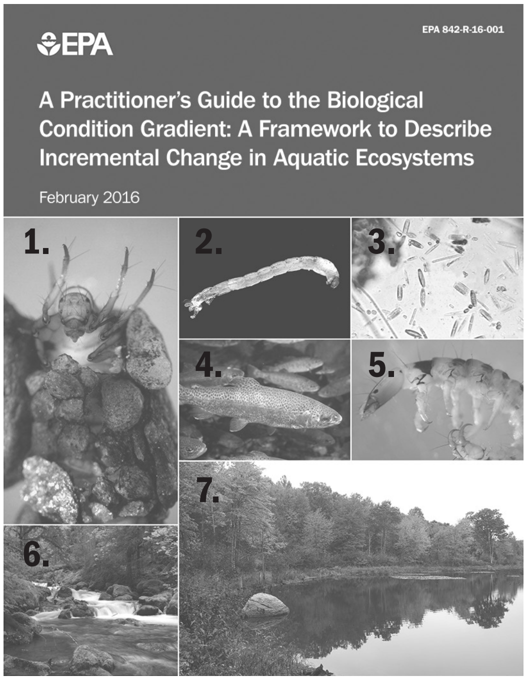
EPA 842-R-16-001

A Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems

February 2016



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Contact Information

For more information, questions, or comments about this document, please contact Susan Jackson, U.S. Environmental Protection Agency, at Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, Mail Code 4304T, Washington, DC 20460 or by email at jackson.susank@epa.gov.

Citation

USEPA. 2016. *A Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems*. EPA-842-R-16-001. U.S. Environmental Protection Agency, Washington, DC.

Contributing Authors

Susan Jackson, USEPA Office of Water, Office of Science and Technology, Washington, DC
Jeroen Gerritsen, PhD, Tetra Tech, Inc., Owings Mills, Maryland
Susan Davies, Midwest Biodiversity Institute, Columbus, Ohio[*]
Lucinda Johnson, PhD, Associate Director and Senior Research Associate, Natural Resources Research Institute, University of Minnesota Duluth, Minnesota

Appendix B Case Study Authors

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Ed Rankin, Midwest Biodiversity Institute, Columbus, Ohio

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Emily Shumchenia, PhD, E&C Enviroscape, LLC; Giancarlo Cicchetti, PhD, and Marguerite C. Pelletier, PhD, USEPA Office of Research and Development, National Health and Environmental Effects Research Laboratory–Atlantic Ecology Division, Narragansett, Rhode Island

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Patricia Bradley[**] and Deborah Santavy, PhD, USEPA Office of Research and Development, National Health and Environmental Effects Research Laboratory–Gulf Ecology Division, Gulf Breeze, Florida

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Chris Yoder, Research Director, Midwest Biodiversity Institute, Columbus, Ohio

Technical Editors

Susan B. Norton, PhD, USEPA Office of Research and Development, National Center for Environmental Assessment, Alexandria, Virginia
Douglas Norton, USEPA Office of Water, Office of Wetlands, Oceans and Watersheds, Washington, DC
Clair Meehan, Tetra Tech, Inc., Fairfax, Virginia

---

[*] Formerly with the Maine Department of Environmental Protection and state co-chair for the expert workgroup that developed the conceptual Biological Condition Gradient Framework. See Davies and Jackson 2006.

[**] Patricia Bradley retired from USEPA in October 2015. Since that time, she has joined Tetra Tech, Inc.

Acknowledgements

Thank you to the following scientists and state, territorial, county and tribal agencies for their leadership and support with development and piloting of the biological condition gradient.[***] There were additional experts involved for each of the case examples presented in this document.

State, Territorial, and Tribal BCG Workgroup Members and Pilots (2000–2015)
Alabama Department of Environmental Management – Lisa Huff
Alabama Geological Survey – Patrick O'Neill
Arizona Department of Environmental Quality – Patti Spindler
California Department of Fish and Game – Jim Harrington
Colorado Department of Public Health and Environment – Robert McConnell, Paul Welsh
Connecticut Department of Energy and Environmental Protection – Chris Bellucci
Florida Department of Environmental Protection – Russ Frydenborg, Ellen McCarron, Nancy Ross
Idaho Department of Environmental Quality – Mike Edmondson
Kansas Department of Health and Environment – Robert Angelo, Steve Haslouer, Brett Holman
Kentucky Department for Environmental Protection – Tom VanArsdall
Maine Department of Environmental Protection – David Courtemanch, Susan Davies, Leon Tsomides, Tom Danielson, Jeanne DiFranco, Beth Connors
Maryland Department of the Environment – Richard Eskin, George Harmon, Matthew Stover
Maryland Department of Natural Resources – Scott Stranko
Minnesota Pollution Control Agency – Will Bouchard, Greg Gross
Mississippi Department of Environmental Quality – Leslie Barkley, Natalie Guerdon
Montana Department of Environmental Quality – Randy Apfelbeck, Rosie Sada
Montgomery County, Maryland, Department of the Environment – Kenneth Mack, Jennifer St John, Keith Van Ness
Narragansett Bay National Estuary Program – Tom Borden, Program Director
New Jersey Department of Environmental Protection – Kevin Berry, Thomas Belton
Nevada Division of Environmental Protection – Karen Vargas
North Carolina Department of Environment and Natural Resources – David Lenat, Trish MacPherson
Ohio Environmental Protection Agency – Jeff DeShon, Dan Dudley
Ohio River Valley Water Sanitation Commission – Erich Emery
Oregon Department of Environmental Quality – Doug Drake, Rick Hafele
Pennsylvania Department of Environmental Protection – Dustin Shull, Gary Walters
Pyramid Lake Paiute Tribe – Dan Mosley
Rhode Island Department of Environmental Management – Chris Deacutis
Texas Commission on Environmental Quality – Mark Fisher, Charles Bayer, William Harrison, Ann Rogers
Upper Mississippi River Basin Association – David Hokanson, Deputy Director
Vermont Department of Environmental Conservation – Doug Burnham, Steve Fisk
Virginia Department of Environmental Quality – Alexander Barron, Larry Willis
Washington State Department of Ecology – Robert Plotnikoff
Wisconsin Department of Natural Resources – Joseph Ball, Edward Emmons, Robert Masnado, Greg Searle, Michael Talbot, Lizhu Wang

---

[***] Affiliations of each individual are those at the time of participation in the BCG development and/or pilots. Since that time, a number of these individuals have changed affiliations or have retired.

U.S. Environmental Protection Agency
Office of Water: Chris Faulkner, Thomas Gardner, Susan Holdsworth, Susan Jackson, Kellie Kubena, Douglas Norton, Christine Ruff, Robert Shippen, Treda Grayson, William Swietlik, Lester Yuan

Regional (R) Offices: Peter Nolan, Margherita Pryor, Hilary Snook, Diane Switzer (R1), Jim Kurtenbach, Thomas Belton, Eveylyn Huertas, David Cuervas (R2), Maggie Passmore, Gregory Pond, Louis Reynolds (R3), Ed Decker, Jim Harrison, David Melgard, Eve Zimmerman (R4), Ed Hammer, David Pfeifer (R5), Philip Crocker, Charlie Howell (R6), Gary Welker (R7), Tina Laidlaw, Jill Minter (R8), Gary Wolinsky, Terry Fleming (R9), Gretchen Hayslip (R10)

Office of Environmental Information: Wayne Davis

Office of Research and Development: Laurie Anderson, Britta Bierwagen, Patricia Bradley, Karen Blocksom, Susan Cormier, Giancarlo Cicchetti, William Fisher, Joseph Flotermirsch, Timothy Gleason, Philip Larsen, Frank McCormick, Susan Norton, Marguerite Pelletier, Kenneth Rocha, Deborah Santavy, Danielle Tillman
U.S. Geological Survey
Evan Hornig, Ken Lubinski, Caroline Rogers

Scientific Community (Academic, Non Governmental, and Private Sector)
David Allan, University of Michigan
David Braun, The Nature Conservancy
Don Charles, Philadelphia Academy of Natural Sciences at Drexel University
Jan Ciborowski, University of Windsor
Michael Barbour, Jeroen Gerritsen, Benjamin Jessup, Clair Meehan, Michael Paul, Jennifer Stamp, Tetra Tech, Inc.
Richard Hauer, University of Montana
Charles Hawkins, Utah State University
Donald Huggins, Central Plains Center for Bioassessment
Bob Hughes, Oregon State University
Lucinda Johnson, University of Minnesota Duluth
James Karr, University of Washington
Dennis McIntyre, Great Lakes Environmental Center
Gerald Niemi, University of Minnesota
Jan Stevenson, Michigan State University
Denice Wardrop, Pennsylvania State University
Edward Rankin and Chris Yoder, Midwest Biodiversity Institute

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Executive Summary

The Clean Water Act (CWA) established a long-term objective to restore and protect the biological integrity of the nation's waters. In the more than 40 years since the passage of the CWA, there has been considerable progress in the science of aquatic ecology and in the development of biological monitoring and assessment techniques to support implementation of the Act. The U.S. Environmental Protection Agency (EPA) published its first guidance document on biological assessments and criteria in 1990. Since then, aquatic science and its application in state water quality programs has advanced significantly. States, territories, and authorized tribes (herein identified as "states") now routinely use biological information to directly assess the biological condition of their aquatic resources, track changes in their condition, and develop biological criteria to set expectations for maintaining biological integrity.

This document is designed for scientists engaged in biological assessments of water bodies. It outlines a conceptual framework, the Biological Condition Gradient (BCG), for states to use to more precisely define and interpret baseline biological conditions, help evaluate potential for improvement in degraded waters, and measure and document incremental changes in condition along a gradient of anthropogenic stress. The conceptual framework can be populated with state or regional data to develop a quantitative model and establish numeric thresholds. The BCG is intended to complement existing biological assessment and criteria methods and approaches.

What is the Biological Condition Gradient?

The BCG is a conceptual, scientific framework for interpreting biological response to increasing effects of stressors on aquatic ecosystems. The framework was developed based on common patterns of biological response to stressors observed empirically by aquatic biologists and ecologists from different geographic areas of the United States. Scientists from 21 states, one interstate basin association, and one tribe were involved in BCG development, in addition to scientists from EPA, the U.S. Geological Survey, universities, and the private sector. The framework describes how 10 characteristics of aquatic ecosystems change in response to the increasing levels of stressors, from an "as naturally occurs" condition (e.g., undisturbed/minimally disturbed condition) to severely altered conditions. The characteristics, defined in this document as "attributes," include aspects of community structure, organism condition, ecosystem function, and connectivity. The BCG framework can be considered analogous to a field-based dose-response curve where the dose (x-axis) represents increasing level of anthropogenic stress, and the response (y-axis) represents biological condition.

Who Will Use the Biological Condition Gradient and For What Purpose?

Currently most states are using biological assessment information to support their water quality management programs. The BCG contributes to the EPA biological assessment and criteria "toolbox," which includes biological indices, models, statistical approaches, and guidance. The BCG builds upon and complements these approaches to provide a more refined and detailed measure of biological condition and can help water quality management programs to:

- More precisely define and measure biological condition for specific waters;
- Identify and protect high quality waters;
- Evaluate potential for improvement in degraded waters;
- Track changes in condition;

- Develop biological criteria; and
- Clearly communicate the likely impact of water quality management decisions to stakeholders.

These applications support CWA programs such as 305(b) assessments and reports, 303(d) listing of impaired waters, and the Total Maximum Daily Load program implementation. The document includes examples of how states are using, or are considering using, the BCG to support their water quality management programs.

Why Now?

As the first BCG projects have been completed, there has been increasing interest in the BCG by other state water quality management programs. Based on informal discussion with state water quality managers and scientists who have been directly engaged in BCG development, their primary motivation for using a BCG has been to more precisely define baseline conditions, better understand the quality of their reference sites, identify high quality waters as candidates for additional protection, help evaluate the potential for restoration of degraded waters, and document incremental improvements as best management practices are implemented. In all cases, the states have emphasized the value of the BCG to help communicate to the public the biological condition of their waters in context of the CWA integrity objective and the likely outcomes of water quality management decisions.

Because of the interest in BCGs, it is important now to document the status of model development, discuss current strengths and limitations, and provide examples of how states are developing and applying the BCG. This document provides a template and step-by-step process for constructing robust BCGs, drawing from the lessons learned during a decade of testing by interstate, state, territorial, and local government water quality management programs. As BCG development and calibration continues, it is expected that the BCG process will be refined and improved.

Biological Condition Gradient Development: Decision Rules

This document describes the steps that entail convening an expert panel in order to construct narrative descriptions and quantitative rules for assigning sites to BCG levels. Different approaches to developing quantitative rules are discussed (e.g., mathematical set theory, derivation and calibration of biological indices, and multivariate statistical and/or predictive modeling approaches). The core objective of the panel process is to elicit expert judgment on defining ecologically significant change in the biotic community and to document the underlying rationale for the judgments. By using a process to elicit expert judgment, first narrative and then quantitative rules emerge and are tested and refined based on the current state of the science, expert knowledge, and available data. The intended end product is a set of well-vetted and transparent decision rules that can be readily understood and implemented by state water quality program managers and scientists. Routine use of a quantitative BCG model by state water quality management programs requires well documented and transparent decision rules so that assessments can be made for newly sampled water bodies without reconvening the expert panel.

Specifically, the document presents:

- An approach to quantify the conceptual BCG framework and develop a numeric model. This approach is based on elicitation of the experts' decision criteria and incorporation those of criteria into a numeric decision model using a mathematical set theory approach (e.g., fuzzy logic). This approach has been tested and refined in most of the BCG projects to date.

- Considerations and approaches for relating the BCG with the state's existing biological assessment methods and tools such as multimetric biological indices. To date, most states have developed biological indices.
- An example of a state approach to quantify the conceptual BCG. This approach involves development of statistical models that predict (or simulate) the expert decisions.

Building on these initial efforts, it is expected that additional methods to quantify the conceptual BCG will be identified and tested.

The Stress Axis

The x-axis of the BCG framework, the Generalized Stress Axis (GSA), conceptually describes the range of anthropogenic stress that may adversely affect aquatic biota in a particular area. It is a theoretical construct. As multiple stressors are usually present in a system, the GSA seeks to represent the cumulative stress that may influence biological condition. Typically, states have defined a stress gradient using single or a combination of known, measurable stress gradients that in reality represent a portion of the stressors impacting a water body. The conceptual GSA provides a framework to assist in development of as comprehensive and robust a quantitative stress gradient as possible to support BCG development. A well-defined, quantitative GSA, and the underlying data used to develop it, may serve as a nexus between biological and causal assessments, thereby linking management goals and selection of management actions for protection or restoration. However, a systematic testing of technical approaches to define and apply a GSA to BCG development has not been conducted. This document discusses technical issues to consider and provides examples of approaches to quantify a GSA. Opportunities in the future may include piloting methods for application of national, regional, or basin scale databases and methods to support state efforts to quantify a GSA for a specific geographic region and water body type.

Document Organization

Chapters 1 and 2 explain the purpose and scientific underpinnings of the BCG. Chapters 3 and 4 present methods on how to define and quantify the BCG biological axis, the biological levels of condition that span undisturbed to severely altered conditions. Chapter 5, supported by Appendix A, provides an overview, framework, and examples to describe the stress axis of the BCG model, the GSA. Examples of how states have developed and applied the BCG are presented in Chapter 6. To date, use of the BCG to support water quality management has primarily been for fresh water, perennial streams. However, work underway is presented in Appendix B on BCG development for large rivers, estuaries, and coral reefs.

Chapter 1. Introduction to the Biological Condition Gradient

1.1 Document Purpose

The Clean Water Act (CWA) established a long-term objective to, among other things, restore and protect the biological integrity of the nation's waters (Figure 1). In the more than 40 years since the passage of the CWA, there has been considerable progress in the science of aquatic ecology and in the development of biological monitoring and assessment techniques to support implementation of the Act (USEPA 2011a, 2013a). Since the U.S. Environmental Protection Agency (EPA) published its first guidance document on biological assessments and criteria, aquatic science and its application in state water quality programs has advanced (USEPA 1990, 2002, 2011a, 2013a). States, territories, and authorized tribes (herein referred to as "states") now routinely use biological information to directly assess the condition of their aquatic resources, track changes in biological condition, and develop biological criteria to set expectations for maintaining biological integrity.

Figure 1. Stream and wadeable river, two examples of waters covered under the CWA.

Under the CWA, states have the primary authority to implement their water quality programs with EPA review for consistency with the CWA requirements, which include implementing regulations. As a consequence, states have independently developed technical approaches to assess biological condition and establish thresholds (Hawkins 2006; USEPA 2002). Although these different approaches have fostered innovation, they have complicated a nationally consistent approach to interpreting the condition of aquatic resources. A consistent approach to interpreting biological condition will allow scientists, water resource managers, and stakeholders to share a common understanding and language to describe the condition of their waters, as well as share data and information across jurisdictional boundaries (Davies and Jackson 2006).

In addition to using a variety of approaches for assessing and interpreting biological condition, states have created a range of different aquatic life use (ALU) classes to describe the expected biological condition of their waters. At one end of the spectrum, states have adopted a general narrative statement that replicates the ALU goal identified in the CWA (e.g., protection and propagation of fish, shellfish, and wildlife). At the other end are more detailed approaches that describe the expected species, assemblages, or habitats (e.g., salmonids, warmwater habitat, coldwater fisheries) or that specify levels of condition (e.g., excellent, good, fair). Currently, most states have established one general ALU class, with a single threshold for assessing attainment. A limitation of a single ALU class is that the full range of biological conditions along a human disturbance gradient is limited to only two categories: pass and fail. Water bodies assigned to a single ALU class could include a range of biological conditions found in undisturbed to moderately disturbed landscapes, or, in some cases even include highly disturbed conditions where anthropogenic impacts are widespread and pervasive. As a result, a water body supporting biological conditions characteristic of higher quality waters could degrade to a lower level of water quality yet still be categorized as meeting its ALU. In contrast, for water that is severely degraded, the designated ALU might not be achievable in the short term, and therefore incremental improvements due to management actions will not be measured or acknowledged. A scientific framework that describes incremental biological changes along the full gradient of human disturbance helps water quality managers identify and protect high quality waters and track incremental improvements in degraded waters.

This document outlines a conceptual framework, the Biological Condition Gradient (BCG), that states can use to more precisely describe existing, or baseline, biological condition; help evaluate potential for improvement in condition; and measure incremental changes in condition along a gradient of human disturbance, i.e., anthropogenic stress. The conceptual framework can be populated with state or regional data to develop a quantitative model. It is intended to complement existing biological assessment and criteria methods and approaches.

This document reports on the current status of quantitative model development and application. As BCG development and calibration continues, it is expected that the BCG process will be further refined and improved.

1.2 Background: When and Why?

In 2000, EPA convened a technical expert workgroup to identify scientifically sound and practical approaches that would help states use biological assessments to better determine existing conditions and potential for improvement, more precisely define ALUs, and develop biological criteria. The workgroup consisted of scientists from federal, state, and tribal water programs, an interstate basin association, the academic research community, and the private sector (see Davies and Jackson 2006 for a list of workgroup members). The overarching objective of this effort was to develop a common framework and language for interpreting biological condition. In the subsequent four years, the workgroup met annually with drafts of the framework undergoing review and preliminary testing between meetings. The effort was primarily guided by the practical experience of scientists and water quality program managers from the 21 states, the interstate basin association and tribe participating in the workgroup. The workgroup developed the conceptual BCG framework to describe levels, or tiers, of biological response to increasing levels of stressors. The conceptual BCG was developed and tested through a series of data exercises using a diverse array of data sets with initial focus on freshwater perennial streams and wadeable rivers.

The workgroup activities coincided with a National Research Council (NRC) review of EPA's Total Maximum Daily Load (TMDL) program and publication of its report *Assessing the TMDL Approach to Water Quality Management* (NRC 2001). Among other recommendations, the NRC recommended the use of biological assessments to better understand water quality and the establishment of a more precise, descriptive approach to goal-setting as a step towards improving decision making and establishing appropriate ALU goals. For example, rather than stating that a water body needs to be "fishable," the ALU would ideally describe the expected fish assemblage or population (e.g., salmonid, coldwater fishery, warmwater fishery), as well as the other biological assemblages necessary to support that fish population. Additionally, levels of expected condition would be defined based on potential of a water body to achieve a higher level of condition (e.g., salmonid spawning versus migration; undisturbed and minimally disturbed conditions versus moderately or highly disturbed). The NRC recommendation to more precisely define designated ALUs was taken into account by the BCG workgroup as they developed the BCG framework. Since completion of the conceptual BCG framework (Davies and Jackson 2006), many states have further developed and refined quantitative BCG models (see Table 4, Chapter 3). In conjunction with other water quality management technical tools, the state programs that have developed and applied the BCG have done so to help:

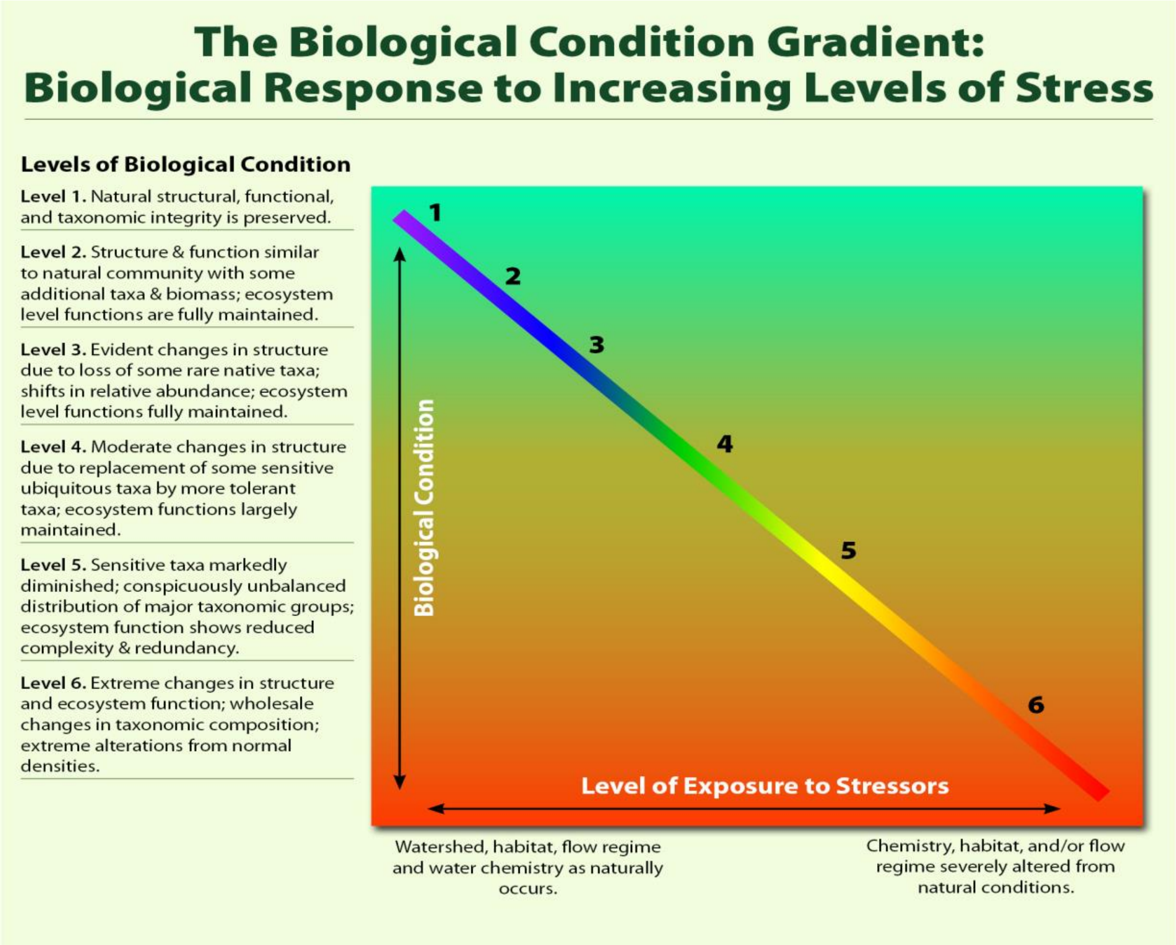
- Set scientifically defensible, ecologically-based aquatic life goals based on existing conditions and potential for improvement;
- Determine baseline conditions and measure impacts of multiple stressors or system altering conditions (e.g., climate change) on aquatic life;
- Further the use of monitoring data for the assessment of water quality standards (WQS) and tracking changes in biological condition;
- Identify high quality waters for protection (e.g., Tier III antidegradation); and
- Communicate to stakeholders the likely impact of decisions on protection and management of aquatic resources.
- Develop biological criteria.

When asked about the most immediate, value-added benefits to their water quality management programs from the development of a quantitative BCG model, state water quality program managers and scientists cited the ability to measure and document incremental improvements due to management actions and better identify and protect high quality waters.

The BCG conceptual framework, quantitative model development, and implementation reflects an improved understanding of aquatic ecosystems and their biota resulting from more than 40 years of assessment data and advances in use of these data in state water quality management programs. This document represents the culmination of four years of workgroup deliberations, including four workgroup meetings and two workshops to "road test" the conceptual BCG framework, followed by ten years of development and application of quantitative BCG models in state programs. Over the past ten years, the BCG has been developed for perennial streams, including headwater streams, using expert consensus to develop narrative and numeric decision rules to assign sites to BCG levels. The use of the BCG to complement or refine existing state measures such as Indices of Biotic Integrity (IBIs) is being explored. Application of the BCG to water bodies other than perennial streams is underway for large rivers, estuaries, and coral reefs. These latter efforts show promise for expanding the application of the BCG beyond streams to more complex systems.

1.3 The Biological Condition Gradient: Brief Overview

The conceptual BCG is a scientific framework for interpreting biological response to increasing effects of stressors on aquatic ecosystems (Figure 2). The framework was developed based on common patterns of biological response to stressors observed empirically by aquatic biologists and ecologists from different geographic areas of the United States (Davies and Jackson 2006). It describes how characteristics of aquatic ecosystems that are typically measured by state water quality management programs change in response to increasing levels of stress (see Table 1). The characteristics, defined as attributes, include properties of the communities (e.g., tolerance, rarity, native-ness) and organisms (e.g., condition, function) and are more fully described in Chapter 2.



The Biological Condition Gradient: Biological Response to Increasing Levels of Stress

Levels of Biological Condition

Level 1. Natural structural, functional, and taxonomic integrity is preserved.

Level 2. Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained.

Level 3. Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained.

Level 4. Moderate changes in structure due to replacement of some sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained.

Level 5. Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy.

Level 6. Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities.

Watershed, habitat, flow regime and water chemistry as naturally occurs.

Chemistry, habitat, and/or flow regime severely altered from natural conditions.

Figure 2. Conceptual model of the BCG. Although in reality the relationship between stressors and their cumulative effects on the biota is likely nonlinear, the relationship is presented as such to illustrate the concept.

The BCG can be considered analogous to a field-based dose-response curve where the dose (x-axis) represents increasing levels of stressors, and the response (y-axis) represents biological condition. Stressors are physical, chemical, or biological factors that induce an adverse response from aquatic biota (USEPA 2000b). For example, high concentrations of certain metals, nutrients, or sediment can adversely impact, or stress, aquatic biota. Loss of suitable aquatic habitat or presence of aquatic invasive species can also adversely impact the aquatic biota expected for a specific water body. These stressors can cause aquatic ecosystems to change from natural conditions and exhibit altered compositional, structural, and functional characteristics. The degree to which stressors affect the biota depends on the magnitude, frequency, and duration of the exposure of the biota to the stressors. Developing a BCG for a given system characterizes the general relationship between its stressors in total and a water body's overall biological condition. Multiple stressors are usually present, and thus, the stress x-axis of the BCG seeks to represent their cumulative influence as a Generalized Stress Axis (GSA),[1] much as the y-axis generalizes biological condition. The x and y axes of the BCG serve as a framework to organize, relate, and help reconcile the mosaic of factors and interactions that exist, parts of which will be characterized and measured using biological, chemical, physical, and/or land use/land cover indicators.

Table 1. Ecological characteristics (i.e., attributes) used to develop the BCG

Attribute	Description
I	Historically documented, sensitive, long-lived, or regionally endemic taxa
II	Highly sensitive taxa*
III	Intermediate sensitive taxa
IV	Intermediate tolerant taxa
V	Tolerant taxa
VI	Non-native or intentionally introduced species
VII	Organism condition
VIII	Ecosystem function
IX	Spatial and temporal extent of detrimental effects
X	Ecosystem connectance

*Note: Identified as *Sensitive-rare taxa* in Davies and Jackson 2006.

The BCG differs from the standard dose-response curve in that the BCG does not represent the laboratory response of a single species to a specified dose of a known chemical, but rather the *in-situ* response of the resident biotic community to the sum of stressors to which that community is exposed. Thus, it is an outcome-based measure and something that can express complex water quality goals such as biological integrity. In this document EPA proposes a BCG that is divided into six levels of biological condition along a generalized stressor-response curve, ranging from observable biological conditions found at no or low levels of stressors (level 1) to those found at high levels of stressors (level 6). States may propose to consolidate or aggregate these levels into fewer levels or further refine and increase the number of levels. Regardless of how many levels a quantitative BCG may ultimately include, it can be crosswalked with the conceptual model. Chapter 6 and Appendix B illustrate examples of ecoregional or state-specific BCGs and how they may be "mapped" onto the conceptual BCG.

Between 2000 and 2005, the original framework was tested at annual workgroup meetings and then at two regional workshops in the Great Plains and in the Arid Southwest. It was tested by determining how consistently the scientists assigned samples of benthic macroinvertebrates or fish to the different levels

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[1] For more information on the Generalized Stress Axis, see Chapter 5.

of biological condition in freshwater streams. Workgroup members identified similar sequences of biological response to increasing levels of stressors regardless of geographic area and predicted that the framework in principal should be applicable to other water body types. These results support the development and application of the BCG as a nationally applicable framework for interpreting the biological condition of aquatic systems (Davies and Jackson 2006).

Understanding the links between stressors (and their sources) with the response of the aquatic biota will help water quality managers to more accurately determine both the existing and potential conditions of the aquatic biota in a specific water body and help predict the stressors that affect that condition (Figure 3). This information will assist water quality program managers in determining the most effective recourse to address biological impairment. There are different approaches and new studies, methods, and large data sets that can assist states to better define and quantify the causal sequence between stressors and their sources and biological responses once biological impairment is identified.[2] Ultimately, the goal of the EPA biological criteria program is to build a stronger technical bridge between biological condition assessments, causal assessments, and the actions taken to protect and restore biological condition. A well-defined BCG x-axis, the GSA, and the science underlying it may help achieve this objective. In Chapter 5, information on approaches and technical challenges to define the GSA are discussed, with examples of a conceptual GSA framework and potential stress indicators included in Appendix A.

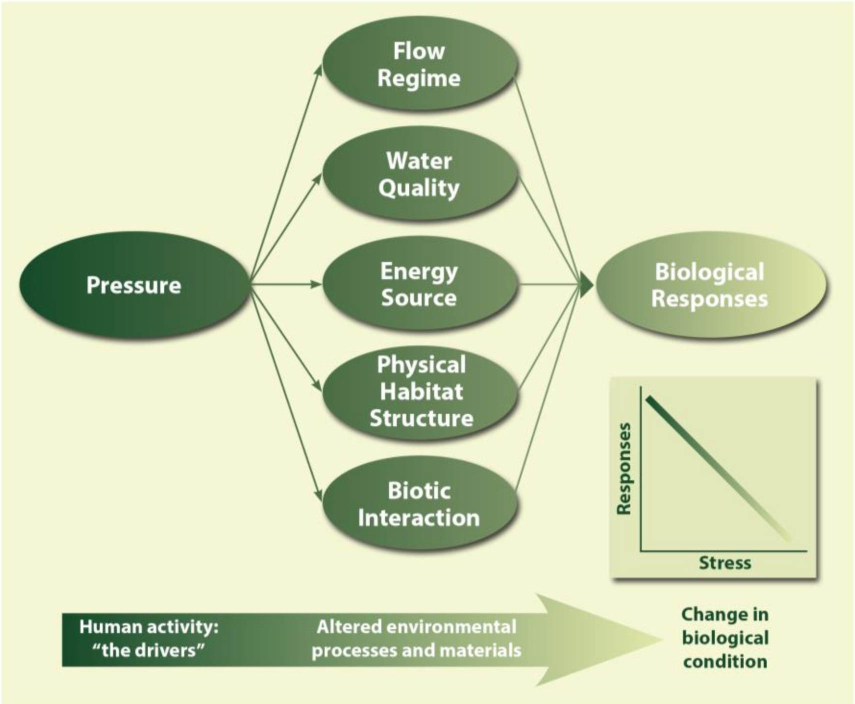

Figure 3. Model illustrating the multiple pathways through which human activities may exert pressure on an aquatic system by altering fundamental environmental processes and materials, creating stressors that may adversely affect the aquatic biota (Source: Modified from figure courtesy of David Allen, University of Michigan).

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[2] See http://www3.epa.gov/caddis/ and http://www.epa.gov/rps/learn-about-recovery-potential-screening-rps. Accessed February 2016.

1.4 Use of the Biological Condition Gradient to Support Water Quality Standards and Condition Assessments

The full objective of section 101(a) of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In the scientific literature, an aquatic system with chemical, physical, and biological integrity has been described as being capable of "supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region" (Frey 1977).

Over the intervening years, the understanding of how to define and measure the integrity of aquatic systems has advanced considerably. The term "integrity" has been further refined in the literature to mean a balanced, integrated, adaptive system having a full range of ecosystem elements (e.g., genera, species, assemblages) and processes (e.g., mutation, demographics, biotic interactions, nutrient and energy dynamics, metapopulation dynamics) expected in areas with no or minimal human disturbance (Karr 2000). The aquatic biota residing in a water body are the result of complex and interrelated chemical, physical, and biological processes that act over time and on multiple scales (e.g., instream, riparian, landscape) (Karr et al. 1986; Yoder 1995). By directly measuring the condition of the aquatic biota, one is able to more accurately define the aquatic community that is the outcome of all these factors.

To help achieve the integrity objective, the CWA also established an interim goal for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water. EPA has interpreted the "protection and propagation" interim goal for aquatic life to include the protection of the full complement of aquatic organisms residing in or migrating through a water body. As explained in EPA's *Water Quality Standards Handbook* (USEPA 2014a), the protection afforded by WQS includes the representative aquatic community (e.g., fish, benthic macroinvertebrates, and periphyton):

> The fact that sport or commercial fish are not present does not mean that the water may not be supporting an aquatic life protection function. An existing aquatic community composed entirely of invertebrates and plants, such as may be found in a pristine tributary alpine stream, should be protected whether or not such a stream supports a fishery. Even though the shorthand expression 'fishable/swimmable' is often used, the actual objective of the Act is to restore the chemical, physical and biological integrity of our Nation's waters (section 101(a)). The term 'aquatic life' would more accurately reflect the protection of the aquatic community that was intended in section 101(a)(2) of the Act.

The representative community of aquatic organisms residing in, or migrating through, a water body will vary depending on the water body type. For example, fish, benthic macroinvertebrates, and periphyton are aquatic assemblages measured by states and tribes when assessing the biological condition of most streams and rivers. However, in headwater streams and many wetlands, amphibians are an important component of the biotic community, and fish may be absent. Large river and estuarine assessments typically include both benthic invertebrates and fish community measures. In coral reefs, coral, sponge, and fish communities are key assemblages to measure and assess. The BCG offers a framework to provide more detailed and descriptive statements of the aquatic community expected in an undisturbed or minimally disturbed aquatic community, as well as potential incremental changes that might be expected in community characteristics with increasing levels of anthropogenic stress.

1.4.1 Use of the Biological Condition Gradient to Support Aquatic Life Use Assessments

While section 101(a) of the CWA establishes the objective to restore and maintain the chemical, physical, and biological integrity of the nation's waters, other sections of the CWA establish the programs and authorities for implementation of this objective. Section 303(c) provides the basis of the WQS program. WQS are components of state (or, in certain instances, federal) law that define the water quality goals of a water body, or parts of a water body, by designating the use or uses of the water body and by setting criteria necessary to protect the uses (in addition to antidegradation requirements).

Although the CWA gives EPA an important role in determining appropriate minimum levels of protection and providing national oversight, it also gives considerable flexibility and discretion to state water quality managers to design their own programs and establish levels of protection above the national minimums. CWA section 303 directs states to adopt WQS to protect the public health and welfare, enhance the quality of water, and serve the purposes of the CWA. "Serve the purposes of the Act" (as defined in sections 101(a), 101(a)(2), and 303(c) of the CWA) means that WQS should include provisions for restoring and maintaining chemical, physical, and biological integrity of state waters; provide, wherever attainable, water quality for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water (i.e., "fishable/swimmable"); and consider the use and value of state and tribal waters for public water supplies, propagation of fish and wildlife, recreation, agricultural and industrial purposes, and navigation. Further requirements for WQS can be found at 40 *Code of Federal Regulations* (CFR) Part 131.

State WQS provide the foundation for water quality-based pollution control programs. With the public participating in their adoption (see 40 CFR 131.20), such standards serve the dual purposes of (1) establishing the water quality goals for a specific water body and (2) providing the regulatory basis for the establishment of water quality-based treatment controls and strategies beyond the technology-based levels of treatment required by sections 301(b) and 306 of the CWA. The WQS serve as, among other things, the basis for ALU attainment decisions, National Pollutant Discharge Elimination System (NPDES) permit limits, and the targets for TMDLs.[3]

40 CFR Part 131.10(a) of the WQS regulation requires that states specify appropriate water uses to be achieved and protected. A water body's designated uses are those uses specified in WQS, whether or not they are being attained (40 CFR 131.3(f)). *The designated use of a water body is the most fundamental articulation of the water body's role in the aquatic environment as defined by society*. All of the water quality protections established by the CWA follow from the water body's designated use. As designated uses are critical in determining the water quality criteria that apply to a given water body, determining and clearly defining the appropriate designated use is of paramount importance in establishing criteria that are appropriately protective of that designated use. In addition, the regulations establish a rebuttable presumption that the uses of protection and propagation of fish, shellfish, and wildlife and recreation in and on the water are attainable and must apply to a water body, unless it has been affirmatively demonstrated that such uses are not attainable.

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[3] For more information about Water Quality Standards, see the WQS Regulation at http://www.epa.gov/wqs-tech/final-rulemaking-update-national-water-quality-standards-regulation (Accessed February 2016) and EPA's Water Quality Standards Handbook at http://www.epa.gov/wqs-tech/water-quality-standards-handbook (Accessed February 2016).

Biological assessments can be effectively used to help subcategorize the ALU designations. For example, states may adopt subcategories of a use and set the appropriate criteria to reflect varying needs of such subcategories of uses to differentiate between coldwater and warmwater fisheries (see 40 CFR 131.10(c)). States may also adopt seasonal uses, such as the use of streams or rivers for migratory or spawning purposes (40 CFR 131.10(f)). One major challenge in assigning designated uses for aquatic life to surface waters is separating the natural differences inherent in aquatic ecosystems and appropriately classifying them by type (e.g., naturally coldwater vs. warmwater streams) and location (e.g., ecoregion) from the differences that result from exposure to anthropogenic stressors. Natural or "naturally occurring" conditions can be interpreted as comparable to the range of physical, biological, and chemical conditions observed in undisturbed to minimally disturbed reference sites (Stoddard et al. 2006). When developed using reference data sets from long term biological monitoring and assessment programs, the boundaries for the upper BCG levels can be described in a narrative form and quantified to document the observed natural conditions. The BCG thus provides a descriptive framework to help biologists and water quality managers interpret their aquatic life goals relative to natural conditions. By more fully accounting for natural differences in aquatic ecosystems, designating more specific ALUs helps to reduce a major source of uncertainty and error in water quality management.

The BCG can be used by state programs not only to develop detailed narrative descriptions of ALU goals in terms of the expected biological community, but also to help develop numeric biological criteria for measuring attainment of the goals (USEPA 1990, 2011a). Water quality *criteria* are elements of state WQS expressed as constituent concentrations, levels, or narrative statements representing a quality of water that supports a particular use. When criteria are met, water quality is expected to protect the designated use (40 CFR 131.3). Once adopted into standards, criteria can serve as the basis for (1) controls on point and nonpoint source pollution concentrations to protect aquatic life, (2) statements of expectations for the condition of aquatic life in a water body, and (3) guidelines helpful in water quality planning (e.g., tracking of cumulative loads of point and nonpoint source pollutants). Biological criteria have been defined as narrative expressions or numeric values of the biological characteristics of aquatic communities based on appropriate reference conditions.

1.4.2 Use of the Biological Condition Gradient to Define Levels of Condition

By designating uses and articulating narrative and numeric criteria, states can establish environmental goals for their water resources and measure attainment of these goals. When designating uses, a state may weigh the environmental, social, and economic consequences of different use designations. Water quality regulations allow the state, with public participation, flexibility in weighing these considerations and adjusting designated uses over time. Clearly defining the uses that appropriately reflect the current and potential future uses for a water body, determining the attainability of those goals, and appropriately evaluating the consequences of a designation can be a challenging task.

A principal function of designated uses in WQS is to communicate the desired condition of surface waters to water quality managers, the regulated community, and the public. For designating ALUs, an effective approach is one that readily and transparently translates narrative biological descriptions of the ALU into quantitative measures, such as biological index values. The index values can be adopted into the WQS as biological criteria and thresholds established for assessing attainment. The indices should respond in predictable ways to stress so that degradation can be detected early and incremental improvements tracked. States that have developed robust biological assessment programs typically strive to distinguish different levels of biological condition. States have either made these levels explicit in their WQS by adopting detailed biological descriptions of ALUs, or they have implicitly done so by recognizing levels of condition in their monitoring protocols for assessing attainment of ALU.

Although the benefits of specificity might apply to any of the designated uses described in CWA section 303, the benefits are particularly relevant for ALUs, because a broad range of biological conditions can be interpreted as supporting an ALU. For example, biological conditions in a minimally disturbed stream in a wilderness area would likely support a biotic community close to what would naturally be expected, whereas the biological condition in a stream in a more developed watershed might be measurably impacted relative to the wilderness stream, the degree of impact dependent upon effectiveness of best management practices (BMPs) that have been implemented. Under non-specific ALU classification with a single ALU threshold, both streams might be judged as meeting the designated ALU, and a threshold might be set that does not protect the higher biological conditions in the wilderness stream from degrading. By specifically articulating ALU goals for systems with different levels of human disturbance, deterioration can be detected and preventive management actions can be triggered earlier in the process prior to serious and irretrievable degradation. The BCG provides a framework for defining management goals and designated uses for water bodies having different levels of biological condition.

Chapter 2. The Biological Condition Gradient: Fundamental Concepts

The BCG is a scientific framework that supports more refined interpretation of biological condition even when assessment approaches may differ. The BCG combines scientific knowledge with the practical observations and experience of biological assessment practitioners (Figure 4) with the needs of resource managers. In conjunction with other environmental data and information, it can be used by environmental practitioners to help:

- Determine the environmental conditions that exist, relative to naturally-derived conditions—The BCG provides a common language with which to interpret and communicate current ecological conditions relative to baseline conditions that are anchored in level 1 of the BCG, "as naturally occurs."
- Decide what environmental conditions are desired—The BCG can be used with expert groups and stakeholders to set easily communicated environmental goals.
- Plan for how to achieve these conditions—The BCG provides a scientific basis for planning, restoration, protection, and monitoring by providing a common language and a pathway to shared quantitative goals.

Figure 4. Biologists conducting stream and lake assessments.

The BCG translates the theoretical and empirical work of researchers and practitioners to create a nationally-applicable model that helps to link management goals for resource condition with the quantitative measures used in biological assessments. As discussed in Chapter 1, the conceptual BCG was developed and tested by an expert workgroup that included scientists from 21 states, an interstate basin association, and a tribe. The BCG was designed to describe ecological response to anthropogenic stressors in sufficient detail so that a site can be placed into a level[4] along the BCG continuum through use of the core data elements collected by most state monitoring programs (USEPA 2013a). This framework can be used to organize biological, chemical, physical, and land cover data and information to interpret changes in assemblage composition and structure, spatial and temporal size of disturbance, and declines in function and connectivity relative to a baseline of undisturbed or minimally disturbed conditions.

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[4] A full description of the BCG levels is provided in section 2.3.

The BCG provides an interpretative framework explicitly linking science and monitoring information to goals in water quality standards and criteria and, thus, aids in management decision making (Davies and Jackson 2006). Each of the proposed six levels of the BCG is described via a detailed narrative that communicates ecological characteristics associated with that condition level. In this way, the descriptive gradient can be used to interpret numeric metric scores into a fuller understanding of their ecological meaning and importance. Once calibrated to local data, the BCG creates a bridge between biological metric scores and the condition levels with which they are commonly associated.

2.1 The Scientific Foundation of the Biological Condition Gradient

The practice of using biological indicators to assess water quality is over a century old, and the scientific foundation of the BCG is based on many decades of biologists’ accumulated experience with biological assessment and monitoring. The Saprobien System is a concept based on organism tolerance proposed by Lauterborn in 1901 and further developed by Kolkwitz and Marsson (Davis 1995). This system uses benthic macroinvertebrates and planktonic plants and animals as indicators of organic loading and low dissolved oxygen (DO). It has been updated since its initial development and is currently used in several European countries. The limnologists Thienemann and Naumann developed the concept of trophic state classification for lakes in the 1920s (Cairns and Pratt 1993; Carlson 1992). Both the Saprobien System and lake trophic state classifications describe a response gradient (or response classes for lakes) to nutrient pollution. The Saprobien System was explicitly developed to assess human pollution in rivers, but the trophic state concept was originally developed to describe natural conditions in lakes and only later became a concept to describe pollution-induced eutrophication (e.g., Vollenweider 1968). The 1950s marked the development of Beck’s biotic index in the U.S. and Pantle and Buck’s Saprobic Index in Europe, both of which were directly based on the Saprobien System (Beck 1954; Pantle and Buck 1955). The Saprobic Index, which led to the development of the widely used Hilsenhoff Index (e.g., Hilsenhoff 1987a, 1987b) in the U.S., could be considered the predecessor of today’s biotic indices (Davis 1995). Later studies used diversity indices based on information theory to describe changes in community structure, richness, and dominance (evenness) as a measure of pollution effects (e.g., Wilhm and Dorris 1966).

Biological information from monitoring programs has been frequently synthesized by constructing biotic indices, such as the IBI (Karr 1981; Karr et al. 1986). The IBI integrates the concept of anchoring the measurement system in undisturbed reference conditions with the measurement of several indicators intended to reflect ecological components of composition, diversity, and ecosystem processes. It thus combines a conceptual model of ecosystem change in response to increasing levels of stressors with a practical measurement system. The BCG is also grounded in the concepts of stress ecology articulated by Odum et al. (1979), Odum (1985), Rapport et al. (1985), and Cairns et al. (1993), describing “natural” conditions and the change in biological condition caused by stressors. To achieve maximum potential application nationwide, the BCG levels were developed based on state biologists’ experiences with water quality management (Courtemanch et al. 1989; Yoder and Rankin 1995a), as well as the practical experience of a diverse group of aquatic scientists from different bio-geographic areas (Davies and Jackson 2006). The BCG:

- Describes a scale of six condition levels, from undisturbed (level 1) to highly disturbed conditions (level 6).
- Synthesizes existing field observations and generally accepted interpretations of patterns of biological change within a common framework.

- Incrementally measures how a system may have departed from undisturbed condition, based on observable, ecological attributes.

In its initial development, the description of biological attributes that make up the model applied best to permanent, hard-bottom streams that are exposed to increases in temperature, nutrients, fine sediments, and other pollutants. This is the stream-type and stressor regime originally described by the model and the one most developed to date, for example, in Alabama, Connecticut, Maine, Maryland, Minnesota, New Jersey, Ohio, and Vermont. The model has been further tested with states in different parts of the country and increasingly in different water body types (e.g., headwater streams, coastal plains freshwater streams, rivers, wetlands, estuaries, and coral reefs) to evaluate the national applicability of the model (see Appendix B for examples). Results have shown good correlation with some necessary refinement of the model attributes to accommodate regional and water body differences. For example, for the southern great plains region, attribute II, originally defined as sensitive-rare taxa, was redefined as *highly sensitive taxa* because rarity of a taxon in the region was not associated with sensitivity to stress. In this region, many rare, native taxa might be highly tolerant to stressors, such as low DO and high temperature. Through similar developmental processes, the BCG, as initially developed and tested, is applicable to other aquatic ecosystems and stressors with appropriate modifications. The BCG should be viewed as a scientific framework that can readily incorporate future advances in scientific understanding. The model building was initially based on expert consensus and then further tested and refined following procedures detailed in Chapter 3. Quantitative approaches for translating the narrative model into numeric values are discussed in Chapter 4.

The value of a conceptual framework such as the BCG is not only that it documents experimentally established knowledge, but that it also promotes a more rigorous testing of empirical observations by clearly stating them in a provisional model (Davies and Jackson 2006). Conceptual models formalize the state of knowledge and guide research. Empirically-based generalizations have led to conceptual models that describe the behavior of biological systems under stress (Brinkhurst 1993; Fausch et al. 1990; Karr and Dudley 1981; Margalef 1963, 1981; Odum et al. 1979; Rapport et al. 1985; Schindler 1987). For example, Brinkhurst (1993) observed that "Everyone knew [in 1929] that increases in numbers and species could be related to mild pollution, that moderate pollution could produce changes in taxa so that diversity remained similar but species composition shifted, and that eventually species richness declined abruptly and numbers of some tolerant forms increased dramatically." Such ecosystem responses to stressor gradients have been portrayed as a progression of stages that occur in a generally consistent pattern (Cairns and Pratt 1993; Odum 1985; Odum et al. 1979; Rapport et al. 1985). Establishing and validating quantifiable thresholds along that progression with empirical data is a priority need for resource managers (Cairns 1981).

2.2 The Biological Condition Gradient Attributes

The BCG framework depicts ecological condition in terms of observable or measurable changes in an aquatic system in response to anthropogenic stress. The characteristics, described as "attributes" in this document, were selected because they corresponded to the characteristics used by state workgroup members to measure biological condition and develop biological criteria. The 10 attributes are discussed below and listed in Table 1. In biological assessments, most information is collected at the spatial scale of a site or reach and the temporal scale ranging from a season to as short as a single sampling event. Many of the attributes that make up the BCG are based on these scales. Site scale attributes include aspects of taxonomic composition and community structure (attributes I–V), organism condition (attribute VI), and organism and system performance (attributes VII and VIII). At larger temporal and spatial scales, physical-biotic interactions (attributes IX and X) are also included because of their importance to state water quality management programs in evaluating longer-term impacts, determining restoration potential, and tracking recovery in specific water bodies.

Information used to assess the ten attributes may be acquired from two sources. Sample-based data from instream monitoring using standardized sampling protocols can produce the most reliable, reproducible form of information and are best used for attributes II–V. Knowledge-based information, such as evidence from natural history surveys, agency records and reports (e.g., stocking reports), academic studies and journal publications, expert observations, and so on, can contribute significantly to BCG development even when methods are inconsistent. Since many of the attributes rely on the positive observation (i.e., presence) of an organism and its relative occurrence in the community, any reliable sources of information can be used to develop and calibrate the BCG for a specific water body and/or region. Attributes I–X are described below (from Davies and Jackson 2006).

Attribute I: Historically Documented, Sensitive, Long-lived, or Regionally Endemic Taxa

Attribute I can be developed using both sample-based and knowledge-based sources. Taxa that are *historically documented* refer to those known to have been supported in a water body or region according to historical records. This attribute was derived to cover taxa that are s*ensitive or regionally endemic* that have restricted, geographically isolated distribution patterns (occurring only in a locale as opposed to a region), often due to unique life history requirements. They may be long-lived and late maturing and have low fecundity, limited mobility, multiple habitat requirements as with diadromous species, or require a mutualistic relationship with other species. They may be among listed Endangered or Threatened (E/T) or special concern species. Predictability of occurrence is often low, and therefore requires documented observation. The presence or absence of a population might provide significant information in an assessment, but there are typically insufficient data to develop the stress response relationships needed to assign these taxa to attributes II through V (as discussed below). Recorded occurrence may be highly dependent on sample methods, site selection, and level of effort, thus requiring use of knowledge-based sources in addition to actual instream sampling. The taxa that are assigned to this category require expert knowledge of life history and regional occurrence of the taxa to appropriately interpret the significance of their presence or absence. Long-lived species are especially important as they provide evidence of multi-annual persistence of habitat condition. For example, many species of freshwater mussels in the Southeast U.S. are highly endemic and have been extirpated in many areas. The presence of freshwater mussels in a stream might signify high quality conditions, but their absence does not necessarily indicate poor conditions if overharvesting of the mussels is the cause.

Attribute II: Highly Sensitive Taxa

Highly sensitive taxa typically occur in low numbers relative to total population density, but they might make up a large relative proportion of richness. In high quality sites, they might be ubiquitous in occurrence or might be restricted to certain micro-habitats. Many of these species commonly occur at low densities, so their occurrence is dependent on sample effort. They are often stenothermic (i.e., having a narrow range of thermal tolerance) or cold-water obligates, and their populations are maintained at a fairly constant level, with slower development and a longer life-span. They might have specialized food resource needs, feeding strategies, or life history requirements, and they are generally intolerant to significant alteration of the physical or chemical environment. They are often the first taxa lost from a community following moderate disturbance or pollution.

In earlier descriptions of the BCG, highly sensitive taxa were called *sensitive-rare* taxa (Davies and Jackson 2006), but experience with calibrating the BCG showed that some highly sensitive species are found at many exceptional sites, and some were occasionally highly abundant (e.g., Snook et al. 2007). The distinguishing characteristic for this attribute category was found to be sensitivity and not relative rarity, although some of these taxa might be uncommon in the data set (e.g., very small percent of sample occurrence or sample density)

Attribute III: Intermediate Sensitive Taxa

Intermediate sensitive taxa were formerly labeled sensitive-ubiquitous taxa (Davies and Jackson 2006), but subsequent development revealed that the experts relied upon the sensitivity of a species to stress rather than whether it was "ubiquitous," though intermediate sensitive taxa are ordinarily common and abundant in natural communities. They tend to have a broader range of tolerances than highly sensitive taxa, and they usually occur in reduced abundance and reduced frequencies at disturbed or polluted sites. These taxa often comprise a substantial portion of natural communities.

Attribute IV: Intermediate Tolerant Taxa

Attribute IV taxa commonly comprise a substantial portion of an assemblage in undisturbed habitats, as well as in moderately disturbed or polluted habitats. They exhibit physiological or life-history characteristics that enable them to thrive under a broad range of thermal, flow, or oxygen conditions. Many have generalist or facultative feeding strategies enabling utilization of diverse food types. These species have little or no detectable response to moderate stress, and they are often equally abundant in both reference and moderately stressed sites. Some intermediate tolerant taxa may show an "intermediate disturbance" response, where densities and frequency of occurrence are relatively high at intermediate levels of stress, but they are intolerant of excessive pollution loads or habitat alteration.

Attribute V: Tolerant taxa

Tolerant taxa are those that typically comprise a low proportion of natural communities. These taxa are more tolerant of a greater degree of disturbance and stress than other organisms and are, thus, resistant to a variety of pollution or habitat induced stress. They may increase in number (sometimes greatly) under severely altered or stressed conditions. They may possess adaptations in response to organic pollution, hypoxia, or toxic substances. These are the last survivors in severely disturbed systems and can prevail in great numbers due to lack of competition or predation by less tolerant organisms, and they are key community components of level 5 and 6 conditions.

Attribute VI: Non-native or Intentionally Introduced Taxa

With respect to a particular ecosystem, species fitting attribute VI are any species not native to that ecosystem. Species introduced or spread from one region of the U.S. to another outside their normal ranges are non-native, or non-indigenous. This category also includes species introduced from other continents and referred to as "alien" species. Attribute VI can also include introduced disease or parasitic organisms. This attribute represents both an effect of human activities and a stressor in the form of biological pollution. Although some intentionally introduced species are valued by large segments of society (e.g., gamefish), these species might be as disruptive to native species as undesirable opportunistic invaders (e.g., zebra mussels). Many rivers in the U.S. are dominated by non-native fish and invertebrates (Moyle 1986), and the introduction of non-native species is the second most important factor contributing to fish extinctions in North America (Miller et al. 1989). The BCG identifies the presence of native taxa expected under undisturbed or minimally disturbed conditions as an essential characteristic of BCG level 1 and 2 conditions. The BCG only allows for the occurrence of non-native taxa in these levels if those taxa do not displace native taxa and do not have a detrimental effect on native structure and function. Condition levels 3 and 4 depict increasing occurrence of non-native taxa. Extensive replacement of native taxa by tolerant or invasive, non-native taxa can occur in levels 5 and 6. Attribute VI may rely on either sample-based or knowledge-based sources.

Attribute VII: Organism Condition

Organism condition is an element of ecosystem function, expressed at the level of anatomical or physiological characteristics of individual organisms. Organism condition includes direct and indirect indicators such as fecundity, morbidity, mortality, growth rates, and anomalies (e.g., lesions, tumors, and deformities). Some of these indicators are readily observed in the field and laboratory, whereas the assessment of others requires specialized expertise and much greater effort. Organism condition can also change with season or life stage, or occur as short-term events making assessment difficult. The most common approach for state programs is to forego complex and demanding direct measures of organism condition (e.g., fecundity, morbidity, mortality, disease, growth rates) in favor of indirect or surrogate measures (e.g., percent of organisms with anomalies, age or size class distributions) (Simon 2003). Organism anomalies in the BCG vary from naturally occurring incidence in levels 1 and 2 to higher than expected incidence in levels 3 and 4. In levels 5 and 6, biomass is reduced, the age structure of populations indicates premature mortality or unsuccessful reproduction, and the incidence of serious anomalies is high. This attribute has been successfully used in stream indices based on the fish assemblage (Sanders et al. 1999; Yoder and Rankin 1995a). Incidence of disease is being evaluated as an indicator of organism condition for the coral reef BCG (see Appendix B-3).

Attribute VIII: Ecosystem Function

Ecosystem function refers to any processes required for the performance of a biological system expected under naturally occurring conditions. Naturally occurring conditions have been typically interpreted as those conditions found in undisturbed to minimally disturbed conditions but some processes can be sustained under moderate levels of disturbance. Examples of ecosystem functional processes are primary and secondary production, respiration, nutrient cycling, and decomposition. Assessing ecosystem function includes consideration of the aggregate performance of dynamic interactions within an ecosystem, such as the interactions among taxa (e.g., food web dynamics) and energy and nutrient processing rates (e.g., energy and nutrient dynamics) (Cairns 1977).

Additionally, ecosystem function includes aspects of all levels of biological organization (e.g., individual, population, and community condition). Altered interactions between individual organisms and their abiotic and biotic environments might generate changes in growth rates, reproductive success, movement, or mortality. These altered interactions are ultimately expressed at ecosystem-levels of organization (e.g., shifts from heterotrophy to autotrophy, onset of eutrophic conditions) and as changes in ecosystem process rates (e.g., photosynthesis, respiration, production, decomposition).

At this time, the level of effort required to directly assess ecosystem function is beyond the means of most state monitoring programs. Instead, in streams and wadeable rivers, most programs rely on taxonomic and structural indicators to make inferences about functional status (Karr et al. 1986). For example, shifts in the primary source of food might cause changes in trophic guild indices or indicator species. Although direct measures of ecosystem function are currently difficult or time consuming, they might become practical in the future (Gessner and Chauvet 2002). The BCG conceptual model includes ecosystem function for future application.

Attribute IX: Spatial and Temporal Extent of Detrimental Effects

The spatial and temporal extent of stressor effects includes the near-field to far-field range of observable effects of the stressors on a water body. Such information can be conveyed by biological assessments provided the spatial density of sampling sites is sufficient to convey changes along a pollution continuum (USEPA 2013a). Use of a continuum provides a method for determining the severity (i.e., departure from the desired state) and extent (i.e., distance over which adverse effects are observed) of an impairment from one or more sources. Yoder et al. (2005) detailed this approach in their historical assessment of large rivers in Ohio. As with attribute VIII above, attribute IX has not yet been developed and applied in BCG models for specific streams and wadeable rivers. It is included for future development and application. State scientists involved in the development of the BCG conceptual model stated that this attribute was important to include for future testing and development. Some state biological monitoring and assessment programs document the spatial and temporal extent of stressor effects and use the information to predict the recovery potential of a degraded stream, as well as the risk of degradation in high quality streams. This information informs water quality management decisions on prioritization of actions. The National Hydrography Dataset (NHD) (USGS 2014), together with biological assessment information from attributes I–VIII can be an important tool to help evaluate position and extent of condition and stressors in a water body or watershed by mapping the locations (i.e., spatial distribution) of the biological samples.

Attribute X: Ecosystem Connectance

Attribute X refers to the access or linkage (in space/time) to materials, locations, and conditions required for maintenance of interacting populations of aquatic life. It is the opposite of fragmentation and is necessary for persistence of metapopulations and natural flows of energy and nutrients across ecosystem boundaries. Ecosystem connectance can be indirectly expressed by certain species that depend on the connectance, or lack of connectance, within an aquatic ecosystem to fully complete their life cycles and thus maintain their populations. Diadromous fish species are one such example—their absence or presence can provide information on the presence or absence of critical habitats to support different life stages. However, the inverse of connectance, isolation, is important for some species (e.g., amphibians, which are negatively impacted by fish that gain access to amphibian habitat via artificial or natural connections). This difference dependence upon connectance underscores the importance of well-defined BCG levels 1 and 2 as the benchmark for interpreting change in the BCG attributes. The NHD can be an important tool to evaluate the extent of connections (or occurrence of barriers or habitat disconnects) in a water body or watershed. A habitat mosaic measure is being evaluated as an indicator of ecosystem connectance in the estuarine BCG (see Appendix B-2).

2.3 The Biological Condition Gradient Levels

The BCG has been divided into six levels along a generalized stressor-response continuum to provide discrimination of different levels of condition that are detectable, given current assessment methods and well-designed monitoring protocols. Since the BCG is a continuum, in principle it is possible to determine more or fewer levels depending upon the discriminatory power of a state water quality management program (USEPA 2013a). The six levels are proposed as a hypothetical framework for which the practical concerns of the state would determine the number of levels that can be implemented. For example, in most forested perennial stream ecosystems it may be technically possible to discriminate six classes in the condition gradient, ranging from undisturbed to highly disturbed conditions (Davies and Jackson 2006). However, some states or regions may only be capable of discriminating two or three levels, given current technical program capabilities, while others might be capable of discerning six or more levels based on highly proficient programs and robust data sets (USEPA

2013a). In addition, some regions of the country may not currently support level 1 water conditions. *Regardless of the number of levels a state can detect, the BCG framework is to be a starting point for a state to think about how to use biological information to better determine existing conditions and potential for improvement and how to use the information to better communicate biological condition and to set water quality objectives*.

The six levels of the BCG are described as follows (modified from Davies and Jackson 2006).

