figure 48). The ability to produce objective descriptions of stressor extent and relationships between stressors and biological condition holds even greater potential to influence CA's resource management programs. Better understanding of these relationships is leading to significant improvements in the state's ability to prioritize limited resources and to have more meaningful discussions about issues of concern with the public and with other agencies (Figure 49).

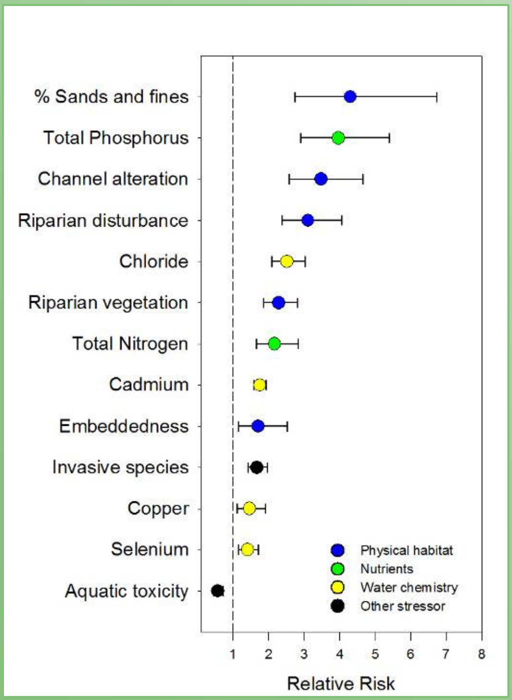

Figure 48. Relative risk of biological impairment associated with a series of habitat and chemistry variables in southern California streams.

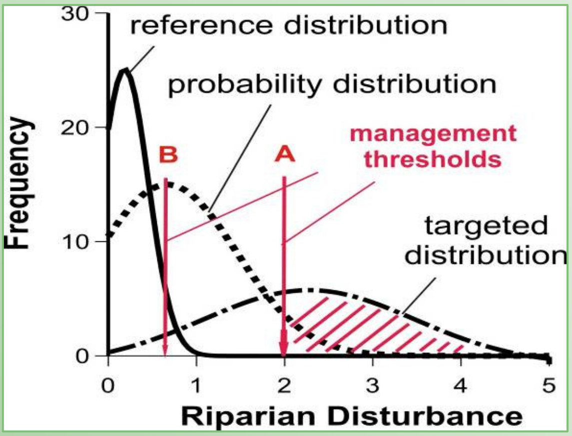

Figure 49. The combination of probability and reference distributions provides objective context for interpreting targeted monitoring data.

Support for biocriteria development

California's extensive probability datasets have given the state a solid foundation to move toward using ecological indicators for regulatory purposes, such as biocriteria development and refining reference condition. Probability data have also played an important role in the development of the technical elements of California's biocriteria policy, which is currently in progress.

Fostering inter-agency collaboration

California's statewide probability survey, the Perennial Streams Assessment, serves as a highly effective tool for encouraging collaboration with regional monitoring programs and federal agencies. For example, two successful monitoring partnerships in urban areas (southern coastal California and the San Francisco Bay Area) worked with the Assessment to create monitoring programs that were compatible with the Assessment's design and that allowed them to coordinate efforts and effectively use data across regional groups. Partnerships with federal agencies have the potential for similar benefits in rural areas.

Partnerships like those in California enable programs to do more with limited monitoring resources and provide feedback that improves the monitoring program. They help connect partners' management needs to the right data. California is using this approach to accelerate its progress toward the widespread use of ecological indicators in aquatic resource protection, including the development of multiple indicator assemblages (such as algae and wetland vegetative condition) and tools for a variety of aquatic resource types, including non-perennial streams, wetlands, and large rivers.

Glossary of Terms

Benthic macroinvertebrates: Aquatic insects (often in larval stages) such as dragonfly larvae and beetles, crustaceans such as crayfish, worms, and mollusks. These small creatures live throughout the stream bed attached to rocks, vegetation, and logs and sticks or burrowed into stream bottoms.

Biological assemblages: Key groups of animals and plants — such as benthic macroinvertebrates, fish, or algae — that are studied to learn more about the condition of water resources.

Biological integrity: The state of being able to support and maintain a balanced community of organisms with a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Ecoregions: Ecological regions that are similar in climate, vegetation, soil type, and geology; water resources within a particular ecoregion have similar natural characteristics and similar responses to stressors.