- **Level 1, Natural or native condition**—*Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability.* Level 1 represents biological conditions as they existed (or still exist) in the absence of measurable effects of stressors and provides the basis for comparison to the next five levels. The level 1 biological assemblages that occur in a given biogeophysical setting are the result of adaptive evolutionary processes and biogeography. For this reason, the expected level 1 assemblage of a stream from the arid southwest will be very different from that of a stream in the northern temperate forest. The maintenance of native species populations and the expected natural diversity of species are essential for levels 1 and 2. Non-native taxa (attribute VI) might be present in level 1 if they cause no displacement of native taxa, although the practical uncertainties of this provision are acknowledged (see section 2.2). Attributes I and II (i.e., historically documented and sensitive taxa) can be used to help assess the status of native taxa when classifying a site or assessing its condition.
- **Level 2, Minimal changes in structure of the biotic community and minimal changes in ecosystem function**—*Most native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability.* Level 2 represents the earliest changes in densities, species composition, and biomass that occur as a result of slight elevation in stressors (e.g., increased temperature regime or nutrient pollution). There might be some reduction of a small fraction of highly sensitive or specialized taxa (attribute II) or loss of some endemic or rare taxa as a result. The occurrence of non-native taxa should not measurably alter the natural structure and function and should not replace any native taxa. Level 2 can be characterized as the first change in condition from natural, and it is most often manifested in nutrient-polluted waters as slightly increased richness and density of either intermediate sensitive and intermediate tolerant taxa (attributes III and IV) or both. These early response signals have been observed in many state programs as illustrated in Figure 5, which shows slight to moderate increases of mayfly density in response to increases in conductivity in Maine streams. Mayfly taxa typically have been identified in Maine as sensitive ubiquitous taxa and show an increase to initial levels of some stress (e.g., an increase in conductivity or nutrient pollution), followed by a decrease in abundance as stress levels continue to rise.

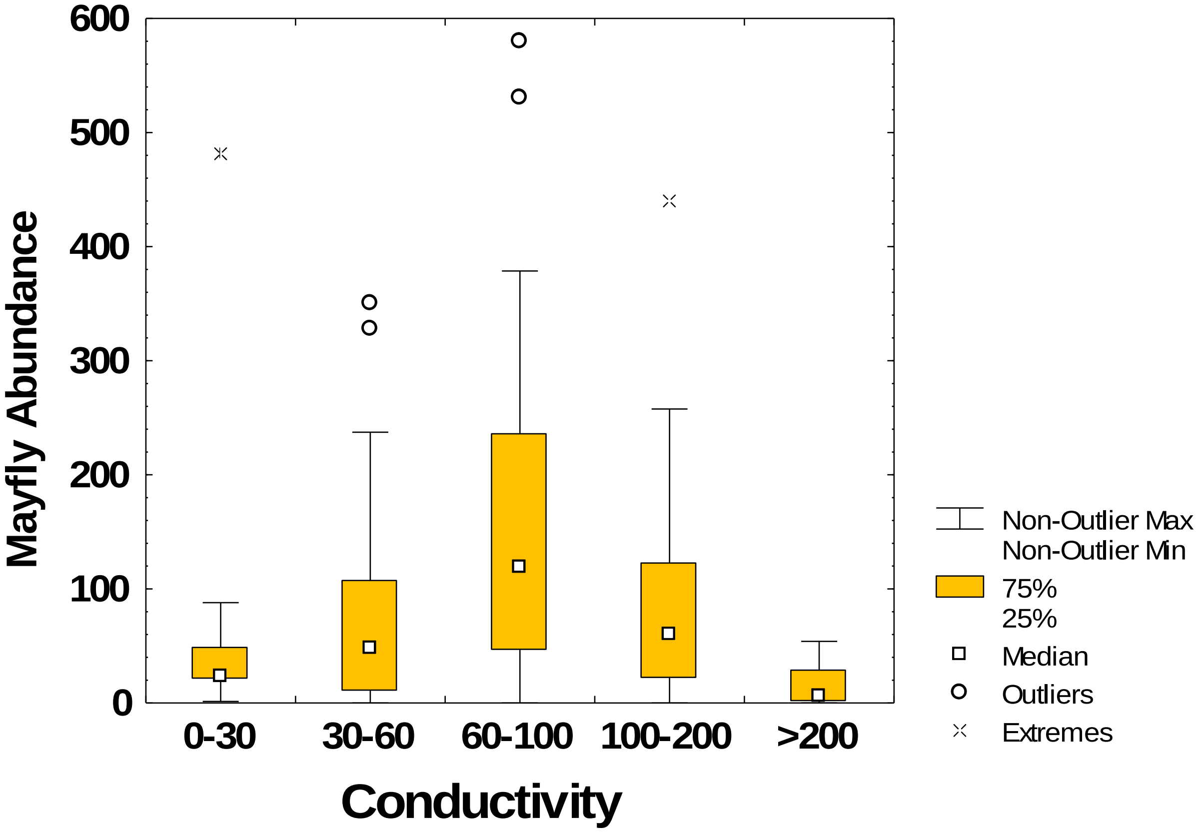

Figure 5. Response of mayfly density to stress in Maine streams as indicated by a gradient of increasing conductivity.

- **Level 3, Evident changes in structure of the biotic community and minimal changes in ecosystem function**—*Evident changes in structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa, but sensitive-ubiquitous taxa are common and relatively abundant; ecosystem functions are fully maintained through redundant attributes of the system.* Level 3 represents readily observable changes that, for example, can occur in response to organic pollution or increased temperature. The "evident" change in structure for level 3 is interpreted to be perceptible and detectable decreases in highly sensitive taxa (attribute II), and increases in sensitive-ubiquitous taxa or intermediate organisms (attributes III and IV). Attribute IV taxa (intermediate intolerance) might increase in abundance as an opportunistic response to nutrient or organic inputs.
- **Level 4, Moderate changes in structure of the biotic community with minimal changes in ecosystem function**—*Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes.* Moderate changes of structure occur as stressor effects increase in level 4. A substantial reduction of the two sensitive attribute groups (attributes II and III) and replacement by more tolerant taxa (attributes IV and V) might be observed. A key consideration is that some attribute III sensitive taxa are maintained at a reduced level, but they are still an important functional part of the system (i.e., function is

maintained). While total abundance (density) of organisms might increase, no single taxa or functional group should be overly dominant.

- **Level 5, Major changes in structure of the biotic community and moderate changes in ecosystem function**—*Sensitive taxa are markedly diminished or missing; conspicuously unbalanced distribution of major groups from those expected; organism condition shows signs of physiological stress; ecosystem function shows reduced complexity and redundancy; increased build-up or export of unused materials.* Changes in ecosystem function (as indicated by marked changes in food-web structure and guilds) are critical in distinguishing between levels 4 and 5. This could include the loss of functionally important sensitive taxa and keystone taxa (attribute I, II, and III taxa), such that they are no longer important players in the system, though a few individuals may be present. Keystone taxa control species composition and trophic interactions, and are often, but not always, top predators. As an example, removal of keystone taxa by overfishing has greatly altered the structure and function of many coastal ocean ecosystems (Jackson et al. 2001). Additionally, tolerant non-native taxa (attribute VI) may dominate some assemblages, and changes in organism condition (attribute VII) may include significantly increased mortality, depressed fecundity, and/or increased frequency of lesions, tumors, and deformities.
- **Level 6, Severe changes in structure of the biotic community and major loss of ecosystem function**—*Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor; ecosystem functions are severely altered.* Level 6 systems are taxonomically depauperate (i.e., low diversity and/or reduced number of organisms) compared to the other levels. For example, extremely high or low densities of organisms caused by excessive organic pollution, severe toxicity, and/or severe habitat alteration may characterize level 6 systems. Non-native taxa may predominate.

2.3.1 Bringing the Biological Condition Gradient Levels and Attributes Together

The BCG narrative portrays general patterns of biological and ecological response common across regions, as measured by the BCG attributes. Table 2 organizes the ten BCG attributes into six categories: community structure, non-natives, condition, function, landscape, and connectivity. Attributes I through V have been combined in one category in Table 2—structure and compositional complexity. This category typically includes measures of the number, type, and proportion of individual taxa within an assemblage (e.g., benthic macroinvertebrates, fish, and algal assemblages). These attributes are the foundation of most state biological assessment programs for streams and wadeable rivers. The five taxonomic attributes characterize biological sensitivity to the cumulative impact of stressors (e.g., highly, intermediate, or tolerant taxa). In addition to the sensitivity-based attributes, biologists have also used assemblage richness and balance, assemblage abundance or biomass, and keystone or habitat-structuring species (e.g., reef-building corals) to define attributes and distinguish levels of condition along a stress gradient. Attributes respond to stressors in distinctly different ways so that there are predictive, quantitative measures along the full range of stress levels (Figure 6, Table 3). Defining and quantifying these changes along the full gradient of stress effects is necessary for developing reliable, predictable measures for incremental changes in biological condition. For example, highly sensitive taxa might disappear from a community in early, or low, levels of stress. Tolerant taxa might become more dominant as stress increases, not only because they might thrive, but also because there are fewer sensitive species and the proportion of tolerant taxa in the entire community increases. Intermediate tolerant taxa might not provide a significant signal under most conditions if they are present under a wide range of stress. However, the absence of this group of taxa in highly stressed conditions can help document highly disturbed conditions, and their reappearance may indicate initial response to management actions for restoration. As work proceeds on applying the BCG to other water body types and developing approaches for including additional assemblages (e.g., periphyton, amphibians, birds) and new methods for sampling and analyzing aquatic life (e.g., DNA analysis), it is expected that these attributes will be refined and comparable detailed descriptions for the remaining attributes will emerge.

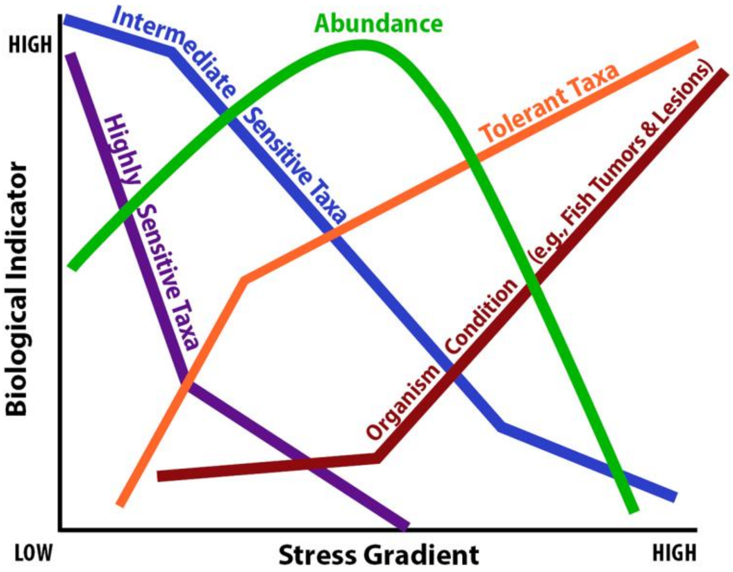

Figure 6. Hypothetical examples of biological response to the cumulative impact of multiple stressors.

Table 2. BCG: Ecological Attributes

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
STRUCTURE	Structure and Compositional Complexity (Attributes I–V) See Table 3 for detailed descriptions for these attributes.	Community or habitat structure and complexity. May also recognize loss of habitats or species due to human activities. Examples include macroinvertebrate or fish indices, phytoplankton or zooplankton community measures, epifaunal measures, biotope mosaics, presence/quantity of sensitive taxa or biotopes, wetland vegetative indices, etc.	Community composition is as naturally occurs, except for global extinctions based on observations from water bodies with similar habitat and ecoregion without measurable human-caused stressors (this includes chlorophyll a levels, biotope mosaics, species composition including large, long-lived, and sensitive species; patterns of vegetation are as naturally occurs)	Minor changes in natural occurrences of biotopes or patterns of vegetation, slight decreases in sensitive species, and slight increases in tolerant species	Evident changes in biological metrics (decreases in sensitive species and increases in more tolerant species, evident changes in vegetation patterns); may be slight decreases in biotope or habitat area; biotope mosaic basically intact	Significant changes in biological metrics (marked decreases in sensitive species [including large or long-lived taxa] and increases in tolerant species, evident changes in vegetation patterns); biotope mosaic slightly altered with replacement of natural habitats/biotopes with tolerant or non-naturally occurring components; detectable loss in some biotope types or habitat area	Most sensitive, large and/or long-lived taxa are absent, with a dominance in abundance of tolerant taxa; significant shifts in species diversity, size, and densities of remaining species; biotope mosaic significantly altered with many natural habitats/biotopes lost with replacement by tolerant or non-naturally occurring components; evident loss in biotope or habitat area	Sensitive, large, and/or long-lived taxa largely absent; possible high or low extremes in abundance of remaining taxa; marked reduction in species diversity and in size spectra of remaining organisms; near complete loss or alteration of natural biotope mosaic with marked loss in biotope or habitat area

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
NON-NATIVES	Non-Native Taxa (Attribute VI)	Status of non-native species. May include measures of the impact of invasive and non-native species. Examples include estimated numbers of species or individuals, relative density or biomass measures of natives and non-natives, or replacement of native species	Non-native taxa, if present, do not significantly reduce native taxa or alter structural or functional integrity	Non-native taxa may be present, but occurrence has a non-detrimental effect on native taxa	Non-native taxa may be prominent in some assemblages (e.g., crustaceans, bivalves, fish) and some sensitive native taxa may be reduced or replaced by equivalent non-native species (e.g., replacement of native trout with introduced salmonids)	Increased abundance of tolerant non-native species (e.g., Common Carp, non-native centrarchids, Common Reed) or native species (e.g., salmonids) only maintained by regular stocking	Some assemblages (e.g., mollusks, fishes, macrophytes) are dominated by invasive non-native taxa (e.g., Silver Carp, Zebra Mussels, Eurasian Watermilfoil); or increasing dominance by tolerant non-native species such as Common Carp	Same as level 5; not distinguishable based on non-native species alone
CONDITION	Organism Condition (Attribute VII)	Measures condition of individual organisms, including anomalies and diseases. Examples include external anomalies, lesions, disease outbreaks (local or widespread), coral bleaching, seagrass condition, fish pathology, and frequency of diseased or affected organisms	Diseases and anomalies are consistent with naturally occurring incidents and characteristics	Diseases and anomalies are consistent with naturally occurring incidents and characteristics	Incidences of diseases and anomalies may be slightly higher than expected conditions	Incidences of diseases and anomalies are slightly higher than expected. For example, coral bleaching events may occur sporadically and result in slightly elevated mortality. Anomalies in fish occur in a small fraction of a population	Disease outbreaks are increasingly common, anomalies are increasingly common, particularly in long-lived taxa where biomass may also be reduced (e.g., bleaching events are frequent enough to cause mortality of corals). Anomalies, such as deformities, erosion, lesions, and tumors in fish, occur in a measurable fraction of a population	Host species in which diseases and anomalies have been observed are now absent, so diseases might be difficult to detect. Anomalies, disease, etc. may occur across multiple species or taxa groups

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
FUNCTION	Function (Attribute VIII)	Measures of energy flow, trophic linkages and material cycling. They may include proxy or snapshot structural metrics that correlate to functional measures. Examples include photosynthesis: respiration ratios, benthic: pelagic production rates, chlorophyll a concentrations, macroalgal biomass, bacterial biomass and activity	Energy flows, material cycling, and other functions are as naturally occur; characterized by complex interactions and long-lived links supporting large, long-lived organisms	Energy flows, material cycling, and other functions are within the natural range of variability; characterized by complex interactions and long-lived links supporting large, long-lived organisms	Virtually all functions are maintained through operationally redundant system attributes, minimal changes to export and other indicative functions. Some functions increased due to pollution or low level disturbance (e.g., production, biomass, respiration)	Most functions are maintained through operationally redundant system attributes, though there is evidence of loss of efficiency (e.g., increased export or decreased import, there may be shifts in benthic: pelagic production rates	Loss of some ecosystem functions are manifested as changed export or import of some resources and changes in energy exchange rates (photosynthesis: respiration ratios, benthic: pelagic production rates, respiration or decomposition rates)	Most functions show extensive and persistent disruption, shifts to primary production, microbial dominance, fewer and shorter-length trophic links and highly simplified trophic structure, marked shifts in benthic: pelagic production rates
LANDSCAPE	Spatial and Temporal Extent of Detrimental Effects (Attribute IX)	Measures of a landscape's capacity, contributing surface water to a single location, to maintain the full range of ecological processes and function that support a resilient, naturally occurring aquatic community. The functions and processes to be measured include hydrologic regulation, regulation of water chemistry and sediments, hydrologic connectivity (see also attribute X), temperature regulation, and habitat provision	N/A—A natural disturbance regime is maintained	Limited to small pockets and short duration	Limited to a local area or within a season	Mild detrimental effects may be detectable beyond the local area and may include more than one season	Detrimental effects extend far beyond the local area leaving only a few islands of adequate conditions; effect extends across multiple seasons	Detrimental effects may eliminate all refugia and colonization sources within a region or catchment and affect multiple seasons

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
CONNECTIVITY	Ecosystem Connectance (Attribute X)	Observations of exchange or migrations of biota between adjacent water bodies or habitats. Important measures within the area being studied may be strongly affected by factors adjacent to or larger than the immediate study area. Metrics may include dams, causeways, fragmentation measures, hydrological measures, or proxies such as characteristic migratory species	System is naturally connected, or disconnected, in space and time, exchanges, migrations, and recruitment from adjacent water bodies or habitats are as naturally occurs	System is naturally connected, or disconnected, in space and time, exchanges, migrations, and recruitment from adjacent water bodies or habitats are as naturally occurs	Slight loss, or increase, in connectivity between adjacent water bodies or habitats (e.g., between upstream and downstream water bodies), but colonization sources, refugia, and other mechanisms mostly compensate. May also be increase in connectivity due to canals, interbasin transfers	Some loss, or increase, in connectivity between adjacent water bodies or habitats (e.g., between upstream and downstream water bodies), but colonization sources, refugia, and other mechanisms prevent complete disconnects or other failures	Significant loss, or increase, in ecosystem connectivity between adjacent water bodies or habitats (e.g., between upstream and downstream water bodies or habitats) is evident; recolonization sources do not exist for some taxa, some near-complete disconnects or connect exist	For many groups, a complete loss in ecosystem connectivity in at least one dimension (either spatially or temporally) lowers reproductive or recruitment success or prevents migration or exchanges with adjacent water bodies or habitats, frequent disconnects or other failures. For other groups, a complete loss in ecosystem disconnect in at least one dimension lowers reproductive or recruitment success (e.g., predation of amphibians by fish in once isolated headwater streams)

Table 3. BCG Matrix: Taxonomic Composition and Structure Attributes I–V

	BCG Levels					
Ecological Attributes	1 Natural or native condition Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability	2 Minimal changes in the structure of the biotic community and minimal changes in ecosystem function Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability	3 Evident changes in structure of the biotic community and minimal changes in ecosystem function Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive-ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system	4 Moderate changes in structure of the biotic community and minimal changes in ecosystem function Moderate changes in structure due to replacement of some sensitive-ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes	5 Major changes in structure of the biotic community and moderate changes in ecosystem function Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build- up or export of unused materials	6 Severe changes in structure of the biotic community and major loss of ecosystem function Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor; ecosystem functions are severely altered
I Historically documented, sensitive, long-lived or regionally endemic taxa	As predicted for natural occurrence except for global extinctions	As predicted for natural occurrence except for global extinctions	Some may be marginally present or absent due to global extinction or local extirpation	Some may be marginally present or absent due to global, regional, or local extirpation	Usually absent	Absent
II Highly sensitive taxa	As predicted for natural occurrence, with at most minor changes from natural densities	Most are maintained with some changes in densities	Some loss, with replacement by functionally equivalent sensitive-ubiquitous taxa	May be markedly diminished	Usually absent or only scarce individuals	Absent
III Intermediate sensitive taxa	As predicted for natural occurrence, with at most minor changes from natural densities	Present and may be increasingly abundant	Common and abundant; relative abundance greater than sensitive-rare, taxa	Present with reproducing populations maintained; some replacement by functionally equivalent taxa of intermediate tolerance.	Frequently absent or markedly diminished	Absent
IV Intermediate tolerant taxa	As predicted for natural occurrence, with at most minor changes from natural densities	As naturally present with slight increases in abundance	Often evident increases in abundance	Common and often abundant; relative abundance may be greater than sensitive- ubiquitous taxa	Often exhibit excessive dominance	May occur in extremely high or extremely low densities; richness of all taxa is low
V Tolerant taxa	As naturally occur, with at most minor changes from natural densities	As naturally present with slight increases in abundance	May be increases in abundance of functionally diverse tolerant taxa	May be common but do not exhibit significant dominance	Often occur in high densities and may be dominant	Usually comprise the majority of the assemblage; often extreme departures from normal densities (high or low)

2.4 How the Conceptual Biological Condition Gradient was Developed, Tested, and Evaluated

The conceptual BCG model was developed and tested by an expert workgroup primarily composed of scientists from government and the research community (Davies and Jackson 2006). This section summarizes how the BCG conceptual model was tested to the satisfaction of the expert workgroup and peer reviewers (from Davies and Jackson 2006). For examples on constructing BCG models and quantitative decision rules applied to specific assemblages and habitats, please see Chapters 3 and 4.

A matrix was created that summarized biologists' experience and knowledge about how biological attributes change in response to stress in aquatic ecosystems (Davies and Jackson 2006). In building the model, the workgroup followed an iterative, inductive approach, similar to means-end analysis (Martinez 1998). The workgroup understood that the primary value of the model is as a tool for shared learning and as a framework for communication.

The workgroup began by testing whether biologists from different parts of the country would draw similar conclusions regarding the condition of a water body using simple lists of organisms and their counts. This approach was initially based on Maine's experience, in which expert biologists independently assigned samples of macroinvertebrates to *a priori* defined levels of biological condition defined by differences in assemblage attributes (Davies et al. 1995; Davies et al. In press; Shelton and Blocksom 2004).

To provide a functional framework for practitioners, the workgroup described how each of the 10 attributes varies across six levels of biological condition along a gradient of increasing anthropogenic stress (i.e., human disturbance). The general model was then described in terms of the biota of a specific region (Maine). Based on 20 years of monitoring data, the Maine BCG describes how the relative densities of specific taxa, with varying sensitivities to stress, change across the BCG levels of condition (Davies and Jackson 2006).

To test the general applicability of the BCG to sampling data taken from other stream systems across the country, the workgroup evaluated how consistently individual biologists classified samples of aquatic biota based on the attributes incorporated into the BCG. Government, field, and research biologists participated in the data exercise. The full workgroup was divided into breakout groups according to region (northeast, south-central, northwest, arid southwest/great plains) and assemblage (fish or invertebrates) expertise. Samples were selected from invertebrate and fish data sets to span as many of the BCG levels as possible (i.e., to span the full gradient of conditions). The invertebrate samples and fish samples used in the tests were collected from six different regions within the U.S. (northeast, mid-Atlantic, southeast, northwest, southwest, central) and included only basic descriptors of stream physical characteristics (e.g., substrate, velocity, width, depth), taxonomic names, densities, and in some cases, metric values. These data represent the basic core elements common to nearly all biological monitoring programs. Participants were asked to place each sample into one of the six condition levels, and they were cautioned not to apply a simple relative quality ranking since all six levels did not necessarily occur within the data sets. Biologists relied primarily on differences in relative abundances and sensitivities of taxa (i.e., attributes I–VI) to make level assignments, because this was the information typically collected in state monitoring programs and the data needed to evaluate the status of the other attributes were not available. Percent concurrence among the individuals was calculated to assess the level of agreement among biologists when applying the BCG to raw data. Perfect concurrence was set to equal the product of the number of raters by the number of streams.

In the first stage of the data exercise, between-biologist differences were evaluated by asking all workgroup participants to rate a single data set of 6–8 samples. The breakout groups were then asked to classify samples from larger and more variable data sets. The groups were also instructed to summarize their interpretations and to identify biological responses to changes in conditions not captured by the BCG. Finally, the workgroup participants identified how, from their perspectives, the BCG levels corresponded to the CWA biological integrity objective and interim goal for protection of aquatic life (e.g., protection and propagation of fish, shellfish, and wildlife).

Overall, workgroup members independently agreed on placement of sites in the same BCG levels for 82% of the benthic macroinvertebrate samples and 74% of the fish samples. When assignments differed, the range of variation among workgroup members was within one level in either direction for all samples with a few exceptions. BCG levels were revised following full workgroup discussion so that transitions were more distinct.

Each of the breakout groups independently reported that the ecological characteristics corresponding to BCG levels 1, 2, 3 and either some or all of BCG level 4 characteristics were generally compatible with how they assess the CWA's interim goal for protection of aquatic life. The experts unanimously agreed that BCG levels 1, 2, and 3 attained the CWA goal and BCG levels 5 and 6 did not. Opinions differed among the experts on whether all or some aspects of BCG level 4 characteristics were compatible with attaining this goal. For example, the workgroup extensively discussed what constituted an acceptable degree of replacement of sensitive taxa by tolerant taxa. However, experts united in a clear consensus that the BCG process provided detailed, readily transparent documentation of the expert logic and underlying science for establishing BCG levels. Additionally, expert discussion on implementation of the BCG framework to interpretation of condition included the following programmatic considerations:

- *The technical rigor of the monitoring program that produced the condition assessments*—Conceptually, a less rigorous monitoring program produces assessments with a greater degree of uncertainty, or precision, and potentially lower accuracy. In lieu of improving the program's technical rigor, or to compensate for uncertainty associated with monitoring programs of lower technical rigor, some experts recommended that a more protective, e.g., conservative, BCG level be used to measure attainment of the CWA ALU goal.
- *Protection of high quality conditions*—The experts identified the characteristics described by BCG levels 1 and 2 as consistent with their understanding of the CWA "biological integrity" objective. Concern was expressed that a single threshold comparable to BCG level 4 is not protective of high ecological quality and that water bodies comparable to BCG levels 1, 2, or 3 would likely decline significantly before action would be triggered to address sources of degradation. Experts noted that restoration and remediation costs are typically much higher than costs for prevention. Experts recommended that multiple thresholds protective of existing ALU conditions be established (e.g., thresholds comparable to BCG levels 2, 3, or 4). Alternatively, if only a single threshold is established, some experts recommended that the threshold should be protective of higher level conditions comparable to BCG level 3.

Workgroup members reported that key concepts were important with respect to classifying samples into levels and identifying the boundaries in between. For levels 1 and 2, biologists identified the maintenance of native species populations as essential to their understanding of biological integrity. Although many participants noted that methods for distinguishing differences between levels in attribute VIII (ecosystem function) were poorly defined, most nevertheless identified ecosystem function changes (as inferred by marked changes in food-web structure and guilds) as critical in distinguishing between levels 4 and 5.

Discussion following the data exercise revealed that participants mostly used attributes I–V (taxonomic composition, pollution sensitivity), attribute VI (non-native taxa, for levels 2–6 only), and attribute VII (organism condition) to evaluate biological conditions in streams and wadeable rivers. In contrast, because attributes VIII–X (ecosystem function and scale-dependent features) were at that time rarely directly assessed by biologists, the evaluation of these attributes was accompanied by relatively high uncertainty. Additionally, there was considerable discussion regarding to which axis, the biological or stress axis, the attributes for ecosystem connectance and spatial and temporal extent of detrimental effect should be assigned. As an interim measure, the workgroup members recommended including these attributes as components of the biological axis primarily because of the importance state biologists placed on this information in predicting restoration or protection success. The BCG, thus, serves as a guide to interpret condition and is expected to be further refined as development and application continues.

The presence of non-native taxa in level 1 was also the subject of considerable discussion. Knowledge of the extensive occurrence of some non-native taxa in otherwise near-pristine systems conflicted with the desire by many to maintain a conceptually pure and natural level. Further discussion resulted in agreement that the presence of non-native taxa in level 1 is permissible only if they cause no displacement of native taxa, although the practical uncertainties of this provision were acknowledged. The resulting level descriptions, which allow for non-native species in the highest levels as long as there is no detrimental effect on the native populations, has practical management implications. For example, introduced European brown trout (*Salmo trutta*) have replaced native brook trout (*Salvelinus fontinalis*) in many eastern U.S. streams. In some catchments, brook trout only persist in stream reaches above waterfalls that are barriers to brown trout. The downstream reaches can be nearly pristine except for the presence of brown trout. In these places, if society decided to remove the introduced brown trout, and if stream habitat is preserved throughout the catchment, brook trout can potentially repopulate downstream reaches. In the use designation process, recognizing that the entire catchment has the *potential* to attain level 1 condition will inform the public that a very high quality resource exists.

Critical gaps in knowledge and scientific literature were uncovered during the development of the BCG. For example, the workgroup identified the need for regional evaluations of species tolerance to stressors. Tolerance information presented in the current version of the BCG tends to be based on generalized taxa responses to a non-specific stressor gradient. At that time, tolerance information was not available for most taxa and for many common stressors (temperature, nutrients, and sediments). In some cases, tolerance values are based on data collected in other geographic regions or for other purposes (e.g., van Dam's European diatom tolerances are used for North American taxa) (van Dam et al. 1994). In the future, availability of improved tolerance value information can be used to refine the BCG and improve its precision (e.g., Cormier et al. 2013; Whittier and Van Sickle 2010).

Additionally, taxa that are considered tolerant to stressors in one region of the country may not be similarly classified in another region. For example, long-lived taxa have generally been characterized as sensitive to increasing pressure and tend to be replaced by short-lived taxa in stressed systems. As such, the presence of long-lived taxa in a water body has been used to indicate high quality conditions, whereas the predominance of short-lived taxa may indicate degradation. However, in streams in the arid western U.S., extreme changes in hydrology might define the natural regime and an opposite trend might be observed: short-lived taxa can dominate the biological community in natural settings. In these systems, a shift to long-lived taxa may be an indicator of altered, less variable flow regimes due to flow management.

When the expert workgroup was initially developing the conceptual BCG framework (2000–2004), attributes VIII–X were not routinely measured as part of a state biological monitoring and assessment program. However, the state scientists participating in the workgroup deemed these attributes as ecologically important because the extent of ecosystem alteration has important environmental implications in terms of an individual water body's vulnerability to further effects from stressors, as well as potential for mitigation (Davies and Jackson 2006). The state scientists explained that they informally estimated ecosystem function, connectance, and extent of detrimental effects using different surrogate measures (e.g., shift in functional feeding groups) and/or measures of watershed condition (e.g., presence and connection of wetlands and streams, intact forests). This information was used to inform decisions on recovery potential for a water body and prioritize actions to protect high quality conditions.

Additionally, attributes IX and X might play an important role in evaluating longer term impacts, restoration potential, and recoveries. For example, ecosystem connectivity is fundamental to the successful recruitment into and maintenance of organisms in any environment. A single impacted stream reach in an otherwise intact watershed has far more restoration potential than a similar site in a basin that has undergone extensive landscape alteration.

A critical gap that was not discussed in 2005, but is now an area of intensive work, is predicting the impacts of climate change on aquatic systems. Gaining an understanding of how the BCG attributes (I–X) will behave under future climate scenarios, and developing approaches and indicators to measure these impacts, will be important future work for improving the BCG.

2.5 Conclusion

The conceptual BCG framework is a tool to help state water quality management programs better describe their ALU goals and measure increments of change in biological condition along a full gradient of stress—and to use that information to interpret existing conditions, identify high quality waters, and track progress towards achieving desired improvements. The BCG provides a common interpretative framework to assist in comparability of results across jurisdictional (e.g., county, state, national) and program (e.g., water quality and natural resource agencies) boundaries and to communicate this information to the public. In order to use the BCG, states will need to calibrate it to their own habitats and monitoring data and develop a numeric model. Although the BCG is a universal conceptual framework, quantitative calibrations are regionally data set-specific. Additionally, as an added benefit, state water quality management programs have reported that using expert consensus in developing BCGs has proven to be a valuable training tool for their technical staff and field crews. The panel interactions and development of consensus in interpreting data directly contribute to a more uniform approach and shared understanding of the aquatic ecosystems for which the state is responsible. Chapters 3 and 4 describe how a quantitative BCG model can be developed using expert panels and different approaches for quantification of the conceptual framework.

Chapter 3. Calibration of Biological Condition Gradient Models

The purpose of calibrating the BCG is to populate the conceptual model with quantitative data, develop quantitative decision rules to assign sites to BCG levels, and build a bridge from that model to management goals and endpoints. A calibrated BCG has both a narrative and a quantitative scientific description applicable to specific ecological regions or subregions. The BCG level descriptions can be used to describe the biological conditions associated with specific management goals and to support biological criteria development. The scientific description of the BCG can help make the management goals transparent to both decision makers and stakeholders. It can be used to assess baseline conditions and track incremental changes in condition.

This chapter proposes an approach to develop detailed narrative descriptions of BCG levels and attributes. Description and calibration of the BCG are achieved through consensus of expert opinion (Figure 7). The experts define the attributes, and the changes in those attributes, that characterize BCG levels and signal shifts to a different level. The outcome is a multiple attribute decision model that simulates the consensus expert decisions based on a set of quantitative rules. The next chapter provides three approaches to quantify the narrative BCG and develop numeric thresholds for site assignments.

Figure 7. Benthic macroinvertebrate and fish experts developing decision rules for freshwater streams in Alabama.

Use of professional expert consensus has a long pedigree in the medical field, including the National Institutes of Health (NIH) Consensus Development Conferences to recommend best practices for diagnosis and treatment of diseases.[5] In addition to the NIH consensus conferences, other researchers, institutes, and countries develop medical consensus statements, using both the NIH methods and others (Nair et al. 2011).

Recent environmental assessments developed using professional judgment have shown that experts are highly concordant in their ratings of sites, including marine benthic invertebrate communities in California bays (Weisberg et al. 2008). Another example is in nearshore marine environments assessed by an international panel covering European Atlantic, Mediterranean, American Atlantic, and American

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[5] The program ran from 1977 to 2013. For more information, see: http://consensus.nih.gov/. Accessed February 2016.

Pacific habitats and experts (Teixeira et al. 2010). The approach has also been demonstrated effective for developing assessments of sediment quality (Bay et al. 2007; Bay and Weisberg 2010) and a decision model for fecal contamination of beaches (Cao et al. 2013). Likewise, in BCG development, aquatic biologists have come to very tight consensus on the descriptions of individual levels of the BCG, as well as very close agreement on the BCG level assigned to individual sites (e.g., Danielson et al. 2012; Davies and Jackson 2006; Gerritsen and Jessup 2007a; Gerritsen and Leppo 2005; Gerritsen and Stamp 2012; Gerritsen et al. 2013; Jessup and Gerritsen 2014; Kashuba et al. 2012; Snook et al. 2007).

All scientific and technical products, including biological indices used for assessment, include results of professional judgment and assumptions throughout (Scardi et al. 2008; Steedman 1994). The BCG expert consensus approach asks the experts to make judgments on the biological significance of changes in the attributes identified in Chapter 2. For this approach to be credible and valid, the panel should be comprised of experts with a wide and deep breadth of knowledge and expertise and not be constrained to a single agency in order to minimize internal bias. Effective facilitation is essential to prevent domination of the discussion by an individual panel member and to draw out the full range of expert judgement. Additionally, it is essential that the expert logic used in developing the decisions be fully documented so the rules will be transparent and understandable to those that were not members of the expert panel. The objective is to develop a set of decision rules that can be implemented by others not engaged in the expert panel.

3.1 Overview

The first step in calibration of the BCG is to develop detailed narrative descriptions of BCG levels and attributes specific to the water body type and region. Experts are given assemblage species composition and abundance data sets from the region for which they are developing the BCG. In order to minimize pre-conceived judgments, they are also given physical information about the sites (e.g., catchment area, slope, elevation, ecoregion, habitat type) but not the precise locations, land uses, sources, and stressor information. Following discussion of the conceptual model of the BCG, including detailed presentation on the description of the BCG levels and attributes, the experts are asked to put each sample site into one of the BCG levels. Each sample is discussed by the group, and facilitators elicit the reasoning used by the experts in their ratings. The median of the expert ratings is taken as the final BCG level for a sample (Gerritsen and Jessup 2007; Gerritsen and Leppo 2005; Gerritsen and Stamp 2012; Gerritsen et al. 2013; Jessup and Gerritsen 2014; Snook et al. 2007).

After an initial rating of at least 30 samples, the experts are asked to begin to articulate rules or guidelines that they use to make their decisions, starting with the highest level (BCG level 1) and working through level 6. Data evaluations and site assignments continue as rules are articulated and then revisited and further tested. In some situations, it may be necessary for the experts to use historical data and information to develop rules for the highest levels of the BCG when there are no or few samples in the data set that are representative of undisturbed or minimally disturbed conditions. Following the expert meetings, organizers and analysts examine the distributions of the quantitative data with respect to the initial proposed guidelines stated by the experts and the experts' actual BCG decisions. The distribution analysis forms the basis of quantitative boundaries around the experts' proposed rules, and analysts in turn develop quantitative rule-based models. Quantitative rules and performance are in turn reviewed by the expert panels to adjust rules or thresholds as necessary. Reviews and iterative recalibration are typically carried out by webinar and conference call. The panels also rate an independent set of test samples that were excluded from the calibration process.

The outcome of a full BCG calibration, including development of a quantitative model, includes:

- A current state-of-knowledge description of the biological assemblage of water bodies under pre-development, undisturbed condition to serve as a fixed, historic baseline (the level 1 prototype). If there are no BCG level 1 sites available, then this description may be based on historical observations, records, and/or data.
- Descriptions of each identified level of the BCG.
- A set of transparent rules for assigning sample sites to levels of the BCG.
- A quantitative model of the rules, or other technical approach, to assign new samples to levels of the BCG, without reconvening an expert panel.
- A set of BCG condition levels that can serve as management goals for classes of water bodies and as thresholds for biological criteria, if the state so chooses.

There are several key steps to the calibration process (Figure 8):

- **Assemble and organize data—**The BCG is developed using information and data from the state's existing biological monitoring program and/or other data sources (e.g., different data sets or regional pooled data from other states and federal agencies). The data should cover the entire range of conditions and stress within at least one ecological region. The data set should be sufficiently large with a well-defined approach for classification, identification of natural conditions, and criteria for reference site selection. Usually, the BCG cannot be calibrated within small jurisdictions or within urban or agricultural regions only—it requires data from outside the jurisdiction to ensure that the least stressed reference, as well as the full range of other stressors, are represented.
- **Conduct preliminary data analysis/data preparation**—Prior to the calibration workshop, the data must be put in a format that can be readily used by workshop participants. In addition, stressor-response relationships are examined to describe the responses of the assemblages and of individual taxa to the stress gradients represented in the data.
- **Convene expert panel**—The key component of BCG calibration is expert consensus of aquatic biologists on qualitative and quantitative descriptions of the BCG levels. Experts selected should be familiar with the water bodies, identities of species, and species and assemblage responses to stress in the regions of concern. The panel should include experts from not only the state biological assessment program but other state and federal natural resource agencies and research scientists from the academic community. Additionally, experts who regularly work with the regulated community can offer a level of assurance and interpretive assistance about the purpose and value of using the BCG in water quality assessments.
- **Develop quantitative BCG model**—Following the development of decision rules, one of several approaches can be applied to automate assigning water bodies to condition levels in the state database. Approaches discussed in Chapter 4 of this document include multiple attribute decision models, multivariate discriminant models, and development of thresholds for commonly used biological indices (e.g., multimetric indices (MMIs) or predictive model indices (e.g., observed over expected taxa [O/E])).
- **Test models, adjust, and recalibrate**—The development process is iterative and may require several passes through the process to converge on a consistent, locally calibrated BCG that is scientifically defensible.

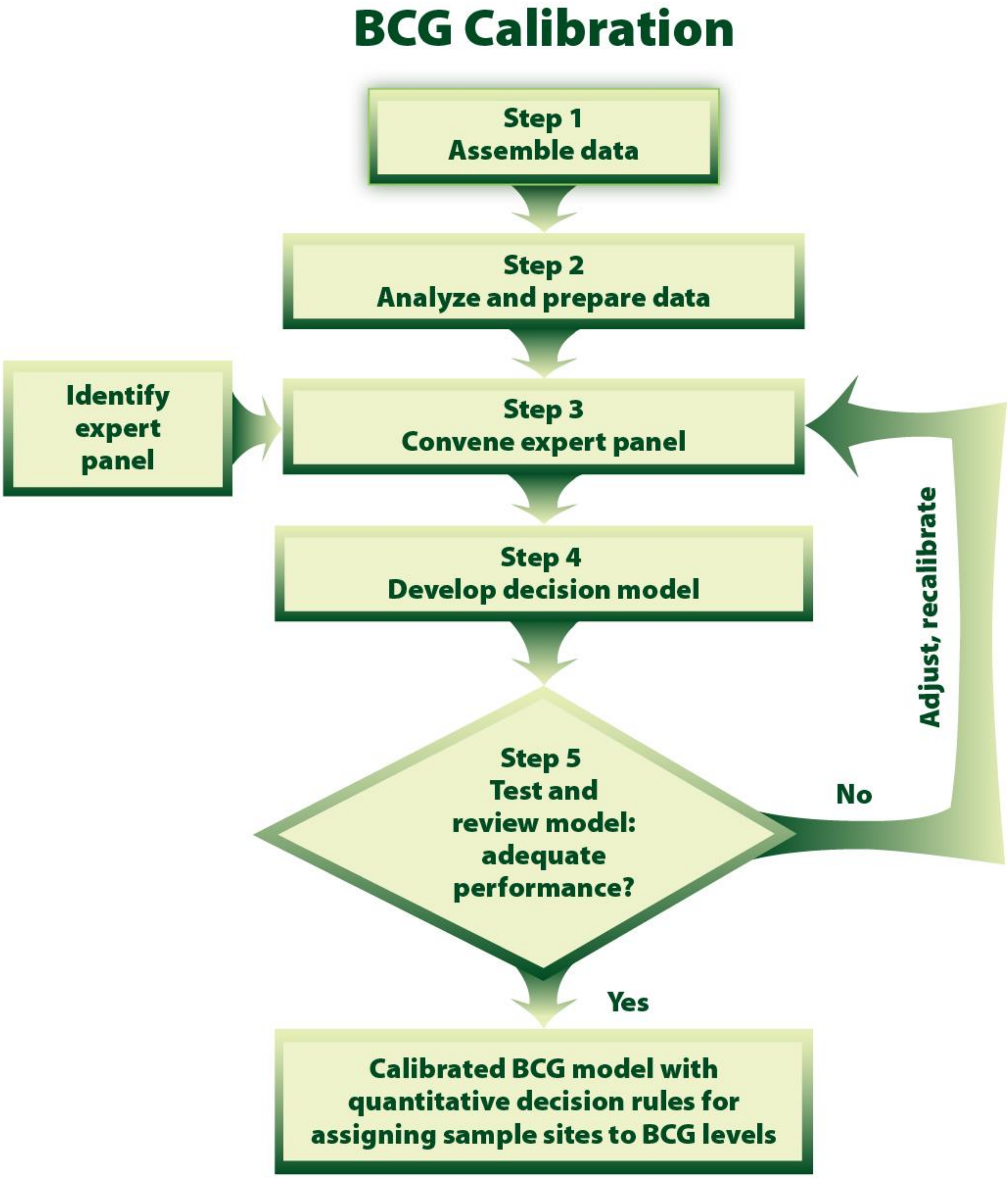


Figure 8. Steps in a BCG calibration.

3.1.1 Case Studies and Applications

Since 2005, several states or other entities (e.g., river basin associations, counties) have either calibrated, or are in the process of calibrating, the BCG (Table 4). Most of the BCG models that have been calibrated to date apply to perennial streams that are exposed to increases in temperature, nutrients, toxic substances, and fine sediments. This is the stream-type and stressor regime originally described by the conceptual model. Nevertheless, the model has been extended and calibrated to large rivers (Appendices B1 and B4; Bradley et al. 2014), estuaries (Appendix B2), coral reefs (Appendix B3; Shumchenia et al. 2015), and lakes (Gerritsen and Stamp 2014). Refinement of the model attributes to accommodate regional and water body type differences for water bodies other than streams and wadeable rivers has occurred without loss of model integrity. Thus, the BCG can be applicable to other aquatic ecosystems and stressors with appropriate modifications.

Section 3.2 below provides a detailed description of the step-by-step process that has been used to calibrate BCG models. Chapter 4 provides approaches to quantify the expert-derived BCG model, and case studies drawn from Table 4 illustrate different components of the process.

Table 4. BCG calibration and testing projects

State/Region	Water body type (if applicable)	Biological Assemblages	Objective	Status (Citation)
Alabama	Highland streams and wadeable rivers	Benthic macroinvertebrates and fish in high gradient streams	Calibrated BCG model and automated decision model for invertebrates (all streams) and fish (3 regions)	Complete (Jessup and Gerritsen 2014)
	Coastal plains streams	Benthic macroinvertebrates and fish in low gradient streams	Calibrated BCG model and automated decision model for invertebrates and fish	In progress
California	Streams	Algae	Calibrated BCG model and decision model for stream algae	In progress
Connecticut	High gradient streams and wadeable rivers	Benthic macroinvertebrates	Calibrated BCG model and automated decision model; also calibrated to Connecticut's macroinvertebrate MMI	Complete. (Gerritsen and Jessup 2007b)
		Fish	Calibrated BCG model and automated decision model; also calibrated to Connecticut's fish MMI	Complete (Stamp and Gerritsen 2011)
Illinois	Streams	Benthic macroinvertebrates and fish	Calibrated BCG model and automated decision model	In progress
Indiana	Streams and rivers	Fish	Calibrated BCG model and automated decision model	In progress
Maine	Streams and wadeable rivers	Algae	Calibrated BCG model to assign ALUs per Maine's 3 designated use classes and technical approach for benthic macroinvertebrates	Complete (Davies and Tsomides 2002; Davies et al. In press; Danielson et al. 2012)
	Wetlands	Benthic macroinvertebrates	Calibrating automated decision model to assess tiered designated ALU classes	In progress
Maryland, Montgomery County	Streams	Benthic macroinvertebrates and fish (quantitative), salamanders (qualitative)	Calibrated BCG model to communicate monitoring information on condition	Stamp et al. 2014

State/Region	Water body type (if applicable)	Biological Assemblages	Objective	Status (Citation)
Minnesota	Streams and wadeable rivers	Benthic macroinvertebrates and fish	Calibrated BCG model and automated decision model for nine stream types; also incorporates Region 5 coldwater results	Complete (Gerritsen et al. 2012)
	Lakes	Fish	Calibrated BCG model and automated decision model for four lake types	Complete (Gerritsen and Stamp 2014)
New England	High gradient streams and wadeable rivers	Benthic macroinvertebrates	Cross-calibrated BCG model and automated decision model for multiple sampling methodologies	Complete (Snook et al. 2007)
New England	Large rivers	Fish	Calibrated BCG model and automated decision model	In progress
New Jersey	High and low gradient streams and wadeable rivers	Benthic macroinvertebrates	Calibrated BCG model and automated decision model	Complete (Gerritsen and Leppo 2005)
	Streams and wadeable rivers	Diatoms	Calibrated BCG model and automated decision model	In progress
Pennsylvania	High gradient streams and wadeable rivers	Benthic macroinvertebrates	Conceptual model and verbal description of BCG levels, calibrated to Pennsylvania's MMI	Complete (Gerritsen and Jessup 2007a)
Puerto Rico and U.S. Virgin Islands	Stony coral reefs	Stony corals and resident reef fish	Calibrated BCG model and automated decision model	In progress (Bradley et al. 2014)
Rhode Island	Estuaries	Seagrass extent, benthic community, shellfish production, primary productivity in Greenwich Bay, Rhode Island	Conceptual BCG model anchored in natural conditions prior to 1850 and showing changes	Complete (Shumchenia et al. 2015)
		Habitat mosaic indicator as measure of whole system condition for Narragansett Bay	In progress	In progress preparation, Shumchenia et al. in review)
Upper Mississippi River Basin	Large rivers	Fish	Calibrated BCG model and automated decision model	In progress
Vermont	Streams and wadeable rivers	Benthic macroinvertebrates	Calibrated BCG model and biological criteria	VT DEC 2004

3.2 Step One: Assemble and Organize Data

Evaluating data quality and preparing it for rule development is critical for an efficient and effective expert panel meeting. The data should cover the entire range of conditions and stress within at least one ecological region. Typically state databases have been used in the stream BCGs developed to date, but large regional databases, either a single data set or pooled data sets, have also been used (e.g., Upper Mississippi Basin BCG and New England River BCG (see Appendices B1 and B4)). Combining data sets presents a unique set of challenges for experts in interpreting site data and detecting consistent patterns of biological change in response to increasing stress. If different data sets are combined, decisions on how the data sets are reconciled must be well documented for the experts to successfully use the data in rule development. When BCG rules are developed for more than one assemblage, typically different data sets are used for each assemblage and the rules are developed and applied independently. The rules for the different assemblages are tested jointly as a later step in the BCG model development.

There are three tasks required for assembling and organizing data prior to convening an expert panel:

1. **Obtain Data**—In preparation for the calibration process, relevant data are extracted from the database. Data should include the biological survey (taxonomic identification and counts) and all related data on the geo-referenced sampling site: locations and characteristics; catchment data including area, slope, land use characteristics, and physical habitat; chemical water quality data; and field observations by sampling personnel. Evaluation and documentation of the quality of the data set is an essential component of the BCG approach, including documentation of technical issues and concerns that should be further addressed through additional data collection and analysis. Section 3.2.1 discusses elements of a data set and monitoring program that should be evaluated and documented.
2. **Determine Natural Classification**—In order to prevent natural variability from confounding responses to stress, it is necessary to determine a natural classification system for the water bodies under consideration (if not already complete) (USEPA 2013a). If there is only a collection of data, and no agreed-upon classification system, substantial analytical effort might be needed to develop it. Classification is beyond the scope of this document; see Barbour et al. (1999), Hawkins et al. (2000a), USEPA (2013a), Olivero and Anderson (2008), and Olivero Sheldon et al. (2015) for references to classification approaches for freshwater streams. Selection of a classification method was one of the first tasks the coral reef expert panel undertook prior to successful rule development (see Appendix B3). The classification decision has implications for statistical sampling design and monitoring protocols.
3. **Organize Data Tables**—A comprehensive and relational database is a requirement for a high quality monitoring program (USEPA 2013a). Data can be organized in spreadsheets for the panel workshops (see Figure 12 for an example of datasheet used in BCG development to date). For permanent storage, retrieval, archiving, and to maintain a quality record, a relational database will be necessary (e.g., Oracle®, MS-Access®, Sequel Server®).

Quantitative assessment within the BCG framework requires consistent, high quality biological, physical, chemical, and geographic monitoring information. The technical foundation of monitoring determines the degree of confidence with which the information can be used to support water quality management decision making, including calibration of the BCG. This section describes data requirements consistent with EPA's recommended program review of biological assessment programs (USEPA 2013a).

All BCG developments to date have used existing state or federal agency monitoring data. There have been no monitoring programs specifically designed for BCG development. However, recommendations on the technical elements of a monitoring program that would produce good data for BCG development are not different from the requirements for a high-quality program specified by EPA (2013a) and are discussed below. This document is not guidance for monitoring design, optimal effort, or sampling methods. Instead, it focuses on minimum requirements for BCG development, including consistently sampled aquatic biota; water quality and habitat observations adequately matching the biological sampling; and land use/land cover information (e.g., from the NHD coverage). Consistency and adequacy of a data set are evaluated by the expert panel, analysts, and facilitators, and documentation of BCG development includes recommendations on specific technical areas where further development would strengthen or refine the quantitative BCG model and underlying decision rules.

3.2.1 Data Requirements: Understanding the Quality of the Data Set

EPA described 13 technical elements contributing to quality of biological assessment programs (USEPA 2013a). These elements are listed below and constitute the technical underpinnings important for a biological assessment program to be able to discriminate levels of condition along a gradient of disturbance (Table 5). Selected elements of biological assessment program design and data collection, compilation, and interpretation important for BCG development are discussed below. For a more complete description, see EPA's *Biological Assessment Program Review: Assessing Level of Technical Rigor to Support Water Quality Management* (USEPA 2013a). It is recommended that these elements be considered when assembling a data set for BCG calibration. Understanding the technical strengths and limitations of the data sets to be used in the calibration will help guide development of the BCG and its application.

Table 5. Definitions of the technical elements (USEPA 2013a)

	Technical Element	Definition
Biological Assessment Design	Index Period	A consistent time frame for sampling the assemblage to characterize and account for temporal variability.
	Spatial Sampling Design	Representativeness of the spatial array of sampling sites to support statistically valid inference of information over larger areas (e.g., watersheds, river and stream segments, geographic region) and for supporting WQS and multiple programs.
	Natural Variability	Characterizing and accounting for variation in biological assemblages in response to natural factors.
	Reference Site Selection	Abiotic factors to select sites that are least impacted, or ideally, minimally affected by anthropogenic stressors.
	Reference Conditions	Characterization of benchmark conditions among reference sites, to which test sites are compared.
Data Collection and Compilation	Taxa and Taxonomic Resolution	Type and number of assemblages assessed and resolution (e.g., family, genus, or species) to which organisms are identified.
	Sample Collection	Protocols used to collect representative samples in a water body including procedures used to collect and preserve the samples (e.g., equipment, effort).
	Sample Processing	Methods used to identify and count the organisms collected from a water body, including the specific protocols used to identify organisms and subsample, the training of personnel who count and identify the organisms, and the methods used to perform quality assurance/quality control checks of the data.
	Data Management	Systems used by a monitoring program to store, access, and analyze collected data.
Analysis and Interpretation	Ecological Attributes	Measurable attributes of a biological community representative of biological integrity and that provide the basis for developing biological indices.
	Discriminatory Capacity	Capability of the biological indices to distinguish different increments, or levels, of biological condition along a gradient of increasing stress.
	Stressor Association	Relationship between measures of stressors, sources, and biological assemblage response sufficient to support causal analysis and to develop quantitative stressor-response relationships.
	Professional Review	Level to which agency data, methods, and procedures are reviewed by others.

3.2.1.1 Biological Assessment Design Elements

The first four technical elements are particularly critical aspects of sampling design to consider when evaluating data for BCG calibration, and they involve selection of sites and times for sampling to obtain representative and statistically valid information (USEPA 2013a). The fifth element, reference condition, is also discussed below but in relation to its role relative to the BCG benchmark, BCG level 1 (e.g., anthropogenically undisturbed reference condition).

Index Period

Sampling index periods are selected based on known ecology to minimize or account for natural variability, maximize sampling gear efficiency, and maximize the information gained on the assemblage (Barbour et al. 1999; USEPA 2013a). For temperate fresh water bodies, index periods are typically a span of 3–6 months during the growing season.

Spatial Sampling Design: Representative of Stress Gradient

The objective of BCG calibration is to characterize the biological response across a generalized stress gradient from undisturbed to highly disturbed conditions. The BCG should be developed for specific natural classes, such as ecoregions or physiographic provinces. Sample coverage must be representative of the ecoregion(s), as well as the stress gradients that can occur. Case examples of characterizing stress gradients are given later in this chapter (section 3.3.1) and discussed more generally in Chapter 5. Achieving representativeness might require using data from outside of the jurisdictional boundaries of a state so that ecoregional expectations are as fully sampled and defined as possible. In addition to representativeness, the data should have sufficient sample size to support the calibration. As a rule-of-thumb, 30 or more samples for each water body class (at a minimum for levels 2–5, and levels 1 and 6, if regionally available) are generally required (see natural classification below). If samples are not sufficient, then BCG development should be delayed until enough data are acquired.

Calibration of the BCG model requires data points (samples) along the stress gradient from low to high levels of stress. An expert panel examines the sites and assigns the sites to BCG level based solely on the biological information. Having the stress information ensures that the expert panel sees sites that are representative of the stress gradient. Ideally, the data set needs to include the full gradient of conditions and complement of stressors (e.g., pollution sources, invasive species, habitat disturbances) that are common to a state or region, such that the full gradient of assemblage response is included in the model development.

Natural Variability: Classification

Biological assessment based on knowledge of the biota under undisturbed or minimally disturbed reference sites forms expectations for natural conditions. Many natural regional and habitat characteristics (e.g., stream size, slope, dominant natural substrate) also affect the species composition of undisturbed water bodies. Accordingly, a critical step in developing a biological assessment program is to classify the natural conditions to the extent that they affect the biological indicators (e.g., Barbour et al. 1999; Gibson et al. 1996; Hawkins et al. 2000a). The term classification includes development of continuous models that explain natural variability of biological assemblages. For example, fish species richness is strongly dependent on catchment area or average flow. Modeling approaches that combine both discrete and continuous variables (e.g., general linear models) may be especially powerful if the data support them. Failure to properly classify sites can cause the BCG calibration to fail, yielding assessment errors that can undermine confidence in results. Classification of natural conditions should be complete and satisfactory to experts. If not, time and resources will be necessary to develop the classification system.

Reference Site Selection

Obtaining a representative stress gradient requires that the data set is large enough to include the full range of disturbance, from undisturbed to highly disturbed conditions. Data owners and field personnel should document the comprehensiveness of the data set with respect to coverage of the full range, or not, of disturbance. It might be necessary to obtain data from neighboring states or regions to ensure that the gradient is represented in the data set. A minimum of 30 to 40 sites might be sufficient to calibrate the BCG depending upon both the characteristics of the natural system and the quality of the data set. Characterization of the quality of reference sites is essential to defining the range of conditions in the data set the experts will be using to develop decision rules. The criteria used by states to select their reference sites inform this determination.

Reference Condition

In this document, the terms "undisturbed," "minimally disturbed," and "least disturbed" conditions are used when referring to the level of anthropogenic stress to which a water body and its surrounding watershed may be subject. These terms are well defined by Stoddard et al. (2006). The level of stress associated with the reference sites used by the state to define reference condition is the critical information needed for BCG calibration. In many cases, the state's reference condition is not comparable to the BCG benchmark for undisturbed or minimally disturbed conditions. This is important information, not only for the BCG calibration but also for water quality program managers and the public.

BCG calibration is not based on least disturbed reference sites, because least disturbed sites are typically the "best of what is left" and may mistakenly be perceived by the public as the best that can be because undisturbed conditions no longer exist (e.g., Dayton et al. 1998; Papworth et al. 2008; Pauly 1995). In this case, expectations for improvements might be set lower than the potential for a water body to improve. Part of the BCG process can include developing a description of undisturbed conditions that may include consideration of contemporary, empirically least stressed sites and historical descriptions; paleolimnological investigations; and museum records. The description of an undisturbed condition may be narrative and perhaps incomplete, but its documentation helps provide a transparent and clear framework for the public to understand what biologically may have already been lost from their waters as well as potential for what could be restored. In many of the BCGs that have been developed, undisturbed and minimally disturbed conditions have been combined for practical purposes and categorized as representing BCG levels 1 and 2.

3.2.1.2 Methodological Elements

The second set of technical elements are aspects of quality in sampling, processing, and data management. Data used for calibration must be consistent, or be made consistent in post-processing. It is especially important to examine methods when biological assessment data from multiple sources are to be pooled. For information on combining data derived from multiple sources, see Gerritsen et al. (2015). Elements of sampling methodology include:

Taxa and Taxonomic Resolution

The biological response data should be the taxonomic composition and related information from one or more biological assemblages in water bodies: benthic macroinvertebrates, fish, periphyton, aquatic macrophytes, phytoplankton (lakes and estuaries), and zooplankton (lakes and estuaries). To develop the model, a knowledgeable panel of experts is required for each assemblage.

Experience has shown that "lowest practical" identification, to species when possible, is superior for BCG calibration, because species differ in their characteristics within genera. Species identification is necessary for fish assemblages, but genus-level identifications are adequate for BCG calibration using benthic macroinvertebrates. When pooling data, the taxonomic resolution must be standardized to the lowest common level among the data sets.

Sample Collection

Field methods should be consistent and well-documented. The objective of the sampling methods should be to obtain consistent samples that are representative of the target biological assemblage (see Barbour et al. (1999) and USEPA (2013a) for discussions of sample collection methods). The BCG has been cross-calibrated for several sampling methods used in New England and in the Upper Midwest (Gerritsen and Stamp 2012; Snook et al. 2007). Where possible, initial BCG development in a new region is done with data from a single sampling methodology and then can be calibrated and tested with data generated using different sampling methods. Level of effort is a key consideration in sample design. Many of the BCG attributes (attributes I, II, VI, VII, IX, and X) are particularly sensitive to level of effort. Certain key taxa may be sparse, seasonal, or patchy in their distribution and easily missed by a standardized field collection method. In making a site assessment, other supplemental information (e.g., natural history surveys, fishery agency reports and observations, academic studies), beyond just the collected samples, should be included in making a level determination. This will lend an additional layer of confidence and improve the result.

Sample Processing

Laboratory processing of samples (except fish) is recommended (USEPA 2013a; Yoder and Barbour 2009). Macroinvertebrate and diatom samples are typically processed to a standardized count representing a constant sampling effort. In some cases, if subsampling efforts are mixed, it is possible to randomly subsample larger efforts to smaller efforts (e.g., 300-count subsamples randomly subsampled further to match 100-count subsamples).

Data Management

Identification of reference and stressed sites requires that the monitoring database be comprehensive, including watershed and site characteristics, habitat measurement, and physical and chemical water quality measurements. Physical and chemical measurements should be made at the same time and place that the biological community information is collected. Non-biological data, including catchment area, slope, land use, site, habitat, and physical and chemical water quality data are used to determine a site's natural classification and stressor status, such as whether it is a reference site or a stressed site, and where it is located along the stress gradient.

Data should be stored in a relational database so that queries can retrieve relevant information (e.g., biological data, chemical data, physical measurements) on site, geo-referenced location, multiple measurements from multiple sampling times, and catchment data. Data stored in spreadsheets or warehoused in such a way that physical, chemical, and accurate geo-reference cannot be located are of limited use and might require substantial costs to fill in missing information and for quality assurance (Gerritsen et al. 2015). Exceptions should be made for historic information and data that may not be amenable to spreadsheets. These data may not be suitable for a relational database but should be retained because they may provide important qualitative information and context that can be used to inform BCG development.

3.2.1.3 Analysis and Interpretation Elements

Ecological Attributes

These are the measurable attributes of a biological community that are representative of biological integrity and which provide the basis for developing a BCG model. The BCG attributes (Table 1) are the basis for this technical element. The selection of attributes might depend on the spatial scale and specific water body being assessed. Each attribute provides some information about the biological condition of a water body. Combined into a conceptual model comparable to the BCG, the attributes can offer a more complete picture about current water body conditions and also provide a basis for comparison with naturally expected water body conditions. All states that have applied a BCG for streams, rivers, and wetlands have used the first seven attributes that describe the composition and structure of the biotic community on the basis of the tolerance of species to stressors. Where available, they have included information on the presence or absence of native and nonnative species, and, for fish and amphibians, used measures of overall condition (e.g., size, weight, abnormalities, and tumors). Though not measured directly in state or tribal stream biological assessment programs, the last three BCG attributes of ecosystem function and connectedness and spatial and temporal extent of stressors can provide valuable information when evaluating the potential for a stream, river, or wetland to be protected or restored.