In-stream fish habitat: Areas fish need for concealment and feeding, such as large wood within the stream banks, boulders, undercut banks, and tree roots.

Intermittent (ephemeral) streams: Streams that flow only during part of the year, such as in the spring and early summer after snowmelt, or only in direct response to precipitation.

Macroinvertebrate Multimetric Index: The sum of a number of individual measures of biological condition, such as the number of taxa in a sample, the number of taxa with different habits and feeding strategies, etc.

National Hydrography Dataset (NHD) Plus: Comprehensive set of digital spatial data — based on U.S. Geological Survey 1:100,000 scale topographic maps — that contains information on surface water features such as streams, rivers, lakes, and ponds.

Nutrients: Substances such as nitrogen and phosphorus that can over-stimulate the growth of algae and other plants in water. Nutrients in streams and lakes can come from agricultural and urban runoff, leaking septic systems, sewage discharges, and similar sources.

O/E (Observed/Expected) Ratio of Taxa Loss: A ratio comparing the number of taxa expected (E) to exist at a site to the number that are actually observed (O). The taxa expected at individual sites are based on models developed from data collected at reference sites.

Perennial streams: Steams that flow throughout the year.

Physical habitat: For streams and rivers, the area in and around the stream or river, including its bed, banks, in-stream and overhanging vegetation, and riparian zone.

Probability-based design: A type of random sampling technique in which every element of the population has a known probability of being selected for sampling.

Reach: Stream segment.

Reference condition: The least-disturbed condition available in an ecological region, determined based on specific criteria, used as a benchmark for comparison with sampled sites in the region.

Riparian: Pertaining to a stream or river and its adjacent area.

Riparian disturbance: A measure of the evidence of human activities in and alongside streams and rivers, such as dams, roadways, construction, pastureland, and trash.

Riparian vegetative cover: The vegetation corridor alongside streams and rivers. Intact riparian vegetative cover reduces pollution runoff, prevents streambank erosion, and provides shade, lower temperatures, food, and habitat for fish and other aquatic organisms.

Streambed sediments: Fine sediments and silt on the streambed. In excess quantities, they can fill in the habitat spaces between stream cobbles and boulders, and suffocate macroinvertebrates and fish eggs.

Stream order: Stream size, based on the confluence of one stream with another. First-order streams are the origin or headwaters. The confluence or joining of two first-order streams forms a second-order stream, the confluence of two second-order streams forms a third-order stream, and so on.

Stressors: Effects or substances that are stressful to — and therefore degrade — aquatic ecosystems. Stressors can be chemical (e.g., nutrients), physical (e.g., excess sediments on the streambed), or biological (e.g., competing invasive species).

Taxa: Plural of “taxon”; groupings of living organisms, such as phylum, order, family, genus, or species. Scientists organize organisms into taxa in order to better identify and understand them.

Transect: A path or line along which one counts and studies various aspects of a stream, river, or other study area.

Wadeable streams: Streams that are small and shallow enough to adequately sample by wading, without a boat.

Sources and References

General references

Lang, B. n.d. Columbia River. www.ccrh.org/river/history.htm (accessed August 15, 2012).

Delaware River Basin Commission. 2012. Basin information. www.state.nj.us/drbc/basin (accessed August 15, 2012).

General Accounting Office. 2000. *Water Quality — Key EPA and State Decisions Limited by Inconsistent and Incomplete Data.* GAO/RCED-00-54.

H. John Heinz Center for Science, Economics and the Environment. 2002. *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States.* New York: Cambridge University Press.

Moving Waters: The Colorado River and the West. 2001. Information droplets. www.movingwaters.org/faq.html (accessed August 15, 2012).

National Academy of Public Administration. 2002. *Understanding What States Need to Protect Water Quality*. Academy Project Number 2001-001.

National Research Council. 2001. *Assessing the TMDL Approach to Water Quality Management.* Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction. Washington, DC: National Academies Press.

Stoddard, J.L., J.S. Kahl, F.A. Deviney, D. DeWalle, C.T. Driscoll, A. Herlihy, J.H. Kellogg, P. Murdoch, J.R. Webb, and K. Webster. 2003. *Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990*. EPA/620/R-03/001. Washington, DC: U.S. Environmental Protection Agency.