Discriminatory Capacity

This technical element addresses the degree of sensitivity of the BCG model in distinguishing incremental change along a continuous gradient of stress. Detailed descriptions of biological change along a gradient of stress can provide the conceptual basis for refined ALUs for specific ecotypes and regions leading to biological criteria development. Additionally, depending on the sensitivity, or discriminatory capacity, of the BCG model, the information can be used to help identify high quality waters and establish incremental goals for improving degraded waters. Six general increments of change can be described for each of the BCG's ecological attributes (for example, see Table 3). These incremental changes can serve as a template for developing biological criteria that represent aspects of biological integrity and which show a predictable, measurable response to increasing levels of stress.

The number of increments that can realistically be distinguished in a BCG model is dependent not only on the water body ecotype and natural classification factors that define biological assemblage characteristics, but also on the effect of anthropogenic stressors. For example, the sensitivity of an index developed for a forested, high-gradient stream might support distinguishing five or even six increments of quality along a continuous stressor gradient, while an intermittent, seasonal, or desert stream may yield fewer increments. Some of this difference is due to inherent natural characteristics of the assemblages, and some might be due to current limitations of science and practice.

Stressor Associations

Stressor association refers to the use of biological assessment data at appropriate levels of taxonomy to develop relationships between measures of biological response and anthropogenic stressors, including both stressors and their sources (Huff et al. 2006; Miller et al. 2012; Yuan 2010; Yuan and Norton 2003). This element includes examination of biological assessment data for patterns of response to categorical stressors (Riva-Murray et al. 2002; Yoder and DeShon 2003; Yoder and Rankin 1995a). A capability for developing these relationships extends the use of biological assessments from assessing condition to informing identification of possible causes and sources of a biological impairment at multiple scales.

Stressor association is directly dependent on a high level of technical development of other elements, particularly the elements for spatial sampling design, taxa and level of taxonomic resolution, database management, and discriminatory capacity. These elements are important building blocks for the data collection and analysis needed to more confidently identify stressors and their sources and to estimate stressor-response relationships. For example, the ability to estimate these relationships relies on paired stressor and response sampling at appropriate spatial and temporal scales and a level of taxonomic resolution and index sensitivity sufficient to detect incremental biological changes along a stress gradient. Also, a relational database that supports complex queries enables efficient and full utilization of data. A high level of technical development for each of these elements and others provides the foundation for stressor association.

Professional Review

Professional review and testing of the BCG quantitative decision rules should be conducted by experts outside of the panel to evaluate and improve model objectivity and scientific defensibility and to refine and improve the model. Because of the specific knowledge of the expert panel for any given BCG, discussion with the outside peer reviewers as part of, or, following the review, will facilitate use of review results and simultaneously address questions from the reviewers.

3.3 Step Two: Preliminary Data Analysis and Data Preparation

Before an expert panel is convened to describe the BCG levels, it is necessary to reduce and prepare the data for the panel's use during the workshops and webinars. In addition, it is useful to conduct exploratory data analyses to visualize empirical relationships of the biotic assemblages. Analysis and data preparation include:

1. **Characterizing Stress Gradients—**Identifying stress gradients to select sites for BCG calibration that are representative of stress gradients in the region, from undisturbed to highly disturbed levels of condition. If undisturbed conditions do not exist, the level of disturbance should be recorded and efforts made to collect historical data and records that may help the panel develop a conceptual, descriptive condition level absent of anthropogenic influence (BCG level 1). See Chapter 5 for further discussion.
2. **Analyzing Taxon Response Relationships—**Using the stress gradient(s) to examine stressor-response of individual taxa to augment known or surmised species tolerances and traits with empirical information on responses observed in the field, as well as to develop species distribution maps of species observed in the data set. This step also ensures that all panelists have the same information available to them, as some panelists may be more familiar with the monitoring data set than others. See Chapter 5 for further discussion.
3. **Preparing Data Work Sheets—**Identifying and formatting a calibration data set for the workgroup's calibration exercise.

This section discusses the preliminary analysis and data manipulation prior to calibration workshops.

3.3.1 Data Preparation: Characterize Stress Gradients

Water bodies are subject to a wide variety of anthropogenic stressors, and multiple stressor situations are common. However, few state data sets are sufficiently large and complete to be able to analytically separate the effects of individual stressors. To help select sites for the calibration exercises, a practical approach is to consider all stressors together without regard for interactions among them (Smith et al. 2001), or to use aggregate land cover as a summation of sources of potential stressors to streams (e.g., Landscape Development Intensity Index [LDI]; Brown and Vivas 2005). Stressor-response analysis with multiple, independent stressor gradients is currently an area of active research (e.g., Baker and King 2010; Norton et al. 2015), but it is beyond the scope of this document.

Quantitative Gradients

Identifying stress gradients relevant to the data sets at hand will be facilitated by some exploratory data analysis to identify biological responses to the stressors. Scatter plots are generally the most useful and efficient, but more detailed analysis can be done if desired, including regression analyses, quantile regression, and classification and regression tree (CART) analysis (Death and Fabricius 2000), and other models. The purpose of these analyses is not diagnostic, as BCG calibration does not include identifying the most likely causes for biological impairment. The purpose is to develop a database suitable for discerning patterns of biological response to increasing levels of stress.

Scatter plots can be examined for every stressor that will be included in a stress gradient, as well as for aggregated sources of stress such as land use/land cover. For this purpose, scatter plots are simple graphical displays of a response variable on the y-axis, against a presumed correlated parameter on the x-axis (e.g., Figure 9). Examples of stress variables examined for some of the BCG applications are shown in Table 6.

Table 6. Examples of quantitative stressor variables that have been used for BCG projects

Project	Quantitative Disturbance gradient
Minnesota streams	Human Disturbance Score (HDS)
Connecticut streams (fish)	% Developed area
Minnesota lakes	% Urban + Agricultural + Mining land use
	Trophic State Index
Maine stream algae	Total phosphorus
Maine stream benthic macroinvertebrates	% Impervious surface
Northern Piedmont region of Maryland	% Impervious surface
	Habitat index
Alabama	Human Disturbance Gradient (HDG)
Illinois	Habitat index
	% Impervious surface
	Total nitrogen
Indiana	% Impervious surface

3.3.1.1 Example—Using Land Use/Land Cover Indicators to Develop a Quantitative Stress Gradient (Minnesota, Alabama, Maryland Piedmont)

Measures of land use and land cover have been used as surrogate indicators of stressor effects. Table 6 contains a list of these type of indicators that have been used for GSA development (For more information on the GSA, see Chapter 5). In the Northern Piedmont of Maryland, the workgroup selected imperviousness as a primary stress indicator (Stamp et al. 2014, see Chapter 6). The percent imperviousness in a watershed or a catchment was available for all sites in the data set. Based on scatterplots like the one shown in Figure 9, the level of imperviousness has a clear impact on biological assemblages. Imperviousness was considered during the sample selection process to ensure that the full stress gradient was represented in the BCG model calibration data set. Imperviousness was also used to generate the taxon-response plots that helped inform BCG attribute assignments (see section 3.3.2).

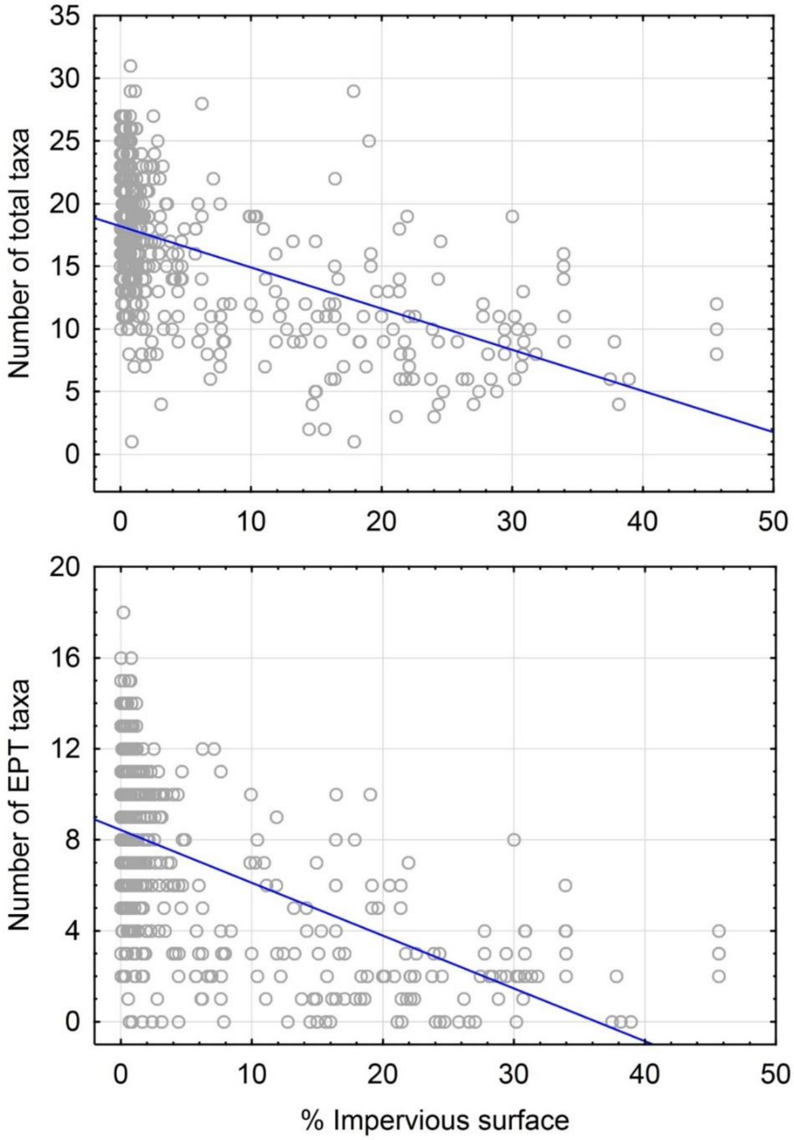


Figure 9. Scatterplots of number of total taxa (upper) and number of EPT taxa (lower) versus % impervious surface in the macroinvertebrate data set for streams in the Northern Piedmont of Maryland. Plots are fit with a linear trend line.

In some instances, quantitative stress gradients have been developed to capture multiple stressors in one integrated score. Examples include Minnesota's Human Disturbance Score (HDS) and Alabama's Human Disturbance Gradient (HDG). Input variables for the Minnesota HDS and the Alabama HDG are listed in Table 7 and Table 8, respectively. The Alabama HDG utilizes the LDI (developed by Brown and Vivas (2005)), which associates land uses with a scale of disturbance intensity and weights the index score based on land uses in the upstream catchment. Alabama Department of Environmental Management (ADEM) has used the HDG to assign its stream reaches to one of eight HDG categories based on the percentile of its overall HDG score, with categories 1–3 representing the top 25th percentile of watershed condition.

Table 7. Input variables for Minnesota Pollution Control Agency's (MPCA's) HDS (MPCA 2014a)

HDS Metric	Scale	Score
Animal unit density	watershed	10
Feedlot density	watershed	adjust
Feedlot proximity	local	adjust
Point source density	watershed	10
Point source proximity	local	adjust
Percent disturbed riparian habitat	watershed	10
Riparian condition rating	local	10
Percent agricultural land use	watershed	10
Percent agricultural land use within 100-m riparian buffer	watershed	adjust
Percent agricultural land use on ≥ 3% slope	watershed	adjust
Percent impervious surface	watershed	10
Urban land use proximity	local	adjust
Percent of stream distance modified by channelization	watershed	10
Site channelization rating	local	10
Road/stream intersection (road crossing) density	watershed	adjust

Table 8. Input variables for Alabama's HDG (Source: Lisa Huff, ADEM, personal communication)

The LDI associates land uses with a scale of disturbance intensity and weights the index score based on land uses in the upstream catchment, such that land uses that produce higher levels of disturbance receive higher LDI coefficients (Brown and Vivas 2005).

Variable	LDI coefficient	Source
Population density/km^2	1	2000 U.S. Census
% Urban	8	2006 National Land Cover Database
% Barren	8.6	
% Pasture	3.1	
% Cropland	4.7	
Road density	8.3	2010 Census TIGER/Line Shapefiles
# Stream/road crossings	8.3	

Ordinal Stress Gradient(s)

Where there are many measured stressors, it is possible to develop an ordinal, generalized stress gradient by summing and ranking the number of different stressors observed at distinct sites. A site is given a score of 1 for each stressor observed there (e.g., copper above a chronic screening threshold, excess nutrients, poor habitat score, upstream discharge), and the site score is the sum of all stressor scores. Sites with scores of 0 are candidates for "least stressed" within the context of the region. Categories of stress can be defined using measured stressors (e.g., contaminants and habitat condition) from the monitoring data, with watershed information that identifies sources of stress. The categories are a mixture of both sources and measured stressors and will inevitably be correlated to some extent. The categorization can identify a gradient of stress levels comparable to levels of disturbance (e.g., undisturbed, minimally disturbed, highly disturbed conditions (Stoddard et al. 2006)).

Stressors, whether individual or categories, can be screened by examining the response of individual taxa to the stressor or source (Figure 10)—if there is no response, the stressor should not be used in developing the ordinal gradient.

After relevant stressors and sources have been categorized, sites can be identified according to the number of stressors and sources in low, medium, or high categories. Sites where all stressors and sources are "low" qualify as least stressed, and sites where many stressors are "high" qualify as most stressed. Depending on the number of sites and stressors, intermediate categories can also be identified. Depending on the level of stressors detected in the "least stressed" category, undisturbed or minimally disturbed conditions may not be included in the data set. If this is the case, expert judgment on undisturbed or minimally disturbed conditions can be elicited based on historical observations, records, and data. Although a qualitative assessment, this information provides context for the quantitative information (e.g., "least stressed" conditions do not present undisturbed or minimally disturbed conditions).

3.3.1.1 Example: Connecticut Ordinal Stress Gradient

To identify sites to use in a BCG calibration exercise for Connecticut, analysts developed an ordinal stress gradient to apply to sample sites. The approach was to screen measured stressors for association with biological measurements and identify thresholds (stressor concentrations) below which no effects or association could be detected and screening thresholds above which association was strong. This was not an attempt to do a causal analysis (Norton et al. 2015), but simply a screening based on pairwise associations.

Connecticut DEP had sampled dissolved metals and several other water quality parameters simultaneously with each stream biological sample. For example, Figure 10 shows the number of Plecoptera (stonefly) taxa and dissolved copper concentration in Connecticut stream sites. High numbers of stonefly taxa (> 4) only occur when copper is less than 0.008 mg/L, and nearly all samples where copper was greater than 0.008 mg/L had fewer than 4 stonefly taxa (Figure 10). For the stressor gradient, the threshold for low copper stress was set at < 0.008 mg/L, and the threshold for high copper stress was set at > 0.008 mg/L. Note that there is not inference of causality, only screening of associations.

Stress categories were identified for Connecticut monitoring sites based on land use and water chemistry parameters in the database. Urban land use, natural land cover, population density, and chloride concentration were all good predictors of biological condition. Connecticut Department of Energy and Environmental Protection (CT DEEP) defined six stress categories for streams, based on the distribution of stressor parameters in the database.

CT DEEP's thresholds for the "least stressed" category (Table 9) were determined from stressor-response scatterplots of sensitive taxa in the samples versus the stressor parameters (dashed line in Figure 10). Screening thresholds for metals (Table 9) were determined from stress-response scatterplots of number of mayfly or stonefly taxa in the samples vs. metal concentrations (Figure 10). These two orders are generally considered highly sensitive to metal contamination (e.g., Buchwalter and Luoma 2005). Metals not included in Table 7 (aluminum, cadmium, mercury, lead, selenium) were either not associated with biological responses (no observable stress-response), or they were not detected in most observations in the data set. Using the criteria of Table 9, least disturbed sites were identified as sites with all eight stressor values in the "least stressed" category, and highly disturbed sites were identified as sites with four or more stress values in the "high" category. The screening allowed selection of sites for calibration to cover the range from "least disturbed" to putative "highly disturbed."

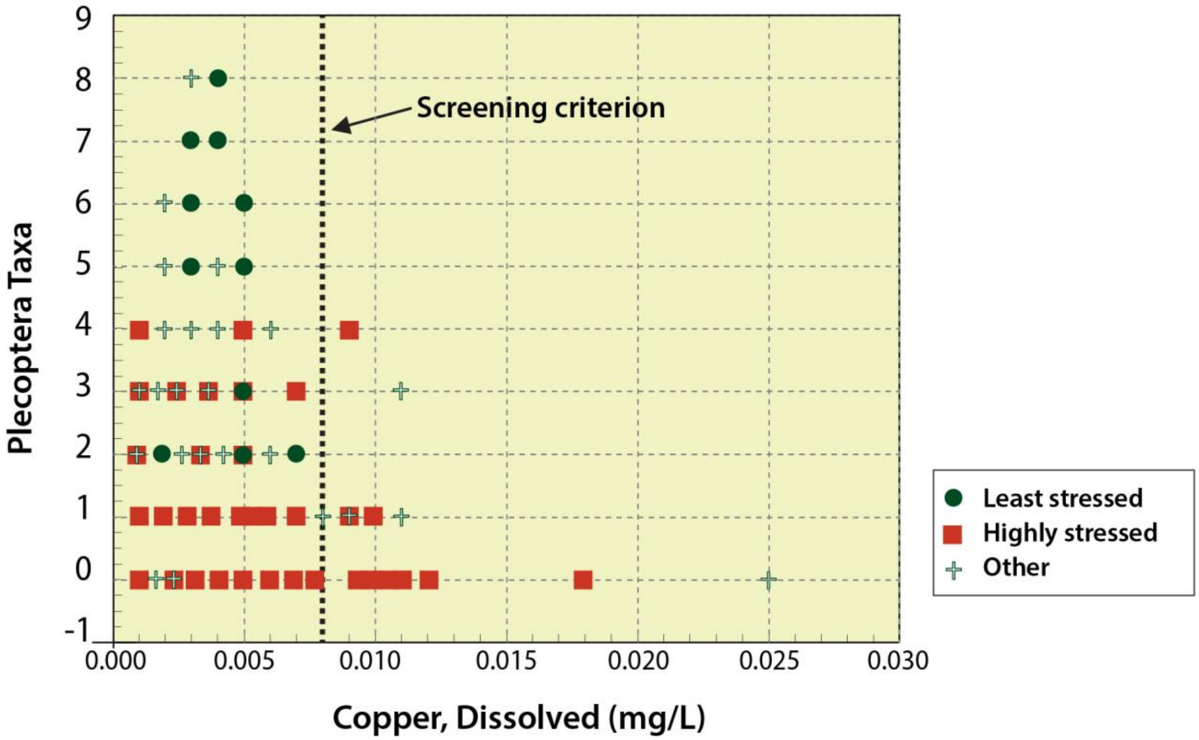


Figure 10. Number of Plecoptera (stonefly) taxa and dissolved copper (Cu) concentration, Connecticut sites. The screening criterion, (0.008 mg/L Cu) was estimated by eye from the presence of stoneflies at low Cu concentrations, and their near absence above 0.008 mg/L Cu. In the calibration, least stressed sites were required to have Cu < 0.008 mg/L (among other criteria). The screening criterion separates sites with no detectable influence of copper from those where copper may be a factor (among others) in loss of Plecoptera.

Table 9. Example screening thresholds for stressor gradient (Connecticut)

Parameter	Stress Category				
	Least Stress	Slight Stress	Moderate Stress	High Stress	Severe Stress
Catchment parameters					
Natural land cover*	> 80%	70%–80%	60%–70%	< 60%	
Developed land	< 10%		10%–25%	> 25%	
Impervious surface	< 4%		4%–10%	> 10%	
Water quality, non-metals					
Chloride	<15 mg/L	15–20 mg/L	20–30 mg/L	> 30 mg/L	
Water quality, metals					
Copper	< 0.008 mg/L			≥ 0.008 mg/L	
Iron	< 0.4 mg/L			≥ 0.4 mg/L	
Nickel	< 0.01 mg/L			≥ 0.01 mg/L	
Zinc	< 0.02 mg/L			≥ 0.02 mg/L	
Decision criteria for stress level	All parameters lowest stress category	Land cover or chloride Slight category; All others lowest category	Any one nonmetal allowed High category; All others Moderate or lower	Up to three non-metals High; Any metals High	All non-metals High-Severe; Any metals High

*defined as the sum of deciduous, conifer, open water, and all wetland categories

3.3.2 Data Preparation: Analyze Taxon Stressor-Response

An early task of the expert panel is to assign taxa to the attributes I through VI for development of stream and river BCGs. These are the primary attributes that are used to assess sites among BCG levels 2 through 6 for streams and rivers. Attribute VII, which provides information on organism condition (especially of long-lived organisms), is a general indicator of organism health, such as deformities, anomalies, lesions, tumors, or excess parasitism. This attribute has been used with great success in indices based on the fish assemblage. To date, attributes VIII through X have not been consistently applied to biological assessment and BCG development for streams and rivers. These attributes are also being explored for application in larger, more complex systems such as large rivers, estuaries, and coral reefs (see Appendix B). Additionally, these attributes may be more easily assessed, quantifiable, and amenable to rule development using spatial analysis.

Attribute assignment uses both empirical data analysis and expert judgment. Typically, tolerances of many genera or species are available from well-known compendia on macroinvertebrates (e.g., Barbour et al. 1999; Hilsenhoff 1982; Merritt et al. 2008). The published tolerances are broad and might not apply to species or genera in the data set at hand, but they provide a convenient initial value for the panel to consider. To augment the published tolerances and traits information, local data are also evaluated empirically to determine whether the published values, or the expert's opinions, are supported by the local data.

While it is tempting to rely only on the empirical analysis and "let the data tell the story," in practice, many data sets are not sufficient to determine tolerance of all taxa. For example, a taxon that occurs in five samples is too infrequent in the data set to estimate its tolerance. Nevertheless, it may be a taxon where the tolerance is well-established; for example, *Limnodrilus hoffmeisteri* is a worm characteristic of severe organic enrichment associated with untreated sewage discharge, and Brook Trout is a highly sensitive fish species in streams of northeastern North America. Both of these organisms are relatively uncommon in regions of the country with a high degree of development and with regulated discharges.

However, their biology and tolerance are well-known. Similarly, there are likely to be other taxa for which the assembled experts have substantial experience, but that might be insufficiently represented in the data set. Presentation of the stress-response analysis ensures that all experts in the workgroup are aware of, and familiar with, the data set at hand and associations that exist in that data set.

Empirical analysis of the data set being used in the calibration can greatly assist the attribute assignment. After developing a stressor gradient, it becomes possible to support assignment of taxa to attributes based on biological responses to the stressor gradient. This is similar to the analysis often used to identify tolerance groups (e.g., Yuan 2004, 2006).

Several different statistical approaches can be applied to examine individual species' response to stressors: (1) correlation tables and simple scatter plots, (2) central tendencies, (3) environmental limits, (4) optima, and (5) curve shapes (Yuan 2006). Correlations and scatter plots show the strength and shape of a stress-response. Tolerance values expressed in terms of central tendencies attempt to describe the average environmental conditions under which a species is likely to occur; tolerance expressed in terms of environmental limits attempt to capture the maximum or the minimum level of an environmental variable under which a species can persist; and tolerance expressed in terms of optima define the environmental conditions that are most preferred by a given species. These types of tolerances are expressed in terms of locations on a continuous numerical scale that represent the environmental gradient of interest. Both abundance-based and presence/absence-based models can be built using these statistical approaches. See Yuan (2006) for analytical methods.

3.3.2.1 Example: Stressor-response of Macroinvertebrates (Maryland Piedmont) and Fish (Minnesota Lakes)

When panelists assign taxa to attribute groups I–VI, they rely on a combination of empirical examination of taxon occurrences at sites that span a human disturbance, or stress, gradient, as well as professional experience as field biologists who have sampled water bodies in the areas of interest. During the attribute assignment process, panelists are provided with taxon-response plots in which the frequency and abundance of the taxa are plotted over the range of the disturbance gradient (Yuan 2006). Several different statistical models can be used to generate these plots, including:

- Weighted averaging to estimate optima and tolerance values (abundance based).
- Cumulative distribution function median and extreme limits (presence/absence).
- Logistic regression (linear, nonlinear, generalized additive model) median and extreme limits (presence/absence).

Taxon-response plots can be used to infer central tendencies (average environmental conditions under which a species is likely to occur), tolerance limits (maximum or minimum levels of an environmental variable under which a species can persist), and optima (environmental conditions that are most preferred by a given species).

The panelists use these plots to help inform BCG attribute assignments, particularly for attributes II (highly sensitive), III (intermediate sensitive), IV (intermediate tolerant), and V (tolerant). Taxa in these attribute categories are expected to follow the response patterns shown in Figure 11.

Prior to generating the plots, stressor variables are selected based on considerations such as availability of quantitative field-collected data and responsiveness of the biological assemblage to the stressor, or a stressor index such as Minnesota's HDS (Table 6). In one example, taxon-response plots were generated for two stressor variables—imperviousness and habitat index scores—based on data from the Northern Piedmont of Maryland (Stamp et al. 2014). For Minnesota lakes, the group examined taxon-response plots for urban/agricultural/mining land use in the contributing watershed and the trophic state index (Gerritsen and Stamp 2014). Examples of taxon-response plots from these two projects can be found in Figure 12. In these examples, there was good agreement between the taxon-response plots and attribute assignments, but this does not always happen. In cases of disagreement, the group relies on consensus professional opinion, unless contradicted by an overwhelming response in the data analysis. To interpret the graphs in Figure 12, the points are actual data of relative abundance, the curve represents the capture probability (logistic regression generalized additive model fit and confidence interval following Yuan 2006), and the red vertical dashed lines represent the optimum (50%) and tolerance (95%) values. Curves are smoothed to facilitate comparison to the "ideal" plots of Figure 11.

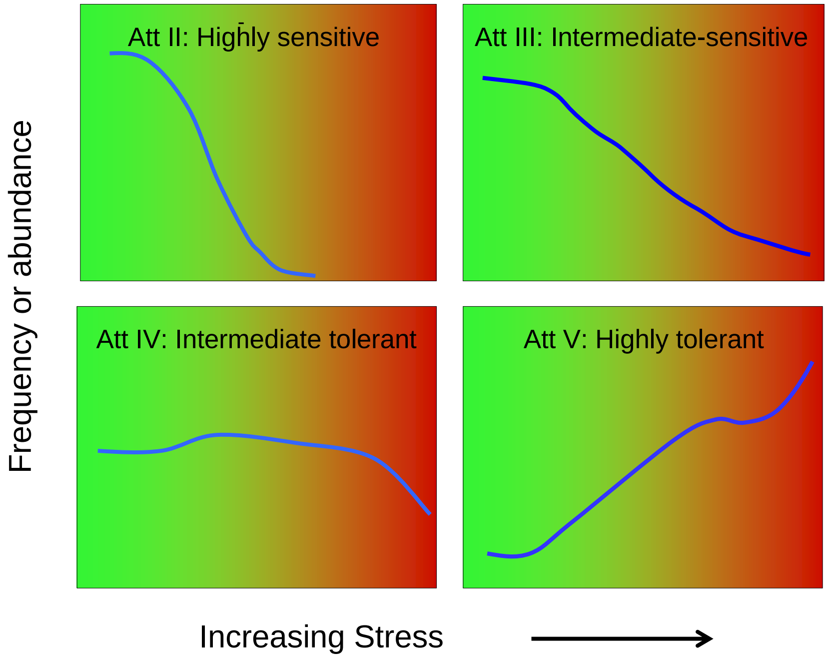


Figure 11. The frequency of occurrence and abundances of attribute II, III, IV, and V taxa are expected to follow these patterns in relation to the stressor gradient. Attribute II taxa have a high relative abundance and high probability of occurrence in minimally-disturbed sites. Attribute III taxa occur throughout the disturbance gradient, but with higher probability in better sites. Attribute IV taxa also occur throughout the disturbance gradient, but with roughly equal probability throughout, or with a peak in the middle of the disturbance range. Attribute V taxa occur throughout the disturbance gradient, but with higher probability of occurrence, and higher abundances, in more stressed sites.

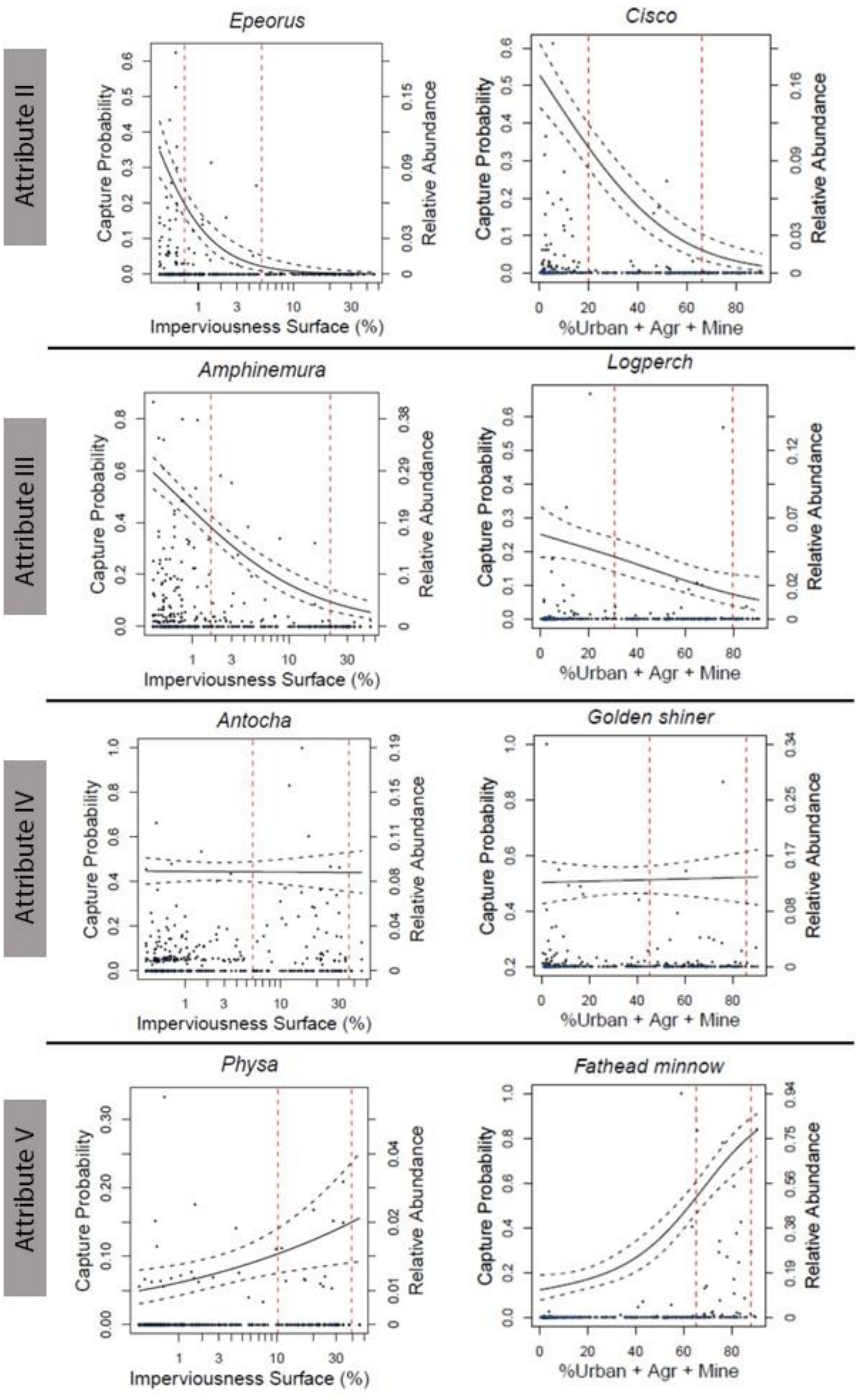


Figure 12. Examples of attribute II (highly sensitive), III (intermediate sensitive), IV (intermediate tolerant), and V (tolerant) taxon-response plots for the Northern Piedmont of Maryland and Minnesota lakes. The plots on the left show responses of four macroinvertebrate taxa from the Northern Piedmont of Maryland to impervious surface (the x-axis is log-transformed). The plots on the right show responses of five fish taxa from Minnesota lakes to urban/agricultural/mining land use.

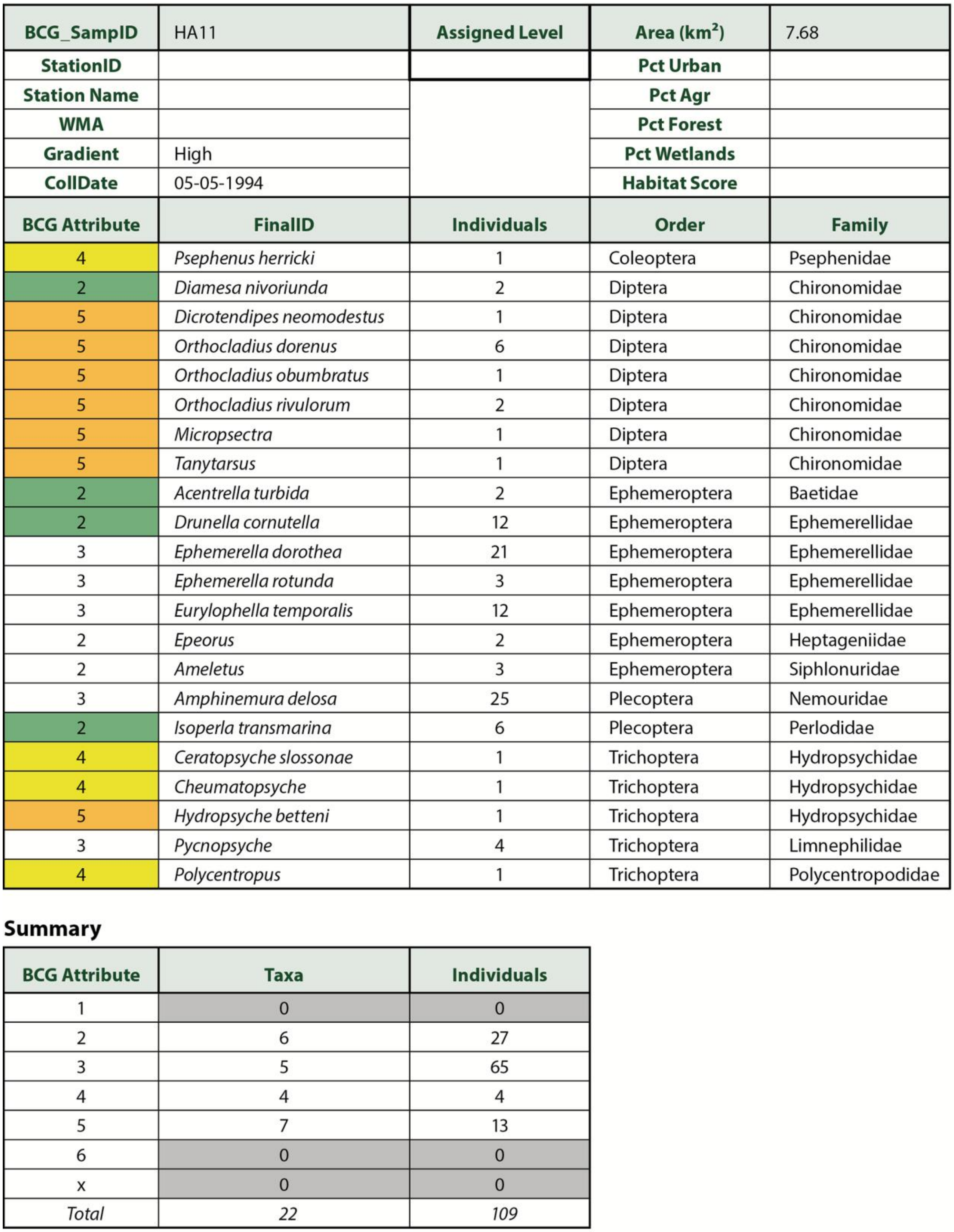
3.3.3 Data Preparation: Organize Data for Expert Panel

The expert panel will need to work with a taxon list for the database and with sample data. The taxon list should include the taxonomic hierarchy for each genus or species in the database, and it should be sorted taxonomically for ease of use. Information to be included for each species should include known tolerance/sensitivity from other sources (e.g., published Hilsenhoff tolerances, trophic guild, spawning guild, habit, habitat preference). For lists of taxa that include some of these characteristics, see Barbour et al. (1999) and Merritt and Cummins (1996).

The panel will also need to work with data sheets from individual sites. Figure 13 is an example of a data sheet that has been used in stream BCG development. These sheets should include all taxa, counts, and the panel-assigned attribute for each taxon, sorted taxonomically. Attribute assignments (left-hand column, Figure 13) are finalized during the expert panel meeting, and they are entered into the tables at that time.

In a typical workshop, the expert panel should have data available from approximately 20 to 40 sites from a single water body class, which are selected (by data analysts, not panelists) from the entire range of the stressor gradient. There should be good representation of least stressed sites, as well as most stressed sites, and all categories of stress in between. The sites selected are typically a subset of sites used to develop the stress-response curves (Figure 12).

Although the data analysts have selected cover the range of disturbance, stress information on individual sites is not provided to the expert panel. In BCG development, the rating should be done "blind" without knowledge of stressors or levels of disturbance to minimize preconceived perceptions and bias.



BCG_SampID	HA11	**Assigned Level**	**Area (km^2)**	7.68
StationID			**Pct Urban**	
Station Name			**Pct Agr**	
WMA			**Pct Forest**	
Gradient	High		**Pct Wetlands**	
CollDate	05-05-1994		**Habitat Score**	

BCG Attribute	FinalID	Individuals	Order	Family
4	*Psephenus herricki*	1	Coleoptera	Psephenidae
2	*Diamesa nivoriunda*	2	Diptera	Chironomidae
5	*Dicrotendipes neomodestus*	1	Diptera	Chironomidae
5	*Orthocladius dorenus*	6	Diptera	Chironomidae
5	*Orthocladius obumbratus*	1	Diptera	Chironomidae
5	*Orthocladius rivulorum*	2	Diptera	Chironomidae
5	*Micropsectra*	1	Diptera	Chironomidae
5	*Tanytarsus*	1	Diptera	Chironomidae
2	*Acentrella turbida*	2	Ephemeroptera	Baetidae
2	*Drunella cornutella*	12	Ephemeroptera	Ephemerellidae
3	*Ephemerella dorothea*	21	Ephemeroptera	Ephemerellidae
3	*Ephemerella rotunda*	3	Ephemeroptera	Ephemerellidae
3	*Eurylophella temporalis*	12	Ephemeroptera	Ephemerellidae
2	*Epeorus*	2	Ephemeroptera	Heptageniidae
2	*Ameletus*	3	Ephemeroptera	Siphlonuridae
3	*Amphinemura delosa*	25	Plecoptera	Nemouridae
2	*Isoperla transmarina*	6	Plecoptera	Perlodidae
4	*Ceratopsyche slossonae*	1	Trichoptera	Hydropsychidae
4	*Cheumatopsyche*	1	Trichoptera	Hydropsychidae
5	*Hydropsyche betteni*	1	Trichoptera	Hydropsychidae
3	*Pycnopsyche*	4	Trichoptera	Limnephilidae
4	*Polycentropus*	1	Trichoptera	Polycentropodidae

Summary

BCG Attribute	Taxa	Individuals
1	0	0
2	6	27
3	5	65
4	4	4
5	7	13
6	0	0
x	0	0
Total	*22*	*109*

Figure 13. Example data table for site assessment, showing how site data may be arranged for a panel's assessment. Attribute summary information is included at the bottom. Note that stressor information is blank—the panel rates sites without knowledge of stressors.

3.4 Step Three: Convene an Expert Panel

The expert workshop to calibrate the BCG is central to BCG development. Calibrating a BCG requires refining the generalized conceptual model to reflect regional conditions (Davies and Jackson 2006). The process has several steps:

- An expert panel of ecologists and field biologists is assembled.
- The panel assigns taxa to attributes I–VI. This step makes use of the taxon-response analysis described in section 3.3, combined with the experience and judgment of panel members.
- The panel assigns a set of sites to levels of the BCG. In this step, the panel also develops a general description of the native aquatic assemblages under natural, undisturbed conditions. The description of natural conditions requires biological knowledge of the region, a natural classification of the assemblages, and, if available, historical descriptions of habitats and assemblages.
- The panel develops narrative and quantitative decision rules to assign sites to BCG levels.

3.4.1 Expert Panel

An expert panel provides specific technical descriptions of each BCG level through the process of assigning sites to the levels. The panel should consist of (1) ecologists with strong field and identification experience with organisms represented in the monitoring data; (2) ecologists with knowledge of the natural history of the organisms and organism tolerances; (3) water quality experts; and, if possible, (4) one or more persons familiar with the historical background and context of water bodies of the region. This expertise could include knowledge of historic vegetation cover of the region and changes to the present or past distributions from museum records and old accounts of the taxa in the species list. Past experience with panels suggests that an ideal number of participants for each assemblage group is between 8 and 12; fewer than 8 results in a narrow diversity of expertise and viewpoints represented, yet a panel with more than 12 participants can become unwieldy and slow in identifying individual opinions. Panel meetings should also include a facilitator familiar with the BCG calibration process; staff familiar with the data and analysis already done (section 3.3); and recorder(s) to record decisions, expert logic, and important discussion points.

In the introductory session of the workshop, the panel is introduced to the BCG concept and ground rules for assessing sites and developing decision rules. Panel members must have sufficient time to digest and discuss the process and feel comfortable with it. This requires one or more introductory sessions to familiarize them with the conceptual BCG model, applications, calibration, and the data and procedures to be used. These sessions may be done as webinars to save time in the face-to-face panel meetings. For several of the BCG development efforts, two to three webinars have been conducted with the expert panel and have proven to be very effective in educating the panelists about the BCG. These webinars have also been useful in addressing questions and issues ahead of the workshop that would otherwise have sidetracked the work of the panel during the face to face meeting. Additionally, a dry run with the panelist in use of data spreadsheets and evaluating the data can result in new information and insight from the panelists that can be incorporated into developing the BCG. A very useful initial exercise is a “practice run” to rate approximately three sites that the facilitation team has reason to believe might be relatively good condition, mediocre condition, and poor condition, respectively. This allows panelists to experience the process on which they will be spending considerable time. Upon completion of the introductory session, the panel begins work, as explained in the following sections.

3.4.2 Assign Taxa to Attributes

Prior to calibrating BCG levels, the panel assigns taxa in the database to the taxonomic attributes (attributes I to VI). Assignments of taxa to attributes rely on examination of empirical stress-response relations, as well as professional experience of field biologists who have sampled the water bodies of the region. In this way, the professional opinions of the workgroup can be tested with the empirical data (Figure 12). Several taxa may have insufficient data within the statewide data set. The wider collective experience of the workgroup can enhance the empirical database with experience with under-represented taxa, and knowledge of natural history.

In cases of disagreement between empirical analyses and professional opinion, the group can employ a weight of evidence approach, including consensus professional opinion and strong and consistent response shown in the data analysis (Figure 12). To save time in the face-to-face panel workshop, attributes and assignment of taxa to the (taxonomic) attributes can be introduced in the pre-workshop webinars, and each expert is asked to assign taxa to attributes as homework. Experts are also given results of the stressor-response analyses of individual taxa. The facilitation team compiles the experts' taxon assignments prior to the workshop, and participants discuss each taxon to develop consensus assignments.

After the taxa are assigned to the attributes, the attribute numbers should be entered into the site-specific data sheets (Figure 12).

3.4.2.1 Example: Alabama Taxon Assignments

Prior to the face-to-face BCG workshop for northern Alabama streams, panelists received taxa lists from the facilitation team and were asked to make preliminary attribute assignments based on (1) relevant literature and (2) taxon-response plots showing relationships between the frequency and abundance of the taxa over the range of the Alabama HDG. The facilitation team compiled the results and used them as a starting point for the attribute assignment component of the workshop, during which panelists made assessments based on consensus professional opinion. Once the attribute assignments were made, the facilitator entered them into a master taxa worksheet, which automatically updated the attribute assignments in the sample worksheets (Figure 13). Table 10 shows the distribution of macroinvertebrate and fish taxa across attribute categories for northern Alabama streams.

Table 10. Distribution of macroinvertebrate and fish taxa across the BCG attributes in northern Alabama

BCG Attribute		Macroinvertebrates			Fish		
		# of taxa	% of individuals	Examples	# of taxa	% of individuals	Examples
I	Historically documented, sensitive, long-lived, or regionally endemic taxa	1	0.2	Gastropods: *Fontigens*	6	2.7	Bankhead Darter, Crown Darter, Holiday Darter, Sipsey Darter
II	Highly sensitive taxa	110	16.7	Beetles*: Optioservus*, Mayflies: *Heptagenia*, *Leucrocuta*, Caddisflies: *Brachycentrus, Glossosoma*, Stoneflies*: Leuctra, Tallaperla*	15	6.8	Burrhead Shiner, Cahaba Shiner, Bigeye Shiner, Goldline Darter, Warpaint Shiner, Blenny Darter
III	Intermediate sensitive taxa	136	20.6	Beetles*: Macronychus,* Mayflies: *Stenonema, Isonychia,* Midges: *Tvetnia, Brillia,* Caddisflies: *Chimarra,* Odonata: *Macromia*	38	17.4	Shadow Bass, Black Redhorse, Rock Bass, Northern Studfish, Southern Studfish, Bigeye Chub, Tuskaloosa Darter, Rainbow Shiner
IV	Taxa of intermediate tolerance	173	26.2	Midges: *Polypedilum, Tanytarsus, Rheotanytarsus, Thienemannimyia,* Beetles*: Stenelmis,* Dragonflies: *Boyeria,* Mayflies: *Baetidae*	76	34.7	Longear Sunfish, Alabama Hog Sucker, Banded Sculpin, Alabama Shiner, Silverstripe Shiner
V	Tolerant native taxa	67	10.2	Caddisflies: *Cheumatopsyche,* Worms: *Oligochaeta,* Midges: *Ablabesmyia, Dicrotendipes,* Dragonflies: *Argia,* Flies: *Simulium,* Gastropods: *Physella*	29	13.2	Bluegill, Blackbanded Darter, Largemouth Bass, Striped Shiner, Spotted Bass, Blacktail Shiner, Blackspotted Topminnow
Va	Opportunistic tolerant taxa	—	—	—	9	4.1	Creek Chub, Bluntnose Minnow, Redbreast Sunfish, Western Mosquitofish, Eastern Mosquitofish, Green Sunfish, Largescale Stoneroller, Yellow Bullhead
VI	Non-native taxa	2	0.3	*Corbicula* and Astacidae	5	2.3	Common Carp, Fathead Minnow, Goldfish, Grass Carp, Red Shiner
X	Migrating fish (surrogate for ecosystem connectance)	—	—	—	2	0.9	American Eel, Atlantic Needlefish
—	No attribute assignment (insufficient information)	171	25.9	Coarse identifications and uncommon occurrences	39	17.8	Uncommon occurrences
Totals		***660***	***100***		***219***	***100***	

3.4.3 Assign Sites to Condition Levels

Working from a description of undisturbed communities and the species composition data from example sites, the panel assigns sites to the levels of the BCG. These site assignments are used to describe changes in the aquatic communities for lower levels of biological condition, leading to a complete descriptive model of the BCG for the region. Throughout this process, the panel makes use of the prepared data (Figure 12 and Figure 13) to examine species composition and abundance data from sites with different levels of cumulative stress, from least stressed to severely stressed.

3.4.3.1 Description of Natural, Undisturbed Conditions

First, the panel attempts to reconstruct the native aquatic assemblages under natural, undisturbed conditions. This is an application of historical ecology (McClenachan et al. 2015), and if resources are available, a formal effort should be made to describe the historical conditions. The description of natural conditions requires biological knowledge of the region, a natural classification of the assemblages, and, if available, historical descriptions of the habitats and assemblages. A useful exercise is to ask each panelist to describe the community of an undisturbed, natural system. This develops a best professional judgment description of undisturbed communities for the region that is, at best, qualitative.

Descriptive studies of historic and prehistoric distributions of species can be useful in developing a description of pre-settlement or pre-industrial conditions. For example, most classic fish distribution monographs draw heavily on early descriptions and collections by 19th century naturalists (e.g., descriptions in *The Fishes of Ohio*; Trautman 1981) to develop estimates of pre-settlement distributions for as many species as possible. Fish and mollusks have also been investigated from native and early settler middens to derive distributions of harvested species, and these can be combined with other studies to develop more comprehensive descriptions (e.g., Angelo et al. 2002, 2009).

For example, in Kansas, few streams have completely escaped the effects of large-scale agricultural and livestock practices implemented over the past 150 years (Angelo et al. 2009). Although many of the biological surveys from the mid-1800s were performed after the start of intensive agriculture, they still provide valuable documentation of the occurrence of several freshwater species that soon disappeared from specific watersheds or the region as a whole. Museum collections and other historical records indicate that many creeks and smaller rivers in the Great Plains supported a variety of predominately eastern fish and shellfish species, most requiring clear water and relatively stable stream bottoms. In fact, Kansas was once home to more than 50 Unionid mussel species. Today, several mollusk species are no longer found in most of their original habitats (Figure 14). Over the past 150 years, at least 11 aquatic molluscan taxa have become extinct in Kansas, and an additional 23 species are currently designated as endangered, threatened, or vulnerable.

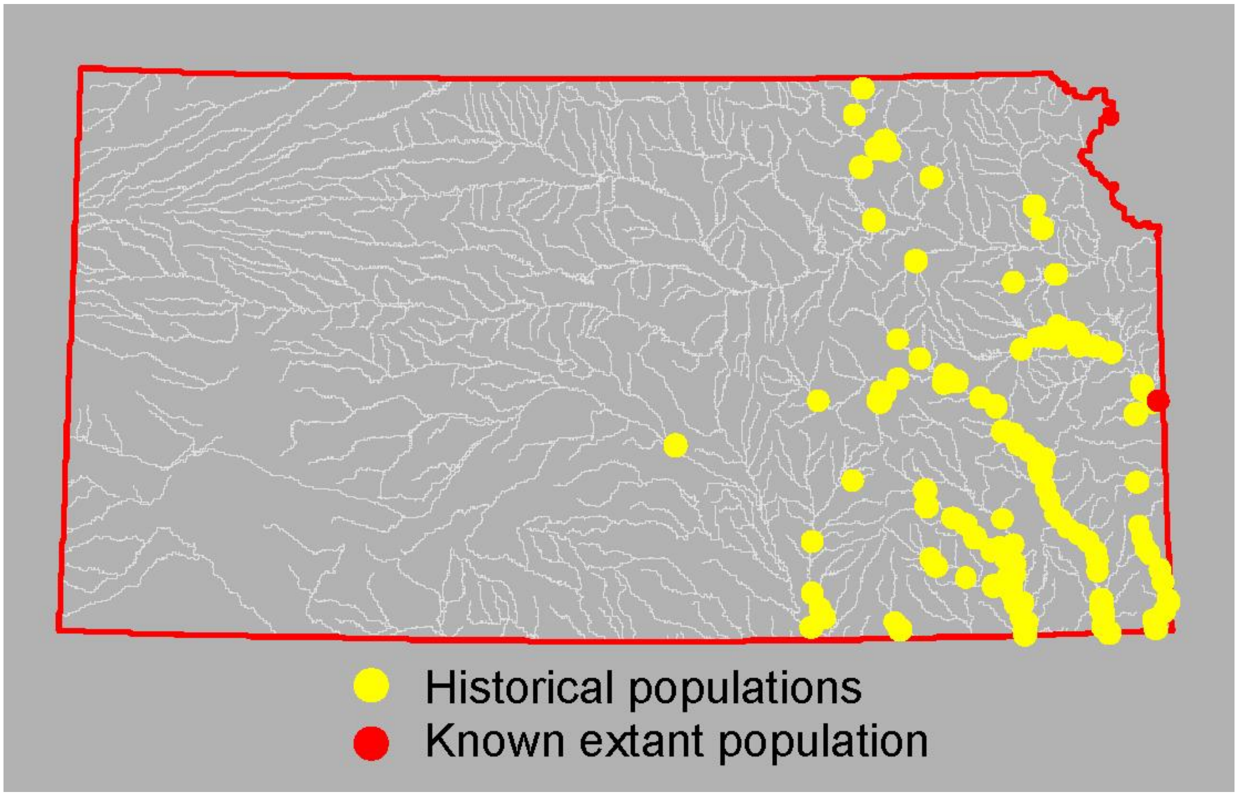


Figure 14. Decline in geographical distribution of black sandshell mussel in Kansas (after Angelo et al. 2009).

A description of undisturbed conditions may also be developed more quantitatively if databases, expertise, and resources are available. With the growth of biological monitoring, there have been several recent attempts to develop predictive statistical models of biological composition (typically metrics, but also taxa) using multiple regression (e.g., Waite et al. 2010) or other modeling approaches (e.g., random forests [DeWalt et al. 2009]; Threshold Indicator Taxa ANalysis (TITAN) [Baker and King 2010]). These model approaches can be used to extrapolate to undisturbed conditions and predict relevant metrics (Waite et al. 2010), composition, or individual species ranges (DeWalt et al. 2009) under undisturbed conditions. They are especially useful if museum records, paleolimnological investigations, or historical descriptions do not apply (e.g., invertebrates were typically of less interest than fish to early explorers and many naturalists).

There are challenges and drawbacks when using historical data to reconstruct natural stream conditions. It takes a great deal of time and commitment to piece together numerous bits of information, especially considering the limitations and inconsistencies inherent in historical data. Much of the information is not directly comparable to modern assessment data, largely because results from previous studies and observations are often based on different sampling methodologies. Sometimes the data are not applicable because they were obtained after settlers significantly impacted the land, but often such physical habitat data are missing or incomplete. Finally, some regions settled early in the history of the nation may simply lack definitive historical data on the baseline biological condition.

As an example, Shumchenia et al. (2015) constructed the first estuarine BCG framework that examines changes in habitat structure through time. Using historical data and descriptions, including maps, navigational charts, land use descriptions, sediment cores, and shellfish landings, they described a minimally disturbed range of conditions for the ecosystem, anchored by observations before 1850. Like many estuaries in the U.S., the relative importance of environmental stressors changed over time, but even qualitative descriptions of the biological indicators' status provided useful information for defining condition levels. In addition to helping conceptually define the biotic community expected in an undisturbed or minimally disturbed environment, the BCG was used to show that stressors rarely acted alone and that declines in one biological indicator influenced the increase or decline of others.

3.4.3.2 Assignment of Current Sites

The panel works with data tables showing the species and attributes for each site (Figure 13). In developing assessments, the panel works "blind," that is, no stressor information is included in the data table. Only non-anthropogenic classification variables are shown (in Figure 13, watershed area and gradient). Sites are selected by the facilitation team to span the range of stress that occurs in the region, from the least stressed to the most stressed. Panel members discuss the species composition and what they expect to see for each level of the BCG.

A typical site assignment proceeds as follows: The facilitator projects the data onto a screen (Figure 13) and calls out some salient data on the site, including area, gradient, total taxa, and possibly some summary metrics. Panelists take several minutes to look at the data, and each panelist proposes a BCG level for the site, along with principal reasons for the decision. The site and decision reasons are discussed by the panel, and panelists are allowed to change their decisions, if desired.

Following assignment of 20 or more sites to levels of the BCG, the panel develops a description of each level, along with rules that are expected to be met by each level, starting from the highest quality condition observed in the data set (e.g., level 1) and working down to the most severely altered condition (e.g., level 6). The description and rules can be as quantitative as the panel cares to make them. Examples of water bodies that might have low resolution include intermittent and ephemeral streams, wetlands, and tidal fresh portions of estuaries. Also, BCG levels might be absent from the data set. In most developed states, there is general recognition that BCG level 1 is exceedingly rare or absent. BCG level 6 is often absent from data sets because the most egregious pollution has been remediated, leaving level 5 as the poorest quality observed. Level 6 may sometimes be observed in older data (pre-1985). If a panel determines that two or more levels cannot be discriminated, then they are typically combined into one; for example "levels 3–4" or "levels 5–6." This should only be done when the panel determines that the levels cannot be discriminated, not simply because one or more levels happen to be absent from the given data set.

Assessing biological condition and assigning sites to a level of the BCG are based on the detailed attribute descriptions developed earlier for the water body and region for which the model is being developed, plus other taxonomic attributes the panel agrees are important. It is entirely possible to determine biological condition with a subset of the attributes. For example, biological assessment in streams and rivers is currently carried out with indicators very similar to taxonomic and condition attributes I through VII of the BCG, all derived from species composition. However, a measure of the spatial distribution of estuarine habitats for assessing whole estuary condition is under development in Narragansett Bay based on a spatial habitat measure and on the "historic balance" of critical estuarine habitats in Tampa Bay (Cicchetti and Greening 2011; Shumchenia et al. 2015). This indicator is under development as a surrogate for attribute X (ecosystem connectivity), and would provide information on the presence and spatial relationship of habitats critical to a functioning estuarine system. The importance of individual attributes depends on the system being assessed, and information or indicators for all attributes may not be necessary.

As an example, a panel of aquatic biologists from three states (Michigan, Wisconsin, and Minnesota) and four tribal water quality agencies calibrated BCG models for coolwater wadeable streams of the Upper Midwest (Gerritsen and Stamp 2012). Prior to performing site assessments, the group discussed their expectations for sites spanning the different BCG levels. Table 11 contains the narrative descriptions of each of the BCG levels (modified after Davies and Jackson (2006)), as well as lists of fish and macroinvertebrate taxa that the group expected to commonly find in samples from each BCG level. The overall relationship between BCG level and Minnesota's disturbance score is shown in Figure 15.

Table 11. Description of transitional cold-cool assemblages (benthic macroinvertebrate and fish taxa) in each assessed BCG level, Upper Midwest coldwater streams. Definitions are modified after Davies and Jackson (2006) (Source: Gerritsen and Stamp (2012)).

BCG level 1	**Definition:** Natural or native condition—*native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability*
	Fish: If the stream is in a location where brook trout are native, *native brook trout* must be present. Non-native salmonids must be absent. Up to twelve additional taxa, including highly sensitive (attribute I, II, & III) species such as *slimy sculpin* and *brook lamprey*, are also be present. If tolerant taxa are present, they occur in very low numbers.
	Macroinvertebrates: There is a lack of sufficient information to know what the historical undisturbed macroinvertebrate assemblage looked like.
BCG level 2	**Definition:** Minimal changes in structure of the biotic community and minimal changes in ecosystem function—*virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*
	Fish: Overall taxa richness and density is as naturally occurs. Non-native salmonids may be present. If the stream is in a location where brook trout are native, *native brook trout* must be present and must not be negatively impacted by non-native salmonids such as *brown trout*. Other highly sensitive (attribute II) and intermediate sensitive (attribute III) taxa such as *sculpins (mottled or slimy), dace (pearl, finescale, northern red belly, longnose)* and *brook lamprey* are also present. Tolerant taxa may be present but in low numbers.
	Macroinvertebrates: Overall taxa richness and density is as naturally occurs. Most sensitive (attribute II) taxa (e.g., *Trichoptera*: *Glossosoma, Rhyacophila, Lepidostoma, Dolophilodes; Ephemeroptera*: *Ephemerella, Epeorus; Plecoptera: Leuctridae*) and other taxa must be present. These plus intermediate sensitive (attribute III) taxa (e.g., *Ephemeroptera*: *Paraleptophlebia*; *Plecoptera*: *Acroneuria, Isoperla, Paragnetina*; *Trichoptera*: *Brachycentrus, Chimarra*) occur in higher relative abundances than in BCG level 3 samples. Tolerant taxa occur in low numbers.
BCG level 3	**Definition:** Evident changes in structure of the biotic community and minimal changes in ecosystem function—*Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*
	Fish: Overall taxa richness and density is as naturally occurs. Sensitive taxa such as *dace (pearl, finescale, northern red belly, longnose)* and *northern hog suckers* must outnumber tolerant taxa such as *central stonerollers* and *bluegill.* Taxa of intermediate tolerance (attribute IV) such as *white suckers*, *blacknose dace, common shiners, darters (johnny, fantail),* and *creek chub* are common, and some tolerant (attribute V) taxa such as *northern pike, yellow perch,* and *stonerollers* may be present. If extra tolerant taxa such as *green sunfish* and *bluntnose* and *fathead minnows* are present, they occur in very low numbers.
	Macroinvertebrates: Overall taxa richness and density is as naturally occurs. Similar to BCG level 2 assemblage except sensitive taxa (e.g., Ephemeroptera: Paraleptophlebia; Plecoptera: Acroneuria, Isoperla, Paragnetina; Trichoptera: Brachycentrus, Chimarra; Diptera: Diamesa, Eukiefferiella, Tvetenia) occur in lower relative abundance and the most sensitive (attribute II) taxa may be absent. Taxa of intermediate tolerance (attribute IV) (e.g., *Gammarus, Oligochaeta, Simulium; Coleoptera: Optioservus, Stenelmis; Ephemeroptera: Baetis, Stenonema; Trichoptera: Hydropsyche, Cheumatopsyche*) are common, and some tolerant taxa (attribute V) occur in low numbers.

BCG level 4	**Definition:** Moderate changes in structure of the biotic community and minimal changes in ecosystem function—*Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*
	Fish: Sensitive taxa such as *dace (pearl, finescale, northern red belly, longnose)* and *northern hog suckers* are present but occur in very low numbers. Taxa of intermediate tolerance (attribute IV) such as *white suckers, blacknose dace, common shiners, darters (johnny, fantail)* and *creek chub* are common, and some tolerant (attribute V) taxa such as *northern pike, yellow perch* and *stonerollers* are present. When compared to BCG level 3 samples, highly tolerant taxa such as *green sunfish* and *bluntnose* and *fathead minnows* are present in greater numbers.
	Macroinvertebrates: Overall taxa richness is slightly reduced. Sensitive taxa (including EPT taxa) are present but occur in low numbers. Taxa of intermediate tolerance (attribute IV) (e.g., *Gammarus, Oligochaeta, Simulium; Coleoptera: Optioservus, Stenelmis; Ephemeroptera: Baetis, Stenonema; Trichoptera: Hydropsyche, Cheumatopsyche*) are common, as are tolerant (attribute V) taxa (e.g., *Diptera: Cricotopus, Dicrotendipes, Paratanytarsus; Hyalella; Physa; Turbellaria*).
BCG level 5	**Definition:** Major changes in structure of the biotic community and moderate changes in ecosystem function—*Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials.*
	Fish: Overall taxa richness may be reduced. Sensitive taxa drop out. Taxa of intermediate tolerance (attribute IV) such as *white suckers, blacknose dace, common shiners, darters (johnny, fantail),* and *creek chub* are common. There is an influx of tolerant and highly tolerant taxa such as *bluegill*, *yellow perch, largemouth bass, northern pike, central stonerollers, bluntnose minnows, fathead minnows,* and *green sunfish*.
	Macroinvertebrates: Overall taxa richness is slightly reduced. Sensitive taxa may be absent. Taxa of intermediate tolerance (attribute IV) (e.g., *Gammarus, Oligochaeta, Simulium; Coleoptera: Optioservus, Stenelmis; Ephemeroptera: Baetis, Stenonema; Trichoptera: Hydropsyche, Cheumatopsyche*) and tolerant (attribute V) taxa (e.g., *Diptera: Cricotopus, Dicrotendipes, Paratanytarsus; Hyalella; Physa; Turbellaria*) are common. Tolerant taxa occur in higher abundances than in BCG level 4 samples.