U.S. Department of the Interior, National Park Service. 2012. Mississippi River facts. www.nps.gov/miss/riverfacts.htm (accessed August 2, 2012).

U.S. EPA. 2001. *National Coastal Condition Report.* EPA/620/R-01/005. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development and Office of Water.

U.S. EPA. 2004. *National Coastal Condition Report II.* EPA/620/R-03/002. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development and Office of Water.

U.S. EPA. 2006. *National Estuary Program Coastal Condition Report.* Draft. EPA/842/B-06/001. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

U.S. EPA. 2006. *Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams.* EPA/841/B-06/002. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development.

U.S. EPA. 2009. *National Lakes Assessment: A Collaborative Survey of the Nation's Lakes.* EPA/841/R-09/001. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development.

U.S. EPA. 2012. The Missouri River mainstem. www.epa.gov/region07/citizens/care/missouri.htm (accessed August 2, 2012).

Water Education Foundation. 2012. Colorado River facts. www.watereducation.org/doc.asp?id=1025 (accessed August 15, 2012).

Stream and river sampling and laboratory methods

Flotemersch, J.E., J.B. Stribling, and M.J. Paul. 2006. *Concepts and Approaches for the Bioassessment of Non-wadeable Streams and Rivers.* EPA/600/R-06/127. Cincinnati, OH: U.S. Environmental Protection Agency.

Lazorchak, J.M., B.H. Hill, D.K. Averill, D.V. Peck, and D.J. Klemm, eds. 2000. *Environmental Monitoring and Assessment Program—Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Non-Wadeable Rivers and Streams.* EPA/620/R-00/007. Cincinnati (OH): U.S. Environmental Protection Agency.

Peck, D.V., D.K. Averill, A.T. Herlihy, R.M. Hughes, P.R. Kaufmann, D.J. Klemm, J.M. Lazorchak, F.H. McCormick, S.A. Peterson, M.R. Cappaert, T. Magee, and P.A. Monaco. 2005. *Environmental Monitoring and Assessment Program — Surface Waters Western Pilot Study: Field Operations Manual for Non-Wadeable Rivers and Streams.* EPA/620/R-06/003, 2006.Washington, DC: U.S. Environmental Protection Agency.

U.S. EPA. 2004. *Wadeable Streams Assessment: Benthic Laboratory Methods.* EPA/841/B-04/007. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Environmental Information.

U.S. EPA. 2004. *Wadeable Streams Assessment: Field Operations Manual.* EPA/841/B-04/004. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

U.S. EPA. 2004. *Wadeable Streams Assessment: Quality Assurance Project Plan.* EPA/841/B-04/005. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Environmental Information.

U.S. EPA. 2004. *Wadeable Streams Assessment: Site Evaluation Guidelines.* EPA/841/B-04/006. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Environmental Information.

U.S. EPA. 2004. *Wadeable Streams Assessment: Water Chemistry Laboratory Manual*. EPA/841/B-04/008. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Environmental Information.

U.S. EPA. 2007. *National Rivers and Streams Assessment: Field Operation Manual.* EPA/841/B-07/009. Washington, DC: U.S. Environmental Protection Agency.

U.S. EPA. 2007. *National Rivers and Streams Assessment: Laboratory Operations Methods Manual.* EPA/841/B-07/010. Washington, DC: U.S. Environmental Protection Agency.

U.S. EPA. 2007. *National Rivers and Streams Assessment: Quality Assurance Project Plan.* EPA/841/B-07/007. Washington,, DC: U.S. Environmental Protection Agency.

U.S. EPA. 2007. *National Rivers and Streams Assessment: Site Evaluation Guidelines.* EPA/841/B-07/008. Washington, DC: U.S. Environmental Protection Agency.

Probability designs

Olsen, A.R., J. Sedransk, D. Edwards, C.A. Gotway, W. Liggett, S. Rathbun, K.H. Reckhow, and L.J. Young. 1999. Statistical issues for monitoring ecological and natural resources in the United States. *Environmental Monitoring and Assessment* 54: 1-45.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics* 8: 167-195.

Stevens, D.L., Jr., and N.S. Urqhart. 2000. Response designs and support regions in sampling continuous domains. *Environmetrics* 11: 11-41.

Stevens, D.L., Jr., and A.R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4: 415-428.

Stevens, D.L., Jr., and A.R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics* 14: 593-610.

Stevens, D.L., Jr., and A.R. Olsen. 2004. Spatially-balanced sampling of natural resources in the presence of frame imperfections. *Journal of American Statistical Association* 99: 262-278.

Ecological regions

Griffith, G.T., T. Loveland, T. Olsen, and J. Omernik (contributors). 1997. *Ecological Regions of North America — Toward a Common Perspective.* Montreal, QC: Secretariat of the Commission for Environmental Cooperation.

Hamilton, P.A., T.L. Miller, and D.N. Myers. 2004. Water quality in the nation's streams and aquifers — overview of selected findings, 1991-2001. U.S. Geological Circular 1265. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey.

Jacobson, R.B., S.R. Femmer, and R.A. McKenney. 2001. Land-use change and the physical habitat of streams: a review with emphasis on studies within the U.S. Geological Survey Federal-State Cooperative Program. U.S. Geological Circular 1175. U.S. Department of the Interior, U.S. Geological Survey, Reston, Va.

Laroe, E.T., G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac, eds. 1995. *Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems*. Washington, DC: U.S. Department of the Interior, National Biological Service.

Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran. 1998. *Status and Trends of the Nation's Biological Resources*. 2 volumes. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77: 118-125.

U.S. EPA. 2000. *National Water Quality Inventory: 1998 Report to Congress.* EPA/841/R-00/001. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

Fish multimetric indices

Blocksom, K.A. 2003. A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic Highlands streams. *Environmental Management* 31: 0670-0682.

Bramblett, R.G., T.R. Johnson, A.V. Zale, and D.G. Heggem. 2005. Development and evaluation of a fish assemblage index of biotic integrity for northwestern Great Plains streams. *Transactions of the American Fisheries Society* 134: 624-640.

Cutler, D.R., T.C. Edwards, K.H. Beard, A. Cutler, K.T. Hess, J. Gibson, and J.J. Lawler. 2007. Random forests for classification in ecology. *Ecology* 88: 2783-2792.

Emery, E.B., T.P. Simon, F.H. McCormick, P.L. Angermeier, J.E. DeShon, C.O. Yoder, R.E. Sanders, W.D. Pearson, G.D. Hickman, R.J. Reash, and J.A. Thomas. 2003. Development of a multimetric index for assessing the biological condition of the Ohio River. *Transactions of the American Fisheries Society* 132: 791-808.

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

McCormick, F.H., R.M. Hughes, P.R. Kaufmann, D.V. Peck, J.L. Stoddard, and A.T. Herlihy. 2001. Development of an index of biotic integrity for the Mid-Atlantic Highlands region. *Transactions of the American Fisheries Society* 130: 857-877.

Meador, M.R., and D.M. Carlisle. 2009. Predictive models for fish assemblages in eastern U.S. streams: Implications for assessing biodiversity. *Transactions of the American Fisheries Society* 138: 725-740.

Indices of biotic integrity

Barbour, M.T., J.B. Stribling, and J.R. Karr. 1995. Chapter 6: Multimetric approach for establishing biocriteria and measuring biological condition. In W.S. Davis and T.P. Simon, eds. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* pp. 63-77. Boca Raton, FL: Lewis.

Frey, D.G. 1977. The integrity of water — an historical approach. In S.K. Ballentine and L.J. Guarala, eds. *The Integrity of Water.* pp. 127-140. Washington, DC: U.S. Environmental Protection Agency.

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

Karr, J.R., and D.R. Dudley. 1981. Ecological perspective on water quality goals. *Environmental Management* 5: 55-68.

Mebane, C.A., T.R. Maret, and R.M. Hughes. 2003. An index of biological integrity (IBI) for Pacific Northwest rivers. *Transactions of the American Fisheries Society* 132: 239-261.

Observed/expected models

Hawkins, C.P. 2006. Quantifying biological integrity by taxonomic completeness: Its utility in regional and global assessments. *Ecological Applications* 16: 1277-1294.

Hawkins, C.P., R.H. Norris, J.N. Hogue, and J.W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. *Ecological Applications* 10: 1456-1477.

Hawkins, C.J., Y. Cao, and B. Rober. 2010. Method of predicting reference condition biota affects the performance and interpretation of ecological indices. *Freshwater Biology* 55: 1066-1085.