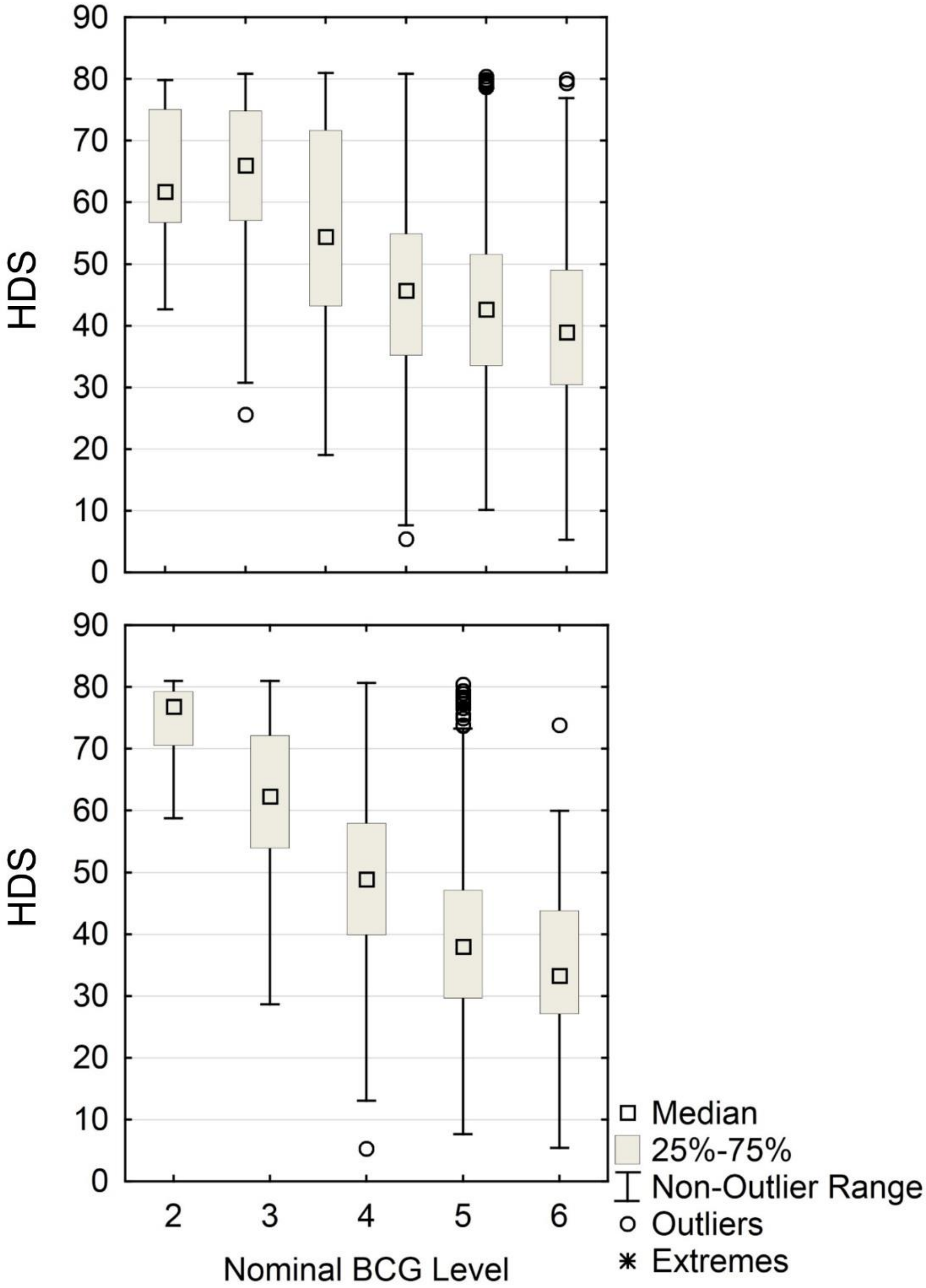


Figure 15. Box plots of HDS for Minnesota streams, grouped by nominal BCG level (panel majority choice) for fish (upper) and macroinvertebrate (lower) samples. HDS scores range from 0 (most disturbed) to 81 (least disturbed) (Gerritsen et al. 2013).

3.4.3.3 Variability in Panelist Biological Condition Gradient Calls

Consistency among panelists is important. In addition to integer BCG levels (e.g., levels 2, 3, 4), panelists also aim to identify sites somewhat better or somewhat worse than the integer levels, up to and including samples that are borderline between adjacent BCG levels. In calibration exercises, intermediate levels have been assigned (+) and (-). This information has been used to help define the threshold where an expert would assign a site to a different BCG level. An expert assigning a site to a BCG level with a (+) or (-) caveat would be asked what additional change in the site data would lead to a different level assignment, and why.

For the BCG project in the Northern Piedmont of Maryland, the macroinvertebrate workgroup assessed 46 calibration samples. Panelists rated samples in the six BCG levels, and modified those with (+) and (-) as desired. Median BCG level assignments were calculated for each sample as the group nominal level.

Deviations of each panelist's assignments from the group median call were estimated, where deviations were assumed to be in quantities of ⅓ BCG level. Deviations are shown in Figure 16. On average, 62% of BCG level assignments matched exactly with the median, 32% were within ±⅓ BCG level, 5% were within ±⅔ BCG level, and 1% differed by one BCG level (Figure 16).

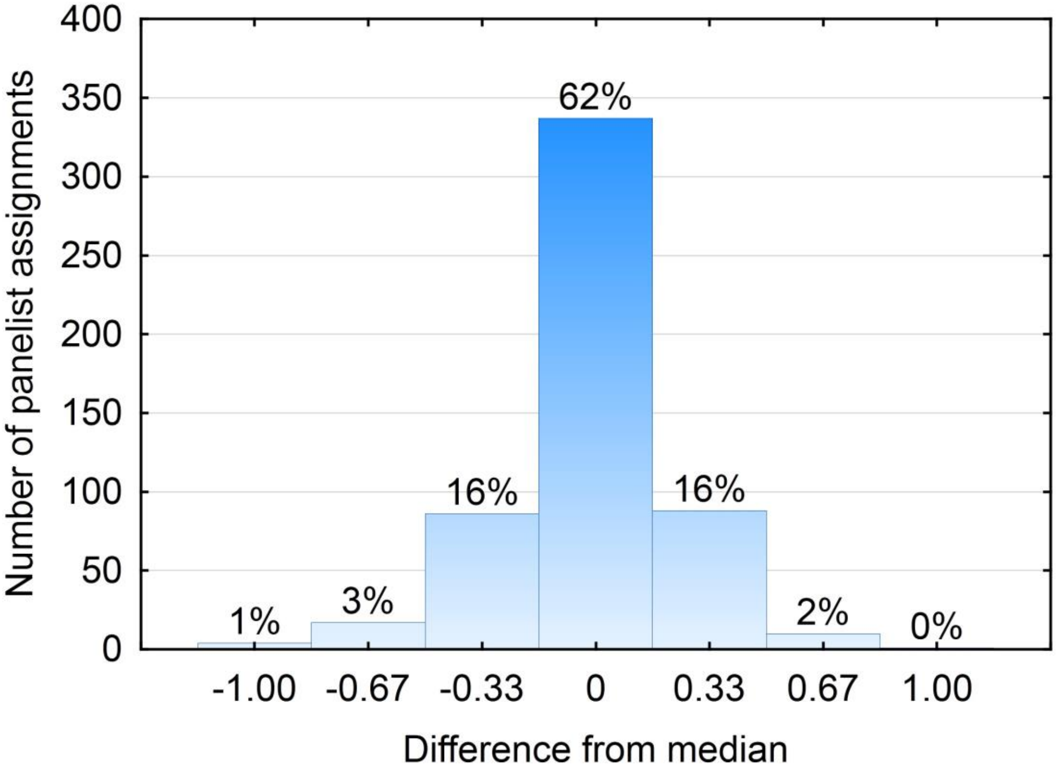


Figure 16. Distribution of individual panelists BCG assignments, as deviations from group sample median, Maryland Piedmont BCG workshop. Percentages above each bar. Data from Stamp et al. 2014.

3.5 Biological Condition Gradient Decision Rules

This chapter described steps to develop narrative descriptions and rules for assigning sites to BCG levels. The core objective of the panel process is to elicit expert judgment on what the experts consider ecologically significant change in the biotic community—and to document the underlying rationale. Through development of expert consensus, first narrative and then quantitative rules emerge, and they are tested and refined based on the current state of the science. Additionally, where gaps in information are identified, the development of decision rules is comparable to formulating a hypothesis, thereby setting up opportunities for applied research that clearly articulate water quality management information needs for goal setting and condition assessments.

The chapter concludes with development of narrative descriptions of BCG levels for specific water bodies within a region or basin. Chapter 4 addresses how to convert these narrative descriptions into narrative then quantitative decision rules for a numeric BCG model. There is no bright line between development of the narrative description and numeric decision rules. In all BCG development efforts to date, preliminary quantitative decision rules have emerged early as part of developing the narrative description and rules. In the first round of data analysis and interpretation, the experts typically formulate their reasoning in the following manner: "I expect more (or fewer) species because …." or "the presence of two or more taxa of attribute III signifies this condition level to me because …." By the second or third round of the data exercise assigning sites to BCG levels, increasingly quantitative statements are provided when experts are asked to explain their logic for assigning sites to BCG levels. These preliminary quantitative statements provide a template for building quantitative decision rules through an iterative, interactive process with the expert panel. Encapsulation of expert judgment provides the transparency and clarity for decision makers and stakeholders to understand the logic and science underpinning ALU goal descriptions and assessments.

Chapter 4. Quantitative Rules and Decision Systems

Routine use of a quantitative BCG model requires a way to automate application of the decision rules so that assessments can be made for newly sampled water bodies without reconvening the expert panel. This chapter discusses approaches to quantify the narrative BCG model and to test and validate the numeric model, corresponding to Steps 4 and 5 of the BCG Calibration process (Figure 8). Quantitative rules rely on sample data using standardized protocols (i.e., most applicable to attributes II–VI). This chapter presents:

- An approach to quantify the conceptual BCG framework and develop a numeric model. This approach is based on elicitation of the experts' decision criteria and incorporation into a numeric decision model using a mathematical set theory approach (e.g., fuzzy logic) (See section 4.1). This approach has been tested and refined in most of the BCG projects to date.
- Considerations and approaches for relating the BCG with the state's existing biological assessment methods and tools (e.g., biological indices such as MMIs and O/E models) (See section 4.2). To date, most states have developed biological indices.
- An additional approach to quantify the BCG narrative decision rules that has been implemented by a state, multivariate linear discriminant modeling. This approach involves development of statistical models that "predict" (or imitate) the expert decisions (See section 4.3). As BCG development and calibration continues, it is expected that the BCG process will be refined and expanded and alternate methods identified and tested.

4.1 Quantitative Rule Development and Application

This approach assumes that because the expert panelists largely agree on BCG ratings for water bodies, they use a common set of decision criteria to achieve the ratings. The approach consists of deriving narrative and numeric decision rules based on expert logic and consensus, including testing of the rules with the expert panel and then with experts outside of the panel. Application of the decision criteria—a set of quantitative rules—can then be applied to any relevant data set or sample.

Quantitative rule and direct decision model development is comprised of the following steps:

- **Elicitation of numeric decision criteria**—During the expert panel meeting, experts are asked for their reasoning behind the decisions. The reasoning is the basis for the BCG level descriptions (Table 11), and also for decision criteria (narrative rules) that the experts use. The narrative rules are elicited from the panel and then quantified.
- **Quantification and testing**—Quantitative rules in turn form the basis of a decision model. A methodology to apply the elicited rules is through a mathematical set theory approach, fuzzy logic (Zadeh 1965, 2008), which mimics human thinking and decision making. Results of the quantitative decision model are compared to the panel's decision, and mismatches are further discussed by the panel to resolve ambiguous or incomplete rules. Ideally, the final model should be tested with an independent data set that was assessed by the panel but not used to calibrate the model. Other approaches to rule elicitation and development include reproducing the expert panel results (but not necessarily their reasoning) with an empirical discriminant analysis model (section 4.2; Davies et al. In press; Shelton and Blocksom 2004), or developing a Bayesian predictive model from the elicitation of reasoning (e.g., Kashuba et al. 2012).

4.1.1 *Elicitation of Numeric Decision Criteria*

Level descriptions in the BCG conceptual model are intentionally general (e.g., reduced richness, increased dominance, loss or replacement of specific assemblages), which allows for different methods, sources of information, and interpretations to be used in rule development. To allow for consistent assignments of sites to levels, it is necessary to formalize the expert knowledge by codifying level descriptions into a set of rules (e.g., Droesen 1996). If formalized properly, water quality management program scientists with adequate data can follow the rules to obtain the same level assignments as the group of experts. This replicability makes the actual decision criteria transparent to stakeholders.

Rules are logic statements that experts use to make their decisions (e.g., "If plecoptera richness is high, then biological condition is high."). Rules on attributes can also be combined (e.g., "If the proportion of highly sensitive taxa (attribute II) is high, the proportion of tolerant individuals (attribute V) is low, and so on, then assignment is BCG level 2.").

Numeric rule development requires discussion and documentation of level assignment decisions and the reasoning behind the decisions. During this discussion, it is necessary to record each participant's level decision (i.e., vote) for the site, the critical or most important information for the decision (e.g., the number of taxa of a certain attribute, the abundance of an attribute, the presence of indicator taxa), and any confounding or conflicting information and how this information was reconciled for the eventual decision.

As the panel assigns example sites to BCG levels, the panel members are polled on the critical information and criteria they used to make their decisions. These form preliminary, narrative rules that explain how panel members make decisions. For example, "For BCG level 2, sensitive taxa must make up at least half of all taxa in a sample." The decision rule for a single level of the BCG does not always rest on a single attribute (e.g., highly sensitive taxa) but may include other attributes as well (intermediate sensitive taxa, tolerant taxa, indicator species, organism condition), so these are termed "Multiple Attribute Decision Rules." With data from the sites, the rules can be checked and quantified. For mathematical fuzzy set modeling, quantification of rules will allow the agency to consistently assess sites according to the same rules used by the expert panel, and it will allow a computer algorithm, or other persons, to obtain the same level assignments as the panel.

Rule development requires discussion and documentation of BCG level assignment decisions and the reasoning behind the decisions. During this discussion, the facilitators record:

- Each participant's decision for the site:
  - The critical or most important information for the decision—for example, the number or abundance of taxa of a certain attribute, the presence of indicator taxa, the absence of certain taxa, and explanation why this information is ecologically important.
  - Any confounding or conflicting information and how this was resolved for the eventual decision.
- Iteration
  - Rule development is iterative, and it usually requires at least two panel sessions.
  - Building from the initial site assignments, preliminary narrative rules are developed. Descriptive statistics of the attributes and other biological indicators for each BCG level

determined by the panel are then developed for testing. These statistical descriptions will be used for testing and refinement as numeric decision rules are developed and vetted.

- Following the initial development phase, the draft rules are tested by the panel with new data to ensure that new sites are assessed in the same way. The new test sites should not have been used in the initial rule development and also should span the range of anthropogenic stress. Any remaining ambiguities and inconsistencies from the first iterations are also resolved at this stage.

4.1.2 Codification of Decision Criteria: Multiple Attribute Decision Criteria Approach

The expert rules can be automated in Multiple Attribute Decision Models. These models replicate the decision criteria of the expert panel by assembling the decision rules using logic and set theory, in the same way the experts used the rules. In the case studies presented later in this chapter, the models replicated expert panel's decisions at greater than 90% accuracy, including tied or intermediate decisions between adjacent BCG levels (e.g., between level 3 and level 4).

Instead of a statistical prediction of expert judgment, this approach directly and transparently converts the expert consensus to automated site assessment. The method uses modern mathematical set theory and logic (called "fuzzy set theory") applied to rules developed by the group of experts. Mathematical fuzzy set theory is directly applicable to environmental assessment, it has been used extensively in engineering applications worldwide (e.g., Demicco and Klir 2004), and environmental applications have been explored in Europe and Asia (e.g., Castella and Speight 1996; Ibelings et al. 2003).

Mathematical fuzzy set theory allows degrees of membership in sets, and degrees of truth in logic, compared to all-or-nothing in classical set theory and logic. Membership of an object in a set is defined by its membership function, a function that varies between 0 and 1. One can compare how classical set theory and fuzzy set theory treat the common classification of sediment, where sand is defined as particles less than or equal to 2.0 mm diameter, and gravel is greater than 2.0 mm (Demicco and Klir 2004). In classical "crisp" set theory, a particle with diameter of 2.00 mm is classified as "sand," and one with 2.01 mm diameter is classified as "gravel." In fuzzy set theory, both particles have nearly equal membership in both classes (Demicco 2004). Measurement error of 0.005 mm in particle diameter greatly increases the uncertainty of classification in classical set theory, but in fuzzy set theory a particle near the boundary would have nearly equal membership in both sets "sand" and "gravel." Fuzzy sets, thus, retain the understanding and knowledge of measurements close to a set boundary, which is lost in classical sets.

Demicco and Klir (2004) proposed four reasons why mathematical fuzzy sets and logic enhance scientific methodology, and these are applicable to BCG development:

- Fuzzy set theory has greater capability to deal with "irreducible measurement uncertainty," as in the sand/gravel example above.
- Fuzzy set theory captures vagueness of linguistic terms, such as "many," "large," or "few."
- Fuzzy set theory and logic can be used to manage complexity and computational costs of control and decision systems.
- Fuzzy set theory enhances the ability to model human reasoning and decision making, which is critically important for defining thresholds and decision levels for environmental management.

4.1.2.1 Rule-based Inference Model

People tend to use strength of evidence in defining decision criteria, and in allowing some deviation from their ideal for any individual attributes, as long as most attributes are in or near the desired range. For example, the definitions of "high," "moderate," "low," etc. are quantitative and can be interpreted and measured to mean different things. An important step in the BCG process is development of expert consensus defining these, or other, general terms and documenting the expert logic that is the basis for the decisions. The decision rules preserve the collective professional judgment of the expert group and set the stage for the development of models that can reliably assign sites to levels without having to reconvene the same group. In essence, the rules and the models capture the panel's collective decision criteria.

An inference model is developed to replicate the panel decision process, and this section describes an inference model that uses mathematical fuzzy logic to mimic human reasoning. Each linguistic variable (e.g., "high taxon richness") must be defined quantitatively as a fuzzy set (e.g., Klir 2004). A fuzzy set has a membership function, and example membership functions of different classes of taxon richness are shown in Figure 17. In this example (Figure 17), piecewise linear functions (functions consisting of line segments) are used to assign membership of a sample to the fuzzy sets. Fuzzy membership functions were assumed to be adequately defined by piecewise linear functions. Metric values below a lower threshold have membership of 0; values above an upper threshold have membership of 1, and membership is a straight line between the lower and upper thresholds. For example, in Figure 17 (top), a sample with 20 taxa would have a membership of approximately 0.5 in the set "Low to Moderate Taxa" and a membership of 0.5 in the set "Moderate Taxa."

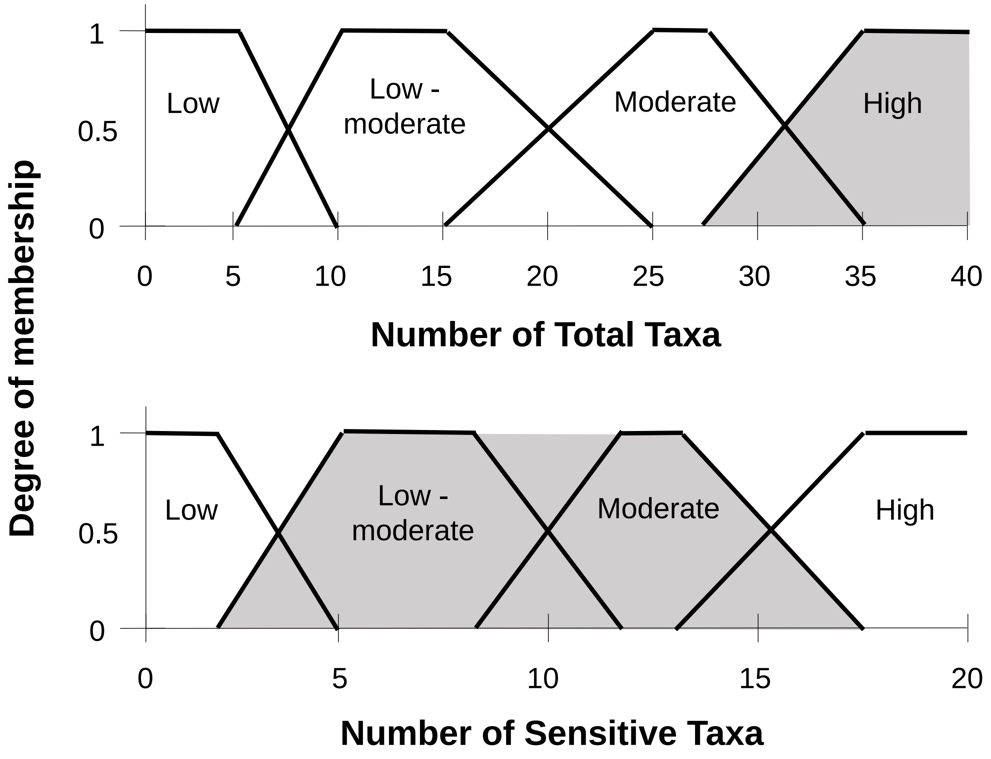


Figure 17. Fuzzy set membership functions assigning linguistic values to defined ranges for Total Taxa (top) and Sensitive Taxa (bottom). Shaded regions correspond to example rules for BCG level 3: "Number of total taxa is high," and "number of sensitive taxa is low-moderate to moderate."

How are inferences made? Suppose there are two rules for determining whether a water body is BCG level 3 (using definitions of Figure 17):

- The number of total taxa is high.
- The number of sensitive taxa is low-moderate to moderate.

In classical set theory, the boundaries between the categories would be vertical lines at the intersections of the membership functions in Figure 17. The rules would then be:

- Total taxa > 30
- Sensitive taxa > 4 and sensitive taxa < 15

If the two rules are combined with an "AND" operator, that is, both must be true, then under classical set theory, if total taxa = 30 and sensitive taxa = 5, the sample would be judged not to be in the set of BCG level 3, because the rule specifies total taxa must be greater than 30. Finding a single additional taxon would result in assessment of BCG level 3. In fuzzy set theory, an AND statement is equivalent to the minimum membership given by each rule:

Level 3 = MIN (total taxa is high, sensitive taxa is low to moderate)

For 30 total taxa, fuzzy membership in "total taxa is high" = 0.5 (Figure 17), and fuzzy membership in "Sensitive taxa is low-moderate to moderate" = 1.0 (Figure 17). Membership of level 3 is then 0.5. In the fuzzy set case, a single additional taxon raises the membership in BCG level 3 from 0.5 to 0.6.

If the two rules are combined with an "OR" operator, then either can be true for a site to meet BCG level 3, and both conditions are not necessary. Crisp set theory now yields a value of "true" if total taxa = 32 and sensitive taxa = 4 (total taxa > 27, therefore it is true). Fuzzy set theory yields a membership of 1 (maximum of 0.5 and 1). Using the fuzzy set theory model, finding a single additional taxon in a sample does not cause the assessment to flip to another level, unlike crisp decision criteria.

Output of the inference model may include membership of a sample in a single level only, ties between levels, and varying memberships among two or more levels. The level with the highest membership value is taken as the nominal level.

4.1.2.2 Quantitative Model Development

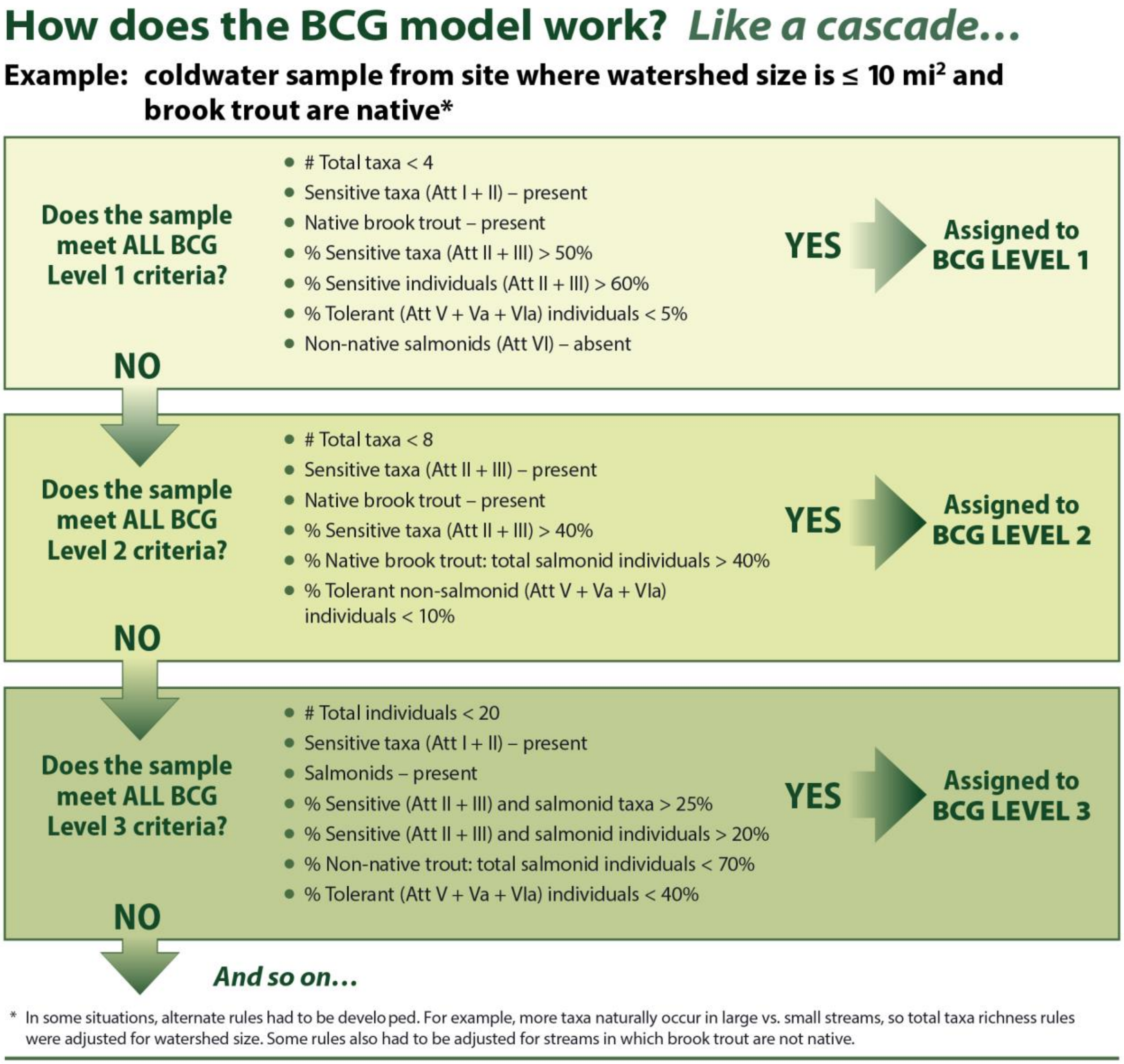
Rules identified by the panel, whether quantitative or qualitative, are compared to data summaries of the panel decisions. In particular, if the panel identified a moderate number of sensitive taxa for BCG level 3, then the analyst (i.e., the individual who develops the quantitative decision model) examines the number of sensitive taxa in samples the panel assigned to BCG level 3. The analyst selects a reasonable minimum of the distribution of sensitive taxa in BCG level 3, say the minimum or a 10th quantile, as the decision threshold. This is repeated for all rules and attributes identified by the panel members as being important to their decisions. As a starting point, a plot of the attribute or metric values as box plots by the panel-designated BCG level can be helpful (see section 4.1.2.3 for an example). This type of graphic shows minimum, maximum, median, and selected quantiles for each metric and BCG level. Sample sizes for each BCG level might be small, especially for the highest and lowest levels (BCG levels 1 and 2, and 6, respectively), and might require more professional judgment from the panel to develop rules.

For a particular attribute or metric, the threshold identified by the panel will typically be the 50% membership value in a fuzzy membership function. For example, if the panel identifies "5 or more" sensitive taxa as a requirement for BCG level 3, then 5 taxa would correspond to 50% membership; 3 taxa may correspond to 0% membership, and 7 taxa to 100%. Because number of taxa are always whole numbers, the membership function is not continuous. Some rules are non-fuzzy: if a rule requires "at least 1" or "presence," then presence receives a membership of 100% and absence receives 0%.

A spreadsheet is convenient for developing the rule-based model. Membership functions and rules for each level and each relevant attribute or metric are laid out in the top row, and data for each sample are arrayed in rows. Sample data are called by the rule formulas and the final decision logic is applied to determine membership in each BCG level for each sample.

In models developed up to now, rules work as a logical cascade from BCG level 1 to level 6. A sample is first tested against the level 1 rules; if a required rule fails, then the level fails, and the assessment moves down to level 2, and so on (Figure 18). Depending on how the expert panel makes decisions and rates samples, component rules for a single level may be (1) all-or-nothing (i.e., all rules must be met); (2) some rules have alternate rules (e.g., a very low percentage of tolerant individuals may substitute for a high percentage of sensitive individuals); or (3) any number n of, say, n + 1 rules must be met. Required rules must be true for a site to be assigned to a level. BCG levels 1 and 2 represent minimally-disturbed, natural conditions, hence the rules tend to be the most restrictive. As assemblages change with increasing anthropogenic influence, the changes may manifest in different effects (decline of sensitive species; and/or increases in abundance or dominance of tolerant individuals), and the rules for the middle levels may have more alternative situations. In the more degraded levels (especially BCG level 5), the rules tend to be simple, reflecting a degraded and simplified assemblage. In the cascading logic from BCG level 1 to 6 (Figure 18), there are no rules for level 6 because it is the bottom "bin" that catches sites that fail rules from levels 1 to 5. Examples of these are shown in the case studies that follow.

Two examples on development of numeric decision rules for streams and wadeable rivers follow. The first example shows development of numeric decision rules for benthic macroinvertebrates and fish for cold- and cool-water streams in the Upper Midwest. The second example highlights use of diatom assemblage data from Northern New Jersey in developing a numeric BCG. Both examples illustrate the BCG development process. Macroinvertebrates follow the classic paradigm that overall species richness is higher in the higher BCG levels (levels 1 and 2), but coldwater fish and diatoms are nearly opposite: overall richness is low in pristine coldwater streams, and diatom richness is low in undisturbed oligotrophic streams. Both are dominated by a small number of highly sensitive taxa. As streams become more disturbed, richness and abundance of intermediate and tolerant taxa increase for both fish and diatoms. In the fish assemblage, sensitive taxa disappear in the most disturbed sites, but sensitive taxa may hang on in highly-disturbed diatom assemblages.



* In some situations, alternate rules had to be developed. For example, more taxa naturally occur in large vs. small streams, so total taxa richness rules were adjusted for watershed size. Some rules also had to be adjusted for streams in which brook trout are not native.

Figure 18. Flow chart depicting how rules work as a logical cascade in the BCG model, from Upper Midwest cold and coolwater example (Source: Modified from Gerritsen and Stamp 2012). For convenience, midpoints of membership functions (50% value) only are shown. For complete rules, see Table 15 and Table 16.

4.1.2.3 Example #1: Quantitative Rules and Decision System for Benthic Macroinvertebrates and Fish, Upper Midwest

Panelists from Indian Nations and the states of Michigan, Wisconsin, and Minnesota calibrated BCG models for fish and macroinvertebrate assemblages in cold and cold-cool transitional wadeable streams of the Upper Midwest (Gerritsen and Stamp 2012). The cool-transitional water macroinvertebrate BCG model was calibrated based on assessments of 37 samples. Panelists made the site assessments using worksheets that contained lists of taxa, taxa abundances, BCG attribute levels assigned to the taxa, BCG attribute metrics, and limited site information, such as watershed area, stream size, average July temperature, and percent forest.

Study Sites

Panelists assigned fish and macroinvertebrate samples from cool-transitional streams to four BCG levels (BCG levels 2–5). Samples were not assigned to BCG level 1 because panelists did not feel that there was enough information to know what the historical undisturbed macroinvertebrate assemblage in this region looked like. Only two of the 37 calibration samples were assigned to BCG level 5 (many of the coolwater sites in this region are in the Northern Lakes and Forests ecoregion). A detailed verbal description of each level is given above in Table 11 (Chapter 3).

Decision rules were initially derived from discussions with the panelists on why individual sites were assessed at a certain level. Panelists made statements such as "BCG level 2 samples should have both a moderate abundance and richness of sensitive taxa (attributes I, II, and III)." These statements were compiled into a set of narrative rules (Table 12).

Table 12. Example of Narrative rules for transitional cold-cool assemblages in Upper Midwest streams (Source: Gerritsen and Stamp (2012))

BCG level 2	**Definition:** Minimal changes in structure of the biotic community and minimal changes in ecosystem function—*virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*
	Fish Taxa richness is low to moderate Brook Trout, if native, are present Total sensitive taxa are one third of taxa richness Abundance of sensitive individuals is low to moderate Brook Trout (if native) are nearly half of all Salmonidae individuals Tolerant individuals may be a small fraction of total
	Macroinvertebrates Taxa richness is moderate to high Highly sensitive (attribute I and II) taxa make up a very small fraction (or more) of total richness and total abundance All sensitive taxa (attributes I + II + III) make up moderate fraction of richness and abundance Sensitive EPT taxa make up at least a small fraction of total richness
BCG level 3	**Definition:** Evident changes in structure of the biotic community and minimal changes in ecosystem function—*Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa, but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*
	Fish Taxa richness is moderate but not high Total number of sensitive taxa is greater than tolerant taxa, OR number of sensitive individuals is twice greater than number of tolerant individuals Single most dominant intermediate taxon (attribute III) is less than half of all individuals Extremely tolerant individuals are a very small fraction of total
	Macroinvertebrates Taxa richness is moderate to high Highly sensitive (attribute I and II) taxa are present Total sensitive taxa (attributes I + II + III) make up small fraction of richness and abundance Most dominant tolerant taxon is less than a small fraction of abundance Sensitive EPT taxa make up at least a small fraction of total richness

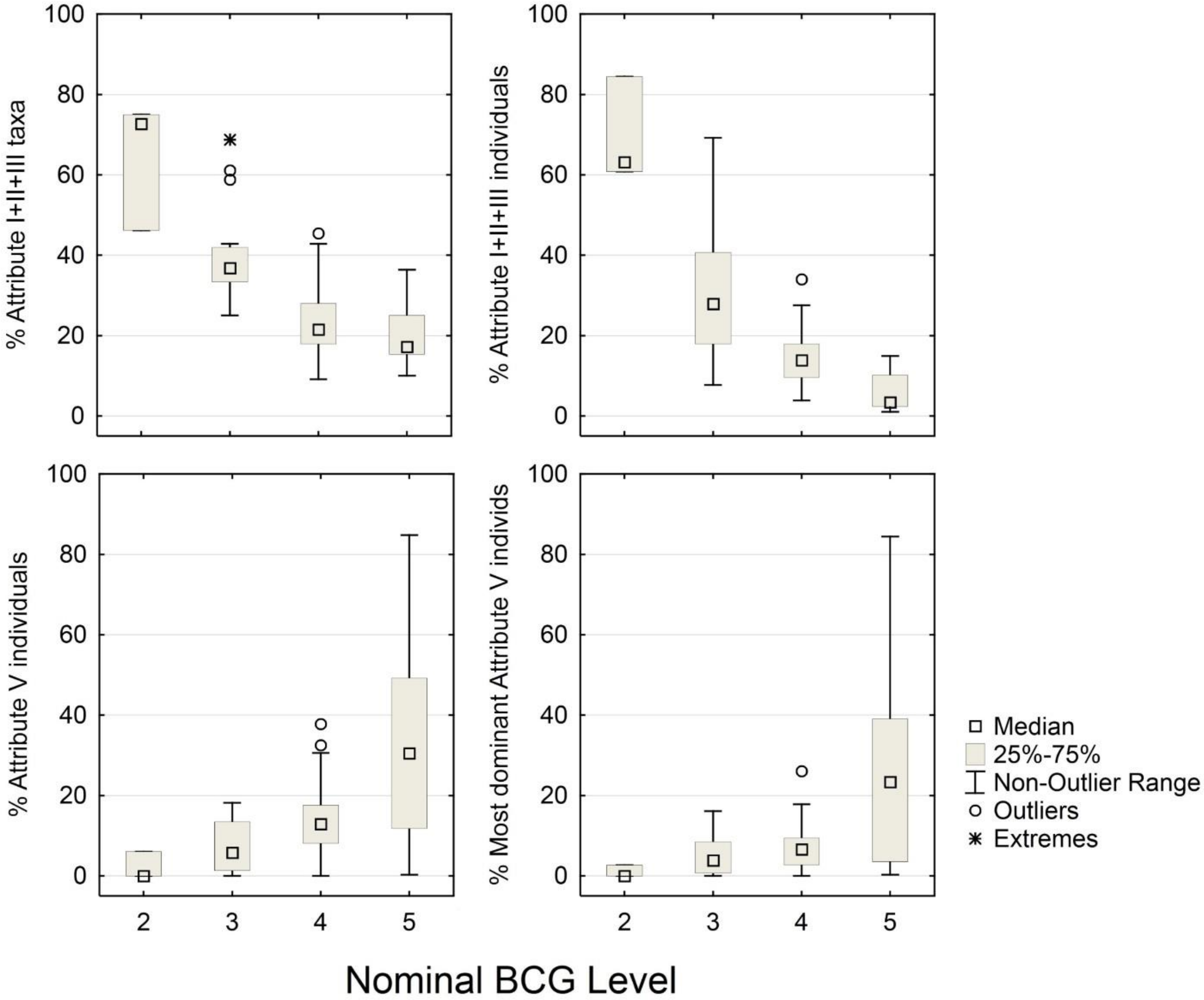


Figure 19. Benthic Macroinvertebrate Taxa: Box plots of sensitive (attribute I+II+III) and tolerant (attribute V) BCG attribute metrics, grouped by nominal BCG level (panel majority choice). These metrics were used in the macroinvertebrate BCG model for coldwater streams in the Upper Midwest.

Using the narrative rules, data were examined for numerical ranges and relationships. For example, examination of the data ranges of attribute I, II, and III taxa for macroinvertebrates (Table 13; Figure 19) showed that the median percent abundance of attribute I, II, and III taxa from BCG level 2 was 75%. The decision rules were adjusted by the empirical distributions of the attribute metrics shown in Table 13 and Figure 19, so that the model would replicate the panel's actual decisions as closely as possible. For the macroinvertebrates, the most important considerations expressed by the experts were percent individuals and percent taxa metrics for attribute II, II+III, IV, and V taxa, and metrics pertaining to three sensitive orders of aquatic insect taxa (e.g., Ephemeroptera, Plecoptera, and Trichoptera (EPT)). Panelists expected BCG level 2 samples to have a moderate presence of highly sensitive (attribute II) taxa, moderate to high total taxon richness, and a low proportion of tolerant (attribute V) taxa. BCG level 3 samples had similar numbers of total taxa but slightly reduced numbers of highly sensitive (attribute II) taxa. Total sensitive taxa (attribute II+III) were still required to be present in BCG level 4 samples, but with reduced richness and abundance. Higher proportions of tolerant (attribute V) individuals occurred in BCG level 4 samples, but could not comprise more than 60% of the assemblage.

BCG level 5 samples were discriminated from BCG level 4 samples by complete loss of sensitive taxa and a further increase in the percent tolerant (attribute V) individuals.

Table 13. Benthic macroinvertebrate taxa: Ranges of attribute metrics in cold-cool transitional macroinvertebrate samples. BCG levels by panel consensus, in the Upper Midwest BCG data set (Gerritsen and Stamp 2012).

Attributes	Metric	BCG Level (Panel Consensus)				
		2 (n=19)	3 (n=13)	4 (n=7)	5 (n=2)	6 (n=1)
0 General	**Total Taxa**	20–63	20–64	13–58	31–56	31
	Total Individuals	91–359	134–407	138–336	294–321	192
II Highly sensitive taxa	**# Taxa**	3–11	0–7	0–1	0	4
	% Taxa	8–28	0–15	0–3	0	13
	% Individuals	6–42	0–7	0–1	0	34
III Intermediate sensitive taxa	**# Taxa**	6–19	7–19	4–17	2–6	16
	% Taxa	19–61	18–49	9–31	6–11	52
	% Individuals	13–55	17–54	3–83	1–9	44
II + III All sensitive taxa	**# Taxa**	10–26	10–24	4–17	2–6	20
	% Taxa	30–71	22–57	11–31	6–11	65
	% Individuals	31–76	20–56	3–83	1–9	78
	SensEPT # Taxa	6–20	6–14	1–6	2–4	13
	SensEPT_% Individuals	18–71	14–47	2–17	1–2	60
IV Intermediate tolerant taxa	**# Taxa**	7–28	7–29	8–32	16–29	9
	% Taxa	26–49	35–53	50–65	52	29
	% Individuals	23–53	43–71	17–87	26–30	21
	% Most Dom Individuals	6–31	8–34	5–27	5–15	7
V Tolerant taxa	**# Taxa**	0–10	1–11	0–9	9–11	0
	% Taxa	0–17	3–22	0–16	20–29	0
	% Individuals	0–22	0–12	0–59	40–72	0
	% Most Dom Individuals	0–17	0–6	0–57	17–59	0

Observations of the attribute metrics from the fish assemblage are shown in Table 14. No attribute I species were identified in the coldwater fish assemblage. The fish assemblage in undisturbed or minimally disturbed coldwater streams typically has few species: native trout, sculpins, and possibly a minnow species. Increases in fish taxa richness in true coldwater is an indicator of degradation. BCG levels 1 and 2 required native trout (Brook Trout), but the native trout could be replaced by non-native salmonids in BCG levels 3 and 4. As with the invertebrates, there was increasing abundance and dominance of tolerant species, both native and non-native, in the poorer condition levels (BCG levels 4 and 5). No BCG level 6 sites were observed in the cold and cool data set. Panelists identified level 5 rules (governing the transition from level 5 to level 6) from their experience with BCG level 6 in warmwater streams.

Table 14. Fish taxa: Ranges of attribute metrics in cold-cool transitional fish samples. BCG levels by panel consensus.

Attributes	Metric	BCG Level (Panel Consensus)				
		1 (n=1)	2 (n=13)	3 (n=14)	4 (n=9)	5 (n=7)
0 General	**Total Taxa**	9	1–15	4–18	10–24	10–17
	Total Individuals	470	11–207	8–598	109–534	102–1483
II Highly sensitive taxa	**# Taxa**	2	0–2	0–2	0–1	0
	% Taxa	22	0–100	0–25	0–7	0
	% Individuals	7	0–100	0–20	0–1	0
III Intermediate sensitive taxa	**# Taxa**	3	0–5	0–5	1–4	0–1
	% Taxa	33	0–67	0–36	4–22	0–10
	% Individuals	68	0–72	0–60	0–44	0–4
II + III All sensitive taxa	**# Taxa**	5	1–5	0–6	1–4	0–1
	% Taxa	56	33–100	0–50	4–22	0–10
	% Individuals	75	14–100	0–60	0–44	0–4
IV Intermediate tolerant taxa	**# Taxa**	4	0–9	1–10	4–12	3–8
	% Taxa	44	0–60	18–63	40–60	29–55
	% Individuals	25	0–83	14–88	39–83	13–93
	% Most Dom Individuals	14	0–39	8–63	18–68	7–48
V Tolerant taxa	**# Taxa**	0	0–1	0–5	3–8	3–7
	% Taxa	0	0–17	0–36	20–40	19–70
	% Individuals	0	0–13	0–20	4–30	1–43
	% Most Dom Individuals	0	0–13	0–16	2–18	1–19
Va Highly tolerant native taxa	**# Taxa**	0	0–1	0–2	0–3	0–5
	% Taxa	0	0–11	0–13	0–13	0–36
	% Individuals	0	0–1	0–1	0–18	0–85
	% Most Dom Individuals	0	0–1	0–1	0–18	0–56
VI Non-native or intentionally introduced taxa	**# Taxa**	0	0–1	0–3	0–1	0–1
	% Taxa	0	0–20	0–43	0–6	0–9
	% Individuals	0	0–25	0–41	0–7	0–2
	% Most Dom Individuals	0	0–25	0–41	0–7	0–2
VIa Highly tolerant non-native taxa	**# Taxa**	0	0	0	0–1	0–1
	% Taxa	0	0	0	0–4	0–6
	% Individuals	0	0	0	0	0–3
	% Most Dom Individuals	0	0	0	0	0–3

BCG Rule Development

For the Upper Midwest, BCG quantitative rule development can be followed by comparing Table 12 (narrative rules), Table 13 (metric distributions), and Table 15 (quantitative rules). In Table 12, the narrative rule for BCG level 2, macroinvertebrate taxa richness is: "Taxa richness is moderate to high" (Table 12). In Table 13, total taxa in BCG level 2 sites ranged from 20 to 63 invertebrate taxa (Table 13), so 20–63 is "moderate to high." The rule for total taxa (Figure 17, BCG level 2, Coolwater) was set at a midpoint of ≥ 20 taxa, with the fuzzy boundaries defined as 16 to 24. The fuzzy boundary of 16–24 defines the lower end of the "moderate" membership function for total taxa in Figure 17; membership functions were assumed to be described by straight-line segments (Figure 17). For the total taxa rule, a site with 20 invertebrate taxa would then have a membership of 50% in BCG level 2; a site with 16 taxa would have a membership of 0 (zero), and a site with 18 taxa would have a membership of 25%. A site with 24 or more taxa would have full (100%) membership in BCG level 2 for the total taxa rule. Note that the total taxa rule is the same for BCG levels 2 and 3; these BCG levels cannot be distinguished based on total taxa. Other rules must be used.

The panel's discrimination between levels 2 and 3 was primarily from richness and abundance of sensitive taxa. Attribute II taxa were always present in BCG level 2, but they were allowed to be absent in BCG level 3 (Table 13). The rules for level 2 required highly sensitive taxa (attribute II) to make up more than 5% of taxon richness and 8% of the individuals, while in level 3 the attribute II taxa were only required to be present (e.g., one taxon, one individual; Table 15). Similarly, total sensitive taxa (sum of attributes II and III) were required to comprise 30% or more of both richness and abundance in BCG level 2, but only 20% of richness, and 10% of abundance in BCG level 3. Here the panel also allowed an exception or alternative in the rules: if sensitive attribute III individuals were particularly abundant (> 40% of the community), then attribute II taxa were allowed to be absent (Alternate rule in Table 15).

The quantitative rules of Table 15 and Table 16 were developed in the same way: panel members expressed why decisions were made, with statements of what they would require to rate a higher BCG level, or what would be lost for them to rate the sample lower. These statements were later compared to the distributions of the metrics in the panel's assessed sites to yield first-iteration quantitative rules and model. The panel would then review the quantitative rules and their assessments and make adjustments to the rules (or assessments) as needed. The final quantitative rules typically emerge after two or three iterations.

Decision rules follow the patterns observed in the distributions of the metrics among BCG levels assigned by the panel. BCG level 2 requires a strong presence of sensitive (attribute II and III) taxa and, for invertebrates, sensitive EPT taxa. Other level 2 rules include minimum numbers of total taxa for invertebrates, maximum number of total taxa for fish, and low dominance of tolerant taxa in both assemblages. It is important here to emphasize that whenever absolute values are used, the sampling effort should be specified.

BCG level 3 decision rules allow slight reductions in sensitive taxa and individuals and increases in tolerant taxa. Total number of taxa requirements are the same as BCG level 2. Since metrics do not decline in lockstep with each other, the panels occasionally allowed alternative rules where an exceptionally good value in one metric could be balanced by a poor value of another. Typically, these were tradeoffs of number of sensitive taxa for number of sensitive individuals. For example, in the invertebrate rules (Table 15), the percent sensitive (attributes I, II, and III) taxa and individuals—were subject to alternate rules: If the value of the percent sensitive taxa metric is > 20%, then the percent sensitive individuals must be > 10%. Alternatively, if the value of the percent sensitive taxa metric is > 40%, then the percent sensitive individuals metric need only be > 5%.

BCG level 4 is characterized by decreased richness and abundance of sensitive taxa. However, sensitive taxa must still be present above a minimum floor. The disappearance of sensitive taxa is what typically discriminates level 5 from level 4, as well as an increase in the percent tolerant (attribute V) individuals (Table 12, Table 16, Table 17).

Table 15. Benthic macroinvertebrate taxa: Decision rules for macroinvertebrate assemblages in coldwater and coolwater (transitional cold-cool) streams; samples with > 200 organisms. Rules show the midpoints of fuzzy decision levels, followed by the range of the membership function. The midpoint is where membership in the given BCG level is 50% for that metric.

BCG Level	Metrics	Coldwater		Coolwater	
		Rule		Rule	
2	# Total taxa	≥ 14 (11–16)		≥ 20 (16–24)	
	% Most sensitive taxa (Att I + II)	> 10% (7%–13%)		> 5% (3%–7%)	
	% Most sensitive individuals (Att I & II)	—		> 8% (6%–10%)	
	% Sensitive taxa (Att II + III)	> 30% (25%–35%)		> 30% (25%–35%	
	% Sensitive individuals (Att II + III)	> 30% (25%–35%)		> 30% (25%–35%)	
	% Most dominant tolerant taxa (Att V)	< 5% (3%–7%)		—	
	% Sensitive EPT taxa (Att I + II + III)	> 10% (7%–13%)		> 10% (7%–13%)	
		Rule	Alt Rule	Rule	Alt Rule
3	# Total taxa	≥ 14 (11–16)		≥ 20 (16–24)	
	# Most sensitive (Att I + II) taxa	—	present	NA	
	% Sensitive taxa (Att II + III)	> 20% (15%–25%)	> 40% (35%–45%)	> 20% (15%–25%)	
	% Sensitive individuals (Att II + III)	> 10% (7%–13%)	> 5% (3%–7%)	> 10% (7%–13%)	> 40% (35%–45%)
	% Most dominant intermediate tolerant taxa (Att IV)	< 50% (45%–55%)		—	
	% Tolerant (Att V) individuals	< 20% (15%–25%)		—	
	% Most dominant tolerant taxa (Att V)	—		< 10% (7%–13%)	
	% Sensitive EPT taxa (Att I + II + III)	> 10% (7%–13%)		> 10% (7%–13%)	
		Rule		Rule	
4	# Total taxa	≥ 8 (6–10)		≥ 14 (11–16)	
	% Sensitive taxa (Att II + III)	> 10% (7%–13%)		> 10% (7%–13%)	
	% Sensitive individuals (Att II + III)	> 5% (3%–7%)		> 6% (4%–8%)	
	% Tolerant (Att V) individuals	< 40% (35%–45%)		< 60% (55%–65%)	
	Number of sensitive EPT taxa (Att I + II + III)	present		present	
		Rule		Rule	
5	# Total taxa	≥ 8 (6–10)		≥ 14 (11–16)	
	% Tolerant (Att V) individuals	< 60% (55%–65%)		—	
	% Most dominant tolerant taxa (Att V)	—		< 60% (55%–65%)	

Table 16. Fish taxa: Decision rules for fish assemblages in coldwater and coolwater (cold-cool transitional) streams. Rules show the midpoints of fuzzy decision levels, where membership in the given BCG level is 50% for that metric.

BCG Level	Metrics	Coldwater				Coolwater	
		Brook Trout (BT) Native		BT Non-native		BT Native	BT Non-native
1						Meets Coldwater level 1, OR Coolwater rules below:	
	# Total taxa	≤4 (2–5)				> 3 and < 14 (2–5 and 11–16)	
	% Most sensitive taxa (Att II)	Present				Present	
	% Brook trout individuals	Present		Absent		Present	Absent
	% Sensitive taxa (Att II + III)	> 50% (45%–55%)				> 40% (35%–45%)	
	% Sensitive individuals (Att II + III)	> 60% (55%–65%)				> 40% (35%–45%)	
	% Tolerant (Att V + Va + VIa) individuals	< 5% (3%–7%)				< 5% (3%–7%)	
	% Non-native salmonids (Att VI)	Absent				Absent	
2	Metrics	BT Native		BT Non-native		BT Native	BT Non-native
		Alt 1	Alt 2	Alt 1	Alt 2		
	# Total taxa	If watershed size ≤ 10 mi^2, < 8 (6–10) If watershed size > 10 mi^2, > 3 and < 14 (2–4 and 11–16)				< 20 (16–24)	
	% Most sensitive taxa (Att II)	Present		NA		Present	NA
	% Brook trout individuals	Present		NA		Present	NA
	% Sensitive taxa (Att II + III)	> 40% (35%–45%)	> 20% (15%–25%)	> 20% (15%–25%)		> 30% (35%–45%)	
	% Sensitive individuals (Att II + III)	NA		> 70% (65%–75%)	NA	> 12% (9%–15%)	
	% Brook trout: total salmonid individuals	> 40% (35%–45%)		NA		> 40% (35%–45%)	NA
	% Tolerant non-salmonid (Att V + Va + VIa) individuals	< 10% (7%–13%)	Absent	NA	< 10% (7%–13%)	< 20% (15%–25%)	

BCG Level	Metrics	Coldwater		Coolwater	
		Rule	Alt Rule	Rule	Alt Rule
		(brook trout native/non-native status not used)			
3	# Total taxa	If watershed size > 10 mi^2, > 5 (3–7)		< 20 (16–24)	
	% Salmonid individuals	Present		–	
	% Sensitive & non-native salmonid (Att I + II + III + VI) taxa	> 25% (20%–30%)		–	
	% Sensitive & non-native salmonid (Att I + II + III + VI) individuals	> 20% (15%–25%)		–	
	% Non-native salmonid (Att VI): total sensitive (Att I + II + III + VI) individuals	< 70% (65%–75%)		–	
	% Sensitive taxa (Att II + III)	–		≥ % Tolerant (Att V + Va + VIa) taxa	NA
	% Sensitive individuals (Att II + III)	–		NA	≥ 2*Tolerant (Att V + Va + VIa) % individs
	% Most dominant intermediate tolerant taxa (Att IV)	–		If watershed size > 10 mi^2, < 40% (35%–45%)	
	% Extra tolerant individuals (Att Va + VIa)	–		< 5% (3%–7%)	
4	**Metrics**	**(no alternate rules)**			
	% Sensitive & salmonid taxa (Att II + III + VI)	> 5% (3%–7%)		> 5% (3%–7%)	
	% Sensitive & salmonid individuals (Att II + III + VI)	> 5% (3%–7%)		> 5% (3%–7%)	
	% Tolerant taxa (Att V + Va + VIa)	< 45% (40%–50%)		–	
	% Extra tolerant individuals (Att Va + VIa)	< 10% (7%–13%)		< 20% (15%–25%	
5	**Metrics**	**(no alternate rules)**			
	# Total taxa	> 2 (1–3)		> 3 (2–4)	
	% Intermediate tolerant taxa (Att IV)	> 10% (7%–13%)		> 10% (7%–13%)	

Model Performance

In general, the fuzzy model identified 75%–80% of samples as primarily a single BCG level (75% membership or greater). Approximately 10%–15% of samples had a large minority membership in an adjacent BCG level to the "nominal" level (25%–40% membership), and approximately 10%–15% of assessments are ruled ties or near-ties between adjacent BCG levels (minority membership > 40%).

To measure model performance with the calibration data sets, two matches in BCG level choice were considered: an exact match, where the BCG decision model's nominal level matched the panel's majority choice; and a "minority match," where the model predicted a BCG level within one level of the majority expert opinion. When model performance was evaluated in this calibration data set, the coldwater macroinvertebrate model matched exactly with the regional biologists' BCG level assignments on 97.6% of the coldwater samples (Table 17). In the single sample without agreement, the model assignment was one level better than the majority expert opinion.

In order to confirm the model, panelists made BCG level assignments on additional samples. When nominal level assignments from the BCG decision model were compared to the panelists' nominal level assignments in the confirmation data set, the model matched exactly with the regional biologists' BCG level assignments on 80% or more of the samples (Table 17). In both cold and coolwater, three confirmation samples were rated differently by model and panel, where the model rated the samples as being one BCG level better than the majority expert opinion. Based on the combined results, in 89% of cases, the macroinvertebrate model predicts the same BCG level as the majority expert opinion.

Table 17. Benthic macroinvertebrate and fish taxa: Model performance—cold and coolwater samples

	Benthic macroinvertebrates				**Fish**			
Model	**Coldwater**		**Cool-transitional**		**Coldwater**		**Cool-transitional**	
Difference	**Calib.**	**Conf.**	**Calib.**	**Conf.**	**Calib.**	**Conf.**	**Calib.**	**Conf.**
2 better	0	0	0	0	0	0	0	1
1 better	2	3	1	3	3	3	3	5
same	39	13	31	15	47	21	38	17
1 worse	1	0	2	0	2	1	1	2
2 worse	0	0	3	0	0	0	0	0
Total # Samples	**42**	**16**	**34**	**18**	**52**	**25**	**42**	**25**
% Correct	**98%**	**81%**	**91%**	**83%**	**90.4%**	**84%**	**90%**	**68%**

4.1.2.4 Example #2: Quantitative Rules and Decision System for Diatoms, New Jersey

New Jersey DEP developed and calibrated a BCG model for sampled diatoms in northern New Jersey streams (Gerritsen et al. 2014). The models were developed using data collected by the Academy of Natural Sciences for New Jersey DEP. Workshop participants included scientists from around the United States. The calibrated BCG models will allow New Jersey to express and assess goals for classes of water bodies in terms of their biological condition.

Study sites

The data set consisted of 42 samples collected from streams and rivers in northern New Jersey. Sites were located in the Northern Piedmont (25), the Northern Highlands (6), the Ridge and Valley (7), the Atlantic Coastal Pine Barrens (3), and the Middle Atlantic Coastal Plain (1) ecoregions (Omernik 1987; Woods et al. 2007). Land-use in the Piedmont is primarily urban and agriculture, whereas in the Highlands and the Ridge and Valley it is predominantly forest and agriculture (USEPA 2000a). Within ecoregions, the study sites had relatively similar natural environmental conditions (e.g., geology, geomorphology), but with a wide range of nutrient concentrations.

A narrative description was derived from discussions with the panelists about why individual sites were assessed at a certain level (Table 18). The rules were calibrated from the narrative description and the 30 calibration samples rated by the group, and the rules were adjusted so that the model would replicate the panel's decisions as closely as possible. Panel members were highly quantitative in their thinking and deliberations, and they developed the first iteration of quantitative rules based on the narrative descriptions.

Rule Development

Rules adopted for the quantitative decision model are listed in Table 19. BCG level 1 has five rules: one on taxa richness, two rules on abundance of sensitive taxa, and two rules on abundance of tolerant taxa. For BCG level 1, sensitive taxa are required to be dominant, and tolerant taxa are very minor constituents of the community. The rules for BCG level 2 are similar to level 1, but all have been relaxed to some extent. The largest relative difference between levels 1 and 2 is that attribute II individuals are required to be highly abundant in level 1 (roughly 35% or more), but they are subdominant in level 2 (10% or more).

In BCG level 4, sensitive individuals are greatly diminished, but still present (9% or more), and tolerant taxa can occur at higher abundances. There are only three rules for BCG level 5: tolerant taxa may not exceed 40% of taxa or 80% of individuals. Samples that fail to meet the BCG level 5 requirements would be assigned to BCG level 6, but no such samples were encountered in this data set.

Model Performance

To evaluate the performance of the 40-sample calibration data set and the 10-sample confirmation data set, the number of samples where the BCG decision model's nominal level exactly matched the panel's majority choice ("exact match"), and the number of samples where the model predicted a BCG level that differed from the majority expert opinion ("anomalous" samples) were assessed. Then, for the anomalous samples, the degree of differences among the BCG level assignments, and also whether there was a bias was examined (e.g., did the BCG model consistently rate samples better or worse than the panelists?).

Two types of ties were taken into account: (1) BCG model ties, where there is nearly equal membership in two BCG levels (e.g., membership of 0.5 in BCG level 2 and membership of 0.5 in BCG level 3); and (2) panelist ties, where the difference between counts of panelist primary and secondary calls is less than or equal to 1 (e.g., 4–4 or 4–3 decisions). If the BCG model assigned a tie, and that tie did not match with the panelist consensus, it was considered to be a difference of half a BCG level (e.g., if the BCG model assignment was a BCG level 2/3 tie and panelist consensus was a BCG level 2, the model was considered to be "off" by a half BCG level; or more specifically, the model rating was a half BCG level worse than the panelists' consensus). The BCG model was also considered to differ by a half level if the panelists assigned a tie and the BCG model did not.

Results show that the diatom BCG model performed well (Table 20). The models assigned scores that are within a half BCG level or better on 100% of the samples in both the calibration and confirmation data sets (Table 18). When half levels were considered, the BCG model rated three of the calibration samples a half level worse than the panelists, and five confirmation samples (two better, three worse). Based on results from the calibration data set, the model has a slight bias towards rating samples a half level worse than the panel consensus.

Table 18. Narrative description of diatom assemblages in six BCG levels for streams of northern New Jersey. Definitions are modified after Davies and Jackson (2006).

BCG level 1	**Definition:** Natural or native condition—*native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability*
	Narrative: BCG level 1 streams in northern New Jersey highlands are oligotrophic, with a mature forested watershed. Unlike macroinvertebrates, the diatom community is relatively depauperate, with typically 15–20 taxa in a 500-count sample. The top dominant taxa are extreme low-nutrient adapted taxa of attributes II and III (e.g., *Achnanthes subhudsonis* or *Achnanthidium rivulare)*. Subdominants (up to 10% abundance) may include attribute IV taxa. Tolerant taxa (attribute V) make up a very small fraction of the community.
BCG level 2	**Definition:** Minimal changes in structure of the biotic community and minimal changes in ecosystem function—*virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*
	Narrative: BCG level 2 streams are very similar to level 1, however, a slight increase in disturbance or enrichment has allowed more diatom taxa to colonize (20–40 total taxa). Richness is slightly higher than level 1, but low nutrient taxa (attribute II and III) are dominant. There may be several tolerant taxa, but their abundance is low.
BCG level 3	**Definition:** Evident changes in structure of the biotic community and minimal changes in ecosystem function—*Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*
	Narrative: Richness is higher than level 2 (> 30 taxa). Dominant taxon may or may not be sensitive (attribute II or III). Tolerant taxa have increased to more than 10% of the assemblage, and some of the tolerant taxa are now in the subdominant category.
BCG level 4	**Definition:** Moderate changes in structure of the biotic community and minimal changes in ecosystem function—*Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*
	Narrative: BCG level 4 sites tend to have the highest taxa richness as more diatom niches open up with increased enrichment, light penetration (from canopy loss), and moderate sedimentation. Sensitive species and individuals are still present but in reduced numbers. The persistence of some sensitive species indicates that the original ecosystem function is still maintained albeit at a reduced level. Intermediate and tolerant taxa may be dominant, sensitive taxa are often still subdominant.
BCG level 5	**Definition:** Major changes in structure of the biotic community and moderate changes in ecosystem function—*Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative: Overall diversity is still high, but may be slightly reduced from level 4. Sensitive species may be present but their functional role is negligible within the system. The most abundant and dominant taxa are tolerant or have intermediate tolerance, and there may be relatively high diversity within the tolerant organisms.
BCG level 6	**Definition:** Major changes in structure of the biotic community and moderate changes in ecosystem function—*Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative: Heavily degraded from urbanization and/or industrialization. No level 6 samples were encountered by the panel.

Table 19. BCG quantitative decision rules for diatom assemblages in northern New Jersey streams. The numbers in parentheses represent the lower and upper bounds of the fuzzy sets. BCG level 6 is not shown, because there are no specific rules for level 6: If a site fails level 5, it falls to level 6. Shaded rules under BCG level 3 are alternate rules, that is, at least one must be true for a site sample to meet BCG level 3.

Attribute metric	Threshold
BCG Level 1	
# Total taxa	≤ 20 (15–25)
% Attribute II+III individuals	≥ 65% (60%–70%)
% Attribute II individuals > % Attribute III individuals; expressed as (% Att II–% Att III)	> 0% (-10% to 10%)
% Attribute V+VI individuals	< 2.5% (1%–4%)
% Most dominant Attribute V or VI taxon	≤ 1% (0%–2%)
BCG Level 2	
# Total taxa	≤ 40 (35–45)
% Attribute II individuals	≥ 10% (5%–15%)
% Attribute II+III individuals	≥ 50% (45%–55%)
% Attribute II+III taxa	≥ 15% (10%–20%)
% Attribute V+VI individuals	≤ 10% (5%–15%)
% Most dominant Attribute V or VI taxon	≤ 5% (3%–7%)
BCG Level 3	
# Attribute II+III taxa	≥ 5 (2–8)
# Attribute II taxa	≥ 1 (0–1)
Most dominant taxon*	Att II or 3
Alt 1: % Attribute II+III taxa	≥ 15% (10%–20%)
Alt II: % Attribute II+III individuals	≥ 15% (10%–20%)
% Attribute V+VI individuals	≤ 30% (25%–35%)
% Most dominant Attribute V or VI taxon	≤ 10% (5%–15%)
BCG Level 4	
% Attribute II+III individuals	≥ 9% (5%–13%)
% Attribute V+VI individuals	≤ 65% (60%–70%)
% Most dominant Attribute V or VI taxon	≤ 40% (35%–45%)
BCG Level 5	
% Attribute V+VI taxa	≤ 40% (35%–45%)
% Attribute V+VI individuals	≤ 80% (75%–85%)

* Dominant taxon must be sensitive (Att II or III); membership = 0 if rule fails

Table 20. Model performance for calibration and confirmation samples. "½ better" indicates models scored the sample ½ BCG level higher than the panel; e.g., Panel score was 4 and model score was 3–4 tie. Half-level mismatches are counted half the value of full matches. No mismatches exceeded ½ BCG level.

Difference (model vs. panel consensus call)	Calibration		Confirmation	
	Number	Percent	Number	Percent
model 1 level better	0	0	0	0
model ½ level better	0	0	2	17
exact match	27	90	7	58
model 1/2 level worse	3	10	3	25
model 1 level worse	0	0	0	0
Total # Samples	30	95	12	79

4.2 Calibrating Indices to the Biological Condition Gradient

Most states have developed biological indices for their streams and wadeable rivers (USEPA 2002). In the initial development of BCGs, common questions asked by states included:

- What is the relationship between the BCG and the state's existing biological index, or indices?
- Does the BCG replace the existing biological index, or indices?
- How can the BCG and the existing biological index, or indices, be used together to better assess ALUs?

The linkage between a biological index and the BCG could be addressed in a state program review (USEPA 2013a) and/or as a topic of discussion within the expert panel. Existing indices could be evaluated for how extensively they include attributes of the BCG or how the BCG decision criteria match up with the metrics that comprise the index. If needed, recommendations for specific technical improvements and analyses can then be made to guide the redevelopment of an index and/or refine the BCG model.

As in section 4.1., the objective is to calibrate a BCG model with a quantitative model, or in this case, an index that will duplicate the expert panel BCG assessments for new samples and water bodies, without having to reconvene the panel. In this approach, a conventional IBI (e.g., Karr 1986) or predictive biological index model (e.g., Hawkins et al. 2000b; Wright 2000) could be calibrated to the expert-derived BCG. While the seminal works about these indices preceded the BCG, they are based on parallel ecological concepts, and to varying degrees each incorporates BCG attributes. As an example of this, Table 21 illustrates the overlap between the 10 BCG attributes and a selection of fish and macroinvertebrate indices for freshwater streams and wadeable rivers. For the fish indices, the metrics used for each capture the more commonly measured attributes I–VI (taxa composition and effects of non-native taxa), but they also address attributes VII (organism condition), VIII (ecosystem function), and X (ecosystem connectance). The routine inclusion of the deformities, erosions, lesions, and tumors (DELT) anomalies metric (e.g., measure of deformities, erosion, lesions, and tumors) in all fish indices contains attribute VI. Functional feeding and reproduction guilds that are routinely included in fish indices might provide a surrogate for attribute VIII. The inclusion of diadromous metrics provides for the direct inclusion of species that depend on access to and from coastal rivers for completing their life cycles. Other metrics that include species that are dependent on free access to a drainage network can illustrate the concept of connectivity in inland streams and rivers. Attribute IX (spatial and temporal extent of detrimental effects) can be accounted for by the spatial extent of the sampling design and is independent of the composition of fish IBIs. For the macroinvertebrate metrics in Table 21, coverage of attributes I–V is provided by most biological indices used by states. It is also possible to develop non-native taxa metrics for attribute VI (presence and effect of non-native taxa) and metrics for attribute X (ecosystem connectance). Biological metrics could serve as a surrogate for attribute X—Unionid mussels might be a good choice given their dependency on fish hosts for dispersal and to sustain their populations. The key point is that (MMIs) have been developed from the same or parallel concepts as the BCG.

Table 21. Cross referencing the 10 BCG attributes with selected fish IBI and macroinvertebrate MMI metrics for streams and wadeable rivers

BCG Attribute	Fish IBI Metrics	Macroinvertebrate Metrics
I. Historically documented, sensitive, long-lived, or regionally endemic taxa	Great River species Sensitive sucker species Native salmonid species American eel numbers & size classes Selected diadromous species	Unionid mussels # of *Pteronarcys* species
II. Highly sensitive taxa	Highly intolerant species Sensitive species Temperate stenotherms Native salmonids	Mayfly & EPT metrics
III. Intermediate sensitive taxa	Moderately intolerant species sensitive species Round-bodied suckers	Mayfly, caddisfly, Tanytarsini midge, EPT metrics
IV. Intermediate tolerant taxa	Included in native species richness Number of minnow species Number of sunfish species	Taxa richness, caddisfly, Dipteran taxa, Non-insect & Other Dipteran taxa
V. Tolerant taxa	Highly tolerant species	Tolerant taxa % Abundance tolerant Taxa
VI. Non-native or intentionally introduced species	Exotic and introduced species of intracontinental origin Non-native species	%*Corbicula; Dreissenid mussels*
VII. Organism condition	DELT anomalies Total native species biomass	Head capsule deformities
VIII. Ecosystem function	Proportion in functional feeding groups Specialist metrics, i.e., fluvial specialists & dependents	%Other Dipteran & non-insects %Filterers %Grazers/scrapers %Clingers
IX. Spatial and temporal extent of detrimental effects	Accounted for in spatial sampling design	(Same as fish)
X. Ecosystem connectance	Diadromous species Native Salmonids Non-indigenous species	Unionid mussel

Indices that are currently in widespread use are of two basic types:

- Indices comprised of metrics that are the aggregation of species/taxa abundance data based on taxonomy, environmental tolerance, functional role, assemblage condition, and organism condition. Each metric is calibrated on a range from best to poorest conditions and also with respect to natural factors such as watershed size. The index development process usually includes an examination of tens to hundreds of candidate metrics and reducing this list to the most relevant and/or responsive 8–12 metrics (approximately). The metrics can be somewhat independent in response to each other and, when summed together, can either dilute or amplify an interpretation. They are useful in observing trajectory, but they may require recalibration to the BCG attributes before they can produce a BCG assessment. Most of this class of indices have been developed for fish, macroinvertebrates, and algae although development for other groups such as Unionid mussels have been attempted (Barbour et al. 1999). Within this broad class of indices are the classic IBIs that follow the seminal guidance of Karr et al. (1986), most of which have been developed for fish assemblages, but some for macroinvertebrates. While the original IBI was developed for central Illinois fish assemblages, Karr et al. (1986) provided guidelines about the possible application to other regions and other aquatic assemblages. This was done knowing that different metrics would be needed, but the goal was to maintain the essential attributes and ecological content of an IBI. Other multimetric approaches have been developed and applied for macroinvertebrates that, while utilizing a generally similar process, are somewhat distinctive from IBIs in having metrics that are predominantly based on taxa attributes (Plafkin et al. 1989; Barbour et al. 1999).
- Predictive models, where the observed species composition at a site is compared to an idealized reference site predicted from a multivariate statistical model. These models develop an expected taxon list and use the O/E ratio (e.g., the River InVertebrate Prediction and Classification System, RIVPACS, e.g., Wright (2000) and the AUStralian RIVer Assessment System, AUSRIVAS, Simpson and Norris (2000)). A second approach has been to use a multivariate similarity index between a specific sample and a centroid defined by undisturbed reference sites (e.g., Percent Model Affinity, Novak and Bode 1992; BEAST, Reynoldson et al. 1995; dissimilarity, Van Sickle 2008). Predictive approaches have also been applied in a multimetric framework, in which expectations for the metrics are based on environmental variables (Chen et al. 2014; Esselman et al. 2013; Moya et al. 2011; Oberdorff et al. 2002; Pont et al. 2006; Pont et al. 2009).

Ideally, the calibration of MMIs are based on minimally disturbed reference sites and with respect to natural classification strata such as bioregions, thermal gradients, and other factors that determine the baseline expectations of a regional aquatic fauna (Stoddard et al. 2006). Some have used all the data assuming that the best, or least disturbed, sites reflect the highest possible condition (Blocksom 2003; Stoddard et al. 2006). Such an assumption should be evaluated by expert opinion before it is accepted that the best condition found in a data set reasonably represents the highest expected condition. Calibration techniques have also evolved from the ordinal approach of Fausch et al. (1984) to continuous calibration techniques (Blocksom 2003; Mebane et al. 2003) that could be applied to BCG development. The expectations for achieving a high level of rigor in this process are described in EPA's Biological Assessment Program Review document (USEPA 2013a). As such, the level of technical rigor achieved in these important calibration steps can also affect the ability to measure condition along the BCG.

As with the development of the BCG, it is also necessary to test an index or model across a gradient of different environmental stressors. The ability to quantify departures from reference-derived thresholds is an important step in evaluating any assessment model.

4.2.1 Biological Condition Gradient Thresholds for Multimetric Indices and Multivariate Models

Indices and models as generally described herein should accurately translate to a position along the BCG. However, the proficiency of a particular index or model to actually accomplish this, at a particular level of resolution, is dependent on the level of detail and rigor applied in construction of the index or model and the calibrated BCG model. EPA (2013a) provides a standardized way to evaluate the technical strengths and gaps in a biological assessment program and to determine how well a particular biological assessment protocol discriminates incremental changes in biological condition (i.e., the higher the level of rigor, the more precision is achieved in incremental measurement along a gradient of stress).

However, simply stratifying an index scoring range along the BCG is neither sufficient nor recommended, especially if an index has not been explicitly developed within the conceptual framework of the BCG or the BCG attributes have not be reconciled with the metrics that comprise the index. For example, metrics in a MMI may have been selected because of strong known response to current or selected stressors and may not comprehensively characterize the full range of biological conditions, while the BCG decision rules are based on benchmarks for undisturbed or minimally disturbed conditions. This has been a challenge, especially with the upper BCG levels where reference analogs to BCG levels 1, 2, 3, or sometimes even 4 either do not exist or have not been identified. If this is the case, it will be necessary to revisit the existing index derivation and BCG model calibration and possibly revise either one, or both, for better correspondence. This task can be accomplished by the state biological assessment and criteria program, but it should be done in collaboration with the full expert panel that developed the BCG model and the underlying quantitative decision rules. As described in Chapter 3, through an iterative process, scoring criteria can be developed for new or refined indices that correspond with biologists' consensus about narrative descriptions of the levels in the BCG.

4.2.1.1 Calibrating Index Scores: Connecticut Stream Example

The set of sites that have been assigned to levels of the BCG are used to calibrate index scores. Index scores for the sites are examined, and, if separation of the index scores among levels is good, then index thresholds can be selected to maximize the ability to discriminate among the levels. This is demonstrated in the Connecticut case example below and by the Minnesota case study where IBI thresholds for refined ALUs were based on the correspondence between their IBIs and BCG levels (section 6.4). In the Connecticut example, BCG calibration and a macroinvertebrate MMI were developed at the same time. The MMI consisted of seven metrics (Table 22; Gerritsen and Jessup 2007b), including an abundance-weighted average of BCG attributes II through VI.

Table 22. Correlations (Pearson r) among Connecticut MMI index metrics

#	Metric	1	2	3	4	5	6	7
1	Ephemeroptera taxa (adj.)	•						
2	Plecoptera taxa	0.58	•					
3	Trichoptera taxa	0.57	0.50	•				
4	% sensitive EPT (adj.)	0.69	0.54	0.52	•			
5	Scraper taxa	0.67	0.50	0.75	0.52	•		
6	BCG Taxa Biotic Index	-0.76	-0.76	-0.68	-0.74	-0.69	•	
7	% dominant genus	-0.61	-0.54	-0.62	-0.59	-0.60	0.66	•

Note: Adj. = Metric scoring was adjusted for catchment size.

The Connecticut stream MMI uses metrics that are similar in objective to the BCG attributes, but which are calculated somewhat differently (e.g., EPT taxa metrics in the MMI include taxa considered to be attributes II, III, IV; and attribute II includes taxa from the EPT orders, as well as a few dipteran and beetle taxa). The total MMI score is based on the average of all metrics, while BCG decisions are based on decision-specific critical attributes (e.g., attributes II and III for the higher levels and attribute V for lower levels). Concordance of the two assessment endpoints is strong (Figure 20). Figure 20 shows the predicted results of the BCG inference model.

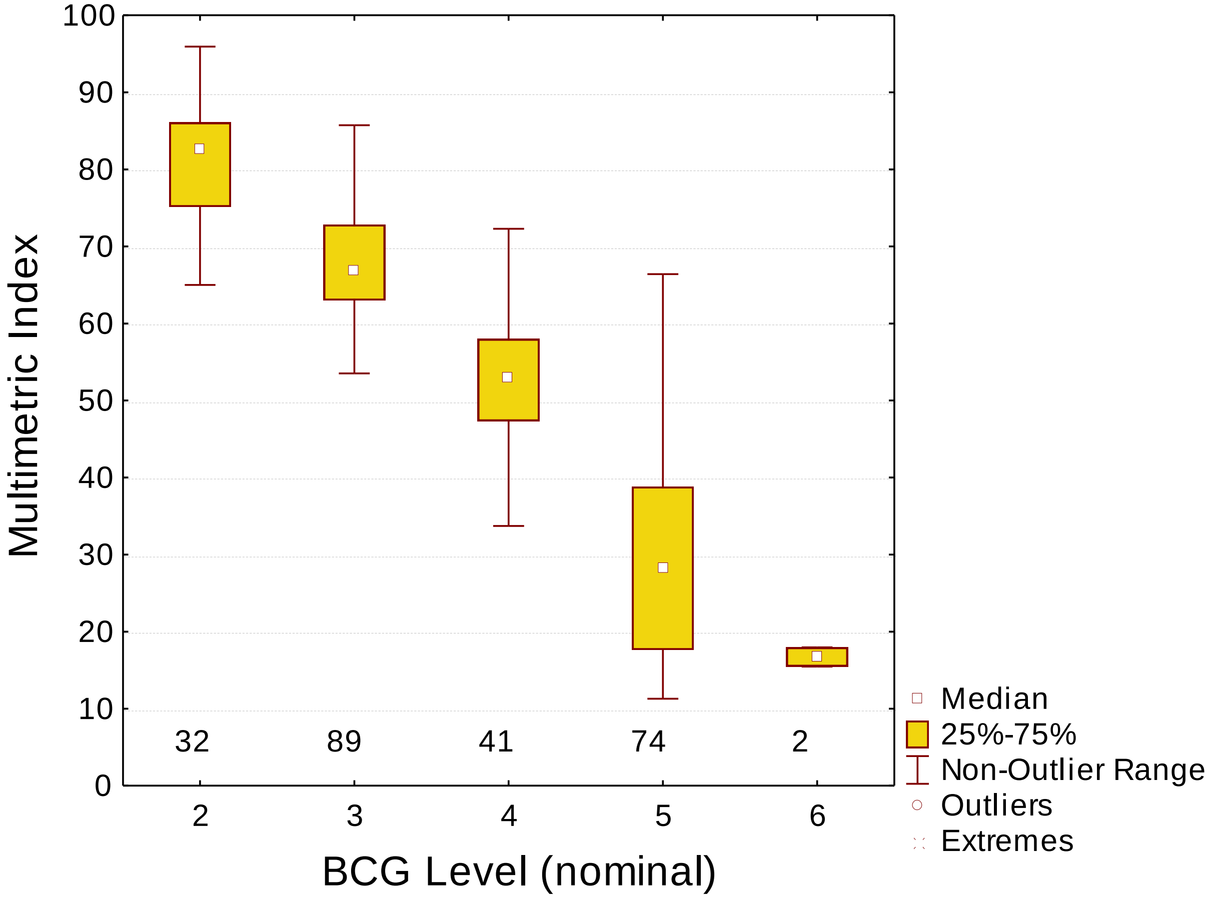


Figure 20. Connecticut MMI by BCG levels, estimated from decision analysis model. Number of samples given below boxes.

In spite of these differences, MMI scores could be used to separate levels (Figure 20). Potential MMI scoring thresholds are given in Table 23.

Table 23. Scoring thresholds for the Connecticut MMI to correspond to BCG levels

BCG Level	MMI Scoring Range
Levels 1, 2	> 75
Level 3	60–74.9
Level 4	43–59.9
Level 5	20–42.9
Level 6	> 20

The BCG decision model and the MMI were in overall concordance on the assessments from the two methods. The scoring range of the MMI was broken into categories corresponding to BCG levels. This resulted in disagreement of 32% of multimetric scores compared to the BCG decision model, but disagreements were never by more than a single level. There was no bias in the direction of disagreement among models, determined by the similar number of MMI assessments that were better or worse than the corresponding BCG assessments.

An additional example of an approach to reconcile an existing index to the BCG is included in Appendix B. This example involves an innovative technique to "back calculate" a historically representative IBI (Appendix B1). In this case it helped to clarify the position of an IBI based on current-day stressors for the Upper Mississippi River.

4.3 Statistical Models to Predict Expert Decisions: Multivariate Discriminant Model Approach

Another approach to quantify expert consensus and develop a BCG model is use of multivariate statistical models to predict expert judgment. For example, Maine DEP developed a set of multivariate linear discriminant models to simulate the expert consensus and predict a site assessment (Danielson et al. 2012; Davies et al. In press), and the United Kingdom Environmental Agency defined ranges of scores of two indices (their RIVPACS index and a tolerance index) that correspond to expert consensus (Hemsley-Flint 2000). Both of these approaches utilize one or more multivariate statistical models to predict the expert judgment in assessments. The following section describes Maine's use of linear discriminant models to discern levels of biological condition.

4.3.1 Approach

The objective of the discriminant model approach is the same as that of the quantitative rule development approach described in section 4.1: to develop a predictive model that will duplicate the decisions of the expert panel, so that new water bodies can be assessed without having to reconvene the panel. As with the rule development, the discriminant model (a multivariate statistical model) uses the same data available to the expert panel.

Discriminant analysis can be used to develop a model that will divide, or discriminate, observations among two or more groups whose membership characteristics have been defined *a priori* (i.e., in advance) of the construction of the model. This is accomplished through use of a model-building or "learning" data set in which samples have been assigned into the groups of interest, for example by expert consensus much like the expert panel process discussed in section 4.1.1. In short, for purposes of calibrating a BCG model, a discriminant function model can be developed from a biological data set where sites in a training data set have previously been assigned to BCG levels. A discriminant function model is a linear function combining those input variables that most successfully contribute to group definition and discrimination among groups. The resulting model yields the maximum separation (discrimination) among the groups (e.g., levels of the BCG). The analysis objectively identifies the best discriminatory variables and weights their relative contribution to the discriminatory model using coefficients. Selection of input variables is aided by initial exploratory data analysis to investigate relationships between biological response variables and physical stream characteristics (width, depth, velocity, elevation, temperature), and by data reduction techniques to eliminate highly correlated variables.

The linear discriminant model (LDM) approach may reveal subtle discriminatory variables within the data set that the biologists might not have recognized as important. This feature of statistical selection of variables contributes to building a highly discriminatory model. In construction of an LDM, input variables can also be included in the model on the basis of the judgment of experts that the variable provides an important link to assessment of the specific biological values that are stated in narrative biological criteria. Once constructed, the model can be used to objectively and consistently determine membership in a BCG level for new observations where the level is unknown. Maine uses this method to determine whether streams are meeting biological criteria for the state's tiered ALUs.

Although it requires statistical expertise to develop, another advantage of discriminant analysis is that it uses established and well-documented statistical methodology, with known confidence limits, and it reports group membership of a sample as probability statements, providing an understanding of the degree of certainty of the reported result. While LDMs require a relatively large set of assigned sites to calibrate the model (approximately 20 per group due to dependence upon having a suitable number of degrees of freedom, Manly 1991; Wilkinson 1989), accuracy of the model to the expert-assigned calibration and test sites can be as high as 89%–97%[6] (Davies et al. In press; Shelton and Blocksom 2004).

Using a discriminant model to develop biological criteria requires both a set of model-building data to develop the model and confirmation data to test the model. If a sufficient number of samples are available, the training and confirmation data may be from the same biological database, randomly divided into two sets (60% to 70% of data for calibration), or they may be drawn from two or more years of survey data. All sites in each data set are assigned to BCG levels by the expert workgroup.

Depending upon the required precision of the model, one or more discriminant function models that function in a hierarchical fashion may be developed from the model-building set to predict level membership from biological data. Building a set of nested, hierarchical models is an effective way of improving overall predictive accuracy (Davies et al. In press). Once developed, the model is applied to the confirmation data set to determine how well it can assign sites to levels using independent data not used to develop the model. More information on discriminant analysis can be found in many available textbooks on multivariate statistics (e.g., Jongman et al. 1987; Legendre and Legendre 1998; Ludwig and Reynolds 1998; Rencher 2003).

4.3.1.1 Example—Maine Discriminant Model for Benthic Macroinvertebrate Assemblages (Source: Shelton and Blocksom 2004)

Maine has four designated use classifications for its streams, AA, A, B, and C, with three corresponding ALUs. Classes AA (Maine's outstanding natural resource waters) and A correspond to BCG levels 1 and 2 (per Maine's narrative criteria, "as naturally occurs"), and they are not distinguishable based on Maine's biological assessment method. Class B ("no detrimental change") corresponds approximately to BCG level 3, and Class C ("maintain structure and function") corresponds approximately to BCG level 4.[7] Streams in poorer condition than Class C, comprising BCG levels 5 and 6, are not in attainment (NA) of minimum state ALU standards. Section 6.5 provides details of implementation and application of

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[6] Based on jack-knife tests of the combined nested LDMs in Maine's two-stage hierarchy of LDM analysis. Results for a new test data set, not used to build the model were 75%–100% accuracy (Davies et al. In press).

[7] The percentage of river and stream miles assigned to each ALU classification in Maine is: Class AA/A-49%; Class B-51%; Class C- 0.4%.

Maine's biological criteria models. After testing multiple statistical modeling techniques (e.g., k-means clustering, Two-Way Indicator Species Analysis, multivariate ordination), the use of best professional judgment of expert aquatic biologists and construction of a set of hierarchical linear discriminant models was selected as the most promising approach to accomplish both technical and regulatory policy goals.

Maine's tiered ALUs and calibration process for benthic macroinvertebrate samples utilizing professional judgment actually predated the formalization of the BCG, and development of the BCG was in fact based, in part, on Maine's approach to biological assessment and biological criteria (Davies and Jackson 2006). The calibration approach in Maine was similar to that described in section 4.1, except that professional judgment was used to place streams into Maine's designated ALU classes (Class A, Class B, Class C) instead of into BCG levels. Maine's tiered ALUs provide an ecologically descriptive gradient of condition tiers, with detailed definitions, to express the expected goal condition for each class. These clearly articulated goals provided the "guiding image" (Poikane et al. 2014; Willby 2011) for biologists to assign samples to classes. Maine DEP developed a set of multivariate linear discriminant models to predict the expert site assessment (Davies et al. 1995; Shelton and Blocksom 2004; State of Maine 2003; Davies et al. In press). The description of the model-building data set below is modified from Shelton and Blocksom (2004):

> The MEDEP [MDEP] originally developed the linear discriminant models based on 145 rock basket samples collected from across the state and representing a range of water quality during 1983–1989. They recalibrated the models in 1998 using a much larger macroinvertebrate database with a total of 376 sampling events (Davies et al. 1999). The final step involved assigning each of the 376 sites in the database to one of four *a priori* groups using the quantifiable measures.

MEDEP also conducts biological assessments of stream algal, wetland macroinvertebrate, and wetland phytoplankton and epiphytic algal assemblages (Danielson et al. 2011, 2012). MEDEP used Maine's narrative biological criteria and the BCG as the foundation of biological assessment models for stream algae, also using the LDM approach outlined here (Danielson et al. 2012). A first step in model-building was to empirically compute tolerance values for algal and macroinvertebrate species that had been collected in Maine's monitoring program. After computing tolerance values, the species were grouped into the BCG framework's sensitive, intermediate, and tolerant attribute groups. MEDEP then modified the model BCG framework for stream macroinvertebrates for stream algae and wetland macroinvertebrates, describing how those assemblages empirically respond to anthropogenic stressor gradients. MEDEP used those modified BCG frameworks and tolerance metrics along with the narrative biological criteria and other metrics to build predictive biological assessment models for the additional assemblages. MEDEP has completed LDM statistical models to predict ALU attainment for both stream algal and wetland macroinvertebrate community data. These models currently are used to help interpret narrative biological criteria. Following adequate testing and standard public review protocols, MEDEP will amend the Maine Biological Criteria Rule[8] to include the stream algal and wetland macroinvertebrate models as numeric biological criteria.

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[8] See Code of Maine Rules, MEDEP, Chapter 579, http://www.maine.gov/dep/water/rules/index.html. Accessed February 2016.

To define *a priori* groups for stream macroinvertebrates, biologists were given data from a set of sites and asked to place the sites into Maine's use classes based on the biological data only (Willby 2011). This set of sites was then used as the calibration data (or "learning" data) for an LDM. The objective of the discriminant model is to replicate ("predict") the professional judgment of the panel of biologists. The excerpt below describes how MEDEP biologists assigned calibration sites to Maine's three classes and to NA (from Davies et al. In press):

> Maine's statutory classes are goal-based and thus do not necessarily correspond to actual biological condition of streams in Maine so legislatively assigned classes could not be used to define groups ... As an alternative approach to defining stream classes, we used "expert knowledge/prior experience" to identify response signals (to different levels of human disturbance) for 30 quantifiable measures of macroinvertebrate community structure (Table 24 below). This classification process was then followed by validation using objective methods to confirm that the *a priori* groupings were, in fact, statistically distinguishable. This approach has been well developed (Anderson 1984; Press 1980). Discriminant analysis and function derivation does not have to rely on classes that only occur in nature. As long as classes are statistically distinct and their members possess a Gaussian distribution within a class, then most assumptions are met (Anderson 1984). To establish *a priori* groups, MDEP biologists, along with independent biologists from other states, and the private stakeholder sector, evaluated benthic macroinvertebrate community data for each stream sample (without knowing site locations or pollution influences) and assigned samples to an aquatic life condition category. The methodology was based on the degree to which each biologist found the sampled community conformed to one of the narrative aquatic life criteria (Class AA/A, B, C; or NA if the community assemblage did not conform to the narrative criteria of the lowest class) as described in the statute and accompanying definitions (Shelton and Blocksom 2004). The panel of biologists received limited habitat data (e.g., depth, water velocity, substrate composition, temperature) in order to evaluate the intrinsic biotic potential of the sampled habitat, but biologists had no knowledge of the site locations, or degree of human disturbance.

Biologist's Classification Criteria

Each biologist reviewed the sample data for the values of a list of measures of community structure and function. Criteria used by biologists to evaluate each measure are listed in Table 24. In 64% of the cases, there was unanimous agreement among the independent raters, and in an additional 34% of the samples, two of the raters were in agreement and one had assigned a different classification. In three of the rated samples, there was disagreement among all three raters (2%).

Table 24. Maine Biologists' Relative Findings Chart Using Macroinvertebrates (Source: Davies et al. In press)

Measure of Community Structure	Relative Findings by Water Body Class			
	A	B	C	NA
Total Abundance of Individuals	often low	often high	variable to high	variable: often very low or high
Abundance of Ephemeroptera	high	high	low	low to absent
Abundance of Plecoptera	highest	some present	low to absent	absent
Proportion of Ephemeroptera	highest	variable, depending on dominance by other groups	low	zero
Proportion of Hydropsychidae	intermediate	highest	variable	low to high
Proportion of Plecoptera	highest	variable	low	zero
Proportion of *Glossoma*	highest	low to intermediate	very low to absent	absent

Measure of Community Structure	Relative Findings by Water Body Class			
	A	B	C	NA
Proportion of *Brachycentrus*	highest	low to intermediate	very low to absent	absent
Proportion of Oligochaetes	low	low	low to moderate	highest
Proportion of Hirudinea	low	variable	variable	variable to highest
Proportion of Gastropoda	low	low	variable	variable to highest
Proportion of Chironomidae	lowest	variable, depending on the dominance of other groups	highest	variable
Proportion of *Conchapelopia* & *Thienemannimyia*	lowest	low to variable	variable	variable to highest
Proportion of *Tribelos*	low to absent	low to absent	low to variable	variable to highest
Proporation of *Chironomus*	low to absent	low to absent	low to variable	variable to highest
Genus Richness	variable	highest	variable	lowest
Ephemeroptera Richness	highest	high	low	very low to absent
Plecoptera Richness	highest	variable	low to absent	absent
EPT Richness	high	highest	variable	low
Proportion Ephemeroptera Richness	highest	high	low	zero
Proportion Plecoptera Richness	highest	high	low	low to zero
Proporation Diptera Richness	low to variable	variable	highest	variable to high
Proporation Ephemeroptera & Plecoptera Richness	highest	high	low to variable	low to absent
EPT Richness divided by Diptera Richness	high	highest	low to variable	lowest to zero
Proporation Non-EPT or Chronomid Richness	lowest	low	intermediate to high	highest
Percent Predators	low	low	high to variable	high to variable
Percent Collectors, Filterers, & Gatherers divided by Percent Predators & Shredders	high	highest	low	lowest
Number of Functional Feeding Groups Represented	variable	highest	variable	lowest
Shannon-Weiner Generic Diversity	low to intermediate	highest	variable to intermediate	lowest
Hilsenhoff Biotic Index	lowest	low	intermediate	highest

Once these groups were determined subjectively and independently by three biologists, univariate and multivariate analysis of variance (ANOVA and MANOVA, respectively) confirmed that the assigned groups were in fact statistically distinct. Following establishment and statistical validation of the groups, MEDEP applied additional analyses to evaluate the necessity to develop stratified models to account for natural factors, such as geographic location and stream size. The uni- and multivariate analyses (cluster analysis, multidimensional scaling, and principle components analysis, in part) suggested that a physically or geographically stratified model for Maine was not warranted. To determine variability in expert judgment assignments, a new test data set was assigned to *a priori* groups by two non-MEDEP biologists, yielding an average concurrence with MEDEP biologists' assignments of 80%. Furthermore, as a check against potential circularity in the model (i.e., "this site looks good, so this must be what good sites look like"), MEDEP chose 27 minimally disturbed sites based on non-biological criteria. These sites were not originally used in the expert assessment or to build the model. This reference data set was used to determine the success of the model to assign them to Class A conditions. These sites had no known point sources and land uses were characterized as 97% forested (3% logged); 2% crop; and 1% residential, industrial, or commercial.

Next, statistical methods and expert judgment were used to identify 26 biological community variables from a list of over 400 variables using stepwise discriminant analysis and iterative backward selection procedures to best assess attainment of the biological goals in the state's ALUs, and to best predict membership of an unknown stream sample to one of the four water quality classes (A, B, C, and NA). These were the methods used by Maine; for alternative approaches to variable selection and optimizing group separation, see Van Sickle et al. (2006). The 26 variables are in Table 25 (four original variables were discontinued following recalibration of the model). Linear discriminant functions were developed from the 26 quantitative macroinvertebrate variables. The discriminant functions determine the probability that a site belongs to a given water quality class. Using a linear optimization algorithm to calculate the discriminant function coefficients, multivariate space distance was minimized between sites within a class, while the distance between classes was maximized. Note that three variables used as predictors in the second-stage models were not calculated directly from the biological data, but instead were probabilities of group membership reported by the First Stage (four-way) discriminant model (see below).

The final, overall discriminant function is calculated using one four-way model and three two-way models. First, using only nine variables and calculated coefficients, the four-way model calculates the probability (range 0.0–1.0) that a site fits into each of the three attainment classes (AA/A, B, or C) and the non-attainment class (NA). The resultant probabilities are then transformed and used as variables in the three two-way models (Table 25). Use of the second stage, two-way models significantly improves the predictive accuracy of the overall model.

Table 25. Measures of community structure used in linear discriminant models for Maine (from MEDEP 2014; State of Maine 2003). Means refer to the mean of three rock baskets sampled at each site.

Model	No.	Measure
First Stage (four-way) model	1	Total mean abundance
	2	Generic richness
	3	Plecoptera mean abundance
	4	Ephemeroptera mean abundance
	5	Shannon-Wiener generic diversity (Shannon and Weaver 1963)
	6	Hilsenhoff Biotic Index (Hilsenhoff 1987a, 1987b)
	7	Relative Chironomidae abundance
	8	Relative Diptera richness (Diptera richness/generic richness)
	9	Hydropsyche mean abundance
Class C or Better model	10	Probability (A+B+C) from First Stage Model
	11	Cheumatopsyche mean abundance
	12	EPT:Diptera richness ratio
	13	Relative Oligochaeta abundance
Class B or Better model	14	Probability (A+B) from First Stage Model
	15	Perlidae mean abundance
	16	Tanypodinae mean abundance
	17	Chironomini mean abundance
	18	Relative Ephemeroptera abundance
	19	EPT generic richness
	21	Sum of mean abundances of: *Dicrotendipes*, *Microspectra*, *Parachironomus,* and *Helobdella*
Class A model	22	Probability of Class A from First Stage Model
	23	Relative Plecoptera richness (Plecoptera richness/generic richness)
	25	Sum of mean abundances of *Cheumatopshyche*, *Cricotopus*, *Tanytarsus,* and *Ablabesmyia*
	26	Sum of mean abundances of *Acroneuria* and *Stenonema*
	28	Ratio of EP generic richness (EP richness/14; 14 is maximum)
	30	Ratio of Class A indicator taxa (Class A taxa/7)

Note: Variable numbers are not sequential; variables 20, 24, 27, and 29 were discontinued following re-parameterization of the model.

The three two-way models further refine the discrimination among classes AA/A, B, or C. These models distinguish between a given class plus any higher classes as a group and any lower classes as a group (i.e., Classes AA/A + B + C vs. NA; Classes AA/A + B vs. Class C + NA; Class AA/A vs. Classes B + C + NA) as depicted in Figure 21, and model performance is shown in Table 26 below (MEDEP 2014; State of Maine 2003; Davies et al. In press). The two-way models are not strictly independent of the four-way model, because they use output probabilities of the four-way model as predictor variables.

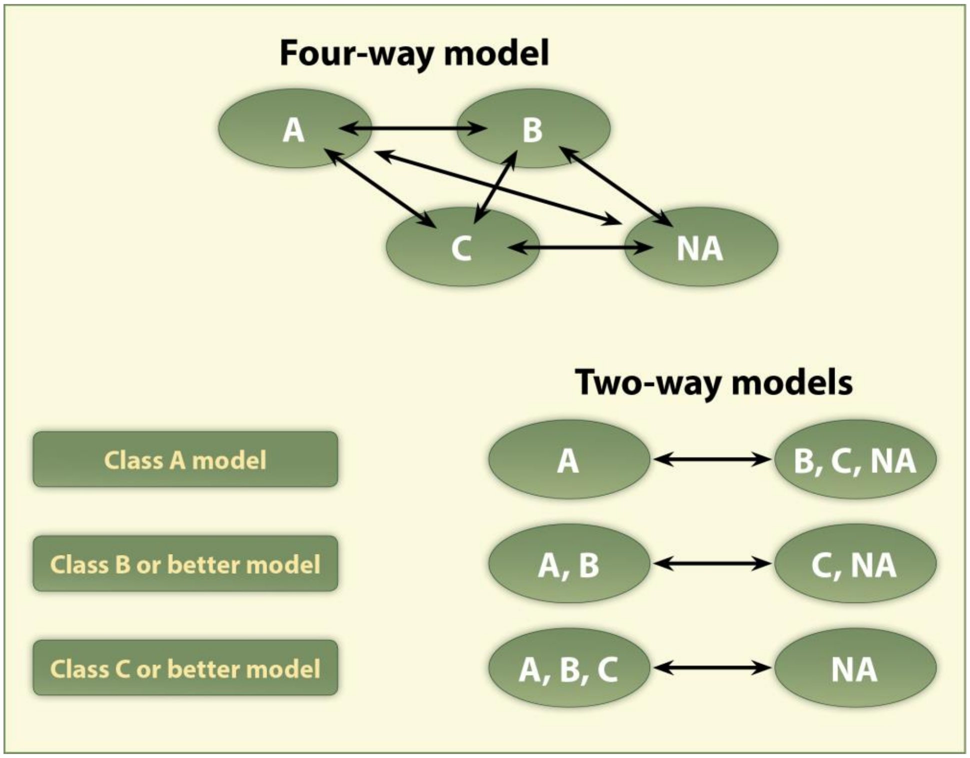

Figure 21. Schematic of four-way and two-way model relationships used by Maine DEP to refine the discrimination among classes (Source: MEDEP 2014).

Table 26. Classification of stream and river sites by two-way linear discriminant models for three classifications. Numerical entries represent the percent of sites classified from *a priori* classes (row) into predicted classes (columns). Therefore, diagonals are % correct classification.

	Final A Classification	
Model Predicted Class		
***A priori* class**	**Class A**	**Classes B,C, or NA**
Class A	90.00% (108)	10.00% (12)
Classes B, C, NA	10.28% (26)	89.72% (227)
	Final B or Better Classification	
Model Predicted Class		
***A priori* class**	**Class B or better**	**Classes C or NA**
Class B or better	96.57% (225)	3.43% (8)
Classes C, NA	11.43% (16)	88.57% (124)
	Final C or Better Classification	
Model Predicted Class		
***A priori* class**	**Class C or better**	**NA**
Class C or better	96.07% (293)	3.93% (12)
NA	14.71% (10)	85.29% (58)

Note: Number in parentheses indicates the number of sites.

Once the probability that a site belongs to a certain class is calculated, the Maine Biocriteria Rule describes the assessment process the Department follows to conclude whether the site attains the minimum standards of its assigned classification (MEDEP 2014; State of Maine 2003). In order to determine whether a site attains at least Class C or is in non-attainment, the probability outcome using the "Class C or better model" is used. If the probability is greater than 60%, then the sample attains Class C or higher, but if it is less than 40% then the site is in non-attainment. If a site falls within 40%–60%, then best professional judgment is used to determine whether the site attains Class C, does not attain Class C, or is indeterminate of Class C. For any site found to be indeterminate, additional monitoring is scheduled in order to make a decision.

Those samples that attain Class C are then tested for Class B attainment using the probability of Class B outcome from the "Class B or better model." If the probability is greater than 60%, then the sites are deemed to attain at least Class B status. Those values below 40% are now considered to be sites that attain to Class C. If a value falls between 40% and 60%, then the outcome is indeterminate of Class B. If the site designated ALU is Class A or Class B, then additional monitoring is conducted to determine to which attainment class the site belongs.

When the probability outcome for a site is 60% or greater using the Class B or better model, it is then tested using the "Class A Model." If the probability of Class A is 60% or greater, then the site attains class A standards. If the value is 40% or less, then the site attains to Class B. If the value is between 40% and 60%, the finding is indeterminate of Class A (though it does attain Class B). Additional sampling will be required if the designated use of the site is Class A. Maine's WQS state that sites determined to attain the standards of the next higher class must be reviewed and considered for re-classification to the next higher class in order to maintain the higher water quality conditions that are being achieved (State of Maine 2004).

The LDM provides a probability of membership result. It explains model performance on a particular sample and can be used to assess the strength of the model decision. Additionally, each of variables can be examined to determine the strength of their contribution to the decision. After the LDM predicts the class attained by a site, a provision in MEDEP regulations (State of Maine 2003) allows for professional judgment to make an adjustment to the evaluation. Any adjustment may be made using analytical, biological, and habitat data. Professional judgment also may be employed when the condition of the stream does not allow for the accurate use of the linear discriminant models. Such factors may include habitat influences (e.g., lake outlets, impounded waters, substrate characteristics, tidal waters), sampling issues (e.g., disturbed samples, unusual taxa assemblages, human error in sampling), or analytical and sample processing issues (e.g., subsample vs. whole sample analysis or human error in processing) (MEDEP 2014; State of Maine 2003).

4.4 Automation of Decision Models

Any of the BCG decision models described above (sections 4.1–4.3) can be automated in databases, spreadsheets, or other commonly available software. Multimetric models have been incorporated into spreadsheet formulas and relational databases (e.g., Environmental Data Acquisition System [EDAS] and many state databases). Discriminant models and other statistical tools can also be coded in R and combined with a database or interactive web pages. More recently, several BCG multiple attribute decision models have been incorporated into MS-Access® applications.

For example, user-friendly automated models have been developed in Microsoft Excel® for the Upper Midwest (Gerritsen and Stamp 2012) and Northern Piedmont region of Maryland (Stamp et al. 2014). Additionally, the Little River Band of Ottawa Indians (LRBOI) has been using the Excel spreadsheets for the Upper Midwest BCG models to obtain BCG level assignments for all of their fish and macroinvertebrate samples from the lower Big Manistee watershed.

Geospatial database technology has advanced in recent years and shows promise for application in water quality management programs, including condition assessments. For example, Maine's discriminant model is incorporated into Maine's Oracle® relational database that is fully georeferenced and linked to the state's spatial database. The state's spatial database and selected, quality assured environmental data, including biological criteria assessment results, are publicly accessible via Google Earth.[9] Linkage between traditional databases that report biological assessment outcomes, and geo-spatial databases connected to natural bio-geophysical factors and disturbance parameters at multiple spatial scales, represent the growing edge of the emerging science of biological assessment.

4.5 Conclusion

A core objective of BCG calibration, from conceptualization to quantification, is to explicitly and transparently link science with management decisions in using biology to interpret ALU goals. This linkage can lead to enhanced stakeholder understanding and engagement in public decision making on goal setting and in assessing current conditions in relation to the ALU goals. However, information on stressors, their sources, and mechanism will be needed to identify actions to restore degraded waters and protect current conditions. Chapter 5 provides a conceptual framework, or template, to assist states in identifying the primary stressors and their sources and mechanisms of action, that impact their waters. This framework can be used by the states to organize data and information on watershed characteristics, hydrologic modifications, and stressors related to ALU goals.

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[9] http://www.maine.gov/dep/gis/datamaps/index.html#blwq. Accessed February 2016.

Chapter 5. The Generalized Stress Axis

The x-axis of the BCG, the GSA, conceptually describes the full range, or gradient, of anthropogenic stress that may adversely affect aquatic biota in a particular geographic area. It is a theoretical construct that in application has been defined by states using known, quantitative stress gradients typically representing a portion of the stressors impacting a water body. The GSA provides a template for development of a quantified stress axis using available databases. Since the BCG curve represents the *in-situ* response of the resident biota to the sum of the stressors to which they are exposed, the GSA should be developed for the same geographic area and water body type for which the BCG is to be developed.

Once quantified, a GSA can serve several purposes. First and foremost, it can be used in development of decision rules for BCG model calibration. Second, the GSA and its underlying data can be used to inform management decisions and assess outcomes. Key applications of a GSA include:

Guide to selection of samples to be used in BCG decision rule development:

- Guide the selection of sites from a data set to ensure that the assessed sites cover as wide and full a range of stressors as possible, within the limits of the data set (see Chapter 3, section 3.3.1).
- Guide the assignment of different taxa to the different tolerance categories specified in the BCG (see Chapter 3, section 3.3.2).

Better link management decisions and outcomes:

- The data collected for developing a stress gradient might be used to help identify and rank sources and stressors within a region, watershed (e.g., 8- or 12-digit hydrologic unit code (HUC8 or HUC12, respectively)), and/or catchment[10] and improve the linkage between biological goals and management actions. Ideally, an improved connection between biological condition and stressors will assist state agencies in prioritizing sources and stressors for action, select effective BMPs, and track improvements. This application will likely occur after BCG development and require causal analysis (e.g., CADDIS; Suter et al. 2002; Norton et al. 2015).
- The data collected in development of the GSA might also be repurposed to inform additional management tools. For example, field-based stressor-response relationships can be used to help develop benchmarks for ALU (protective thresholds for contaminants or excess nutrients or conductivity; e.g., Cormier and Suter 2013; Cormier et al. 2013; USEPA 2011a). In addition, data analyses that describe the distribution of stressors that occur naturally can be repurposed to define background conditions.

This chapter describes the conceptual foundation of the GSA; discusses technical issues to be considered in developing a GSA for specific geographic areas and water body types; and, provides an overview of some approaches for quantifying a GSA.

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[10] *Catchment* is defined as an incremental watershed that drains directly into a stream reach and excludes upstream areas. See: http://nhd.usgs.gov/. Accessed February 2016.

To date, GSAs have been used to develop decision rules to assign sites to BCG levels using known stress gradients and available regional, state, and/or county data (as described in first two bullets above). Some of these GSA applications were explained in the case studies in Chapter 3; they include quantitative gradients based on use of land cover indicators as surrogates for stressors (Minnesota, Alabama; see section 3.3.1.1), and an ordinal gradient based on the sum of cumulative stressors present at a site (Connecticut; see section 3.3.1.2). However, a systematic review and testing of the full suite of potential technical approaches to define and apply a GSA to BCG development has not been conducted. Opportunities in the future may include piloting methods for application of national, regional, or watershed scale data and methods to support state efforts to define and quantify the GSA. Examples of sources of data include EPA's National Aquatic Resource Surveys,[11] the StreamCat data set[12] (Hill et al. 2015), and EPA Office of Research and Development's watershed integrity indicators and map of the ecological condition of watersheds across the country (Flotemersch et al. 2015). Examples of methods that are currently available include the Healthy Watershed Methodology,[13] the Recovery Potential Screening tool (Norton et al. 2009),[14] the Analytical Tools Interface for Landscape Assessments (ATtiLA),[15] and the National Land Cover Database (NLCD).[16] Sources for both data and methods include the Watershed Index Online (WSIO)[17] and EnviroAtlas.[18]

5.1 The Conceptual Foundation of the Generalized Stress Axis

The purpose of this section is to provide a broad conceptual framework and terminology that describes the effects of human activities on biological communities and forms the basis for constructing a GSA. This framework can also be used to facilitate application of research to advance the development and application of the GSA as part of a quantitative BCG model.

The intent of the GSA is to reflect the cumulative degree of anthropogenic stress experienced by aquatic biota. Five major ecological factors that reflect environmental processes and materials determine the biological condition of freshwater aquatic resources: flow regime, water quality, energy source, physical habitat structure, and biotic interactions (Figure 22) (Karr and Dudley 1981). The first four of these factors (flow regime, water quality, energy source, and physical habitat structure) form the construct for a GSA. Appendix A-1 provides an organizing framework for a GSA and illustrates how a GSA might classify sites as high, medium, or no/low levels of stress for two general regions of the U.S., humid temperate and arid, based on these major factors.

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[11] http://www.epa.gov/national-aquatic-resource-surveys. Accessed February 2016.

[12] http://www.epa.gov/national-aquatic-resource-surveys/streamcat. Accessed February 2016.

[13] http://www.epa.gov/hwp. Accessed February 2016.

[14] http://www.epa.gov/rps. Accessed February 2016.

[15] http://www2.epa.gov/eco-research/analytical-tools-interface-landscape-assessments-attila-landscape-metrics. Accessed February 2016.

[16] http://landcover.usgs.gov/. Accessed February 2016.

[17] http://www.epa.gov/watershed-index-online. Accessed February 2016.

[18] http://www.epa.gov/enviroatlas. Accessed February 2016.

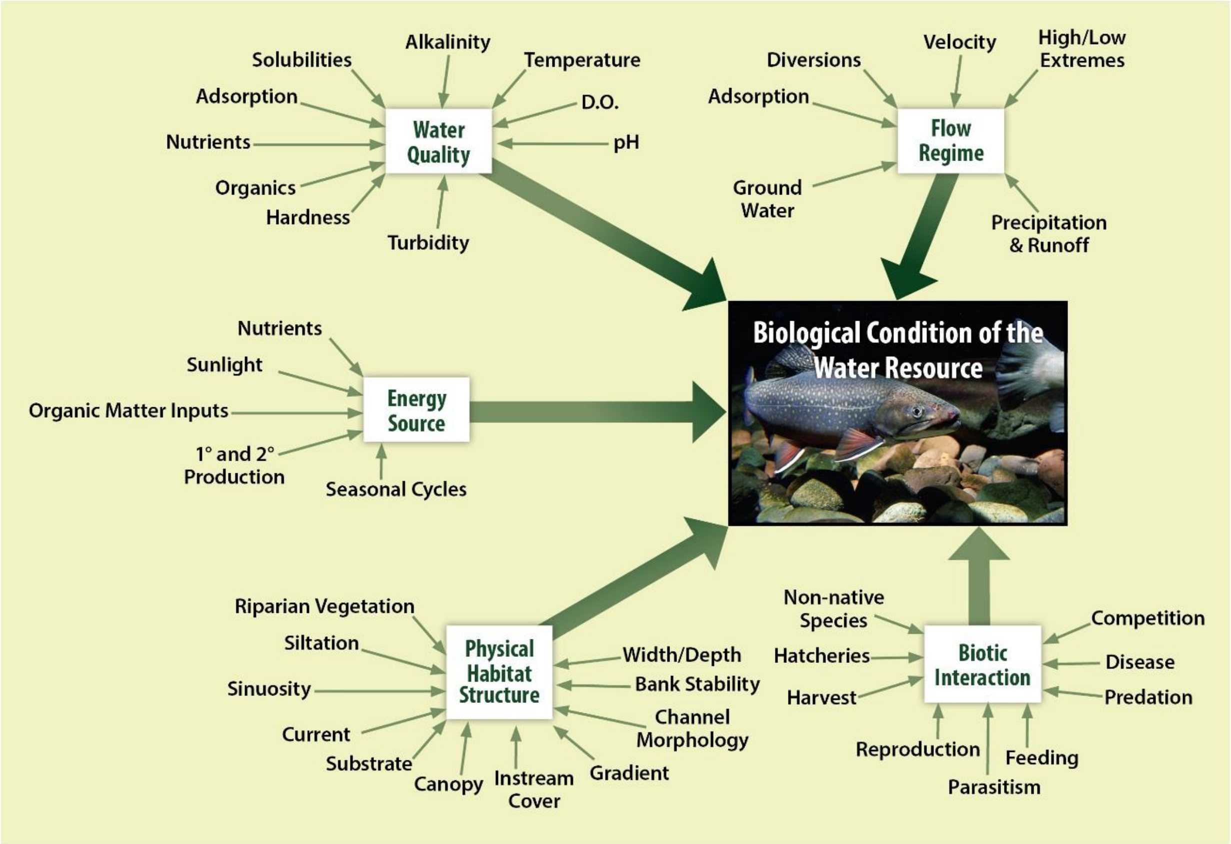

Figure 22. The five major factors that determine the biological condition of aquatic resources (modified from Karr and Dudley 1981). Four of the five factors, flow regime, water quality, energy source, and physical habitat structure, are the basis for the conceptual GSA as described in this document. The fifth factor, biotic interaction, is incorporated as part of the BCG y-axis levels and attributes.

An event or activity that alters one or more of these five factors is called a *disturbance*. Disturbances can occur outside of the stream and riparian zone (e.g., land use changes within the watershed, climate) or within it (e.g., dams, point source discharges). Ecosystems normally have some level of disturbances that occurs within a range of natural variability (e.g., Berger and Hodge 1998; White and Pickett 1985). Anthropogenic activities can cause disturbances that exceed the range of natural variability, and they are said to exert *pressure*[19] upon an aquatic system, or *state*, by altering ecosystem processes and materials, ultimately generating *stressors* that adversely impact biological condition (Niemi and McDonald 2004). The term *pressure* conceptually and mechanistically links larger scale landscape and hydrological alterations to the in-stream stressors that affect aquatic biota (Crain and Bertness 2006; Rapport and Friend 1979; Samhouri et al. 2010; Villamagna et al. 2013). Though different terminology is employed, the *Stressor-Exposure-System Response* paradigm (e.g., Barnthouse and Brown 1994) typically employed in water quality criteria development is comparable in that both conceptual models ultimately help accomplish the same objective—linking human activities to stressors to changes in biological condition (Figure 23) so action can be taken to protect or restore aquatic resources.

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[19] The use of the word pressure in this context has a well-established history in the European environmental literature. Pressure is a term originally proposed by the Organisation for Economic Co-operation and Development (OECD 1998) and used by the European Union in its Water Framework Directive (European Environment Agency 1999).

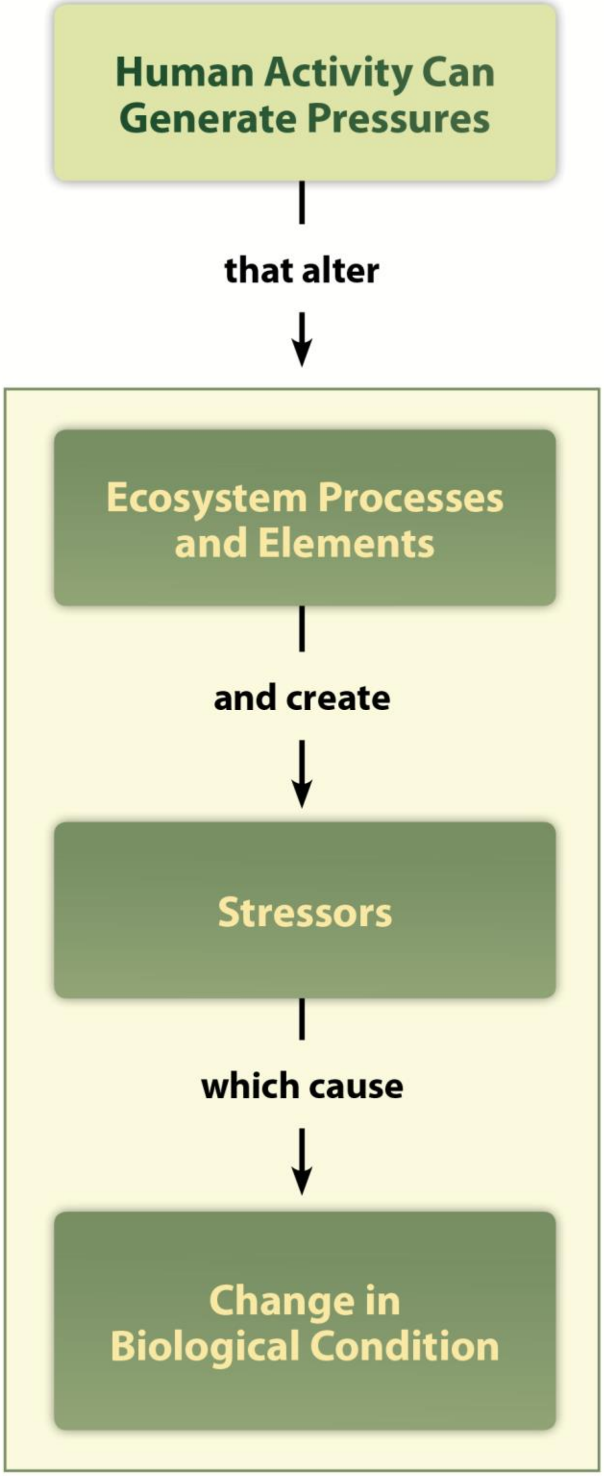

Figure 23. Human activities can cause *disturbances* in the environment that exceed the range of natural variability, generating *pressure* upon an aquatic system that results in altered *environmental processes and materials,* which, in turn, create *stressors* that adversely impact biological condition.

Stressors are the proximate causes of biological effects. They are the link between human activities and the change in biological condition (Figure 23). Stressors can co-occur in time and space when they are generated by the same human activity or source and/or any overlapping activity or source. Stressors may affect more than one aspect of biological condition, and a particular change in biological condition can also be the result of multiple stressors acting simultaneously. Since multiple stressors are usually present, the x-axis is intended to reflect their cumulative spatial/temporal co-occurrence in a GSA, much as the y-axis generalizes biological condition.

Point source discharges of pollutants were the dominant pressures to fresh waters addressed in the initial implementation of the CWA. While this pressure still exists today, water quality managers also face additional challenges stemming from in-stream hydrological modifications, forest harvest, agriculture, and urbanization, as well as emerging pressures associated with the inadvertent or deliberate introduction of invasive species (Ricciardi and MacIsaac 2000), the consequences of greenhouse gas emissions (e.g., Bierwagen et al. 2012), use of pharmaceutical products (Rosi-Marshall and Royer 2012; Rosi-Marshall et al. 2013), and even recreation (Bryce et al. 1999; Poff et al. 2002; Richter et al. 1997). Additionally, stressors can exert both direct effects on the biota and indirect effects through modification of habitat and interactions with other stressors (Karr and Dudley 1981; Karr et al. 1986; Poff et al. 1997; Slivitzky 2001) (Figure 24).

For example, a GSA that considers flow regime changes would consider many stressors and their interactions. Stream flows directly influence stream biota, but they also interact in multiple ways with other in-stream factors including water quality parameters, such as DO and temperature. Altered stream flows are strongly associated with many habitat variables such as channel structure, erosion, bank instability, and lower base flows (Poff et al. 1997; Richter et al. 2003; Poff et al. 2010). All of these factors associated with the flow regime have the capability of affecting species distributions, abundances, life history traits, and competitive interactions (Greenberg et al. 1996; Kennen et al. 2008; Poff and Allan 1995; Poff et al. 1997; Robson et al. 2011; Walters and Post 2011).

Many of the changes to the natural flow regime can be attributed to human activities, such as dam creation, channelization, and impervious surfaces, along with associated removal of natural vegetation, water extraction, and loss of surface water storage capacity (e.g., wetlands) (Poff et al. 1997). Altered flow regimes are also the result of changing climate, with changes observed in precipitation and runoff amounts, seasonal patterns, and timing, frequency, and intensity of large storms (Frich et al. 2002; Karl and Trenberth 2003; Poff et al. 2002). Still, flows vary naturally, and it can be difficult to distinguish anthropogenic disturbance from the range of variation produced by natural processes (e.g., see review by Berger and Hodge 1998). All of these issues should be considered when developing a GSA that reflects the stress associated with flow regime changes.

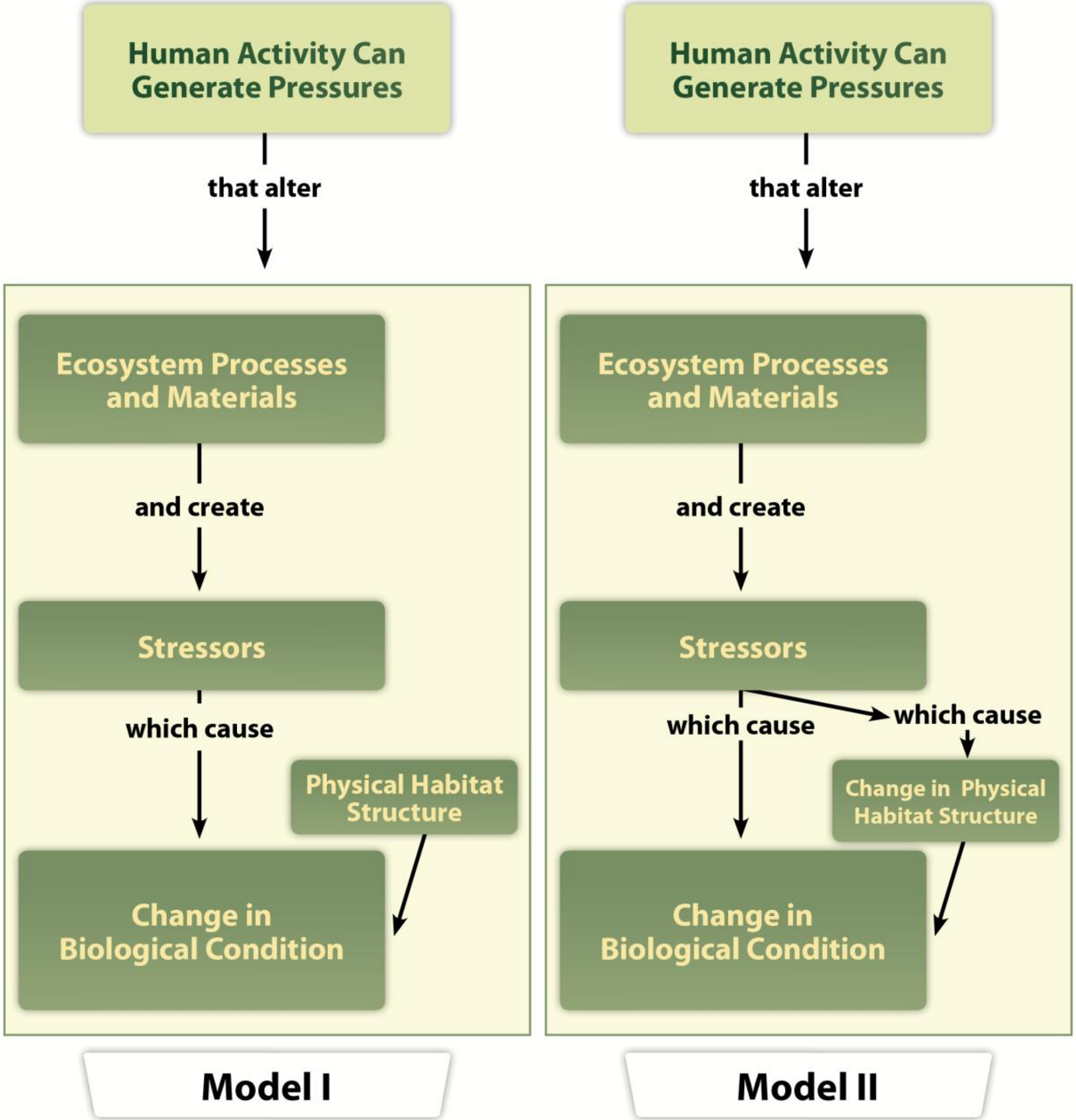

Figure 24. Hierarchical effects of disturbance. When assessing the relationship between stressors and biological effects, one of two implicit models is assumed. Model 1—the biota at a site are determined by the environmental covariates characteristic of the habitat. The stressors associated with a human-related disturbance directly influence biota. Model 2—the biota at a site are determined by the environmental characteristics of the site. However, the stressors associated with a human-related disturbance influence both the physical habitat structure and the biota itself. Consequently, the biological effects reflect the combined direct effects of the stress and the disturbance-mediated habitat alteration (From: Ciborowski et al. unpublished). Comprehensive and integrated monitoring data (biological, chemical, physical) coupled with causal assessment will help distinguish direct from indirect effects (USEPA 2013a).