Van Sickle, J., C.P. Hawkins, D.P. Larsen, and A.T. Herlihy. 2005. A null model for the expected macroinvertebrate assemblage in streams. *Journal of the North American Benthological Society* 24: 178-191.

Wright, J.F. 2000. An introduction to RIVPACS. In J.F. Wright, D.W. Sutcliffe, and M.T. Furse, eds. *Assessing the Biological Quality of Fresh Waters.* pp. 1-24. Ambleside, UK: Freshwater Biological Association.

Periphyton

Bahls, L.L. 1993. *Periphyton Bioassessment Methods for Montana Streams.* Helena, MT: Montana Department of Health and Environmental Sciences.

Baker, E.A., K.E. Wehrly, P.W. Seelbach, L. Wang, M.J. Wiley, and T. Simon. 2005. A multimetric assessment of stream conditoin in the Northern Lakes and Forests ecoregion using spatially explicit statistical modeling and regional normalization. *Transactions of the American Fisheries Society* 134: 697-710.

Clarke, R.T., M.T. Furse, J.F. Wright, and D. Moss. 1996. Derivation of a biological quality index for river sites: Comparison of the observed with the expected fauna. *Journal of Applied Statistics* 23: 311-332.

Stevenson, R.J. 2006. Refining diatom indicators for valued ecological attributes and development of water quality criteria. In: N. Ognjanova-Rumenova and K. Manoylov, eds. *Advances in Phycological Studies.* pp. 365-383. Moscow, Russia: Pensoft Publishers.

Stevenson, R.J., R.C. Bailey, M.C. Harass, C.P. Hawkins, J. Alba-Tercedor, C. Couch, S. Dyer, F.A. Fulk, J.M. Harrington, C.T. Hunsaker, and R.K. Johnson. 2004. Designing data collection for ecological assessments. In M.T. Barbour, S.B. Norton, H.R. Preston, and K.W. Thornton, eds.

Ecological Assessment of Aquatic Resources: Linking Science to Decision-Making. pp. 55-84. Pensacola, FL: SETAC Press.

Stevenson, R.J., R.C. Bailey, M.C. Harass, C.P. Hawkins, J. Alba-Tercedor, C. Couch, S. Dyer, F.A. Fulk, J.M. Harrington, C.T. Hunsaker, and R.K. Johnson. 2004. Interpreting results of ecological assessments. In M.T. Barbour, S.B. Norton, H.R. Preston, and K.W. Thornton, eds. *Ecological Assessment of Aquatic Resources: Linking Science to Decision-Making.* pp. 85-111. Pensacola, FL: SETAC Press.

Stevenson, R.J., B.E. Hill, A.T. Herlihy, L.L. Yuan, and S.B. Norton. 2008. Algal-P relationships, thresholds, and frequency distributions guide nutrient criterion development. *Journal of the North American Benthological Society* 27: 783-799.

Stevenson, R. J., Y. Pan, K. Manoylov, C. Parker, D. P. Larsen, and A.T. Herlihy. 2008. Development of diatom indicators of ecological conditions for streams of the western United States. *Journal of the North American Benthological Society* 27: 1000-1016.

Physical habitat

Bryce, S.A., G.A. Lomnicky, P.R. Kaufmann, L.S. McAllister, and T.L. Ernst. 2008. Development of biologically-based sediment criteria in mountain streams of the western United States. *North American Journal of Fisheries Management* 28: 1714-1724.

Bryce, S.A., Lomnicky, G.A., and P.R. Kaufmann. 2010. Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically-based streambed sediment criteria. *Journal of the North American Benthological Society* 29(2): 657-672.

Buffington, J.M., and D.R. Montgomery. 1999. Effects of hydraulic roughness on surface textures of gravel-bed rivers. *Water Resources Research* 35: 3507-3521.

Buffington, J.M., and D.R. Montgomery. 1999. Effects of sediment supply on surface textures of gravel-bed rivers. *Water Resources Research* 35: 3523-3530.

Cummins, K.W. 1974. Structure and function of stream ecosystems. *BioScience* 24: 631-641.

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

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* 41: 540-551.

Kaufmann, P.R., P. Levine, E.G. Robison, C. Seeliger, and D. Peck. 1999. *Quantifying Physical Habitat in Wadeable Streams*. EPA/600/3-88/021a. Washington, DC: U.S. Environmental Protection Agency.