5.1.1 Technical Issues in Developing a Generalized Stress Axis

This section discusses some of the technical issues to be considered in defining a GSA, including temporal and spatial scales, multiple stressors, legacy effects, and predicted impacts of climate change on aquatic systems. The concepts of spatial and temporal scale are critical issues in adequately defining the GSA. Pressures, stressors, and their effects on biota (e.g., biotic response) operate at different spatial and temporal scales (Glasby and Underwood 1996). Stressors are expressed over temporal and spatial scales ranging from a one-time, localized event (pulse event; Bender et al. 1984) to long-term chronic exposures occurring continuously (press events) over vast landscapes. Additionally, stressors may be introduced through diffuse or point sources delivered from upstream in the channel or watershed, or laterally from riparian, floodplain, or upland sources. Pollutants can also be delivered to a stream, river, lake or wetland from above through atmospheric sources, or below from groundwater sources. Activities in the watershed or along the water body corridor will influence the connectivity and integrity of the water resource. Additionally, climate change can exacerbate the intensity of local stressors (e.g., more heavy rainfalls can produce increased runoff and sediment load).

As discussed previously, human activities can produce multiple stressors, which in turn will affect biological condition. Stressors can interact with one another to create a synergistic response, behaving in an additive or multiplicative manner; they also may counteract one another. The steady accumulation of small pressures in watersheds results in cumulative effects, which add to the challenges of characterizing, evaluating, and managing stressors.

The influence of individual stressors on biological condition in specific water bodies can be particularly difficult to disentangle because each stressor potentially exerts indirect and direct forces. The complexity of interactions among stressors makes it difficult to identify single stressor-single biological effect relationships (Hodge 1997; Noss 1990; Vander Laan et al. 2013). Stressor identification is one causal assessment approach useful for identifying the stressors that cause biological effects (USEPA 2000; Norton et al. 2015).[20]

However, when sufficient data are available, quantitative modeling approaches can be used to describe the complex relationships between pressures, stressors, and their effects on the biota. Niemeijer and deGroot (2008a, 2008b) advocated summarizing the interactions among stressors to create causal networks as a means of better understanding the complex relationships between pressures and their ultimate effect on the biota, and this approach has been applied to streams with qualified success. Allan et al. (2012) used Bayesian Belief Network analysis to characterize the effects of sedimentation on macroinvertebrates in agricultural streams in the U.S. Midwest and in New Zealand affected by sedimentation due to grazing and forestry practices. Riseng et al. (2010, 2011) used Structural Equation Modeling to document relationships between stress and stream biota. They determined that land use effects in total were more important influences on metrics of fish and invertebrate biota than effects of point source discharges.

The concept that human activities produce multiple stressors provides the foundation for one common approach to describing an overall gradient of stress using land cover information as a surrogate for stressor information. In this approach, the GSA is developed using broadly defined, relatively easily measured factors that produce many stressors simultaneously (e.g., amount of urban development or road density in a catchment). Mapping the distribution of pressures, for example land uses associated

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[20] See also http://www3.epa.gov/caddis/. Accessed February 2016.

with particular human activities, has proven to be an effective way of documenting the location of possible sources that produce the stressors that lead to biological degradation (Allan et al. 2013; Brooks et al. 2009; Danz et al. 2005, 2007).

Stressor indicators can be developed from such measures as population density, proportion of land devoted to agriculture or urban development, total miles of roadway, or quantities of water used/released (e.g., Allan et al. 2013; Host et al. 2005, 2011; Hunsaker et al. 1992; Jones et al. 1999, 2001; O'Neill et al. 1988, 1997; Riitters et al. 1995, 1996, 1997). The advent of improved remote sensing, digital technology, and the ability to map land uses has provided an important tool for documenting the location and extent of pressures on the landscape. This approach has been used effectively to assess watershed and coastal conditions such as in the Laurentian Great Lakes for decades where Danz et al. (2005, 2007) and Allan et al. (2013) documented the distribution of the composite stress contributed by human activity throughout the Great Lakes (Figure 25). A simplified form of the Danz et al. (2005) system, the Watershed Stress Index (Host et al. 2011), is currently used to report on the condition of Great Lakes watershed, including tracking progress towards achieving the overall purpose of the binational Great Lakes Water Quality Agreement "to restore and maintain the physical, chemical and biological integrity of the Great Lakes Basin Ecosystem."[21] Allan et al. (2013) used expert assessment to delineate threats to the biological integrity of the Great Lakes themselves. Host et al. (2011) mapped the distribution of watersheds in which specific groups of biota were at least and at greatest risk of degradation due to urban and agricultural pressures.

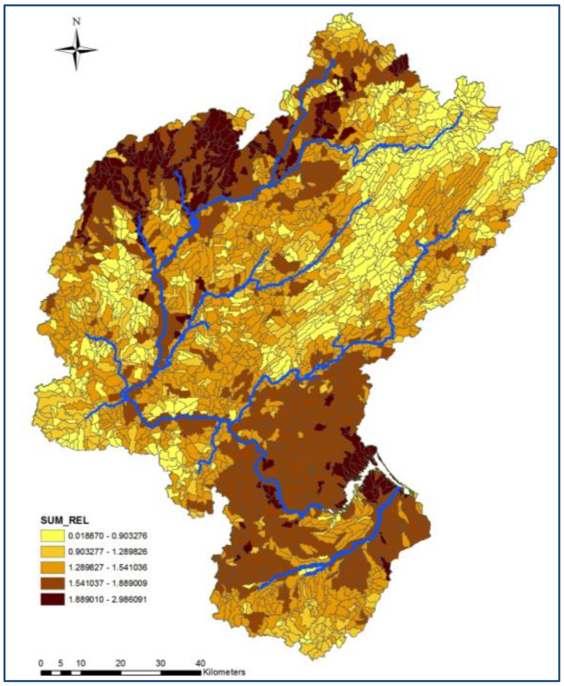

Figure 25. Cumulative stress within the St. Louis River watershed, a tributary to Lake Superior. Darker shading indicates increased stress. The stress score is based on the cumulative sum of % agricultural land use, population density, road density, and point source density. Values were each normalized to a 0–1 scale before summation. This index was used to calibrate water quality responses to stress in the St. Louis River Area of Concern (Bartsch et al. 2015). (Map by Tom Hollenhorst, EPA, Mid-Continent Ecology Division)

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[21] https://www.ec.gc.ca/grandslacs-greatlakes/default.asp?lang=En&n=70FFEFDF-1. Accessed February 2016.

However, although land use can be a useful general pressure indicator, practices within a given land use category can change over time, which may reduce or increase the stressors that are produced by that land use. Local variables can exert important influences on biological conditions that are not captured by remote sensing or other land cover data alone. For example, the incidence of tile drainage is generally not mapped; drainage intensity has increased in some areas of the Midwest resulting in increased annual flows in ditches related to reduced evaporation off of land surfaces (Blann et al. 2009). Miltner (2015) used extensive biological, stressor, and pressure (agricultural practices) data in Ohio and demonstrated that conservation measures have contributed to improved environmental conditions in Ohio headwater streams. Miltner (2015) concluded "that stream physical habitat clearly influences water quality, and therefore structural measures that improve habitat function in channelized streams and drainage ditches are a necessary component of efforts to combat eutrophication." Analyses such as these would not be possible without the accumulation of substantial monitoring data collected at a higher spatial resolution (Blann et al. 2009; Miltner 2015). Additionally, documenting biological conditions at the local reach and watershed scale makes it apparent that broad scale use of indicators such as land cover are not in themselves adequate predictors of biological impairment in specific water bodies. The scale of application is a critical factor—important stressors that act at the local reach and watershed scale can be missed.

An additional caveat in using land cover as a sole basis for GSA development is that the indicators are typically based on current land uses although some types of past land use patterns are available as mapped information. Many human activities in watersheds leave permanent or semi-permanent changes, termed "legacy effects." For example, persistent contaminants such as DDT, PCBs, PAHs,[22] and metals can end up in sediments, and they may be resuspended or buried permanently, depending on the depositional environment. Excess phosphorus may be buried in lake or pond sediments. In eastern U.S. Piedmont and Appalachian highlands, stream valley morphology has changed permanently in many places due to historic land use changes from the colonial period to the present: from initial clearing, to colonial and early American hydropower development, early agriculture, subsequent agricultural abandonment and forest regrowth, followed by recent suburban development (e.g., Maizel et al. 1998; Walter and Merritts 2008). These legacies may account for intermittent stressors in the form of contaminants, nutrients, and sediments that can be eroded and resuspended from historic sedimentation during storm events, or permanent stressors in the form of hydrological modifications or sedimentation. Documenting previous land use and expanding monitoring programs to include appropriate parameters will assist in detection of these stressors.

Regardless of the information used in defining a GSA, the impact of climate change will increasingly need to be taken into account. Climate change is a widespread disturbance that is capable of moving the system outside its natural range of variation, even in the absence of other anthropogenic disturbances, by elevating air and water temperatures, altering flow regimes through changes in the seasonality of precipitation, altering soil moisture regimes, and through changes in the frequency and intensity of storm events and fires (IPCC 2014; Melillo et al. 2014). The effects of changing climatic conditions, whether considered naturally or anthropogenically driven, are superimposed on other anthropogenic stressors generally leading to an exacerbated effect (c.f. Comte et al. 2013; Palmer et al. 2009; Hoegh-Guldberg et al. 2007; Arnell 1999). In general, water quality is likely to be negatively impacted by effects of climate change through altered flow regimes leading to higher peak flows and lower base flows. Altered flow regimes in turn influence extremes in water temperature, DO concentrations, changes in

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[22] DDT: dichlorodiphenyltrichloroethane; PCB: polychlorinated biphenyl; PAH: polycyclic aromatic hydrocarbon

biogeochemical processing, and biotic assemblage structure and function that these factors regulate (Melillo et al. 2014). The effects of heavy downpours are exacerbated by impervious surfaces, leading to greater sediment, contaminant, and nutrient loading. Appendix A-2 provides examples of stressors and potential indicators of climate change under low, medium, and high stress scenarios for humid and arid regions. The BCG with well-defined biological indicators (y-axis) and stress indicators (x-axis) can be used to determine current baseline conditions and track changes in parameters that are associated with climate change, such as flow and temperature.

5.2 Development of a Generalized Stress Axis

In preparation for BCG development (see Chapter 3, sections 3.2 and 3.3), the process to develop a GSA for a specific geographic area and water body type includes a series of steps: classifying sites to reduce natural variability; identifying undisturbed or minimally disturbed conditions; and identifying indicators and the data that will be used to define the gradient of stress.

The first step in GSA development is to classify the aquatic resource (e.g., biogeographic regions, basins, biological considerations) (Herlihy et al. 2008; McCormick et al. 2000; Van Sickle and Hughes 2000; Waite et al. 2000). Classification is also an important component of biological assessment program development (see section 3.2.1.1). The purpose of classification is to reduce variability in natural conditions that can contribute to or influence stressors and biological assemblages. Features such as latitude, climate, geology, and landforms can explain the dominant patterns of variation in stressors across large regions (e.g., Herlihy et al. 2008). These broad-scale classification systems can be supplemented by local-scale features (e.g., slope, groundwater seeps) that can contribute to site-scale patterns in biotic assemblages (Hawkins and Vinson 2000; Pyne et al. 2007; Snelder et al. 2004, 2008; Van Sickle and Hughes 2000).[23]

A second step in GSA development is characterizing undisturbed or minimally disturbed conditions for a particular area. This characterization is the benchmark against which areas to be evaluated will be compared (as discussed in section 3.2.1.1), allowing for development and calibration of indices such as the mIBI and O/E assessment models. For most state biological assessment programs for streams, this step involves use of the state's reference site database. An important consideration when selecting reference sites is whether the reference sites represent undisturbed, minimally disturbed, or least disturbed conditions (Hawkins et al. 2010; Herlihy et al. 2008; Hughes 1985, 1994; Hughes et al. 1986; Moss et al. 1987; Stoddard et al. 2008). In BCG development, descriptions of undisturbed and minimally disturbed reference conditions (e.g., BCG levels 1 and 2) are critical components of model calibration. In some places, calibration may be based solely on historic records or other sources of information. Like level 1 of the BCG, the "low stress" end of the stress axis is anchored in the "as naturally occurs" or undisturbed or minimally disturbed, condition (i.e., no/minimal anthropogenic stressors).

The third step is to identify indicators and data sets that will be used to define the GSA. The major environmental factors shown in Figure 22 can be used as prompts to identify indicators (e.g., Appendix A-3). When evaluating data sets to develop a GSA, it is important to bear in mind that the biological conditions will reflect effects of unknown sources and unmeasured stressors, as well as incorrectly

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[23] A comprehensive review of recent classification systems is beyond the scope of this document. There is still much to be learned about how biotic effects from local vs. catchment scale disturbances differ between catchments that are largely disturbed, and those that are relatively undisturbed (see review by Johnson and Host 2010).

characterized data sets. In this regard, the GSA is only as robust as the data upon which it is based. Characterizing to the extent possible the degree of uncertainty around the stressor-response (i.e., effect) relationships is important. There will always be some level of unexplained variation. But, where relationships between stress, or stressors, and biological response are poorly predicted, further assessments should be conducted. For example, as mentioned above, legacy contaminants from long-defunct industrial activities are typically invisible to remote imaging, yet may wash out periodically in storm events. A water quality assessment conducted for screening purposes is unlikely to capture such rare events. Intensive, directed sampling is more likely to detect the contamination, possibly after determination that a downstream location is biologically impaired from unknown causes and historical land use records are researched.

As explained earlier, this document does not comprehensively review or evaluate the approaches available to define a GSA. The examples discussed below represent several approaches that have been used to define stress gradients and are intended to prompt ideas and enhancements.

5.2.1 Using Land Cover Measures as Stressor Indicators

One approach to quantify a GSA relies upon land cover data. The land cover indicators serve as surrogate indicators for stressors, typically multiple stressors associated with a specific land use. Many human activities that cause stress in aquatic systems can be summarized in land cover delineations. Because land cover can be expressed as a fraction or percent of a watershed, catchment, or zone within the catchment (e.g., riparian corridors), using land cover data provide an obvious initial approach for summing land uses for an overall index of pressure. Land cover data generally do not include information on legacy sources and stressors unless intentionally mapped, nor do the data usually incorporate in-stream measures of water quality or habitat quality. Thus, the methods that rely solely on land cover should be regarded as the "first cut" tool in a toolbox that may contain multiple approaches. If stress-response relationships are poorly predicted by land cover data, subsequent analyses should include a more complete portfolio of stressors that contain both local habitat and water quality variables, as well as potential legacy pressures. Although remote sensing is a useful coarse focus, stressors and their effects on the biota can vary substantially.

The simplest land cover-based GSA is comprised of one, or the sum of several, land covers calculated for the catchment of each aquatic sampling point in the database being used. For example, in the Maryland Piedmont, percent impervious surface was used as a single stressor gradient because of the extent of urban and suburban land use throughout the mid-Atlantic Piedmont (see Chapter 3, sections 3.3.1.1 and 3.3.2.1). As another example, developers of a BCG for fish assemblages in Minnesota lakes used a GSA composed of a simple sum of percentages of urban, agricultural, and mining lands (section 3.3.2.1).

The above land cover-based GSAs do not differentially weight various land uses (as measured by land cover) in terms of their effects on aquatic biota. For example, impervious surface strongly affects stream hydrology, habitat quality, and biology (e.g., Stranko et al. 2008) and effects of agricultural land use depend on its intensity and local agricultural practices. An alternative method, the landscape development intensity index (LDI), weighs the intensity of multiple land uses in a study area (Brown and Vivas 2005). The LDI is a measure of human activity based on a development intensity measure derived from non-renewable energy use in the surrounding landscape. The LDI is calculated using all nonrenewable forms of energy (e.g., electricity, fuels, fertilizers, pesticides, and water (both public water supply and irrigation) (Brown and Vivas 2005)) used directly or implicitly in various land use classifications. Land uses are classified, and an intensity factor is assigned to each land use type (Table 27).

Table 27. Land use classification and intensity factor (LDI coefficient) for Florida landscapes (modified from Brown and Vivas 2005)

Land Classification	Intensity Factor (LDI coefficient)
Natural system	1.00
Natural open water	1.00
Pine plantation	1.58
Recreational/open space – low intensity	1.83
Woodland pasture (with livestock)	2.02
Improved pasture (without livestock)	2.77
Improved pasture – low intensity (with livestock)	3.41
Citrus	3.68
Improved pasture – high intensity (with livestock)	3.74
Row crops	4.54
Single-family residential – low density	6.9
Recreational/open space – high intensity	6.92
Agriculture – high intensity	7.00
Single-family residential – medium density	7.47
Single-family residential – high density	7.55
Mobile home (medium density)	7.70
Highway (2-lane)	7.81
Low intensity commercial	8.00
Institutional	8.07
Highway (4-lane)	8.28
Mobile home (high density)	8.29
Industrial	8.32
Multi-family residential (low-rise)	8.66
High-intensity commercial	9.18
Multi-family residential (high-rise)	9.19
Central business district (average 2-stories)	9.42
Central business district (average 4-stories)	10.00

The LDI has been used as a human disturbance gradient for wetlands (Brown and Vivas 2005; Chen and Lin 2011; Lane 2003; Mack 2006, 2007; Reiss 2004, 2006; Reiss and Brown 2005, 2007; Surdick 2005; Vivas 2007; Vivas and Brown 2006), streams (Brooks et al. 2009; Fore 2003, 2004; Harrington 2014; Stanfield and Kilgour 2012), and lakes (Fore 2005). It has also been used for coral reefs (Oliver et al. 2011). Figure 26 shows application of the LDI for coral reefs. Land use indices similar to the LDI were used to develop BCG calibrations for Minnesota and Alabama (see section 3.3.1.1).

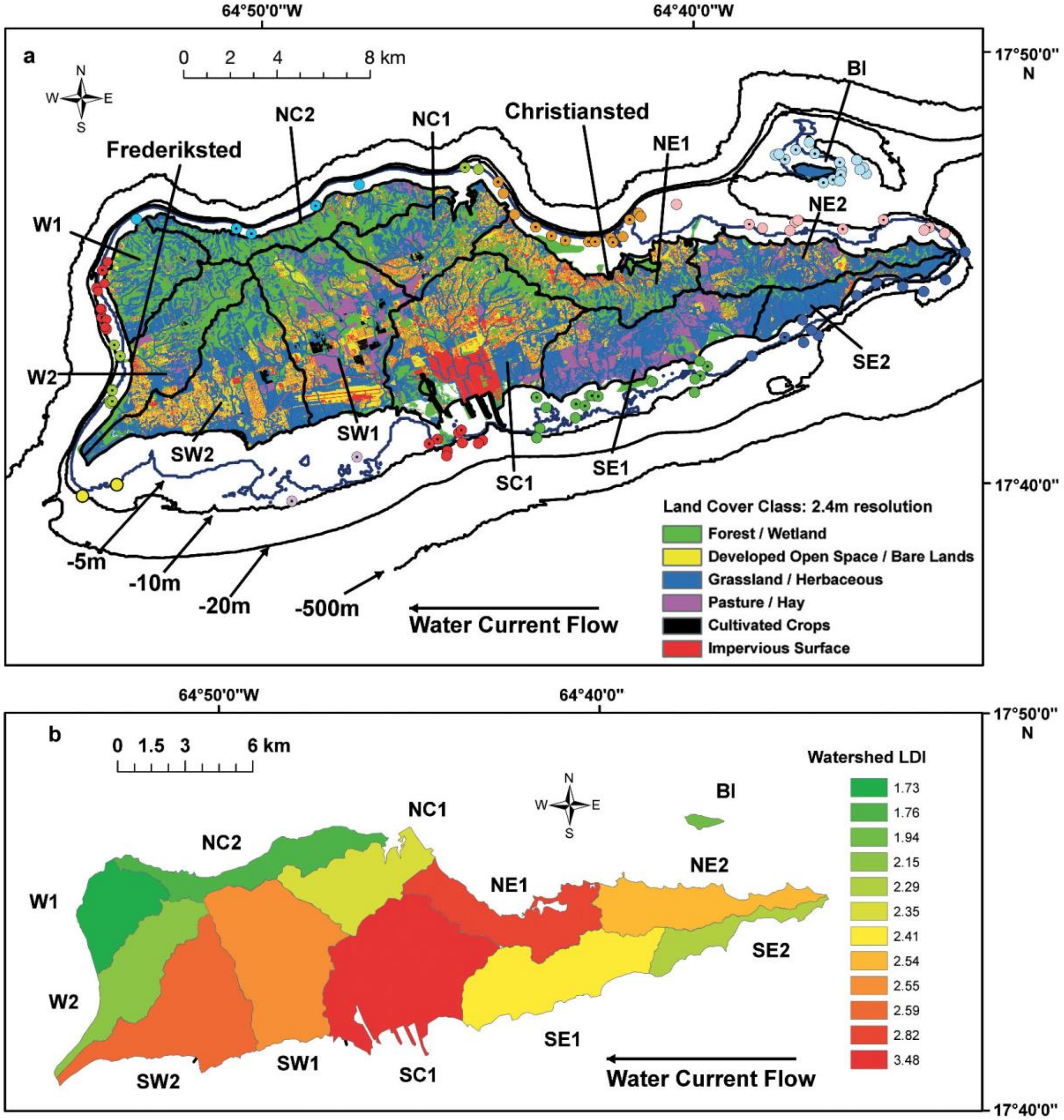

Figure 26. LDI applied to St. Croix watersheds and associated coral stations (Source: Oliver et al. 2011). Top figure shows land use/land cover and EPA coral reef stations. Land use/land cover used in the analysis is shown at 2.4 m resolution. Bottom figure show the watershed LDI values on a green– yellow–red continuum, where green indicates the lowest human disturbance and red indicates the highest. Watershed abbreviations: BI: Buck Island; NC: North Central; NE: Northeast; SC: South Central; SE: Southeast; SW: Southwest; W: West.

Nationally, the LDI has been mapped at HUC12 watershed as part of the WSIO data library using publicly available data from 2001. The WSIO contains mean, median, standard deviations, and sum of values for empower density (derivation of LDI) for a HUC12 watershed, its riparian zone, and hydrologic connected zone. Currently the WSIO data set is being updated nationally with the most recent NLCD data and should be available for use in near future.

5.2.2 Ranking Sites by Summing Stressor Indicators

Another approach to develop a GSA is to tally the number of stressor indicators observed at a particular site and establish a method to score the results. Many examples of this approach have been used across different regions, spatial extents, and ecosystem types (Chow-Fraser 2006; Uzarski et al. 2005). This approach entails identifying observed human activities and observed stressors (and their sources if information is available) and summing them to produce an overall index that can then be used to place sites in order from least to most stress.

The first step for the ordinal approach involves identifying and quantifying, for each site in a biological monitoring database, the relevant data available, including data on sources, in-stream measured water quality, riparian condition, land cover, riverscape alterations, known point source discharges, and observed nonpoint sources. For instream measures, it is important to distinguish non-detects (known and effectively absent) from not sampled (unknown; no data). A conceptual diagram of sources, stressors, mechanisms, and effects is helpful in organizing the information (e.g., Norton et al. 2015).

In the simplest implementation, each stressor indicator is evaluated as being present (1) or absent (0) at a site. The results are added to produce a score for each site. In the Connecticut case example (section 3.3.1.2), stressor indicators included reduced natural land cover, developed land, impervious surface, total chloride (a measure of total point source discharge), and four metals (copper, iron, nickel, zinc). Scoring in the case example was not simply 0–1; some stressor scores could range on an ordinal scale of 0–3, depending on the concentration or intensity of a given stressor. The results were used to divide sites into five overall stress categories ranging from "least stressed" to "severe stressed." The resultant gradient helped identify potential most-stressed, least stressed, and intermediately stressed sites in the BCG development data set. It is important to reiterate that the stress information was hidden from the expert panel during its deliberations.

For development of the BCG in Minnesota, MPCA developed a disturbance index (the HDS) that combined scores associated with land use metrics with additional indicators. The index includes eight primary metrics, which include measures of watershed land use, stream alteration, riparian condition, and known permitted discharges. The disturbance index scores can range from 1, representing completely altered and heavily stressed streams, to 81, representing nearly pristine watersheds. The HDS is described by MPCA (2014e) (see section 3.3.1.1, Table 7). Alabama DEM developed a similar index (see section 3.3.1.1, Table 8).

5.2.3 Using Statistical Approaches to Combine Stressor Indicators

In the U.S. Great Lakes coastal region, principal components analysis (PCA) was used by a team of researchers and investigators participating in the Great Lakes Environmental Indicators (GLEI) Project[24] (Niemi et al. 2007) to reduce over 200 variables into a single gradient, applying measures of anthropogenic pressures as surrogate measures of stressors (Danz et al. 2005). The Danz approach individually considered six different indicators of pressure: agriculture, atmospheric deposition, land cover, human population, point sources, and shoreline alteration. The GLEI team used a watershed-based approach to reflect the premise that the environmental effects of these activities in coastal watersheds can influence environmental conditions in downstream coastal ecosystems. The first principal component from the analysis explained 73% of the variance in the agricultural-chemical (Ag-Chem) variables (reflecting land use, agricultural chemical use, and agricultural-influenced nutrient and

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[24] http://glei.nrri.umn.edu/default/default.htm. Accessed February 2016.

sediment loading) and was interpreted as an overall gradient in stressors across the basin (Figure 27). Environmental effects such as changes in water quality, fish assemblage metrics, and bird abundances were strongly correlated with scores of this stressor gradient, providing verification that the statistically extracted PCA was biologically meaningful (see description of this project by Niemi et al. 2007). The GLEI researchers created a flow diagram (Figure 28) that details their steps for quantifying a stressor gradient (modified from Danz et al. 2005).

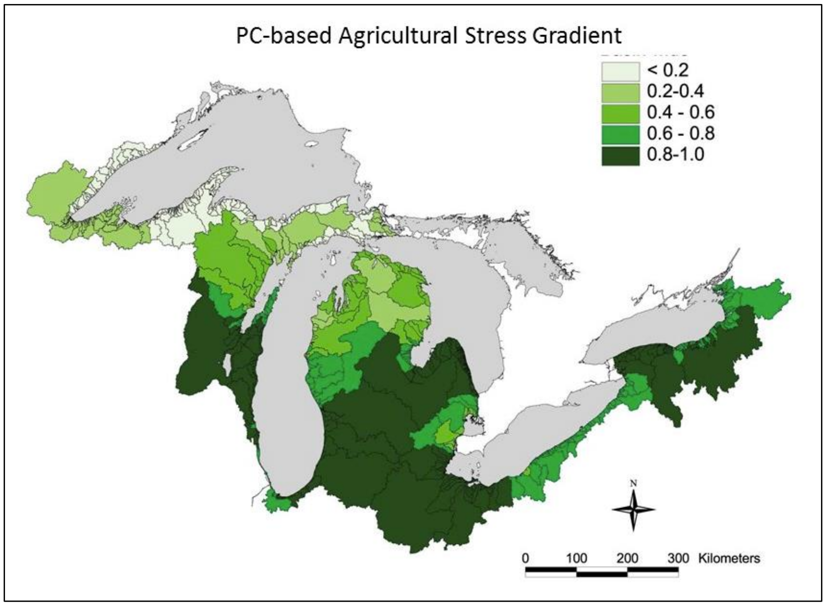

Figure 27. The first principal component of the agricultural variables for the U.S. Great Lakes basin. Darker shading indicates greater amounts of agriculture (Source: Danz et al. 2005).

While the pressure-stressor model eventually developed for the Great Lakes coastal region was visualized as a single gradient from low to high levels of stressors, different individual and combinations of stressors are expected to dominate in different regions. Furthermore, disaggregating the PCA into individual categories of stress could provide important information about potential mechanisms affecting the state of the system.

In addition to PCA, there are other statistical approaches to consider. For example, the use of non-metric multidimensional scaling (NMDS) provides a robust analysis. Unlike PCA, NMDS can deal with non-normal data, data of varying scales, and outliers in the data. Like PCA, NMDS is a multivariate statistical analysis that one can use to look at multiple stressors at the same time to create the GSA.

Biological data can also be used to statistically combine stressor indicators into a GSA. For example, Wang et al. (2008) used Canonical Correspondence Analysis (CCA) to derive the relationship among the biota and stressor and land use data and weight their disturbance index. They then plotted the calculated disturbance index against fish IBI scores and percentages of intolerant individuals, dividing the disturbance index values into five tiers. The first tier was the maximum disturbance index value at which the fish measures did not show an obvious decline. The remaining four tiers were determined by dividing the remainder of the disturbance index values into even categories. Use of biological data ensures that the stressor indicators will be biologically relevant. However, this approach can introduce some circularity into the analysis if the indicators of biological quality are the same as those used to develop the BCG.

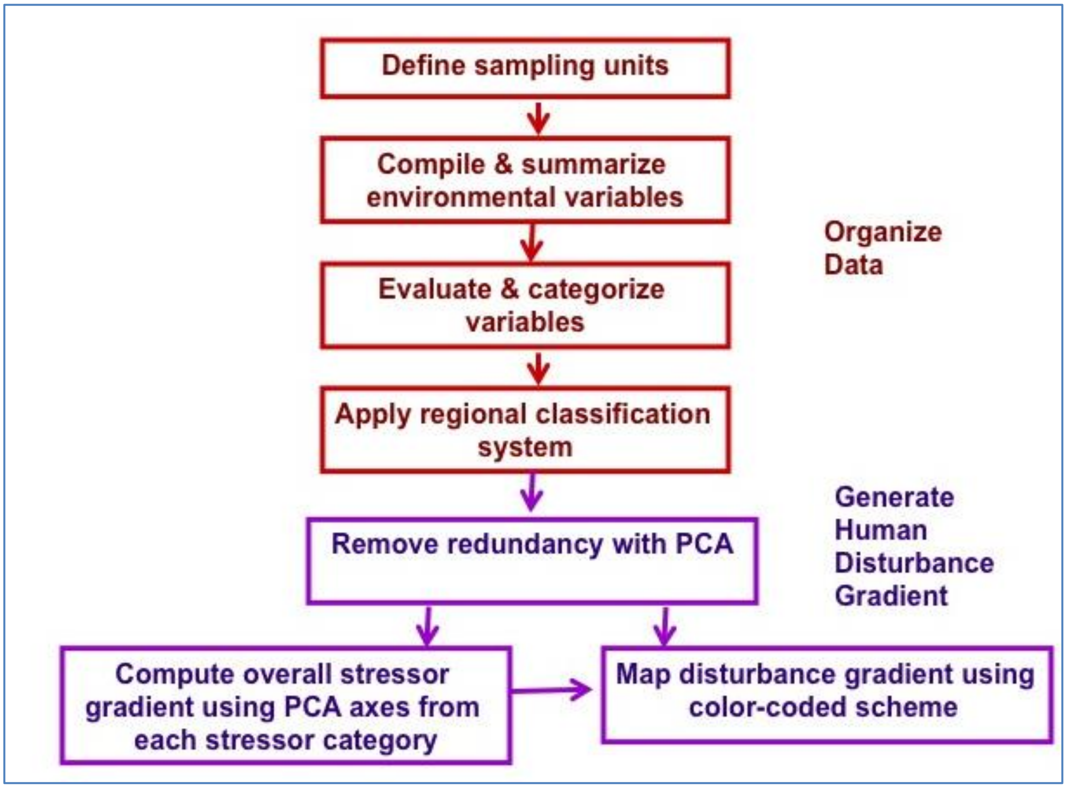

Figure 28. Flow diagram detailing the steps used by GLEI researchers in quantifying their stressor gradient (modified from Danz et al. 2005).

Stressor gradients like that developed by GLEI, or others as referenced above, can be developed at different spatial scales. The GLEI study assessed 5,971 watersheds comprising the Great Lakes basin. Watershed sizes (areas) were lognormally distributed, with a median watershed area of 4.3 km^2 and a mean watershed size of approximately 86.7 km^2 (Ciborowski et al. 2011). However, the gradient can be applied and scaled as needed to other geospatial units. For example, Nieber et al. (2013) conducted this same analysis for watersheds of the north shore of Lake Superior, and Bartsch et al. (2015) scaled their analysis to watersheds of the St. Louis River estuary to assess relationships between stressors and water chemistry.

5.3 Linking the Science with Management Actions

A quantitative BCG model provides a framework for assessing baseline biological condition and, with systematic monitoring, can be used to track changes in biological condition. Ideally, a well-defined GSA and the stressor effects and biotic response models underlying it can be used in conjunction with causal assessments to better link biologically-defined management goals to the actions taken to protect or restore the biological conditions.

A stressor can be traced back to its source or tracked forward to the biological effect via a causal pathway (Figure 29). For example, stream banks that become destabilized due to removal of riparian plants could be the source of excess fine sediment to a stream. Erosion by high flows is the mechanism by which the excess fine sediments are generated, and the resulting in-stream siltation is the stressor. Smothering of bottom substrate habitat and organism gills by these fine sediments are two mechanisms by which biota are exposed and adversely affected. Invertebrate mortality and fish emigration could be some of the environmental outcomes or changes in biotic condition. Further, degradation or loss of recreational fishing could be societal impact of these changes and may prompt a conservation or restoration effort depending upon the circumstances.

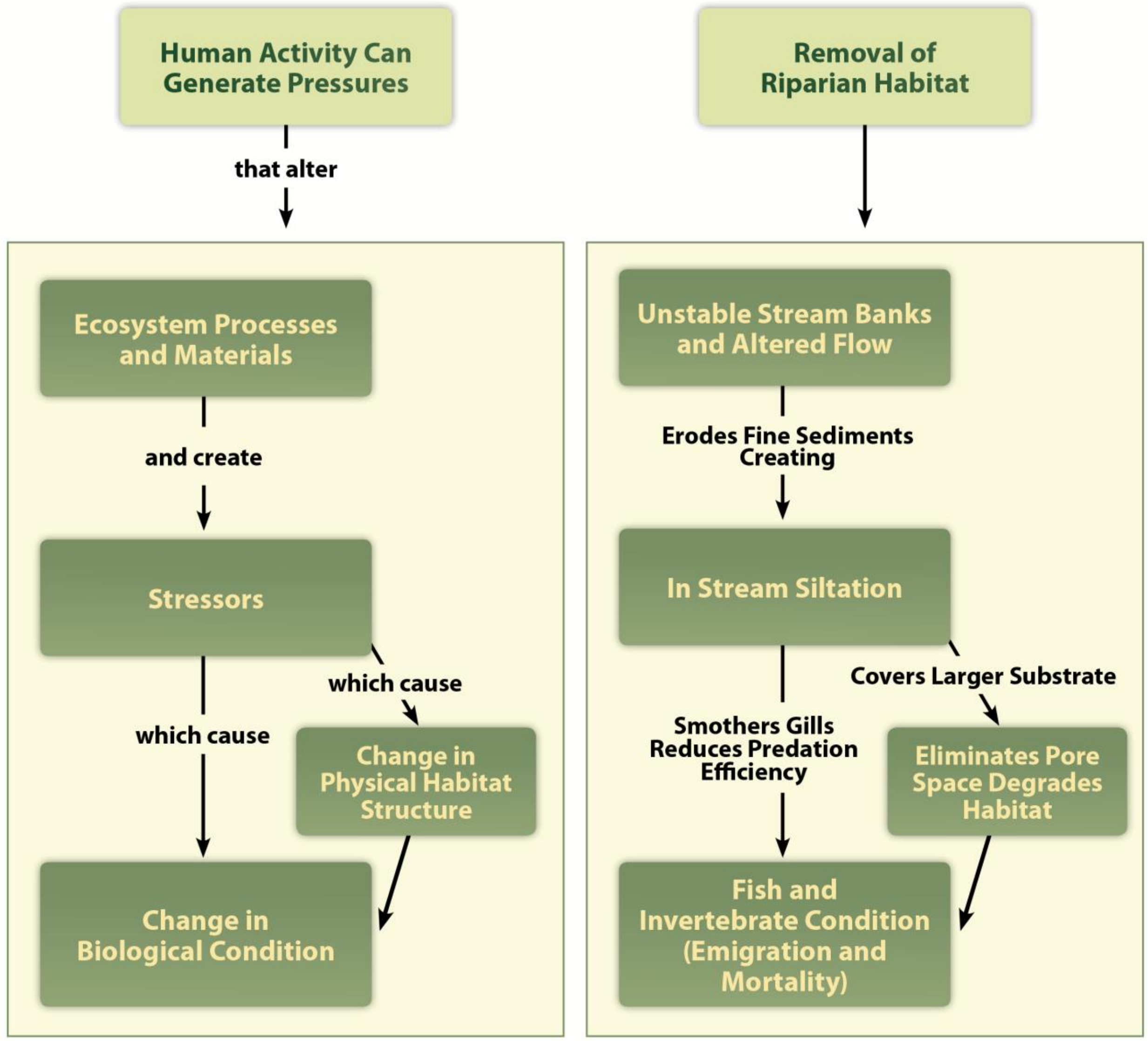

Figure 29. The specific stressor(s) and their intensity (the BCG x-axis—termed the GSA) are created by pressure(s) acting through specific mechanisms. BMPs can be implemented to prevent or reduce effect on the biota through restoration, remediation, and/or mitigation.

Actions can be taken that insulate the aquatic biota from the effects of anthropogenic pressures, helping to maintain or restore the ecological potential of an aquatic system. In the example above, re-establishing the riparian zone would stabilize the banks and prevent further erosion and unchecked flow into the stream. Appendix A-4 and MPCA (2015) provide examples of pressures linked to mechanisms and potential management actions that can mitigate the effect on biota.

Mechanistic processes operate between pressures and stressors and between stressors and their effects on biological condition (Figure 30; Appendices A-3 and A-4). Understanding these mechanisms and how they operate helps in predicting the potential effects of a particular management action. The BCG provides a framework for tracking and documenting incremental improvements in biological conditions resulting from implementation of a single BMP or combination of BMPs.

Integrating monitoring programs with frameworks like the BCG can improve understanding of how human activities, stressors, biological responses, and management actions are linked, providing feedback to guide management decisions. For example, Yoder et al. (2005) reviewed changes to fish assemblages over 25 years based on an intensive pollution survey designed to assess non-wadeable rivers in Ohio. They used the linkages between changes in point source pollution loadings, improvements in instream water quality, and reductions in the extent and severity of biological impairments to document the effectiveness of advanced wastewater treatment on a statewide scale beginning in the late 1970s. At that time the documented improvements in biological condition across all rivers and streams were almost solely in response to water quality-based NPDES permitting for point sources. Rivers predominantly impacted by nonpoint sources showed improvement over a longer timeframe where there was a concerted effort to apply BMPs over a wide enough region. Miltner (2015) was able to document widespread improvements in stream biota and water quality in smaller headwater streams in Ohio. Both of these studies were based on the state's routine biological monitoring and assessment of rivers and streams.

A well-defined GSA, and the underlying data set, can serve as a nexus between biological and causal assessments and provide a link between management goals and selection of management actions for protection or restoration. The basis of the BCG framework is that greater pressures can generate increased levels of stressors, and in turn, increased stressors are associated with reduced biological condition (Figure 30A and B). Typically, the stressors on aquatic systems increase as pressures increase, which results in a consequent decrease in biological condition. Effective management practices can target any point in the web of causal events, mitigating the effects of pressures and reducing stressors with resulting protection or improvement in biological condition (Figure 30C and D).

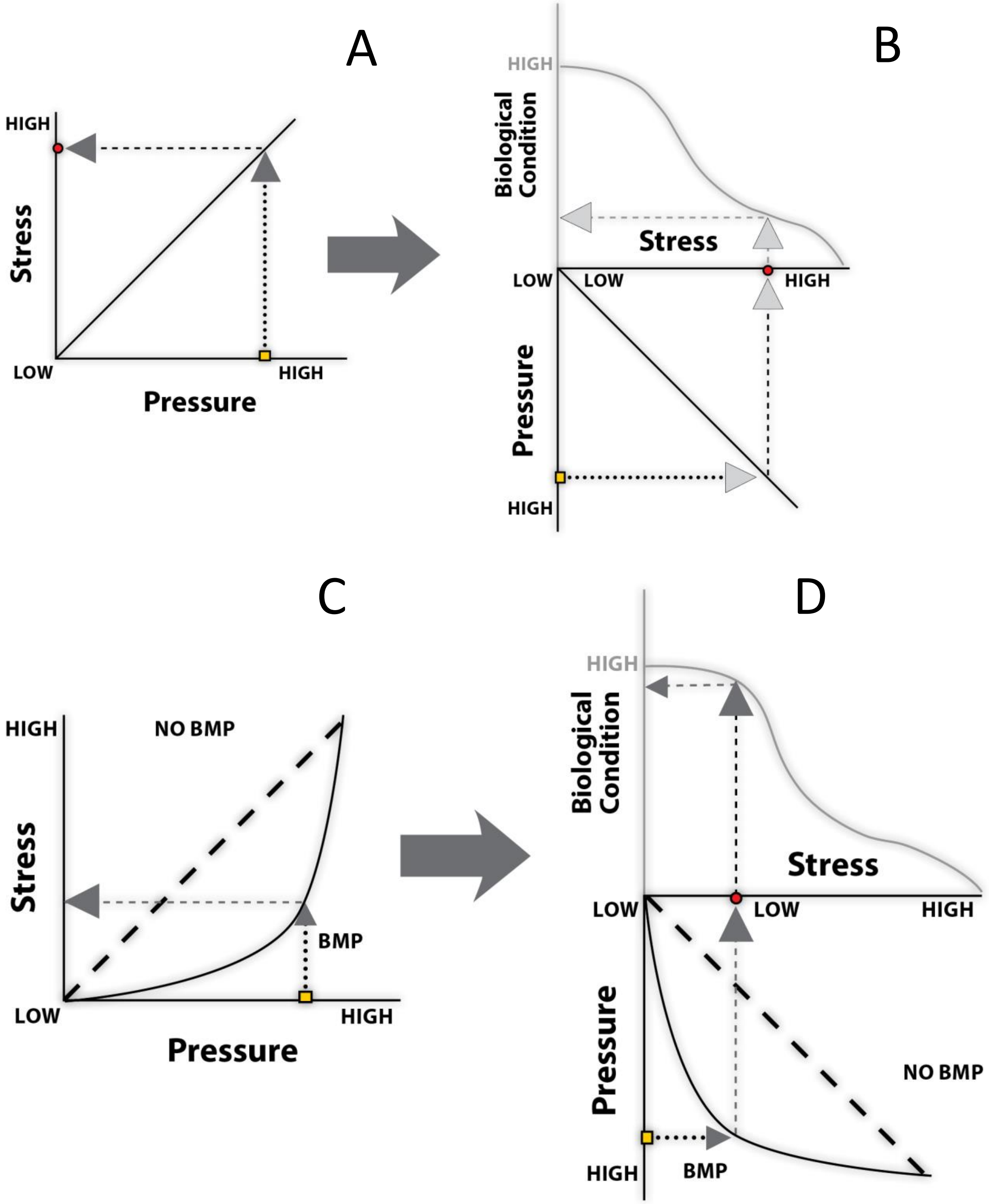

Figure 30. Conceptual Models (CM) A-B: Human activities can generate pressures, ultimately producing stressors (BCG x-axis) that adversely affect the aquatic biota (BCG y-axis). CM C-D: Implementation of a BMP can dampen the translation of pressures into the expression of stress and reduce the adverse effects on the biota (Source: Modified from figure courtesy of Jan Ciborowski, University of Windsor).

5.4 Conclusions

Anthropogenic activities exert *pressures* on aquatic systems by altering ecosystem processes and materials and generating stressors that adversely impact biological condition. Many of these stressors co-occur in time and space, and effects on the biota are cumulative. The relationships between stressors and effects are complicated—stressors may affect more than one aspect of biological condition, and a particular change in biological condition can also be the result of multiple stressors acting simultaneously.

The conceptual GSA describes the range of anthropogenic stress experienced by aquatic biota in a particular geographic area. Once quantified, it is used in the development of the decision rules to assign sites to BCG levels (Chapter 3, section 3.3.1) and ensures that the BCG encompasses the full range of condition along a stress gradient. There is much complexity of interactions and effects from multiple stressors with varying effects on different biotic components of any aquatic system. The GSA represents the sum total of stressors and their sources in concept, but in implementation it is composed of multiple known, quantitative stress gradients that each represent a portion of the actual stress gradient to which the aquatic biota are exposed. The usefulness of the conceptual framework is to provide a template for as thorough and comprehensive a technical approach as possible to develop the BCG x-axis and relate level of stress to the BCG levels and attributes.

Additionally, developing a GSA that reflects the human activities and stressors in a particular geographical area helps in understanding how specific stressors are generated and how they affect biotic condition. The data generated in developing a GSA can be used to help identify and rank sources and their stresses in a particular area and inform management decisions on appropriate actions to protect or improve a water body. The case examples discussed in this chapter and in Chapter 3 illustrate how state and local governments have quantified a GSA as part of developing a BCG model for their specific region or watershed area. As further experience is gained and approaches to define and quantify the GSA evolve, EPA may supplement this document with additional information.

Chapter 6. Case Studies

The BCG can provide critical information to state water quality management programs at the watershed, statewide, and ecoregional scales. A comprehensive monitoring and assessment program is a critical aspect of implementation of the BCG to support water quality management programs. The same data and information that provide baseline condition assessments over time also can provide information to inform trend assessments and track incremental changes in condition. In conjunction with monitoring data, a BCG can be used to help address watershed-specific management needs such as detailed biological descriptions of designated ALUs, identification of high quality waters and impaired waters, and documentation of incremental improvements due to controls and BMPs. This information can also inform TMDL development. This chapter presents six case examples of how states, counties, or municipalities are using, or considering using, the BCG to support water quality management decision making.

The six case examples are:

- 6.1 Montgomery County, Maryland: Using the Biological Condition Gradient to Communicate with the Public and Inform Management Decisions
- 6.2 Pennsylvania: Using Complementary Methods to Assess Biological Condition of Streams
- 6.3 Alabama: Using the Biological Condition Gradient to Communicate with the Public and Inform Management Decisions
- 6.4 Minnesota: More Precisely Defining Aquatic Life Uses and Developing Biological Criteria
- 6.5 Maine: Development of Condition Classes and Biological Criteria to Support Water Quality Management Decision Making
- 6.6 Ohio: Tiered Aquatic Life Use Classes and Comprehensive Water Quality Management Program Support

6.1 Montgomery County, Maryland: Using the Biological Condition Gradient to Communicate with the Public and Inform Management Decisions

6.1.1 Key Message

Montgomery County helped to develop a BCG to better inform the public and county decision makers about a high quality watershed (e.g., undisturbed/minimally disturbed conditions) and the potential outcome of planned development. Local government decision makers were able to understand how these high quality streams compared to other streams in Montgomery County and Maryland. Development plans were modified to protect the streams and watershed and reduce environmental impacts, while allowing development to proceed.

6.1.2 Background: Early County Policy

In 1994, the Maryland-National Capital Park and Planning Commission (M-NCPPC) adopted the *Clarksburg Master Plan & Hyattstown Special Study Area*. The Plan established goals for development of Clarksburg, Maryland, at that time a mostly undeveloped area along a six to eight lane highway corridor outside the Washington, DC metropolitan area. The Plan's goals included development of the town with emphasis on maintaining farmland and open space and promotion of transit-oriented neighborhoods (M-NCPPC 1994). One critical objective of the plan was the protection of environmental resources while accommodating development, such as affording special protection to high quality stream systems, including tributaries to the streams and associated wetlands. The plan specified that development occur in four phases, with requirements that must be met in order for development to proceed from one phase to the next. This staging allowed for consideration of new data and information on the impacts of development on streams and rivers, as well as improvements in mitigation technology and changes in county, state, or federal policies or regulations that might affect implementation of the 1994 plan. For example, in 2008, the County revised the 1994 plan to meet the newly adopted state law requiring the use of Environmental Site Design (ESD) practices to minimize stormwater runoff throughout the county.

Figure 31. Ten Mile Creek, Maryland.

Development in one of the high quality areas slated for development, Ten Mile Creek (TMC) (Figure 31), was afforded special protection under the Master Plan. TMC, a subwatershed[25] of the Little Seneca Creek watershed, was assigned to stage four to ensure that the 1994 development plan could be reviewed and potentially adjusted based on relevant new data and information. This case example shows how the BCG was used to provide information on current conditions in TMC relative to other county subwatersheds and streams in *excellent*, *good*, *fair*,

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[25] A subwatershed is the topographic perimeter of a stream catchment.

or *poor* condition. Information from the BCG was used in conjunction with other data to help inform the County Council in its deliberation on whether or not to adjust the stage four development plan.

6.1.2.1 Ten Mile Creek Subwatershed, Stream, and Tributaries

The TMC subwatershed, stream, and tributaries comprise a headwater stream system in which the majority of tributaries are small and spring fed. Abundant springs and seeps supply cold and clean water that supports a diverse community of fish, benthic macroinvertebrates, and amphibians (Boucher, personal communication, 2014) (Figure 32). The area is highly forested with a low level of impervious surface, < 1% to 3%. TMC is one of three reference watersheds remaining in the county and has supported *good* to *excellent* conditions based on a long term county data set using IBIs for benthic macroinvertebrates and for fish that were developed by the county (MCDEP 2012). TMC and its tributaries are adjacent to both Little Bennett Creek, a natural resource conservation management area, and to the county's agricultural reserve. The location of TMC provides not only a bridge between these two protected areas, but also a cost efficient opportunity to maintain natural flows, clean water, and high biological diversity, and provide for recreational use and appreciation by the public (Figure 33).

Figure 32. Important aquatic species in Maryland's Piedmont headwater streams. Salamanders (Long-tailed, Northern Dusky, and Northern Red); fish (Potomac Sculpin, Rosyside Dace, American Eel); insects (Sweltsa, Paraleptophlebia, Ephemerella).

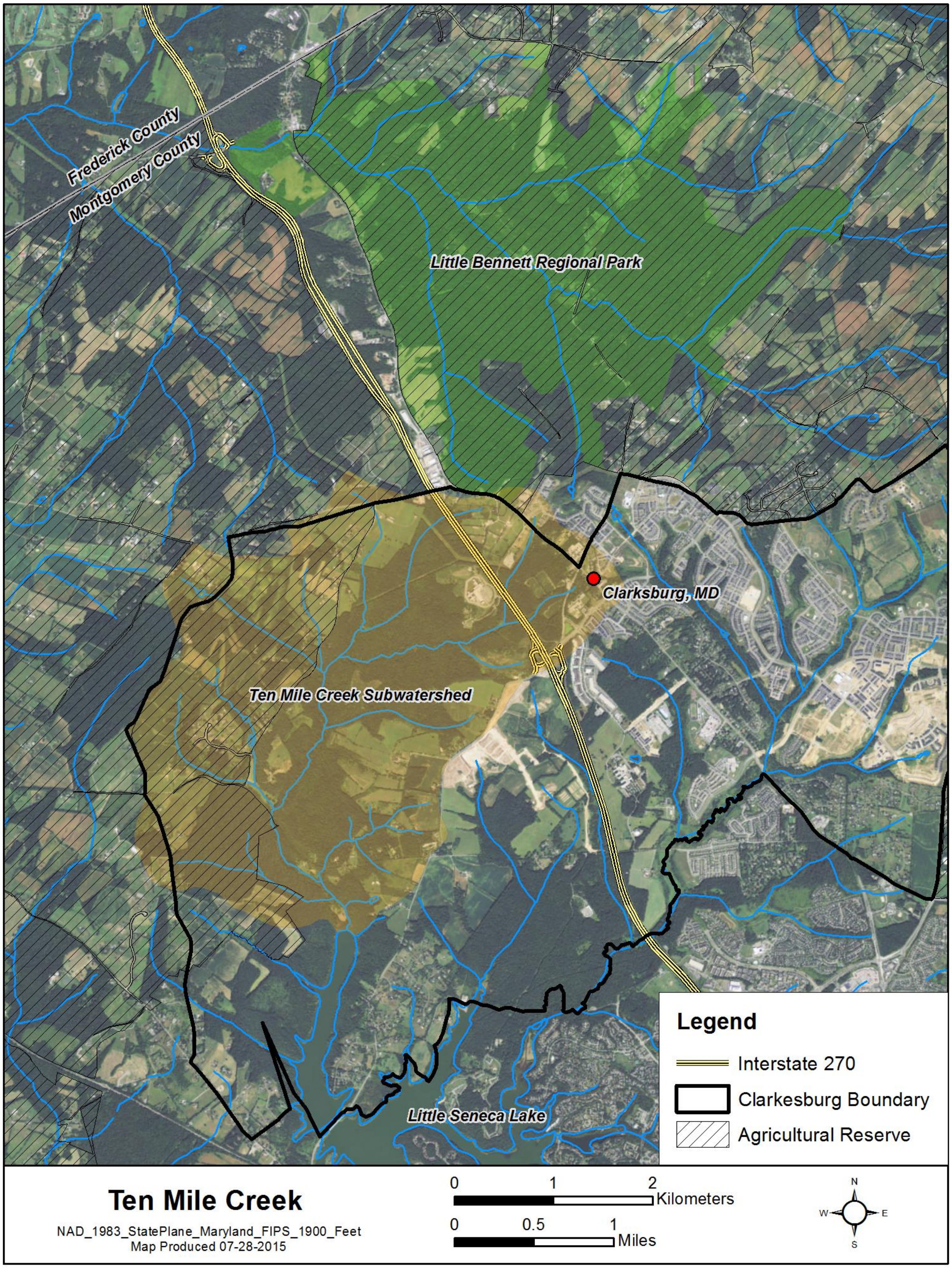

Figure 33. Clarksburg Area and Ten Mile Creek Subwatershed.

6.1.2.2 Monitoring the Impacts of Development

Beginning in 1994, the Montgomery County Department of Environmental Protection (MCDEP) monitored conditions throughout the Clarksburg development area as construction progressed. Analysis included evaluating the effectiveness of BMPs and regulations to minimize both the immediate impacts from construction and the longer term impacts from the subsequent development. Annual monitoring reports were published beginning in 2001 (e.g., MCDEP 2009, 2012). Initial monitoring found stream conditions in the Clarksburg development area ranged from *good* to *excellent* in most sensitive, high quality areas such as the TMC subwatershed. However, by the mid-2000s, the water quality at several good quality streams in the urbanizing areas began to degrade from *good* to *fair* (MCDEP 2009, M-NCPPC 2014a). In October 2012, the Montgomery County Council directed the County Planning Board to undertake a limited amendment of the 1994 Clarksburg Master Plan. Monitoring of earlier Clarksburg developments showed uncertainty about the ability to protect the sensitive environmental resources found in the stage four development area, such as TMC subwatershed, if full development were to occur according to the original 1994 plan.

A number of scientific analyses informed the development of the *Ten Mile Creek Area Limited Amendment to the Clarksburg Master Plan and Hyattstown Special Study Area*. County staff sought to use their extensive monitoring data to further characterize the watershed and to identify analytical ways to present information on the environmental status of County waters. Specifically, staff wanted to assess the current conditions in those waters and the expected changes that would occur in relation to further development in the area. In an effort to further characterize and assess incremental changes in local biological conditions, in 2013 the County embarked on the process of developing a BCG model for the Piedmont region of Maryland using both county and state data for fish and benthic macroinvertebrate assemblages (USEPA 2013b). Observations on the presence of salamanders were also incorporated where data were available. The presence of stream salamander species such as the northern dusky salamander, long tailed salamander, northern two-lined salamander, and the northern red salamander aided in confirming the high quality of streams.

6.1.3 Development of the Biological Condition Gradient

The County saw the BCG as one way to provide more detailed information on streams and their response to land use change. In 2013, scientists from agencies within the state, Delaware, Pennsylvania, Virginia, EPA, consulting groups, and academia convened as an expert panel to develop a BCG for the Northern Piedmont. The goal of this effort was to use data collected primarily from Montgomery County to develop a BCG model to describe changes in the biota in response to increasing stress in the landscape. For example, a BCG level 2 stream would be minimally disturbed and include the presence of native top predator fish (e.g., brook trout) as well as mayflies, stoneflies, and caddisflies. A BCG level 3 or 4 stream would include incrementally higher loss of sensitive species and an increased abundance of tolerant species (e.g., blacknose dace and northern two-lined salamander). A BCG level 5–6 stream would show an abundance of highly tolerant species (e.g., brown bullhead, tubificid and naidid worms).

Experts at the workshop were able to distinguish five distinct levels of biological condition for the Piedmont region within Montgomery County (BCG levels 2–6). There were no BCG level 1 sites. Most TMC sites ranged from a level 3+ to a level 4, although several sites (e.g., primarily headwater streams) were judged as very good quality (a level 2 rating). Narrative and numeric decision rules to consistently describe and quantify site assessments were developed based on mathematical set theory using the fuzzy logic method (Table 28, Table 29, Table 30) and taxa response relationships derived from the county data sets (Figure 34).

Table 28. Description of fish, salamander, and macroinvertebrate assemblages in each assessed BCG level. Definitions are modified after Davies and Jackson (2006).

BCG level 1	**Definition:** Natural or native condition—*native structural, functional and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability*
	Narrative from expert panel: There are no BCG level 1 sites within the Piedmont. All sites have some degree of disturbance, including legacy effects from agriculture and forestry from 100 to 200 years ago. Conceptually, BCG level 1 sites would have strictly native taxa for all assemblages evaluated (fish, salamander, benthic macroinvertebrates), some endemic species, and evidence of connectivity in the form of migratory fish.
	Fish: Examples of endemic species that might be present (depending on the size of the stream) include: Bridle Shiner, Brook Trout, Chesapeake Logperch, Maryland Darter, Trout Perch
	Macroinvertebrates: Sensitive-rare, coldwater indicator taxa such as the mayfly Epeorus, and stoneflies Sweltsa and Talloperla are expected to be present
BCG level 2	**Definition:** Minimal changes in structure of the biotic community and minimal changes in ecosystem function—*virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*
	Narrative from expert panel: Overall taxa richness and density is as naturally occurs (watershed size is a consideration). These sites have excellent water quality and support habitat critical for native taxa. They have many highly sensitive taxa and relatively high richness and abundance of intermediate sensitive-ubiquitous taxa. Many of these taxa are characterized by having limited dispersal capabilities or are habitat specialists. If tolerant taxa are present, they occur in low numbers. There is connectivity between the mainstem, associated wetlands and headwater streams.
	Fish: Highly sensitive (attribute II) and intermediate sensitive (attribute III) taxa such as yellow perch, northern hog sucker, margined mad tom, fallfish and fantail darter are present, as are native top predators (e.g., brook trout). Migratory fish and amphibians (e.g., eel, lamprey, salamanders) are present or known to access the site. Long-tailed and Dusky salamanders are also good indicators, given a complimentary fish community. Non-native taxa such as brown trout or rainbow trout, are absent or, if they occur, their presence does not displace native trout or alter structure and function.
	Macroinvertebrates: Highly sensitive taxa are present—especially coldwater indicator mayflies, stoneflies, and caddisflies (e.g., Epeorus, Paraleptophlebia, Sweltsa, Tallaperla, and Wormaldia)—and occur in higher abundances than in BCG level 3 samples.

BCG level 3	**Definition:** Evident changes in structure of the biotic community and minimal changes in ecosystem function—*Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*
	Narrative from expert panel: Generally considered to be in good condition. Similar to BCG level 2 assemblage except the proportion of total richness represented by rare, specialist and vulnerable taxa is reduced. Intermediate sensitive-ubiquitous taxa have relatively high richness and abundance. Taxa with intermediate tolerance may increase but generally comprise less than half total richness and abundance. Tolerant taxa are somewhat more common but still have low abundance. Taxa with slightly broader temperature or sediment tolerance may be favored.
	Fish: Intermediate sensitive (attribute III) taxa such as fallfish and fantail darter are common or abundant. Taxa of intermediate tolerance (attribute IV) such as channel catfish, least brook lamprey, pumpkinseed and tessellated darter are present in greater numbers than in BCG level 2 samples. Some tolerant (attribute V) taxa such as mummichog and white suckers may be present, but highly tolerant taxa are absent. Pioneering species such as blacknose dace, creek chubs and white suckers may be naturally common in smaller streams. Migratory species such as American Eel may be absent. Two-lined salamanders may occur.
	Macroinvertebrates: Similar to BCG level 2 assemblage except sensitive taxa (e.g., Sweltsa, Tallaperla and Wormaldia) occur in lower numbers. Level 3 indicator taxa include the caddisfly Diplectrona, the mayfly Ephemerella and the stonefly Amphinemura.
BCG level 4	**Definition:** Moderate changes in structure of the biotic community and minimal changes in ecosystem function—*Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*
	Narrative from expert panel: Sensitive species and individuals are still present but in reduced numbers (e.g., approximately 10%–30% of the community rather than 50% found in level 3 streams). The persistence of some sensitive species indicates that the original ecosystem function is still maintained albeit at a reduced level. Densities and richness of intermediate tolerance taxa have increased compared to BCG level 3 samples.
	Fish: 2 or 3 sensitive taxa may be present but occur in very low numbers (e.g., Blue Ridge Sculpin, Fantail Darter, Potomac Sculpin, Fallfish, Rosy-side Dace, River Chub). Taxa of intermediate tolerance (attribute IV) such as tesselated darter, least brook lamprey, longnose dace are common, as well as tolerant taxa like yellow bullhead, red-breast sunfish and bluntnose minnow. Level 4 streams may harbor two to three salamander species (Dusky, Red, and Two-lined).
	Macroinvertebrates: Sensitive taxa (including EPT taxa) are present but occur in low numbers. Taxa such as Diplectrona and Dolophilodes may occur, but other key taxa such as Ephemerella and Neophylax are absent. Taxa of intermediate tolerance (e.g., Baetis, Stenonema, Caenis, Chimarra, Cheumatopsyche, Hydropsyche) occur in greater numbers. Tolerant taxa such as Chironomini and Orthocladiinae are present but do not exhibit excessive dominance.

BCG level 5	**Definition:** Major changes in structure of the biotic community and moderate changes in ecosystem function—*Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative from expert panel: Overall abundance of all taxa reduced. Sensitive species may be present but their functional role is negligible within the system. Those sensitive taxa remaining are highly ubiquitous within the region and have very good dispersal capabilities. The most abundant organisms are typically tolerant or have intermediate tolerance, and there may be relatively high diversity within the tolerant organisms. Most representatives are opportunistic or pollution tolerant species.
	Fish: Facultative species reduced or absent. Tolerant taxa like yellow bullhead, red-breast sunfish, and bluntnose minnow are common. Blacknose dace, creek chubs and white suckers may dominate. Two-lined salamanders might be the only salamander present.
	Macroinvertebrates: Highly sensitive macroinvertebrate taxa are usually absent and Chironomid midges (mostly tolerant Orthocladiinae and Chironomini) often comprised > 50% of the community in level 5 streams.
BCG level 6	**Definition:** Major changes in structure of the biotic community and moderate changes in ecosystem function—*Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative from expert panel: Heavily degraded from urbanization and/or industrialization. Can range from having no aquatic life at all or harbor a severely depauperate community composed entirely of highly tolerant or tolerant invasive species adapted to hypoxia, extreme sedimentation and temperatures, or other toxic chemical conditions.
	Fish: Fish are low in abundance or absent, represented mainly by blacknose dace, green sunfish, bluntnose minnow, or creek chub.
	Macroinvertebrates: May be dominated by tolerant non-insects (Physid snails; Planariidae; Oligochaeta; Hirudinea; etc.)

Table 29. BCG quantitative decision rules for macroinvertebrate assemblages. The numbers in parentheses represent the lower and upper bounds of the fuzzy sets.

BCG Level 2	**rule**	
# Total taxa	> 17 (13–22)	
% Attribute II taxa	≥ 8% (5–10)	
% Attribute II+III taxa	≥ 50% (45–55)	
% Attribute II individuals	≥ 3% (2–5)	
% Attribute II+III individuals	≥ 60% (55–65)	
% Attribute V individuals	≤ 15% (10–20)	
BCG Level 3	**alt 1**	**alt 2**
# Total taxa	> 17 (13–22)	
% Attribute II+III individuals	≥ 40% (35–45)	
# Attribute II taxa	—	≥ 1 (0–2)
% Attribute II+III taxa	≥ 25% (20–30)	≥ 45% (40–50)
% Attribute V individuals	≤ 40% (35–45)	≤ 50% (45–55)
% Most dominant Attribute V individual	≤ 20% (15–25)	—
BCG Level 4	**rule**	
# Total taxa	≥ 15 (10–20)	
% Attribute II+III taxa	≥ 20% (15–25)	
% Attribute II+III individuals	≥ 10% (5–15)	
% Attribute V individuals	≤ 70% (65–75)	
% Most dominant Attribute V individual	≤ 60% (55–65)	
BCG Level 5	**rule**	
# Total taxa	≥ 8 (6–10)	
% Attribute V individuals	≤ 85% (80–90)	
% Most dominant Attribute V individual	≤ 70% (65–75)	

Table 30. BCG quantitative decision rules for fish assemblages in small (0.5–1.4 mi^2), medium (1.5–7.9 mi^2) and larger streams (> 8 mi^2). The numbers in parentheses represent the lower and upper bounds of the fuzzy sets. The mid-water cyprinid taxa metric is comprised of notropis, luxilus, clinostomus, and cyprinella, minus swallowtail shiners.

BCG Level 2	Small		Medium		Large
	rule	alt rule	rule	alt rule	rule
# Attribute I taxa	> 0 (present)		> 0 (present)		–
# Attribute I+II taxa	–		≥ 2 (1–4)		≥ 4 (2–6)
# Attribute I+II+III taxa	> 1 (0–3)	–	–		–
# Sensitive salamander taxa (if surveyed)	–	> 0	–	> 0	–
% Attribute I+II+III taxa	≥ 35% (30–40)		≥ 35% (30–40)		≥ 35% (30–40)
% Attribute I+II+III individuals	–		≥ 50% (45–55)		≥ 50% (45–55)
# Attribute VIt taxa	≤ 2 (1–3)		≤ 2 (1–3)		≤ 2 (1–3)
% Attribute VIt individuals	≤ 5% (3–7)		≤ 5% (3–7)		≤ 5% (3–7)
# Attribute X taxa	–		> 0		> 0
BCG Level 3	**Small**		**Medium**		**Large**
# Attribute I+II taxa	–		–		≥ 1 (0–2)
# Attribute I+II+III taxa	≥ 2 (0–4)		–		–
% Attribute I+II+III taxa	–		≥ 25% (20–30)		≥ 25% (20–30)
% Attribute I+II+III individuals	≥ 25% (20–30)		≥ 25% (20–30)		≥ 25% (20–30)
% Attribute V individuals	–		–		≤ 40% (35–45)
# Attribute VIt taxa	≤ 2 (1–4)		≤ 2 (1–4)		–
% Attribute VIt individuals	≤ 15% (10–20)		≤ 15% (10–20)		≤ 15% (10–20)
# Mid-water cyprinid taxa	> 0		> 1		> 1
BCG Level 4	**Small**		**Medium**		**Large**
# Attribute I+II+III taxa	> 1 (0–3)		> 1 (0–3)		> 1 (0–3)
% Attribute I+II+III individuals	≥ 5% (3–7)		≥ 10% (7–13)		≥ 10% (7–13)
% Most dominant Attribute Va or VIt individual	≤ 65% (60–70)		≤ 65% (60–70)		≤ 65% (60–70)
BCG Level 5	**Small**		**Medium**		**Large**
# Total taxa	> 4 (3–6)		> 4 (3–6)		> 4 (3–6)
# Total individuals	> 100 (90–110)		> 100 (90–110)		> 100 (90–110)
% Attribute V+VIt taxa	–		≤ 65 (60–70)		≤ 65 (60–70)
% Attribute V+VIt individuals	–		≤ 90 (85–95)		≤ 90 (85–95)

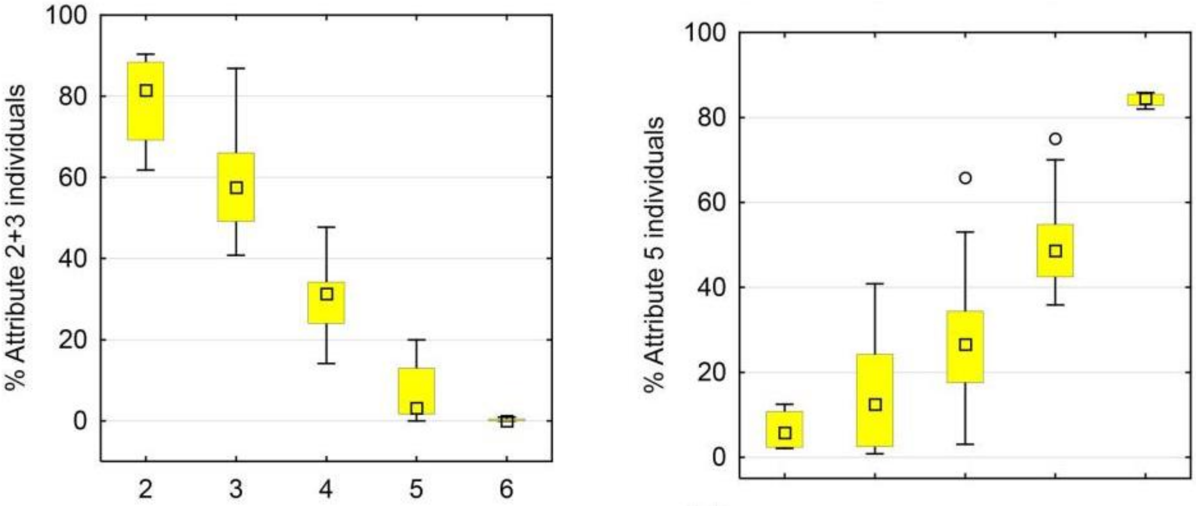

Figure 34. Box plots of sensitive (attribute II+III) and tolerant (attribute V) percent taxa and percent individual metrics for macroinvertebrate calibration samples, grouped by nominal BCG level (expert consensus) (Source: Stamp et al. 2014).

Additional expert panel findings include:

- One headwater site within the TMC watershed (King Spring) was identified as a high quality stream (BCG level 2) with taxa comparable to streams in the adjacent regional park (Little Bennett Regional Park) and with State of Maryland Sentinel Sites for the Piedmont region (Figure 35). Impervious cover for these BCG level 2 sites was at 3% or less. Three other TMC sites with impervious cover ranging between 4% and 11% were rated between BCG levels 3 and 4 (lower condition but considered comparable to "good to fair" conditions). The sites that were approaching BCG level 4 were considered by the experts as candidates for cost effective restoration.
- Sites within the TMC watershed having higher levels of impervious surface were assessed as lower quality. These more degraded sites had elevated levels of specific conductance, an indicator of urban runoff. However, tributaries in excellent to good condition, like King Spring, diluted specific conductance in the lower mainstem TMC.
- Sites within the Piedmont with levels of impervious surface typically higher than 4% showed increasingly degraded aquatic communities. Figure 36 shows average BCG level assignment for benthic macroinvertebrate sampling sites with % sensitive species plotted against % impervious surface. Increased level of impact on the aquatic biota can also be caused by confounding and synergistic effects of other stressors. Additionally, the degree of degradation can be moderated by implementing BMPs. These two considerations likely account for the observed scatter.
- Across Montgomery County both fish and benthic macroinvertebrate assemblages are assessed and may show divergent ratings of condition because of different responses to type and mechanistic pathway of stressors. In some instances, the experts assigned lower condition ratings for the fish community, because there were no or fewer than expected native species. This result was generally attributed to prevention of native fish migration due to dams and other obstacles. Additionally, there was evidence of intrusion of lake fish species from reservoirs so that lake species were dominant over the expected stream species. However, there was sufficient fish habitat and food supply (the benthic macroinvertebrates) to support re-

introduction of native species or migration of other species, such as eel. Depending upon existing temperature regimes, these sites might be excellent sites for re-introduction of native and migratory species.

The decision rules were considered by experts to be applicable to the larger Piedmont region and with minor modification to reflect climate and other latitudinal gradients, useful for assessing biological condition in Piedmont regions in Virginia, Delaware and Pennsylvania.

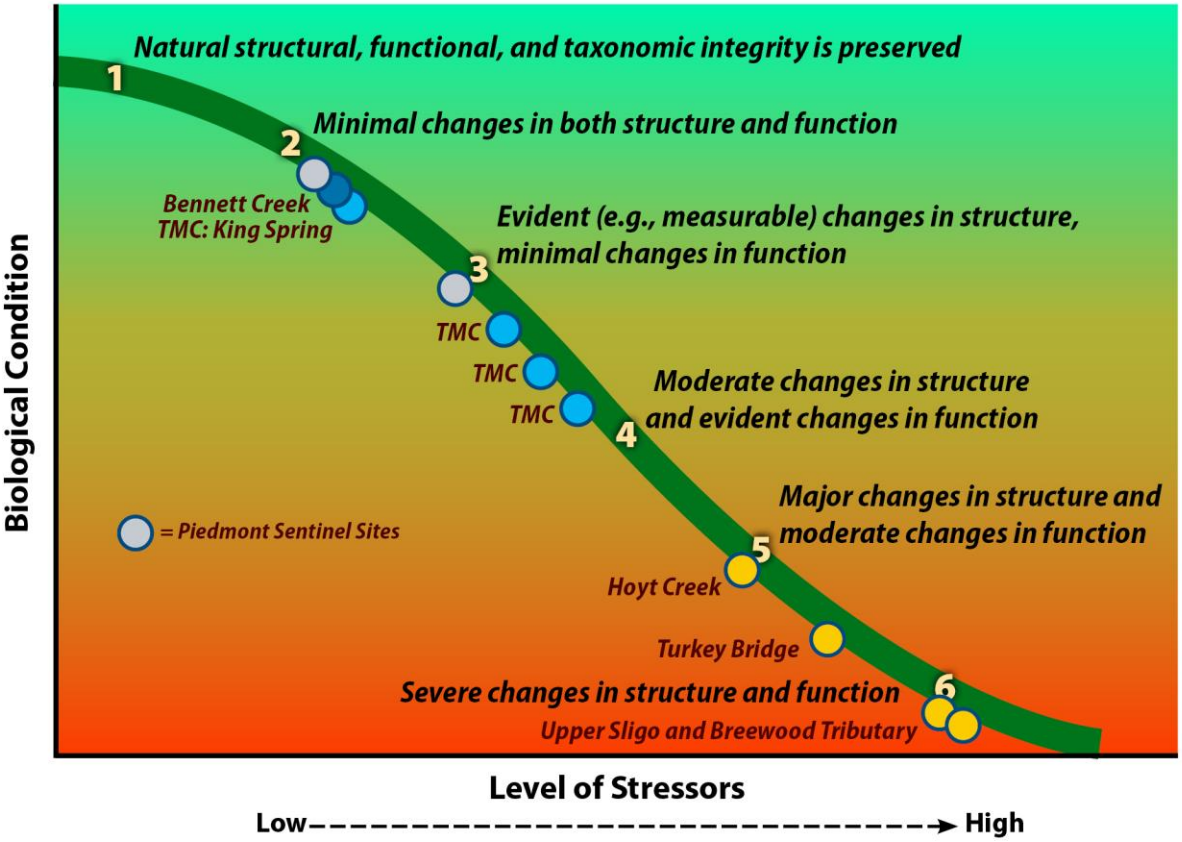

Figure 35. Comparative BCG ratings of macroinvertebrate community data from the county monitoring data set for streams in the TMC watershed and comparable county streams in other watersheds. Data from streams in the State of Maryland Piedmont Sentinel data set were also rated by the experts. The sites were mapped on the gradient according to the expert-derived decision rules for assigning sites to BCG levels.

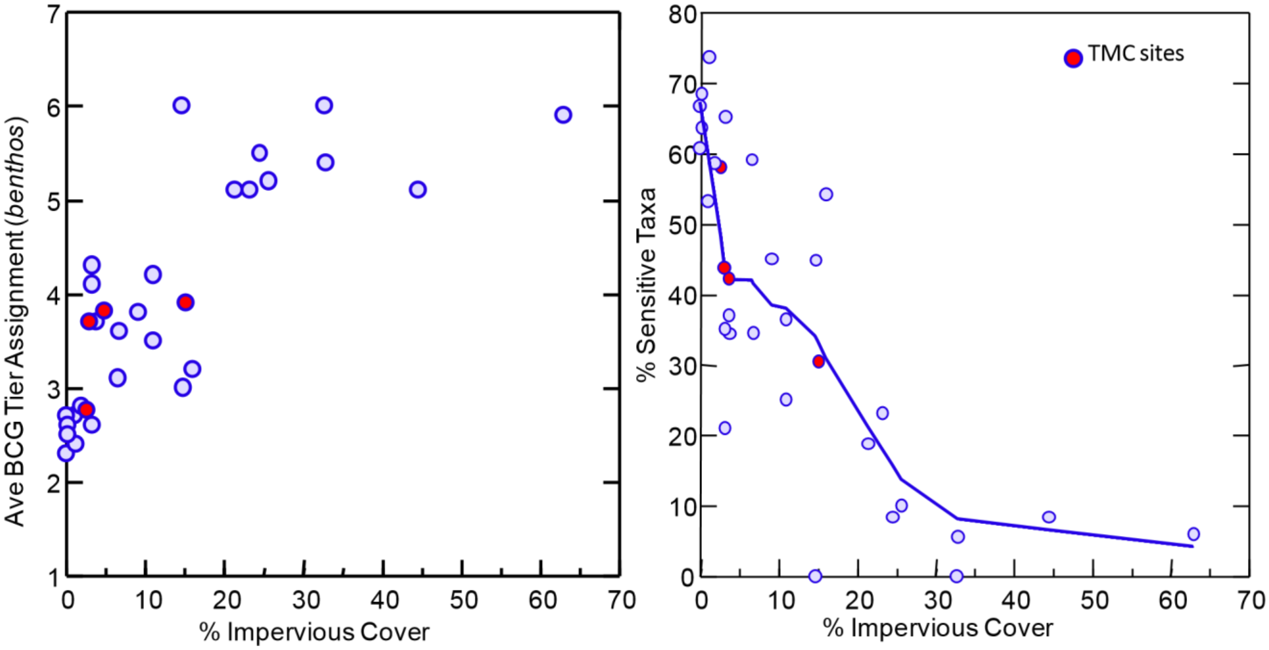

Figure 36. Relationship between average BCG level assignments (left) and % Sensitive Taxa (right) versus % impervious cover. This analysis included sites from throughout the Piedmont Region in Maryland. Ten Mile Creek sites are indicated (red dots).

6.1.4 Use of the Biological Condition Gradient Model in County Planning Decisions

Based on the findings in the environmental analyses associated with the proposed Limited Amendment, the County planning staff and MCDEP scientists concluded that there was significant uncertainty whether high quality aquatic resources assigned special protection, such as TMC subwatershed and streams, would be protected under the 1994 plan. The county planning and MCDEP staff provided several possible development scenarios with predicted outcomes and recommended one option that would modify development in the TMC area while maintaining good environmental conditions (M-NCPPC 2014b). The County Council accepted the recommended option, and it was adopted on April 1, 2014.

The BCG was used in conjunction with expert testimony, peer reviewed literature, research, modeling, and the environmental analysis to inform the County's decision to adopt the 2014 Limited Amendment for Clarksburg. This amendment revised zoning restrictions outlined in the 1994 Master Plan to reduce the impact of development on TMC. The 1994 Master Plan allowed a total impervious cap of 9.8%, while the Limited Amendment proposed a 6.3% impervious surface cap for new development in the most sensitive subwatersheds but allowed a maximum of 15% impervious cover in the Town Center District. The amendment also included a recommendation for increasing forest cover to 65% of the watershed and increasing the size of riparian buffers to better protect the streams and tributaries (M-NCPPC 2014b).

In 2014, the Montgomery County Council adopted the Limited Amendment to the 1994 Clarksburg Master Plan, which focused on TMC. The 2014 Limited Amendment concluded that TMC "warrants extraordinary protection," and offered recommendations for additional zoning restrictions that would allow for continued development, while continuing to study how development and mitigation activities (e.g., implementation of ESD) might affect sensitive water resources in the TMC watershed (M-NCPPC 2014a). The most sensitive streams or tributaries in the TMC system, such as King Spring, are currently at less than 1% impervious cover, so a cap of 6% will likely result in loss of some sensitive species and change from *excellent* to *good,* or potentially *fair*, condition depending on what other development activities occur or protective measures are put in place. For example, the amendment provides for consideration of additional measures (e.g., expanded stream buffer protections) and technology (e.g., ESD) that might minimize these changes (M-NCPPC 2014a). The use of the BCG in conjunction with other data, information, and expert testimony, successfully brought scientific information into the decision-making process and provided for informed decision making that balanced multiple public and private concerns and priorities.

6.1.5 Lessons Learned

Montgomery County found that the BCG framework was a good tool to better articulate current conditions in TMC and illustrate how water quality could be impacted by future development as outlined in the 1994 Master Plan. The 2014 Limited Amendment will allow for continued development with some restrictions on impervious cover. Because the BCG can be used in conjunction with monitoring data to detect incremental changes in stream health, county scientists will be able to closely monitor the effects of using ESD and other BMPs to mitigate the impacts of development on sensitive waters. County officials found that the BCG gave experts and the public a common understanding of water quality issues and allowed for informed policy making.

In the future, the County plans to use the BCG as an interpretative framework to examine restored sites and identify incremental improvements or declines in biological condition. Future use of this information might also include using county data for restoration modeling. In addition, the BCG might be used as one way to reconcile databases maintained at the County-level with those at the state level. Ultimately, one goal of such an effort could be to have county-level data used by the state when classifying streams.

6.2 Pennsylvania: Using Complementary Methods to Assess Biological Condition of Streams

6.2.1 Key message

Pennsylvania Department of Environmental Protection (PA DEP) implements a multi-tiered benchmark decision process for assessing attainment of ALU for wadeable, freestone, riffle-run streams in Pennsylvania. This multi-tiered approach incorporates stream size and sampling season as factors for determining ALU attainment based on benthic macroinvertebrate sampling. A BCG calibrated for freestone, riffle-run streams is used to supplement the state's primary screening tool, the IBI for benthic macroinvertebrates (PA DEP 2013a).

6.2.2 Using Index of Biological Integrity to Assess Aquatic Life Uses

PA DEP has developed a multimetric benthic macroinvertebrate IBI for the wadeable, high gradient, freestone[26] streams in Pennsylvania using the reference condition approach (PA DEP 2012). These streams are non-calcareous, or softwater, free flowing streams and comprise the majority of the state's streams. PA DEP has alternative assessment methods in place for other stream types (i.e., low-gradient pool-gliders, karst- [limestone]-dominated). The IBI provides an integrated measure of the overall condition of a benthic macroinvertebrate community in a water body by combining multiple metrics into a single index value. A number of different metric combinations were evaluated during IBI development. Based on discrimination efficiencies, correlation matrix analyses, and other index performance characteristics, PA DEP selected the following six metrics for inclusion as core metrics in the MMI (PA DEP 2012):

1. **Total Taxa Richness—**This taxonomic richness metric is a count of the total number of taxa in a subsample. Generally, this metric is expected to decrease with increasing anthropogenic stress to a stream ecosystem, reflecting loss of taxa and increasing dominance of a few pollution-tolerant taxa.
2. **Ephemeroptera + Plecoptera + Trichoptera Taxa Richness (EPT)—**This taxonomic richness metric is a count of the number of taxa belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera in a sub-sample—common names for these orders are mayflies, stoneflies, and caddisflies, respectively. The aquatic life stages of these three insect orders are generally considered sensitive to, or intolerant of, many types of pollution (Lenat and Penrose 1996), although sensitivity to different types of pollution varies among specific taxa in these insect orders. This metric is expected to decrease in value with increasing anthropogenic stress to a stream ecosystem, reflecting the loss of taxa from these largely pollution-sensitive orders.
3. **Beck's Index—**This taxonomic richness and tolerance metric is a weighted count of taxa. The name and conceptual basis of this metric are derived from the water quality work of William H. Beck in Florida (Beck 1955). This metric is expected to decrease in value with increasing anthropogenic stress to a stream ecosystem, reflecting the loss of pollution-sensitive taxa.
4. **Shannon Diversity—**This community composition metric measures taxonomic richness and evenness of individuals across taxa in a sub-sample. This metric is expected to decrease in value with increasing anthropogenic stress to a stream ecosystem, reflecting loss of pollution-sensitive

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[26] Freestone is a term familiar to fly-fisherman, denoting streams with little groundwater influence showing high annual variation in flow (spring freshet, summer drought).

taxa and increasing dominance of a few pollution-tolerant taxa. The name and conceptual basis for this metric are derived from the information theory work of Claude Elwood Shannon (Shannon 1948).

5. **Hilsenhoff Biotic Index—**This community composition and tolerance metric is calculated as an average of the number of individuals in a sub-sample, weighted by pollution tolerance values. Developed by William Hilsenhoff, the Hilsenhoff Biotic Index (Hilsenhoff 1977, 1987a, 1987b, 1988; Klemm et al. 1990) generally increases with increasing ecosystem stress, reflecting increasing dominance of pollution-tolerant organisms.
6. **Percent Sensitive Individuals—**This community composition and tolerance metric is the percentage of individuals in a sub-sample and is expected to decrease in value with increasing anthropogenic stress to a stream ecosystem, reflecting loss of pollution sensitive organisms.

PA DEP determined that these six metrics all exhibited a strong ability to distinguish between reference and stressed conditions in testing with benthic invertebrate assemblage data from riffle run habitats in wadeable, freestone streams. When used together in an MMI, these metrics provide PA DEP with a consistent and defensible index for assessing the biological condition of these streams (PA DEP 2012).

6.2.3 Use of the Biological Condition Gradient to Complement Aquatic Life Use Assessments

PA DEP is exploring use of a BCG to describe the biological characteristics of wadeable, freestone streams along a gradient of stress. More than 75% of Pennsylvania is in the hills and low mountains of the Appalachian Highlands, so streams throughout the state are predominantly relatively high gradient (> 1% slope) (Figure 37 and Figure 38). Pennsylvania is largely forested, but there are significant areas where agricultural land use, including row-crops and pasture, is dominant (Figure 39). Limestone and spring-dominated streams occur in parts of southeast, south-central and east-central Pennsylvania. The BCG assessments and model discussed in the case study do not apply to this subset of streams.

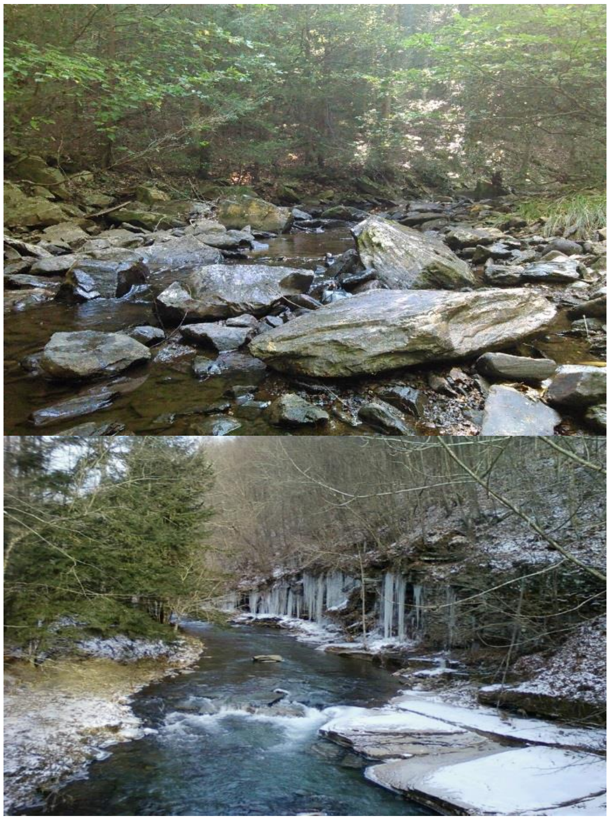

Figure 37. Top: Carbaugh Run, Adams County; Bottom: Rock Run, Lycoming County (Photos courtesy of PA DEP).

Between 2006 and 2008, PA DEP conducted a series of expert workshops to calibrate a BCG along a gradient from minimally to heavily stressed conditions (PA DEP 2013b). To develop the BCG for the wadeable, freestone streams, biologists from PA DEP, in conjunction with external taxonomic experts and scientists (e.g., the Delaware River Basin Commission, Western Pennsylvania Conservancy, and EPA), used the BCG attributes that characterize specific changes in community taxonomic composition (PA DEP 2013b). For example, in the highest levels of the BCG, locally endemic, native, and sensitive taxa are well represented, and the relative abundances of pollution-tolerant organisms are typically lower. With increasing stress, more pollution-tolerant species may be found with concurrent loss of pollution-sensitive species. At the beginning of the expert workshop, the participants assigned a BCG attribute for sensitivity to stress (i.e., attributes I–V) to each macroinvertebrate taxon based on expert knowledge and biological response data. The data used was from sampling sites that spanned a range of condition from reference quality (e.g., at or close to minimally disturbed conditions) to heavily stressed sites (PA DEP 2013b). Using the BCG level descriptions of predicted changes in the attributes as a guide, the expert panel then assigned each site to one of the six BCG levels and developed candidate decision rules (Figure 40, Table 31).

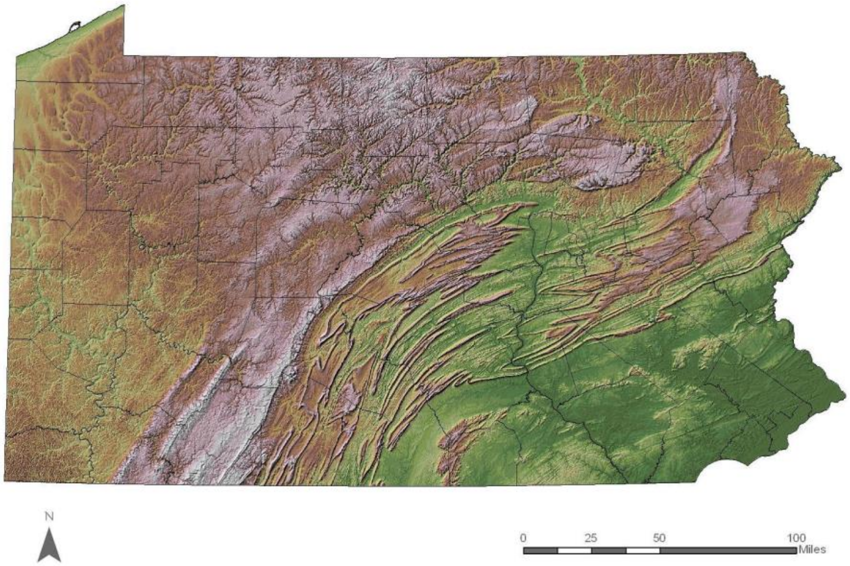

Figure 38. Topographic Map of Pennsylvania.

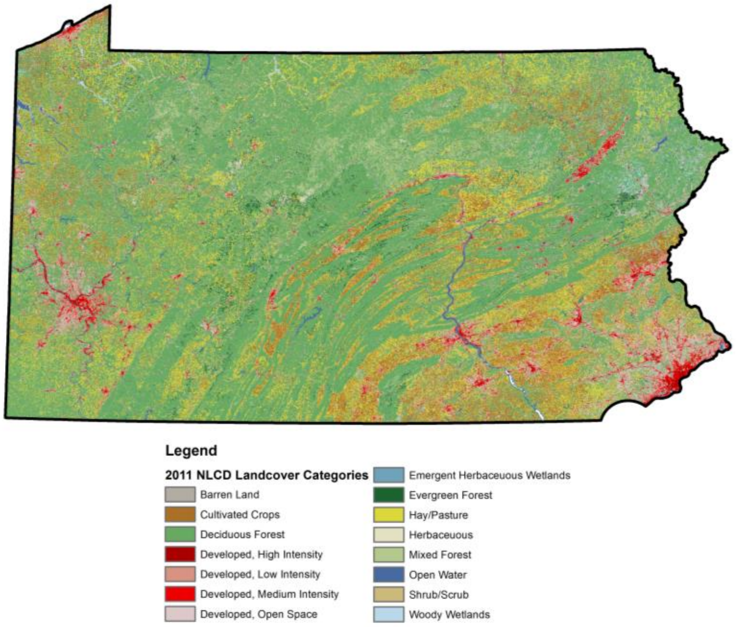

Figure 39. Pennsylvania Land Use.

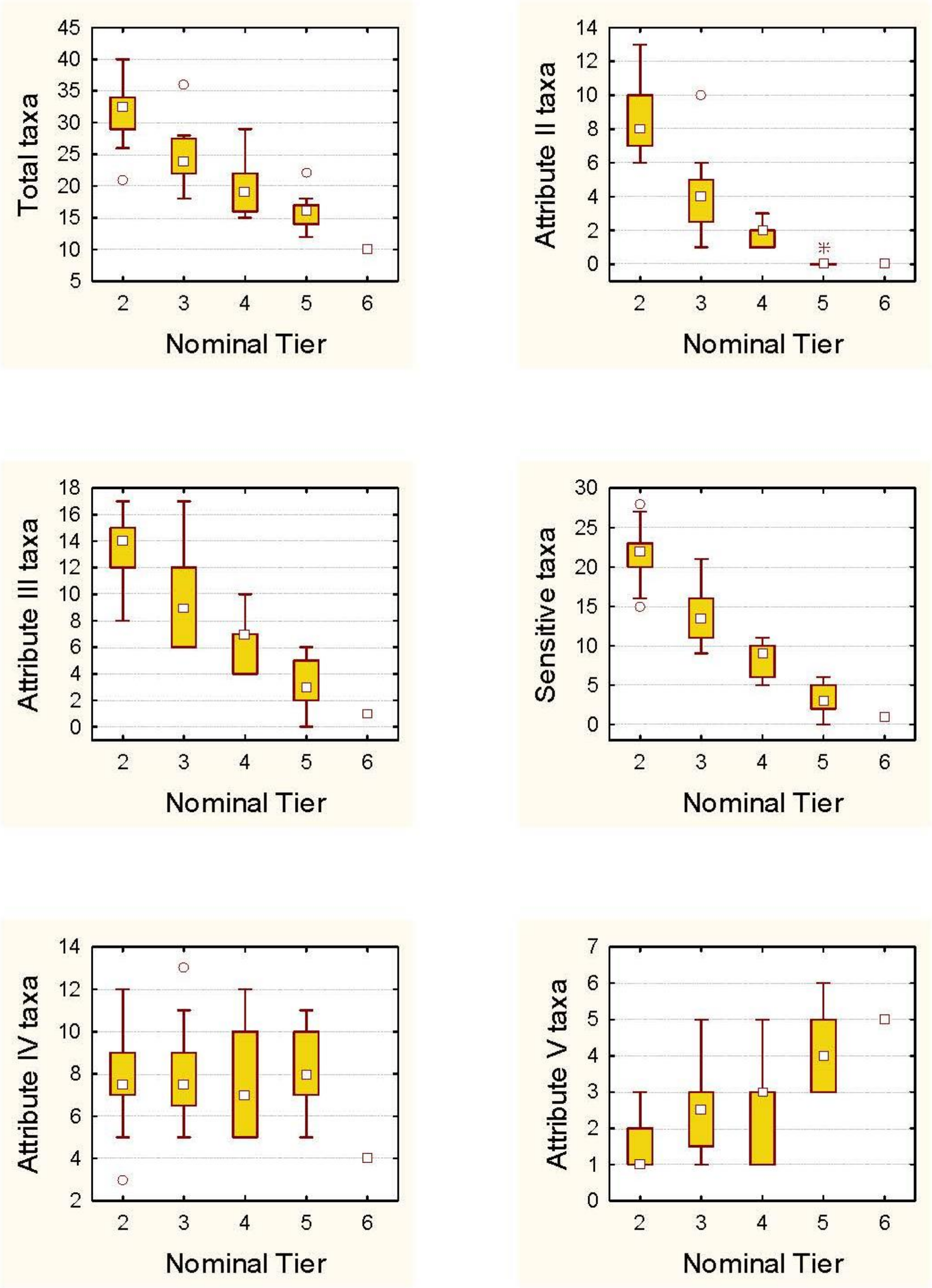

Figure 40. Box plots of BCG metrics, by nominal level (group majority choice). Sensitive taxa are the sum of both attribute II (highly sensitive) and attribute III taxa (intermediate sensitive) (Source: Gerritsen and Jessup 2007c).

Table 31. Potential narrative decision rules for invertebrate samples from Pennsylvania high gradient streams (modified from Gerritsen and Jessup 2007c)

Attributes	BCG Level				
	2	3	4	5	6
All Taxa	> 25 taxa	> 20 taxa		≥ 10 taxa No single taxon ≥ 50% of abundance ≥ 50 individuals in sample	Low richness or low abundance
I. Historically documented, sensitive, long-lived, or regionally endemic taxa	*No rules determined for attribute I*				
II. Highly sensitive taxa	Taxa II ≥ 33% of Taxa III	Taxa II present (> 0)	May be absent (no rule)		
III. Intermediate sensitive taxa	Taxa (II + III) ≥ 50% of all taxa Indiv (II + III) ≥ 50% of all indiv	Taxa (II + III) ≥ 30% of all taxa Indiv (II + III) ≥ 30% of all indiv	Taxa (II + III) present (≥ 10% of taxa, or 2 taxa) Indiv (II + III) ≥ 15%–20% of all indiv		
IV. Intermediate tolerant taxa	*No rules determined for attribute IV*				
V. Tolerant taxa	Few tolerant taxa; Tolerants are small % of total abundance (≤ 5%)	Tolerant individuals ≤ 20% of total abundance	Tolerant individuals ≤ 40% of total abundance		Tolerant individuals may dominate
Indicator taxa	Many EPT taxa; EPT ≥ 15	Tolerant Caddisflies ≤ 20% abundance EPT ≥ 12	Tolerant Caddisflies ≤ 40% abundance EPT ≥ 8	Tube worms not dominant; ≤ 50% of abundance	Mayflies may be absent; Tube worms may dominate

Each sampling site used to develop and test the BCG decision rules had corresponding IBI scores. The IBI uses metrics that are similar in objective to the BCG attributes, but which are calculated differently (PA DEP 2013a). The total IBI score is based on the sum or average of all metrics, while BCG decision rules are based on specific attribute groups and patterns of change along a gradient of stress (e.g., attributes II and III for the higher levels and attribute V for lower levels).

For all the evaluated samples, PA DEP biologists analyzed the relationship between a sample's BCG level assignment with its corresponding IBI score (PADEP 2013b). A strong correlation existed between the calibrated BCG level assignments and the IBI scores (Figure 41). On the basis of this comparative analysis, PA DEP determined that with further testing and evaluation, the IBI scores could potentially be used to discriminate BCG levels. PA DEP is evaluating using the BCG to describe the biological characteristics of streams assessed based on the IBI scores; for example, the reference sites clustered at IBI scores near 80 and above would be interpreted as primarily comparable to BCG levels 1–2. On the basis of taxonomic information, and without knowledge of the IBI scores, the experts assigned these sites to BCG levels 1.5 to 2.5. BCG level 2 represents close to natural conditions (e.g., minimal changes in structure and function relative to natural conditions; supports reproducing populations of native species of fish and benthic macroinvertebrates). This information can meaningfully convey to the public the biological characteristics of waters in the context of the CWA and the goal to protect aquatic life. PA DEP is evaluating use of the BCG to complement the IBI in assessing ALU attainment and to help identify potential high-quality (HQ) or exceptional value (EV) streams. As a first step in application of the BCG, PA DEP has incorporated BCG attributes for taxa sensitivity to stress as part of its protocol for wadeable, freestone streams (Figure 42) (PA DEP 2013a).

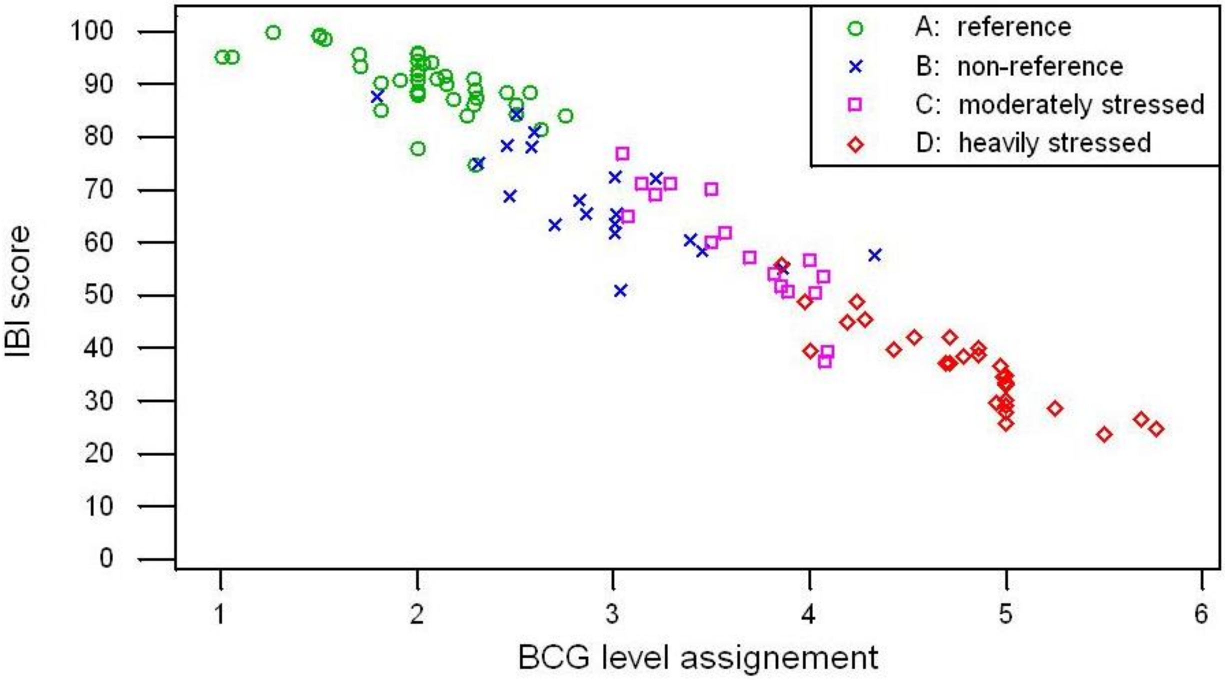

Figure 41. Comparison of calibrated BCG level assignments (mean value) and IBI scores for freestone streams representing range of conditions from minimal to severely stressed.

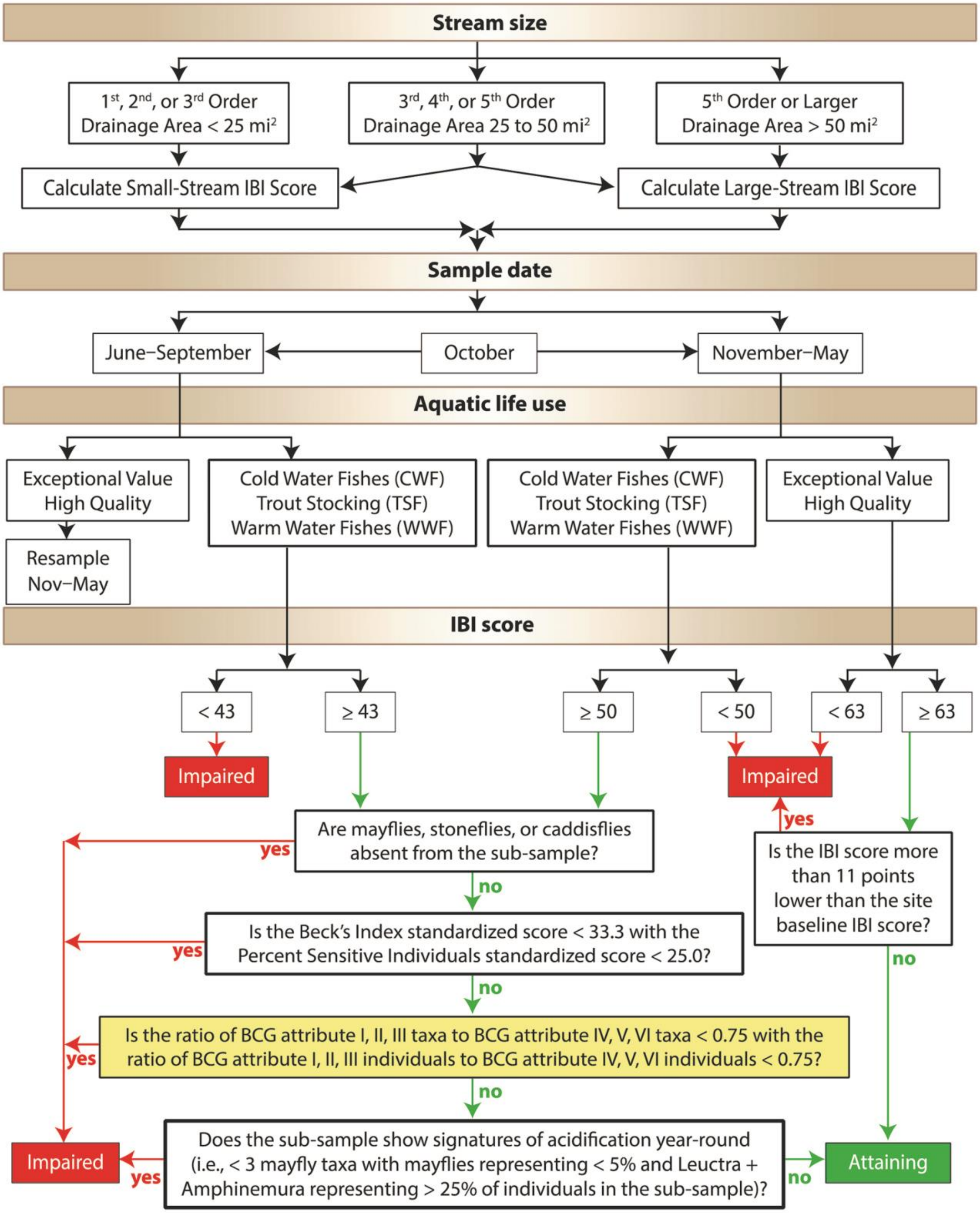

Figure 42. Multi-tiered benchmark decision process for wadeable, freestone, riffle-run streams in Pennsylvania (Modified from PA DEP 2013a). The ratio of BCG attributes for sensitive to tolerate taxa (i.e., attributes I, II, and III to attributes IV, V, and VI) are included as part of attainment determination (see yellow box). Rules have not been defined for attribute I and IV but these attributes are included in the assessment protocol if decision rules are developed in the future and determined to be appropriate to include.

6.2.4 Potential Application to Support Aquatic Life Use Assessments and Protection of High Quality Waters

Pennsylvania's regulations define waters of EV that are of unique ecological or geological significance. EV streams are given the highest level of protection and constitute a valuable subset of Pennsylvania's aquatic resources. To support protection of these waters, PA DEP is considering the use of a discriminant analysis model to evaluate the relationship between condition of the watershed, a stream, and its aquatic biota (e.g., the connection of riparian areas with a stream and the floodplain or the spatial extent of stressors and their sources in the watershed). PA DEP is evaluating the use of a discriminant model that incorporates measures of land use and physical habitat along with IBI scores and the BCG to make distinctions between EV and HQ waters. PA DEP is also evaluating how to consider effects of habitat fragmentation and spatial and temporal extent of stress. The results of this effort could potentially support state water quality management decisions on where to target resources for sustainable, cost-effective protection of EV waters and healthy watersheds. Through this work, PA DEP can provide EPA valuable feedback on the technical development and potential program application for BCG with specific focus on defining indicators for BCG attributes IX (spatial and temporal extent of detrimental effects) and X (ecosystem connectance).

6.3 Alabama: Using the Biological Condition Gradient to Communicate with the Public and Inform Management Decisions

6.3.1 Key Message

ADEM has strategically built a comprehensive biological monitoring program over the past four decades and has, more recently, invested in developing BCGs for streams in all regions of the state. ADEM has identified reference conditions in order to better characterize current water quality condition, and it has built increasing capability in terms of data management. As ADEM's capabilities have evolved, it is applying biological data, biological indices, and the BCG for a variety of management purposes, including identification of high quality waters and waters that need restoration. As part of this process, ADEM has improved its ability to communicate to the public on the condition of streams and to measure incremental improvements in condition. Though the state is developing and applying the BCG and biological assessments on a statewide basis, this case study reports on the development and application of a BCG for the high gradient streams of Northern Alabama.

6.3.2 Program Development

Since 1974, ADEM has been monitoring its surface water quality, and the capabilities of the monitoring program have evolved over time. In 1997, ADEM first formalized a coordinated monitoring strategy to outline its surface water quality monitoring efforts. Today, ADEM collects biological, chemical, and physical data and uses those data to inform management decisions, including assessing the health of state waters, determining whether those waters are meeting their designated uses, and identifying impacts from a variety of sources (ADEM 2012).

ADEM continues to build its monitoring program to meet emerging data needs, and it is currently evaluating the use of its biological data in new ways. ADEM conducted a preliminary critical elements review[27] of its biological assessment program in 2006 to assess the strengths of the technical program. The review highlighted ADEM's efforts to that point, and it included recommendations for enhancements relative to design, methodology, and execution for credible data as a basis of making informed decisions regarding the ecological condition of Alabama's streams. The review resulted in a recommendation that ADEM fully implement its monitoring strategy to accomplish a variety of goals, including more complete development of reference conditions and site criteria, and development and/or refinement of macroinvertebrate, fish, and diatom community assessment methods; ecological attributes; response patterns; and indices along a continuous BCG scale. The review also highlighted the need for an improved and enhanced database management system; improved technical capabilities to carryout survey needs; statewide completion of monitoring unit delineation; and incorporation of up-to-date land cover data sources.

Since the 2006 review, ADEM has continued to make improvements in the technical capabilities of its biological assessment program. In 2008, ADEM used data collected in 1994–2005 to develop MMIs for high and low gradient streams. The indices were used for site assessments with thresholds derived from the reference distribution. At the same time, the biological database was updated to a new platform, integrated into ADEM's centralized surface water database, Alabama Water-Quality Assessment and

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[27] For more information about Critical Element Review, see *Biological Assessment Program Review: Assessing Level of Technical Rigor to Support Water Quality Management* (USEPA 2013, http://www.epa.gov/wqc/biological-assessment-technical-assistance-documents-states-and-tribes. Accessed February 2016.)

Monitoring Data Repository (ALAWADR), which houses chemical, physical, and biological data. In 2009, the database was modified to calculate macroinvertebrate metrics and indices. Incorporating these tools into ALAWADR assisted greatly in the development and testing of ecological attributes, stress-biological response patterns, and indices along continuous BCG and stressor scales. In 2013, ADEM expanded the effort to use data from the 1994–2011 period to incorporate additional reference site data to refine the site classes, and MMIs (Jessup 2013). In these efforts, ADEM considered regional differences in biological habitat and species distribution, and it found that variability was best explained using ecoregions[28] for classification. ADEM calibrated the MMIs to categorize water quality on a scale from *Very Good* to *Very Poor* (Jessup 2013).

In a similar effort spear-headed by the Geological Survey of Alabama, ADEM and the Alabama Department of Conservation and Natural Resources collaborated to develop statewide multimetric fish community indices. In 2004, the Geological Survey of Alabama completed refinement of collection methods developed by the Tennessee Valley Authority and established five site classes, or ichthyoregions, primarily based on ecoregions and basins. Statewide MMIs were completed in 2011–2012.

6.3.3 Index Development

As a result of the work and collaboration among state agencies discussed above, ADEM developed biological indices for both macroinvertebrates and fish statewide. Assessment thresholds were established for both assemblages using similar analytical methods though there were differences in site classification and threshold delineation. First, similar regions for classification were identified for each assemblage, but they were not identical (Figure 43). For site classification, the similarity of species composition relative to ecoregions, drainage basins, and other natural site characteristics was analyzed. Shared environmental variables associated with the ecoregional distinctions for both assemblages included elevation, temperature, and percent cobble and boulder substrate. However, differences in classification for the two assemblages were attributed to the dependence on drainage continuity for fish migrations, whereas macroinvertebrates (especially insects) can move among drainages by flying during adult stages.

Second, for benthic macroinvertebrates, candidate reference sites were identified based on measurements of disturbances both at the site and in the landscape. A watershed disturbance gradient (WDG) was calculated using land use coverage (e.g., percent urban, row crop, and/or pasture in the catchment) and road density (Brown and Vivas 2005; ADEM 2005). Figure 44 shows broad land cover patterns throughout the state. The 25th percentile of the WDG was used as the threshold for selecting candidate reference streams. These reference streams experienced minimal to moderate levels of stress and are considered "least disturbed" conditions (Stoddard et al. 2006). However, for some regions, land use intensity as measured by the WDG was considerably higher and more widespread, reflecting regional patterns in agricultural and urban land use. Reference streams in the regions with more intensive development (e.g., higher WDG scores) generally had lower biological scores (e.g., benthic macroinvertebrate scores) (Table 32). Figure 45 shows the range of land intensity scores in sites assessed by ADEM, including reference sites.

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[28] Ecoregions describe areas with similar features related to geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.

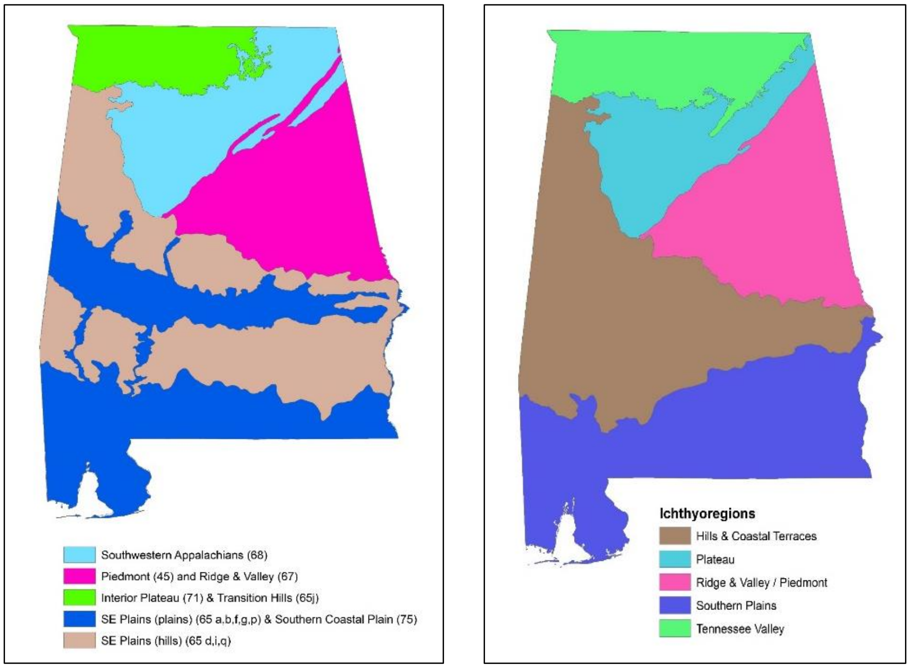

Figure 43. Left: Macroinvertebrate site classes in Alabama; Right: Fish site classes in Alabama.

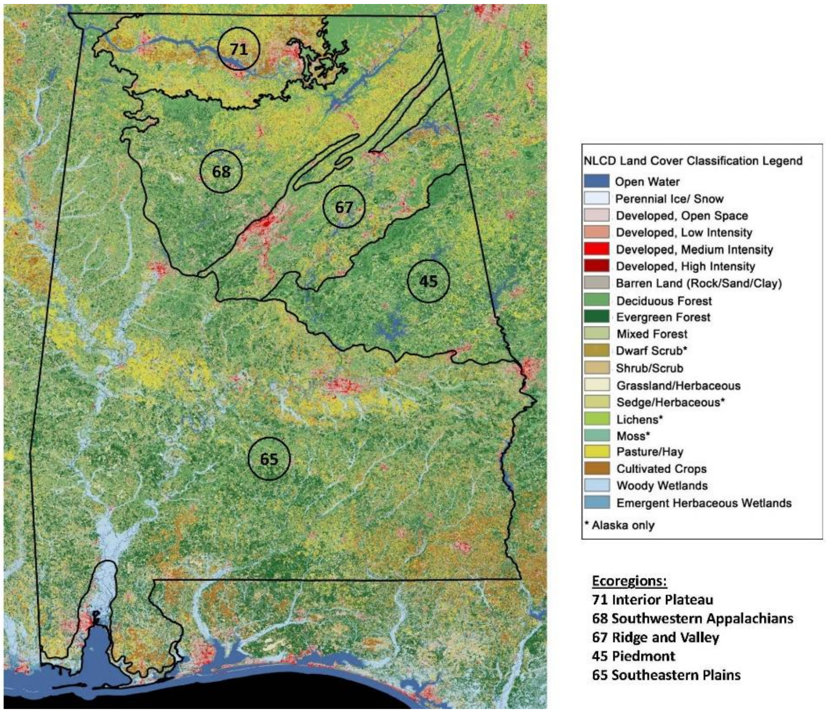

Figure 44. Alabama land use/land cover map.

Table 32. Characterization of Reference Conditions Using WDG and the Alabama Macroinvertebrate MMI for streams. WDG scores increase with level of land use activity.

Macroinvertebrate Site Class	Median Reference WDG Score	Benthic Macroinvertebrate MMI Score: 25th Quantile of Reference

Macroinvertebrate Site Class	Median Reference WDG Score	Benthic Macroinvertebrate MMI Score: 25th Quantile of Reference
Interior Plateau	61	43
Southeastern Plains–Hills	64	47
Piedmont, Ridge & Valley	46	69
Southwest Appalachians	31	58
Southeastern Plains–Plains	90	45

Additionally, there are differences in how the two assemblage indices were scored and benchmarks established. As described above, the benchmark for the macroinvertebrate index was based on a reference condition approach. Reference sites were selected based on abiotic parameters that met predetermined selection criteria and a 25% threshold was established (Table 32). However, for fish, the range of index scores from all sites was divided into five condition categories: excellent, good, fair, poor, and very poor (Figure 46). The thresholds between fish categories were selected to create a balanced distribution of conditions among the sampled sites, with most samples in the fair category, and similar numbers of excellent and good samples compared to poor and very poor samples (Figure 46; O'Neil and Shephard 2011). Thus, the reference condition for macroinvertebrates and the excellent and good categories for fish are not a one for one match. ADEM wanted to develop the BCG model and numeric decision rules so that benthic macroinvertebrate and fish assemblage data could be mapped on the BCG and interpreted against a uniform standard despite differences in sample collection and analysis.

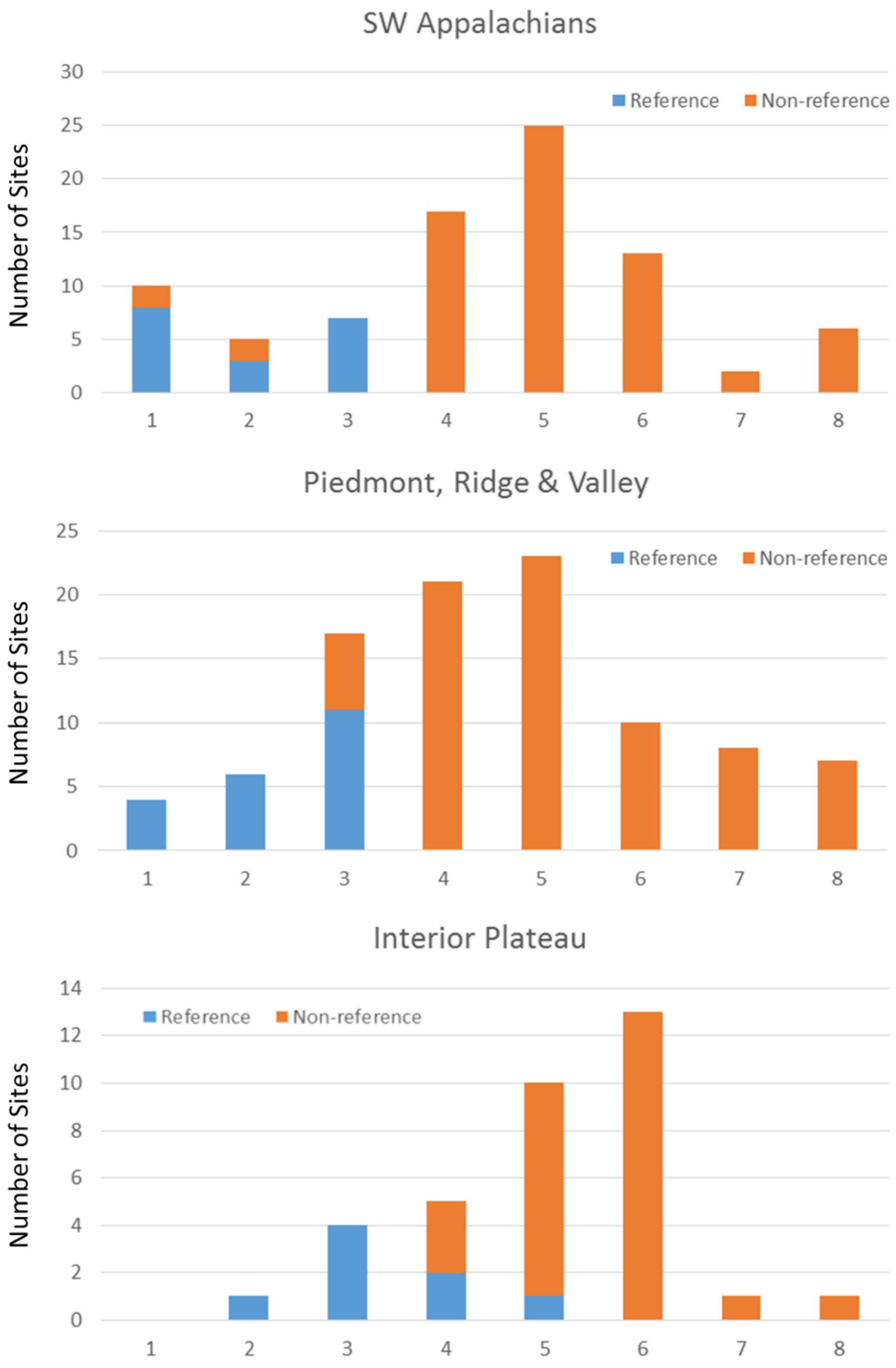

Figure 45. Frequencies of sites in ranked WDG categories (x-axis), distinguishing reference and non-reference sites in each site class. Distributions are based on sites monitored in ADEM's biological assessment program. WDG categories are numerically ranked with increased levels of stress. ADEM converted the WDG scores to ranks 1–8, with lower numbers representing less disturbance.

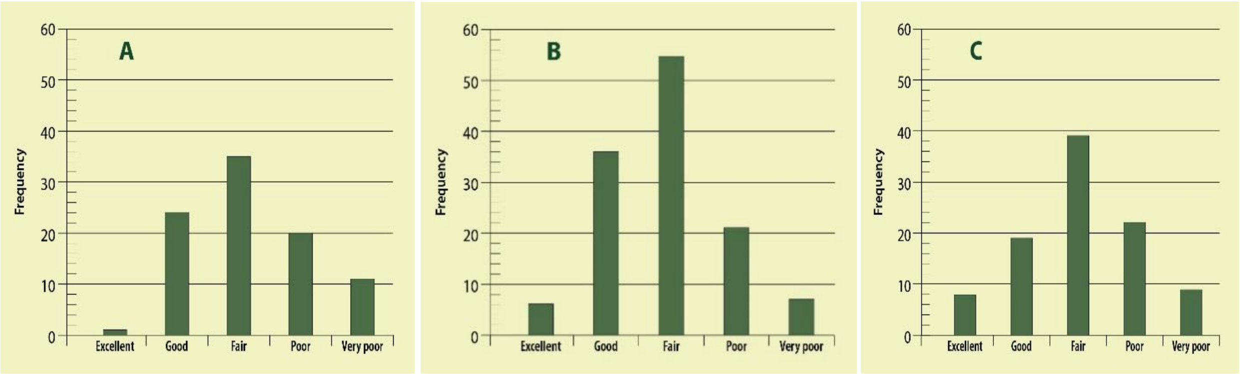

Figure 46. Frequency distribution of fish IBI condition categories for sites in the three ichthyoregions discussed in this case study: the (A) Plateau; (B) Piedmont, Ridge, and Valley; and (C) Tennessee Valley site classes. The x-axis is divided into five condition categories: excellent, good, fair, poor, and very poor.