Kaufmann, P.R., J.M. Faustini, D.P. Larsen, and M.A. Shirazi. 2008. A roughness-corrected index of relative bed stability for regional stream surveys. *Geomorphology* 199: 150-170.

Kaufmann, P.R., D.P. Larsen, and J.M. Faustini. 2009. Bed stability and sedimentation associated with human disturbances in Pacific Northwest streams. *Journal of the American Water Resources Association* 45(2): 434-459.

Kaufmann, P.R., and J.M. Faustini, 2011. Simple measures of channel habitat complexity predict transient hydraulic storage in streams. *Hydrobiologia* 685(1): 69-95.

Reference condition

Bailey, R.C., R.H. Norris, and T.B. Reynoldson. 2004. *Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach*. New York, NY: Kluwer Academic Publishers.

Hughes, R.M. 1995. Chapter 4: Defining acceptable biological status by comparing with reference conditions. In W. Davis and T. Simon, eds. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making for Rivers and Streams.* pp. 31-47. Boca Raton, FL: Lewis.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: The concept of reference condition. *Ecological Applications* 16: 1267-1276.

Other EMAP assessments

Stoddard, J.L., A.T. Herlihy, B.H. Hill, R.M. Hughes, P.R. Kaufmann, D.J. Klemm, J.M. Lazorchak, F.H. McCormick, D.V. Peck, S.G. Paulsen, A.R. Olsen, D.P. Larsen, J. Van Sickle, and T.R. Whittier. 2006. *Mid-Atlantic Integrated Assessment (MAIA) — State of the Flowing Waters Report.* EPA/600/R-06/001. Washington, DC: U.S. Environmental Protection Agency.

U.S. EPA. 2000. *Mid-Atlantic Highlands Streams Assessment*. EPA/903/R-00/015. Philadelphia, PA: U.S. Environmental Protection Agency, Region 3.

Biological condition gradient/quality of reference sites

Davies, S.P., and S.K. Jackson. 2006. The Biological Condition Gradient: A conceptual model for interpreting detrimental change in aquatic ecosystems. *Ecological Applications* 16: 1251-1266.

Lattin, P.D. In preparation. A process for characterizing watershed level disturbance using orthophotos.

Relative risk

Van Sickle, J., J.L. Stoddard, S.G. Paulsen, and A.R. Olsen. 2006. Using relative risk to compare the effects of aquatic stressors at a regional scale. *Environmental Management* 38(6): 1020-1030.

Nutrients

Bourassa, N., and A. Cattaneo. 1998. Control of periphyton biomass in Laurentian streams (Quebec). *Journal of the North American Benthololological Society* 17: 420-429.

Dodds, W.K., and E.B. Welch. 2000. Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19(1): 186-196.

Kelly, M.G. 1998. Use of community-based indices to monitor eutrophication in rivers. *Environmental Conservation* 25: 22-29.

Kelly, M.G., and B.A. Whitton. 1995. The trophic diatom index: A new index for monitoring eutrophication in rivers. *Journal of Applied Phycology* 7: 433-444.

Miltner, R.J., and E.T. Rankin. 1998. Primary nutrients and the biotic integrity of rivers and streams. *Freshwater Biology* 40: 145-158.

Nordin, R.N. 1985. *Water Quality Criteria for Nutrients and Algae: Technical Appendix.* Victoria, BC: Ministry of Environment. www.env.gov.bc.ca/wat/wq/BCguidelines/nutrients/nutrientstech.pdf.

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

Welch, E.B. 1992. *Ecological Effects of Wastewater.* 2nd edition. London, UK: Chapman and Hall.

List of Abbreviations and Acronyms

ANC	acid-neutralizing capacity
CPL	Coastal Plains
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
MMI	multimetric index
NAP	Northern Appalachians
NARS	National Aquatic Resource Surveys
NHD	USGS National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NPL	Northern Plains
NRSA	National Rivers and Streams Assessment
O/E	observed/expected
PCB	polychlorinated biphenyl
qPCR	quantitative polymerase chain reaction
RBS	relative bed stability
SAP	Southern Appalachians
SPL	Southern Plains
TPL	Temperate Plains
UMW	Upper Midwest
USGS	U.S. Geological Survey
WMT	Western Mountains
WSA	Wadeable Streams Assessment
XER	Xeric region