6.3.4 The Biological Condition Gradient

In 2014, ADEM and Geological Survey of Alabama convened an expert panel of scientists from the state, outside agencies, academia, and other research organizations. The charge to the expert panel was to develop a quantitative BCG and to use the BCG to calibrate BCG-based indices for fish and macroinvertebrate assemblages for wadeable streams in Alabama. The first phase of BCG development was on wadeable streams in Northern Alabama in three ecoregions: the Interior Plateau, Southwest Appalachian, and the Piedmont Ridge Valley ecoregions. This case study reports on these results. The second phase of BCG development is underway for the coastal plain streams in central and southern Alabama.

Wadeable streams in northern Alabama are higher gradient relative to streams in the coastal plains of southern Alabama and tend to have a riffle habitat (Figure 47). Experts developed numeric decision rules to predict the BCG level of a stream based on site classes for fish and macroinvertebrates (Jessup and Gerritsen 2014). Models were then developed to replicate the expert decisions for assigning new samples to BCG levels 2–6 without having to reconvene the expert panel. There were no sites in the data set used to develop the BCG that the experts considered comparable to BCG level 1 (undisturbed), so the experts conceptually described the expected biological community for a BCG level 1. The conceptual description provided a shared, narrative starting point for assessing incremental changes from BCG level 1 to BCG level 6. The final modeled BCG levels correctly predicted the expert ratings of actual site data for BCG levels 2–6 in 94% and 96% of cases for macroinvertebrates and fish, respectively.

Figure 47. Example of range in typical northern Alabama streams with riffle-run habitat. Top: Hendriks Mill Branch; Bottom: Hatchet Creek.

As the first step in developing the BCG model for northern Alabama streams, the benthic macroinvertebrate and fish species were assigned BCG attributes corresponding to their prevalence and sensitivity to disturbance. These characteristics were analyzed using abundance of individuals and general additive models (GAMs) based on the capture probability of each taxon along the WDG scale. Experts in the workgroup used the model results and their own experience to assign attributes to each taxon. Taxa with steeply descending model slopes were sensitive to disturbance and were assigned attributes II or III (e.g., highly and intermediate pollution sensitivity) based on the slope of the response curve (e.g., capture probability) (e.g., *Acroneuria* in Figure 48). Taxa with flat slopes were found in a variety of disturbance conditions and were assigned to BCG attribute IV (taxa of intermediate tolerance). Taxa with increasing capture probabilities with increasing disturbance were assigned to BCG attribute V (tolerant taxa) (e.g., *Ferrissia* in Figure 48). In the second step of the BCG process, the experts used the attribute assignments in developing the decision rules for assigning sites to BCG levels (Table 33).

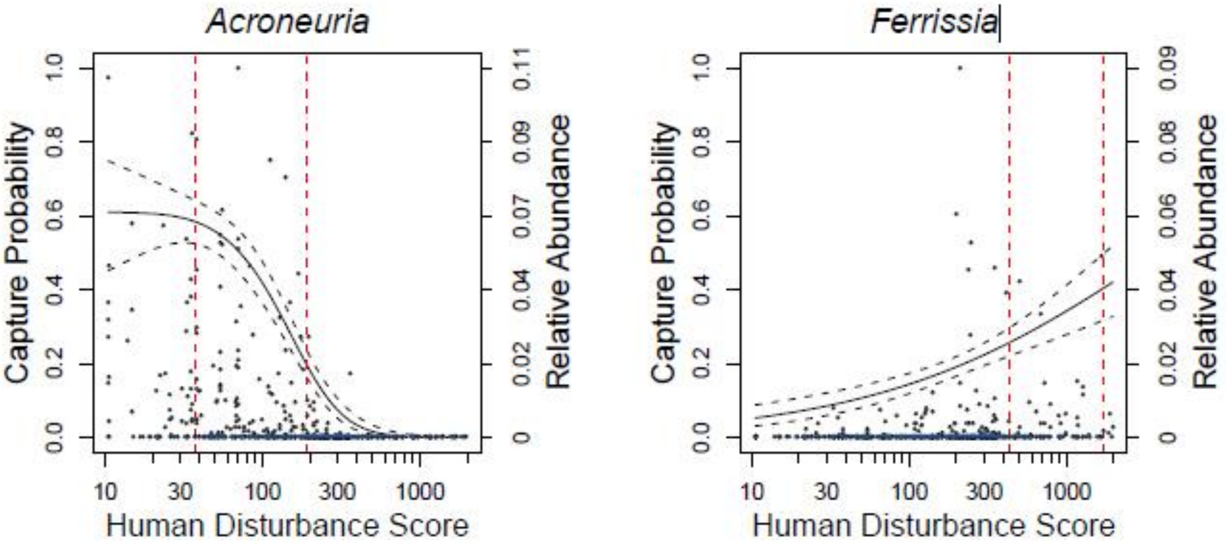

Figure 48. Taxa relative abundance and the GAM slope based on capture probabilities for *Acroneuria* (Plecoptera: Perlidae; attribute III) and *Ferrissia* (Gastropoda: Ancylidae; attribute V).

Table 33. Example of narrative and quantitative rules from Northern Alabama BCG: BCG level 2 narrative and quantitative rules for macroinvertebrates and quantitative rules for fish in northern Alabama. Macroinvertebrate rules apply in all northern Alabama streams. Fish rules are applied by site class (PLA, RVP, and TV) and stream size (Small and Large).

Narrative Macroinvertebrate Rules for BCG Level 2
The sample is considered a level 2 condition if: The number of all taxa in the sample is greater than 50–60 taxa and The number of highly sensitive (attribute II) taxa is greater than 6–10 taxa and The percentage of sensitive (attribute II+III) taxa is greater than 35%–40% of all taxa and The number of sensitive (attribute II+III) EPT taxa is greater than 10–18 taxa and The percentage of individuals in the 5 most abundant taxa is less than 60%–70% and The percentage of individuals in the most abundant 5 tolerant (attribute IV, V, VI) taxa is less than 45%–55% OR the number of all taxa in the sample is greater than 70–80 taxa. If any of these rules is not met at least half-way, the sample is level 3–6, depending on rules for those levels.

Macroinvertebrates: BCG Level 2	**Quantitative Rule**
# Total taxa	≥ 55 (50–60)
# Attribute II taxa	≥ 8 (6–10)
% Attribute II+III taxa	≥ 40% (35–45)
# Attribute II+III EPT taxa	≥ 14 (10–18)
% individuals in the most dominant 5 taxa	≤ 65% (60–70)
% individuals in the most dominant 5 tolerant taxa	≤ 50% (45–55) or Total Taxa > 75 (70–80)

Narrative Fish Rules for BCG Level 2
The sample is considered a level 2 condition if: The number of all taxa in the sample is greater than 10–25 taxa in the PLA and RVP and The number of highly sensitive (attribute I+II) taxa is greater than 0–4 taxa and The number of sensitive (attribute I+II+III) taxa is greater than 5–10 in large TV sites and The percentage of sensitive (attribute I+II+III) taxa is greater than 10%–25% and The percentage of sensitive (attribute I+II+III) individuals is greater than 5%–30% and The percentage of tolerant (attribute V+Va+VI) individuals is less than 15%–30% in the PLA and RVP and The percentage of the most abundant Va or VI individuals is less than 30%–40% in the TV. If any of these rules is not met at least half-way, the sample is level 3–6, depending on rules for those levels.

Fish: BCG Level 2	**PLA**		**RVP**		**TV**	
	Small	**Large**	**Small**	**Large**	**Small**	**Large**
# Total taxa	≥ 15 (10–20)	≥ 20 (15–25)	≥15 (10–20)	≥ 20 (15–25)	—	
# Attribute I+II taxa	> 2 (1–4)		> 0 (0–1)	> 2 (1–4)	> 1 (0–3)	≥ 2 (1–4)
# Attribute I+II+III taxa	—		—		—	> 7 (5–10)
% Attribute I+II+III taxa	≥ 20% (15–25)		≥ 15% (10–20)		≥ 20% (15–25)	
% Attribute I+II+III individuals	≥ 25% (20–30)		≥ 20% (15–25)		≥ 10% (5–15)	
% Attribute V+Va+VI individuals	≤ 25% (20–30)		≤ 20% (15–25)		—	
% Most dominant Attribute Va or VI individuals	—		—		≤ 35% (30–40)	

6.3.5 Application of the Biological Condition Gradient to Support Aquatic Life Use Assessments

Because biotic assemblages may respond to stressors differently depending on the mechanism of action, information from two or more assemblages provides more comprehensive insight into condition of the water, possible sources of stress, and potential for improvements. For example, the presence of small dams along streams and rivers alter natural flow and in stream habitat. These barriers prevent migration of some native species from rivers into streams. Likewise, presence of large reservoirs can introduce lake species into adjacent streams. Both of these impacts could result in a lower rating of biological condition using fish community data. An assessment of the benthic macroinvertebrate community of the same stream might result in a better biological condition rating if there are no additional stressors and physical habitat "as naturally occurs." This information would indicate that habitat and food source for fish exist and inform ADEM or other state agency decision makers that the stream may be a prime candidate for restocking of native species.

The BCG can be used by ADEM to characterize and communicate the biological conditions in the "least disturbed" reference reaches, aiding the interpretation of reference site quality relative to the absolute definitions of the BCG levels. "Least disturbed" reference sites are the best observable landscape and stream sites within a region. They can differ across regions of Alabama because development can be ubiquitous across entire regions of the state. The BCG can be used to interpret biological conditions in the "least disturbed" reference sites based on expert consensus in a manner that is transparent as long as expert judgment and the resulting decision rules are documented. For example, 57% and 44% of sites from ADEM's reference data set for two macroinvertebrate site classes, the Piedmont, Ridge, and Valley and the Southwest Appalachian regions, were assigned as BCG level 2 based on the benthic macroinvertebrate decision rules with the remainder of the sites primarily assigned as BCG level 3 (Figure 49). In contrast, only 13% of reference sites in the Interior Plateau were modeled as BCG level 2 and the majority of sites were assigned to BCG level 3. The differences in BCG levels among the reference sites of the three site classes illustrates how the "least disturbed" reference condition can have different biological meaning. BCG level 2 conditions support an aquatic community comparable to what would be expected under naturally occurring conditions with no or minimal anthropogenic impacts. The biological community characteristic of BCG level 3 includes loss of some native taxa and shifts in relative abundance of taxa relative to BCG level 2. Integration of the reference information and the BCG scale can be used to more clearly communicate to the public the quality of the reference condition for each region. In addition, existing indicators could be calibrated to the BCG scale to refine attainment thresholds. Despite the differences in reference site quality within the ADEM reference data set, there is a comparable relationship with the WDG in all three regions (Figure 50). The scatter observed with increasing WDG could, in part, be attributed to confounding effects and different mechanisms of action of multiple stressors as well as mitigating influence of BMPs that have been implemented.

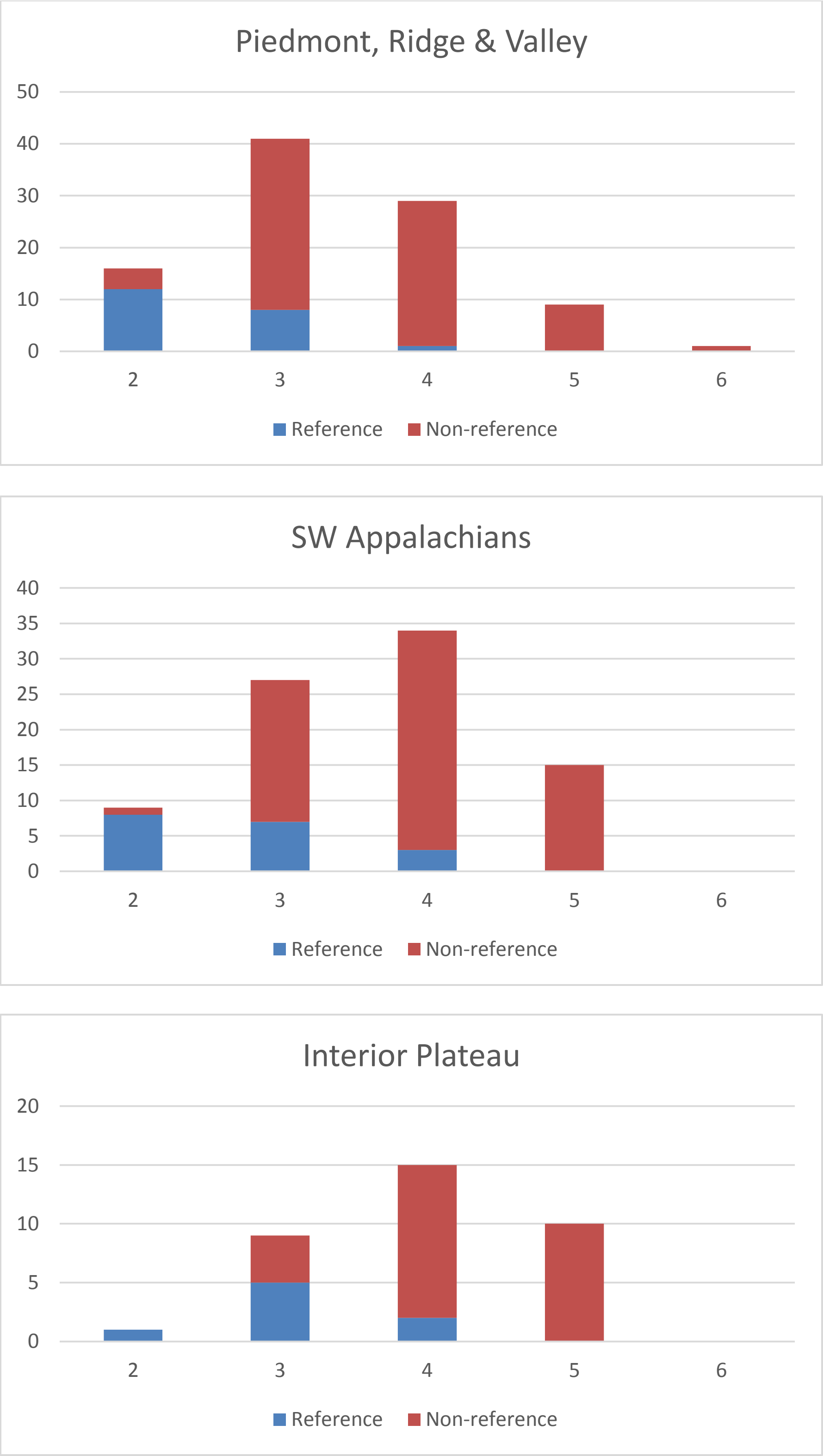

Figure 49. Frequencies of sites (y-axis) in each BCG level (x-axis) in each northern Alabama site class, showing reference sites as the blue portions of the bars. Distributions are based on sites monitored in ADEM’s biological assessment program.

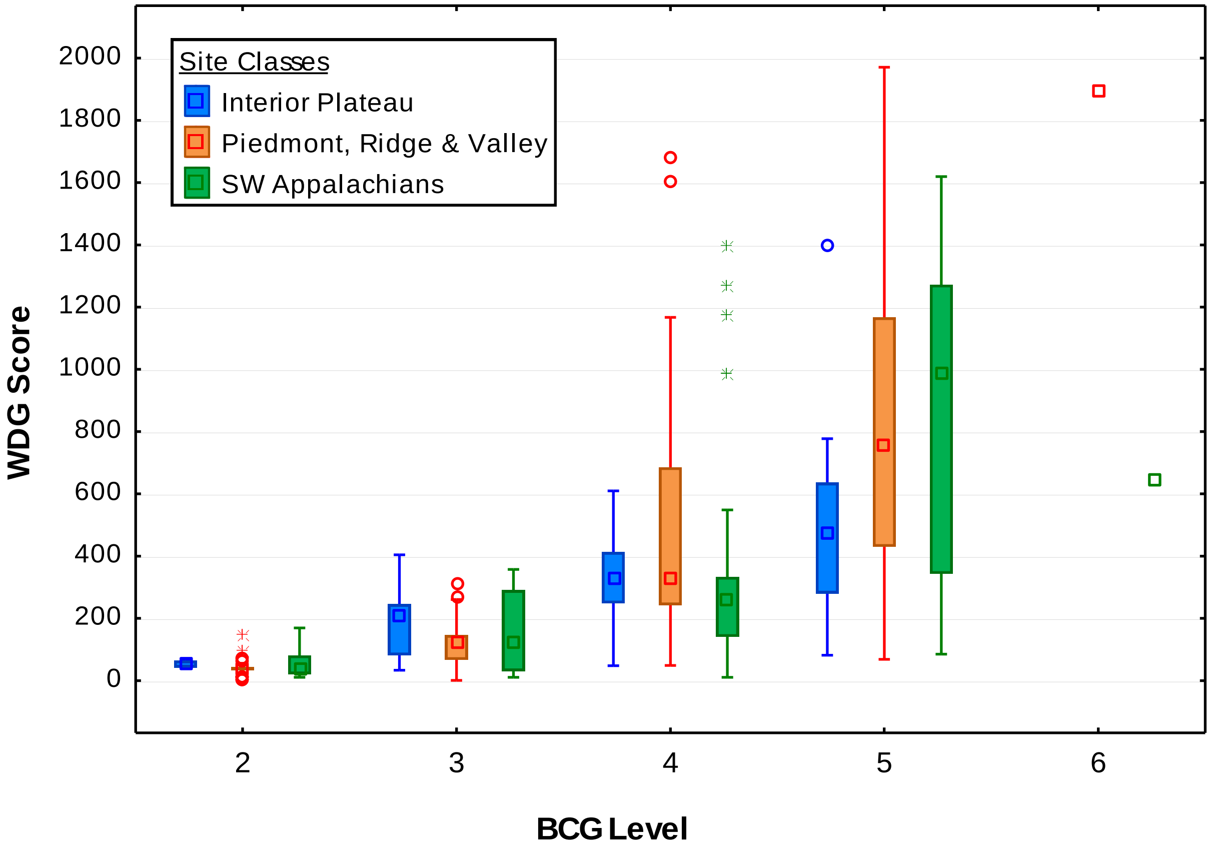

Figure 50. BCG scores and corresponding WDG scores for Northern Alabama. Distributions are based on sites monitored in ADEM's biological assessment program.

6.3.6 Future Applications

With the BCG model now available to characterize multiple levels of biological conditions, goals for protection of high quality waters and for improvements in degraded waters can be better defined. Currently, monitoring, assessment, and restoration focus on the most degraded watersheds throughout Alabama, leaving fewer resources to prevent threatened waters from degrading and becoming listed as impaired. Additionally, because success has typically been defined as a single threshold (i.e., attaining/nonattaining), incremental improvements in water quality and watershed conditions are not effectively measured and documented. Information that conditions are incrementally improving is valuable feedback to management, and stakeholders, including the public. Incremental changes can be observed with a shift in BCG levels or in index values associated with the BCG levels (Figure 51 and Figure 52).

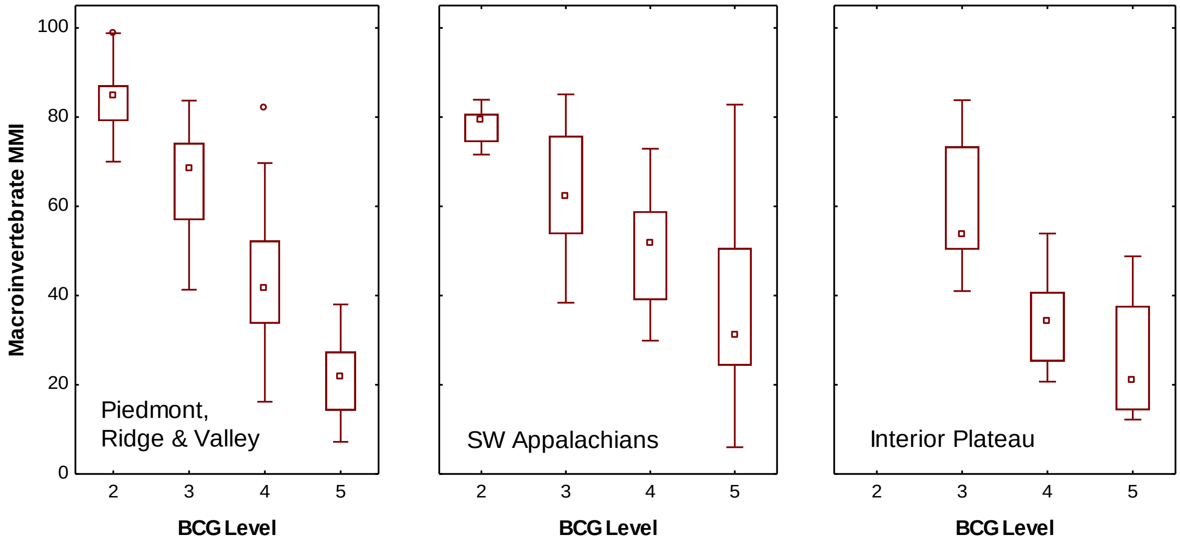

Figure 51. Alabama macroinvertebrate MMI distributions in site classes and BCG levels.

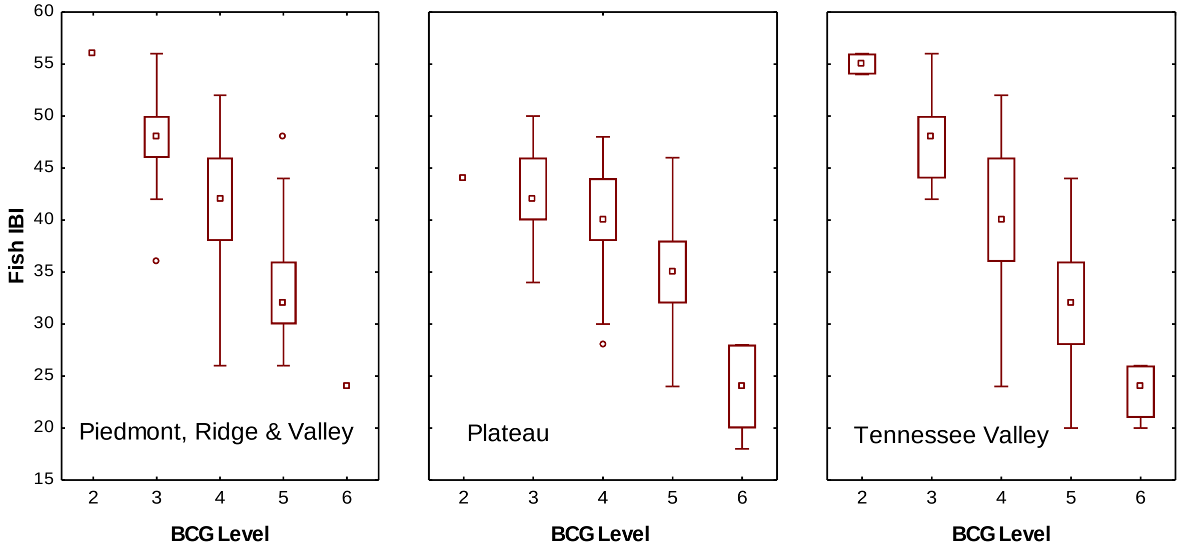

Figure 52. Alabama fish IBI distributions in site classes and BCG levels.

With the BCG, multiple condition levels can be recognized, and each can be associated with different resource status and management goals. For example, sites with BCG level 4, 5, or 6 conditions might be targeted for incremental improvements with interim milestones set based on next BCG level. Streams that score close to the next BCG level could be further prioritized for management actions. Such incremental improvements would document successful management strategies and actions and support adaptive management approaches. For sites supporting BCG level 2 conditions, the management goal might be protection so that the water body continues to support exceptional biological communities. BCG level 2 conditions could be identified using the predictive BCG models and/or the MMI and IBI scores.

As part of its Healthy Watersheds Program,[29] in 2011 EPA acknowledged the need to increase protection of U.S. waters and provided states with a framework and tools. In 2013, ADEM completed the Alabama and Mobile Bay Basin integrated assessment of watershed health (USEPA 2014b). The purpose of this project was to characterize the relative health of catchments across Alabama and the Mobile Bay Basin for the purpose of guiding future initiatives to protect healthy watersheds. The assessment synthesized disparate data sources and types to depict current landscape and aquatic ecosystem conditions throughout the Alabama/Mobile Bay Basin assessment area. The assessment included six distinct, but interrelated attributes of watersheds and the aquatic ecosystems within them, including landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition. A total of 12 indicators were used to characterize the relative health of Alabama's watersheds. By integrating information on multiple ecological attributes at several spatial and temporal scales, it provided a systems perspective on watershed health. To compare the Healthy Watersheds Index (HWI) to BCG assessments, ADEM recalculated the HWI after removing the biological components from the calculation. The comparison showed a clear association between the non-biological HWI scores and the BCG scores (Figure 53). The ranges of HWI scores in each BCG level were similar among site classes, indicating that the BCG reflects differences in watershed integrity despite differences in landscape stressor intensity among site classes.

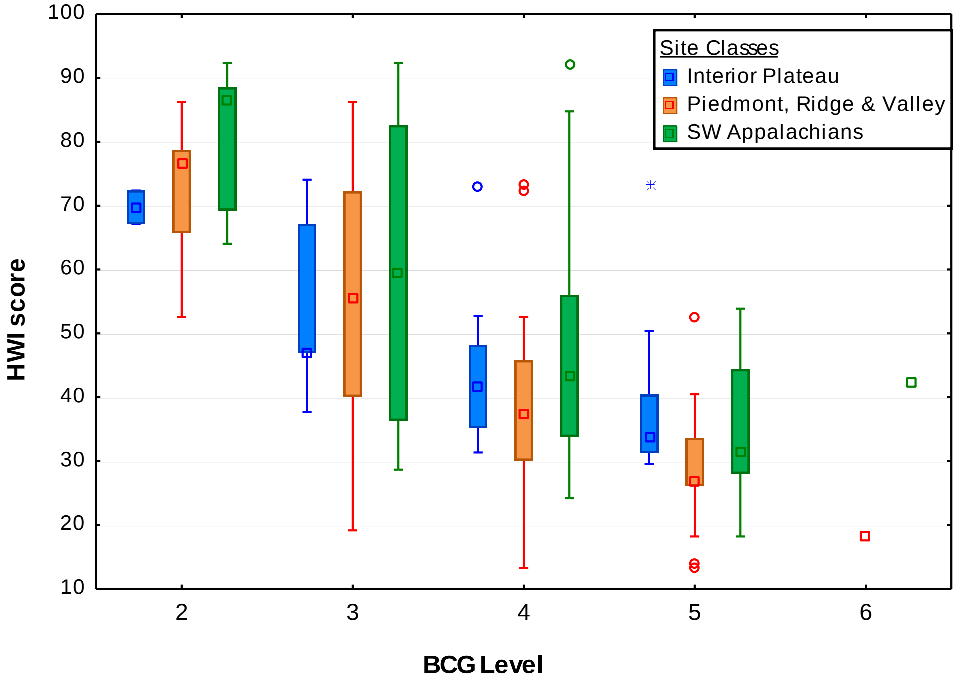

Figure 53. Distributions of Healthy Watershed Index (HWI) scores by macroinvertebrate BCG level and site class.

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[29] More information on the Healthy Watersheds Program is available at: http://www.epa.gov/hwp. Accessed February 2016.

The most pervasive changes to watershed condition are predicted to come from population increase (changes in land and water use) and climate change (USEPA 2014b). Watershed vulnerability can be defined as a combination of an ecological system's exposure, sensitivity, and adaptive capacity to cope with changes in population and climate (IPCC 2007). The adaptive capacity of a watershed to cope with such changes is enhanced by connectivity of habitats and maintenance of floodplain, wetland, and other landscape features in their natural conditions to support natural hydrology and sediment supply. Vulnerability was characterized for Alabama watersheds using indicators of projected changes in precipitation, temperature, impervious cover, and water use (USEPA 2014b). Estimates of watershed health and vulnerability combined with the BCG level scores can potentially be used together to inform management decisions and priorities for protection and restoration.

6.3.7 Conclusion

ADEM developed a BCG model to expand the technical capability of its biological monitoring and assessment program, with four key results. First, ADEM has been able to use the BCG to more accurately characterize the quality of reference sites relative to natural conditions (e.g., no or minimal anthropogenic disturbance). Second, in conjunction with biological indices, ADEM has used the BCG as a tool to help identify high quality streams, evaluate recovery potential of degraded streams, propose incremental biological goals for improvements, and track improvements. Third, ADEM is better able to convey to the public and decision makers more detail about the aquatic community to assist both the public and water quality managers in prioritizing areas for protection and restoration.

Finally, ADEM has found that adding fish community assessments to its biological assessment program produces more robust and comprehensive assessments of aquatic life (USEPA 2013a). Fish assessments are the primary biological indicator used to assess the status of threatened and endangered aquatic species within the state. Macroinvertebrate and fish assessments are generally conducted at different sites to make the most of limited resources and enable ADEM and partner agencies to assess biological conditions at more sites throughout the state. The two assemblages are sensitive to different stressors because of differences in the life cycles and motility of fish and benthic macroinvertebrates. The potential for different kinds of stress, the presence of threatened and endangered species, watershed area, and depth are all factors used to determine which assemblage will be assessed at each site. The BCG provides a common interpretive framework for benthic and fish assemblage data so both sets of information could be mapped on a common assessment scale and the information used to inform management decisions.

6.4 Minnesota: More Precisely Defining Aquatic Life Uses and Developing Biological Criteria

6.4.1 Key Message

Most surface waters in Minnesota are protected for aquatic life and recreation to meet the objectives set forth in CWA section 101(a). In the state, there are two primary sub-classes of streams protected for aquatic life, including a cold water stream class (2A) and a warm water stream class (2B). While the current system of beneficial uses and WQS has served Minnesota well, advances in the fields of biological assessment have led to the recognition that among the diversity of water body types there are variable biological conditions. For example, within rivers and streams, factors such as water body size, geographic location, hydrology, water temperature, and stream gradient influence chemical, physical, and biological composition. The Minnesota Pollution Control Agency (MPCA) recognized that effective water quality management requires a more comprehensive approach in which goals for water quality protection are tailored to specific water body types and uses. In response to these challenges, MPCA is proposing to modify its beneficial use framework for aquatic life. The new framework will allow for better goal-setting processes through the application of a framework that recognizes tiers, or levels, of aquatic life-use based on a stream's type and potential. MCPA is using the BCG to describe existing biological conditions and help provide the technical basis for assigning streams to ALU classes.

6.4.2 Background

MPCA's collection of biological water quality information began in the 1960s as part of an effort to monitor the conditions of state waters and since that time the state has developed a robust biological assessment program (USEPA 2013a). Over the past two decades, MPCA has routinely monitored both fish and benthic macroinvertebrates in streams, and, in combination with assessment of chemical and physical parameters, has used this information to assess the integrity of streams (MPCA 2014b). In the mid-1990s MPCA developed IBIs for fish (F-IBI) and benthic macroinvertebrates (M-IBI) to characterize the health of biological communities, identify stressors, select management actions to protect and restore water bodies, and determine how effective management actions are in meeting those goals. The initial IBIs developed were supported by narrative statements in the state's regulatory language that identified how to calculate an IBI. In 2003 and 2004, IBIs were developed for streams in specific basins of the state, and subsequently MPCA developed IBIs that could be applied statewide (MPCA 2014c, 2014d). Both the M-IBI and F-IBI used today are calibrated for a number of stream environments (e.g., large rivers, moderate-sized streams, headwaters, low-gradient streams, and cold water streams) (MPCA 2014c, 2014d). The IBIs for different stream types minimize the effects of natural differences between streams in order to enhance the signal from anthropogenic stressors. For example, the St. Louis River, a large river in northern Minnesota, naturally has a very different fish fauna compared to a small cold water stream in southern Minnesota such as Beaver Creek (Figure 54). Because the fish communities are naturally different in these habitats, IBI models need to be specific to the stream type so that appropriate expectations for healthy communities can be established. Since 2007, MPCA has monitored the state's rivers and lakes using a 10-year rotating watershed approach.

Minnesota's WQS classify state waters according to their designated beneficial uses (e.g., aquatic life, recreation, drinking water), and the state applies chemical, physical, and biological criteria to protect designated uses. Currently, the majority of surface waters in Minnesota are classified as Class 2,

Figure 54. Left: St. Louis River; Right: Beaver Creek.

protection of aquatic life and recreation[30] (i.e., the "General Use" goal). For streams and rivers, class 2 waters are further distinguished as Class 2A (aquatic life cold water habitat) or Class 2B (aquatic life warm water habitat). Despite the application of chemical, physical, and biological criteria, state scientists determined that a single biological threshold does not reflect existing conditions in high quality waters, nor set attainable restoration goals for degraded waters. For example, the West Branch of the Little Knife River (Figure 55) in the Lake Superior drainage in Minnesota supports fish and macroinvertebrate assemblages that would be expected in environments comparable to BCG level 1 or 2. A contrasting example is Judicial Ditch 7 in southeastern Minnesota (Figure 55). Fish and macroinvertebrate assemblages in this stream do not meet the stream's current aquatic life goal, which is estimated to be comparable to BCG level 4, because it is maintained for drainage. The activities associated with maintaining this ditch for drainage remove the habitat necessary to support natural aquatic assemblages and might limit attainment of the designated ALU. A use attainment analysis (UAA) will support determination of the highest attainable use for these types of streams, and the BCG could provide the basis for setting incremental restoration targets and tracking improvements.

Figure 55. Left: West Branch Little Knife River; Right: Judicial Ditch 7.

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[30] A full definition of *Class 2 water* can be found in Minnesota Administrative Rule 7050.0140, Subp. 3. https://www.revisor.leg.state.mn.us/rules/?id=7050.0140. Accessed February 2016.

6.4.3 Tiered Aquatic Life Uses and Biological Criteria Development

Over the past ten years, state scientists have sought an approach that would capitalize on the state's wealth of biological monitoring data and more specifically define the ALUs of rivers and streams in Minnesota. MPCA is revising the state WQS to more accurately designate ALUs and establish multiple levels (or goals) for aquatic life conditions in the WQS (in Minnesota this is known as the tiered aquatic life use (TALU) framework). Using this framework, Minnesota is proposing to classify rivers and streams based on the best attainable biological condition for a water body. The state is also proposing to subcategorize its designated ALU categories to best reflect a stream or river's current conditions and its ecological potential. This approach requires knowledge of the current condition of water bodies and the stressors affecting them (MPCA 2012). In order to develop TALUs and associated biological criteria, MPCA has capitalized on a variety of past work, including stream classification, IBI development, an HDS, and the BCG (MPCA 2014b). The BCG was used to interpret current conditions and set expectations for biological communities across the state. IBIs are used to determine the biological conditions of state rivers and streams and to determine which ALU best describes the highest attainable biological conditions in a specific water body.

MPCA's application of TALUs will subdivide Class 2 streams into three designated use class tiers (MPCA 2014e):

- Exceptional uses—"High quality waters with fish and invertebrate communities at or near undisturbed conditions."
- General uses—"Waters with good fish and invertebrate communities that meet minimum restoration goals."
- Modified uses—"Waters with legally altered habitat that prevents fish and invertebrate communities from meeting minimum goals."

For each designated use class tier, MPCA has developed biological criteria using biological, chemical, physical, and land use data collected during the 1995–2010 period. MPCA used a multiple lines of evidence approach that included use of the BCG and the reference condition.

In order to identify reference streams, MPCA first calculated an HDS, an index that measures the degree of human activity upstream of and within a stream. MPCA defined stream reference sites as those with an HDS score of 61 or greater; this is a defined least disturbed condition (the upper 25% of the HDS distribution). The reference streams are least influenced by stressors within the context of the current landscape condition of Minnesota (Stoddard et al. 2006), as far as practical from urban areas, point sources, feedlots, and other sources. MPCA also identified a subset of reference streams that satisfied "minimally disturbed" in the northern part of the state where widespread and long-term human disturbance is much less than in the south. MPCA compared the IBI scores for reference and non-reference sites. While MPCA identified some concerns with applicability of the reference condition approach in southern Minnesota due to widespread, high levels of land use and development, the agency determined that reference data sets were sufficient to develop biological criteria in the northern regions and in cold water classes (MPCA 2014b). Reference conditions for the southern region might require an alternate approach to more precisely characterize least disturbed conditions.

During 2009–2012, expert panels were assembled to develop BCG models for both macroinvertebrate and fish assemblages (Gerritsen et al. 2013). The conceptual BCG model (Davies and Jackson 2006) was calibrated by these expert panels using regional data for each of the two assemblages. The narrative descriptions for the different BCG condition levels were used by MPCA to describe each of the three designated use class tiers proposed in the revision to its WQS regulation:[31]

- Exceptional Use—"Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained."
- General Use—"Overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes."
- Modified Use—"Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy."

The MPCA expert panels characterized and calibrated the BCG for both benthic macroinvertebrates and fish for seven classes of warm water streams and two classes of cold and coolwater streams. A summary of the narrative rules includes:

- Taxa richness declined from BCG level 1 to level 6. All level 1 sites were large water bodies (rivers), and might be more influenced by size than by condition
- Attribute I taxa were characteristic of BCG level 1, occurred occasionally in BCG level 2, and were generally absent in levels 3–6
- All sensitive taxa (attributes I, II, and III combined) are common and abundant in levels 1 and 2, somewhat reduced in level 3, decline markedly in level 4, and have almost disappeared from levels 5 and 6.
- Intermediate taxa (attribute IV) are nearly constant throughout the gradient, but are reduced in level 6.
- MPCA divided the tolerant fish category into two: tolerant taxa (attribute V), and highly tolerant taxa (attribute V-a), as well as highly tolerant nonnative (attribute VI-a). The highly tolerant subgroups increased in abundance, dominance and variability at BCG levels 4 to 6, although the natives are represented at all levels.

An example of quantitative BCG rules derived for fish in the two river classes is shown in Table 34.

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[31] Information about Minnesota's WQS process is available at: http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-quality-standards.html. Accessed February 2016.

Table 34. Decision rules for fish assemblages in two classes of Minnesota rivers. Rules show the ranges of fuzzy membership functions. N indicates the number of sites for a given BCG level and stream class in the calibration data set.

Metric	Prairie Rivers	Northern Forest Rivers	
BCG Level 1	N=2	N=3	
Total taxa	> 25–35	> 16–24	
Endemic taxa (Att I)	Present	Present	
Att I+II taxa	> 2–5	> 1–2	
Att I+II+III % taxa	> 45%–55%	> 35%–45%	
Att I+II+III % ind	> 25%–35%	> 45%–55%	
Att Va or VIa Dominance		< 7%–13%	
Tolerant % ind (V + Va + VIa)	< 3%–7%		
Highly tol % ind (Va + VIa)		< 7%–13%	
BCG Level 2	N=6	N=15	
Total taxa	> 16–24	> 6–10	
Att I+II taxa	Present	-	
Att I+II+III % taxa	> 35%–45%	> 25%–35%	
Att I+II+III % Ind	> 15%–25%	> 25%–35%	
Att Va or VIa Dominance		< 7%–13%	
Highly tol % ind (Va + VIa)	< 7%–13%	< 7%–13%	
BCG Level 3	N=25	N=11	
Total taxa	> 11–16	> 6–10	
Att I+II+III % taxa	> 15%–25%	> 15%–25%	
Att I+II+III % Ind	> 7%–13%	> 7%–13%	
Tol % ind (V + Va + VIa)	-	< 25%–35%	
Att Va or VIa Dominance	< 7%–13%	< 10%–20%	
Highly tol % ind (Va + VIa)	< 25%–35%	-	
BCG Level 4	N=31	N=16	
		Alt 1	**Alt 2**
Total taxa	> 11–16	> 6–10	= alt 1[1]
Att I+II+III % taxa	10%–20%	> 15%–25%	> 7%–13%
Att I+ II+III % Ind	0%–1%	> 3%–7%	present
I+II+III+IV % Ind			
Att Va or VIa Dominance	< 35%–45%	< 25%–35%	= alt 1[1]
Tol % ind (V + Va + VIa)		n/a	< 30%–40%
Highly Tol % ind (Va + VIa)	< 45%–55%	< 35%–45%	= alt 1[1]
BCG Level 5	N=12	N=2	
Total taxa	> 11–16	6–10	
Att I+II+III+4 % Taxa			
Att Va or VIa Dominance	< 65%–75%	< 35%–45%	
Highly tol % ind (Va + VIa)		< 55%–65%	
BCG Level 6 (no rules)	N=1	N=0	

[1] "= alt 1" the rule is the same as given under Alt 1 for this metric

MPCA then calibrated the BCG with the state's index for biological assessment of Minnesota's warm water and cold water streams for both the fish and macroinvertebrate assemblages (Figure 56). MPCA has used this information to develop draft numeric biological criteria that would be applied to each designated use class tier—thus directly linking the ALU goal with the state's assessment method (Figure 57). In December 2015, MPCA held a formal public comment period on a proposed revision to the state WQS that would include TALUs.

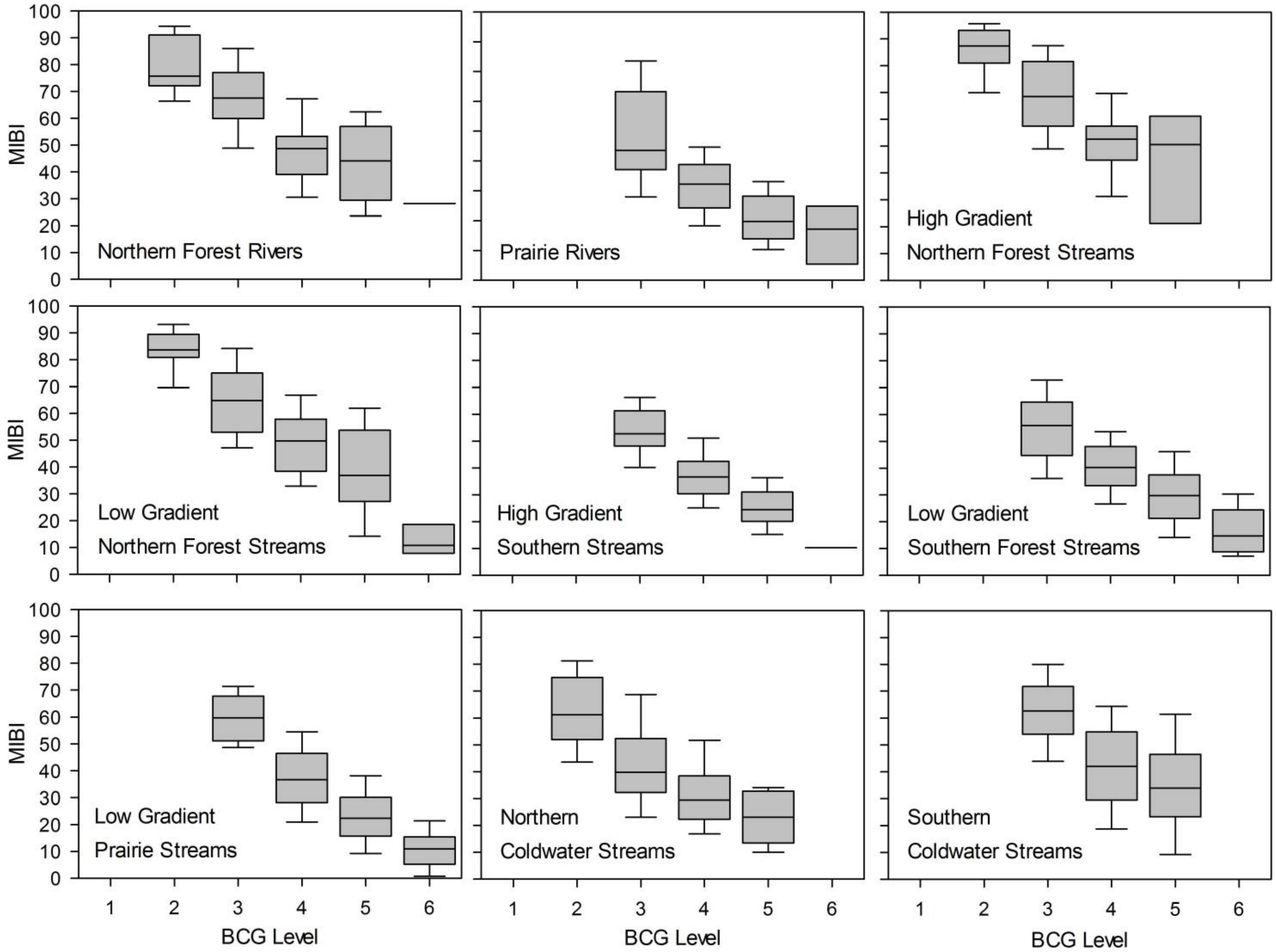

Figure 56. Frequency distributions of IBI scores by BCG level for macroinvertebrate stream types using data from natural channel streams sampled 1996–2011. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles. MPCA also did a calibration of fish index scores with BCG levels assigned to sites.

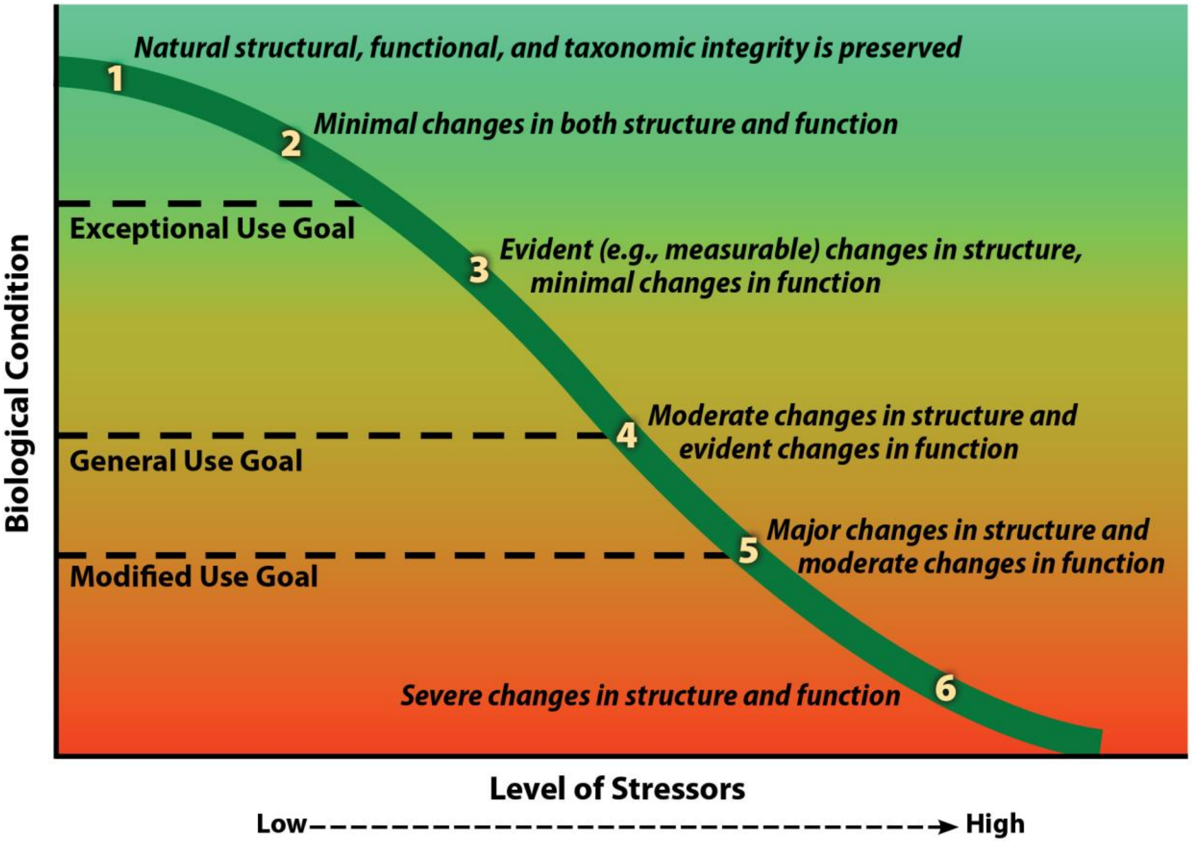

Figure 57. BCG illustrating the location of proposed biological criteria (black dotted line) for protection of Minnesota's TALU goals (Exceptional, General, Modified) (Source: MPCA 2014b).

6.4.4 Benefits of the Biological Condition Gradient

Because the BCG provides a common framework to interpret changes in biological condition regardless of geography or water resource type, Minnesota will be able to make more accurate determinations and classifications of its aquatic resources on a statewide basis. The state will be in position to make decisions on aquatic life designations based on robust and detailed ecological data and information. Another advantage of the BCG is that it provides a means to communicate with the public about existing conditions and potential for improvement for specific water bodies. BCGs were developed for each of Minnesota's aquatic resource classes for streams (e.g., cold water and warm water streams). The development of warm water BCG models involved input from biological experts familiar with biological communities in Minnesota from the MPCA and Minnesota Department of Natural Resources. BCG models were developed for fish and macroinvertebrates for each of the seven warm water stream classes. A cold water BCG involved experts from Minnesota, Wisconsin, Michigan, and several tribes located in those states. In Minnesota this effort included two classes each for fish and macroinvertebrates. Model development for each class involved reviewing biological community data from monitoring sites and then assigning that community to a BCG level. A sufficient number of samples were assessed to develop a model that can duplicate the panel's BCG level assignments. Using the BCG and reference conditions permits MPCA to provide more detailed descriptions of the expected biota for each ALU and to develop biological criteria that are protective, consistent, and attainable across the state (MPCA 2012). These accomplishments will help Minnesota achieve several key goals described below.

Refinement of Biological Standards

Numeric water quality criteria that are codified in the Minnesota WQS are currently based on chemical and physical criteria such as DO, temperature, and pH. These criteria do not directly measure the condition of biological communities that include fish, insects, mussels, aquatic plants, and algae. Biological communities can be monitored as a direct measure of the response of the biota to a wide range of physical and chemical stressors and provide a quantitative measure of the cumulative and synergistic impacts of multiple stressors over time. A major goal of Minnesota's water quality management program is to protect the fish, invertebrates, and other aquatic organisms in the state's waters. Therefore, it is sensible that a direct measurement of these communities is used to monitor their condition.

Ability to Address Natural Variation

One of the strengths of Minnesota's approach is the ability to address the natural variation in water resources across the state. Minnesota's diverse water resources mean that refined biological monitoring tools are needed to reduce errors in assessment and management. For example, streams along the shore of Lake Superior in northern Minnesota are very different from streams in southern Minnesota such that, under natural conditions, the biological communities in streams in each location are expected to be different. The Minnesota BCG framework takes into account these natural differences and requires that comparisons be made between streams with naturally similar biological communities. As the state's database is built through long term monitoring, Minnesota will be able to define current, or baseline, conditions and be in a better position to discern shifts in species composition and structure due to climate change impacts.

Identification of Reference Condition Quality

The biological monitoring program in Minnesota relies on BCG models and the reference condition approach to set expectations for water bodies. The BCG provides a common "yardstick" of biological condition that is rooted in the natural condition. As a result, the BCG can be used to develop biological criteria that are consistent across regions and stream types in Minnesota—particularly important for a state where the range of existing quality is regionally distinct and extreme (i.e., undisturbed to highly disturbed conditions). The reference condition approach identifies water bodies that are least disturbed and uses them to establish the reference condition. Once this reference condition has been established, water bodies with unknown condition can be compared to this baseline. If the condition of the water body is lower than that of the reference condition, it would be considered impacted or stressed. The use of a reference condition relies on the development of accurate expectations for least disturbed sites. The BCG provides a framework for assessing the quality of reference sites relative to undisturbed conditions and can be used to interpret the quality of reference sites, including reference sites in regions where the least disturbed conditions include sites with moderate to higher levels of stress. In these regions, such as in southern Minnesota, the BCG was used to help develop protective ALU goals (MPCA 2014b, 2014e).

Protection of High Quality Water Resources

Minnesota's classification framework and BCGs will be applied in conjunction with another element of states' antidegradation policy. This policy requires:

- Maintenance of existing uses;
- Prevention of degradation of water quality that exceeds levels necessary to support the protection and propagation of aquatic life and recreation unless the state finds that lowering of

water quality is necessary to accommodate important economic or social development (Tier 2 protection); and

- Maintenance of water quality needed to protect outstanding resource waters (Tier 3 protection).

Minnesota is planning to propose a higher tier of ALU (i.e., exceptional use goal) to protect high quality biological communities. Once it has been established that a water body is meeting the requirements associated with an exceptional water resource, the resource needs to be protected to maintain that status. The BCG provides a framework with which to identify candidate high quality streams and rivers for designation as exceptional resources.

Setting Expectations for Modified Water Resources

There are water resources in Minnesota that will not in the near future meet the CWA interim goals due to historical or legacy impacts. These legacy impacts include streams under drainage maintenance or other irreversible hydromodification that preclude attainment of water body goals (e.g., channelized streams and ditches). The BCG provides a framework to monitor and help set realistic expectations for waters that are unlikely to meet ALU goals due to legacy impacts and have been designated as modified water resources. Additionally, as conditions improve, the BCG provides a framework to document and acknowledge these improvements to reflect existing conditions.

6.4.5 Conclusion

In conjunction with numeric biological indices developed for macroinvertebrates, the BCG allows Minnesota to set consistent and protective ALU goals and numeric biological criteria across the state despite the heterogeneity of its water bodies. This heterogeneity is due both to natural conditions and human disturbance, and the BCG provides a framework to characterize and communicate these differences. The BCG described in this case study is applicable to streams and wadeable rivers. Minnesota is currently developing a BCG and biological criteria for lakes using fish assemblage information.

6.5 Maine: Development of Condition Classes and Biological Criteria to Support Water Quality Management Decision Making

6.5.1 Key Message

Clear, technically rigorous goal statements have provided Maine with an effective framework to improve biological condition of streams and rivers. Maine has established four ALU classes (Classes AA/A/B/C) with different ecological expectations. The classes span the range from Maine's interpretation of the CWA interim goal to the ultimate CWA objective "to restore and maintain chemical, physical and biological integrity" (Class AA/A). All rivers and streams in Maine are assigned to one of the four classes in Maine's WQS for planning and management purposes. These TALUs and numeric biological criteria have enabled Maine to inject critical biological information into all aspects of water quality management. Along with the practical experience and scientific advancements demonstrated by other states with strong biological assessment programs, Maine's approach to classification and biological criteria development provided the template for the conceptual BCG (Davies and Jackson 2006). In turn, Maine continues to strengthen and develop its biological assessment program to address other water bodies and include measures of the algal communities in its assessments. The BCG is being incorporated as part of its "toolbox" to accomplish these tasks.

6.5.2 Background

Since the 1960s, prior to adoption of the CWA, Maine water quality law has had a tiered structure based on observations of gradients of water quality conditions. In 1986, Maine revised its water classification law and added TALUs to maintain and restore the structure, function, and biological integrity of aquatic life communities. Maine's TALUs were based on concepts of John Cairns, H.T. Odum, and others who observed declines in biological condition in response to gradients of increasing stressors (Ballentine and Guarraia 1977; Odum et al. 1979, Cairns et al. 1993; Karr and Chu 2000). The four narrative TALU standards in Maine's water classification law describe conditions across a biological gradient ranging from "as naturally occurs" (Classes AA and A) to "maintenance of structure and function" (Class C). Class C is the lowest ALU designation allowed in the state and consistent with Maine's interpretation of the CWA fishable/swimmable interim goal (Table 35; M.R.S.A Title 38 Article 4-A § 464-466). Maine's TALUs for fresh surface waters apply to streams, rivers, and wetlands. Maine has similar TALUs for coastal marine waters (SA, SB, SC). Maine has established a single class for lakes that is equivalent to Class A. Maine's TALUs are based on tiers of biological condition along observed human disturbance gradients. Such stressor-response relationships are also the foundation of the later development of the BCG.

Maine's TALUs are supported by ecologically-based definitions in the law. The narrative definitions in Maine law establish the biological characteristics that are required to attain the standards of each class (Table 35). Class AA and Class A have the same "*as naturally occurs*" aquatic life goals and will hereafter be referred to as Class AA/A; Class AA is more restrictive in allowable permitted activities. For example, no dams or discharges are allowed in Class AA waters. Maine's assessed streams and rivers are predominantly classified as either Class AA/A or B waters, 48.6% and 51%, respectively. Class A/AA waters have been interpreted by Maine as comparable to BCG levels 1 and 2 and class B waters are equivalent to BCG level 3. Less than 1% of Maine's streams and rivers are classified as Class C waters, which have been deemed as comparable to BCG level 4. These waters are primarily in urbanizing areas or downstream of significant point sources. Figure 58 summarizes relationships between Maine's narrative biological, chemical, and physical standards and shows Maine's TALUs in relation to the BCG.

Table 35. Criteria for Maine river and stream classifications and relationship to antidegradation policy

Class	DO criteria	Bacteria criteria	Habitat narrative criteria	Aquatic life narrative criteria*** and management limitations/restrictions	2012 Percentage of Maine waters designated in class ****	Corresponding federal antidegradation policy tiers
AA	As naturally occurs	As naturally occurs	Free-flowing and natural	As naturally occurs**; no direct discharge of pollutants; no dams or other flow obstructions.	3.6%	3 (Outstanding National Resource Water [ONRW])
A	7 ppm; 75% saturation	As naturally occurs	Natural**	Discharges permitted only if the discharged effluent is of equal to or better quality than the existing quality of the receiving water; before issuing a discharge permit the Department shall require the applicant to objectively demonstrate to the department's satisfaction that the discharge is necessary and that there are no reasonable alternatives available. Discharges into waters of this class licensed before 1/1/1986 are allowed to continue only until practical alternatives exist.	45%	2 ½
B	7 ppm; 75% saturation	64/100 mg (g.m.) or 236/100 ml (inst.)*	Unimpaired**	Discharges shall not cause adverse impact to aquatic life** in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous** to the receiving water without detrimental changes to the resident biological community.**	51%	2 to 2 ½
C	5 ppm; 60% saturation; and 6.5 ppm (monthly avg.) when temperature is ≤ 24 °C	125/100 mg (g.m.) or 236/100 (inst.)*	Habitat for fish and other aquatic life	Discharges may cause some changes to aquatic life**, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous** to the receiving waters and maintain the structure** and function** of the resident biological community. **	0.4%	1 to 2

Source: Maine DEP (modified). http://www.maine.gov/dep/water/monitoring/classification/index.html. Accessed February 2016.

Notes:

* g.m. = geometric mean; inst. = instantaneous level.

** Terms are defined by statute (Maine Revised Statutes Title 38, §466).

*** Numeric biological criteria in Maine regulation Chapter 579, Classification Attainment Evaluation Using Biological Criteria for Rivers and Streams http://www.maine.gov/dep/water/rules/index.html. Accessed February 2016.

**** Source: 2012 Maine Integrated Water Quality Report, http://www.maine.gov/dep/water/monitoring/305b/2012/report-final.pdf. Accessed February 2016.

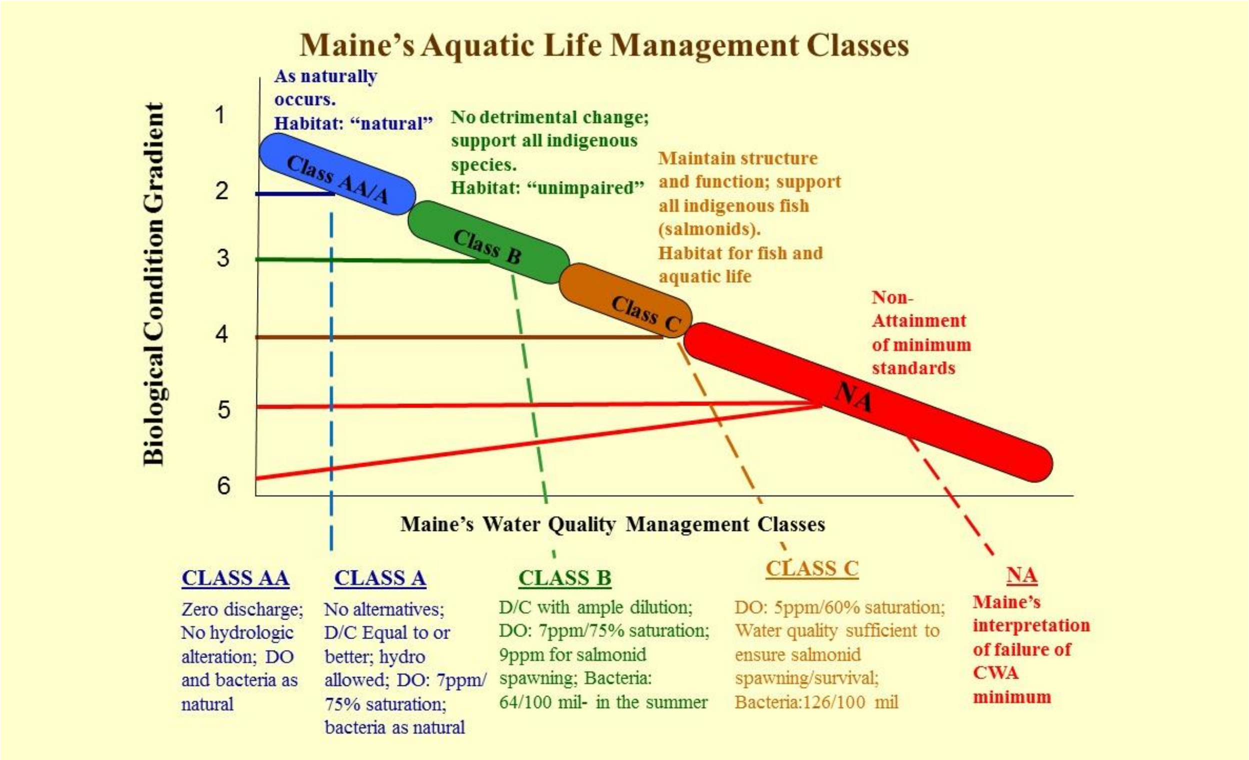

Figure 58. Relation between Maine TALUs, the BCG, and Maine's other water quality standards and criteria. Class AA/A is approximately equivalent to BCG levels 1 and 2. Classes B and C approximate BCG levels 3 and 4, respectively. Non-attainment conditions below Class C are approximately equivalent to BCG levels 5 and 6.

6.5.3 Maine's Numeric Biological Criteria and Tiered Aquatic Life Uses

In 2003, Maine adopted numeric biological criteria in rule for rivers and streams, based on assessment of benthic macroinvertebrates (State of Maine 2003; Shelton and Blocksom 2004; Davies et al. In press). Technical details describing development of the statistical biological criteria models are found in Chapter 4 of this document and in Davies et al. (In press). In short, MEDEP utilized expert consensus to establish four *a priori* groups corresponding to Maine's TALUs, and developed and tested a linear discriminant model (LDM) to predict the probability of a sample attaining ALU goal conditions (Class AA/A, Class B, and Class C). The fourth group, termed "non-attainment" (NA) represents samples that are in poorer condition than Class C. The LDM and accompanying provisions for application are codified in rule and constitute Maine's numeric biological criteria.[32] When confirmed (e.g., by re-sampling and review of data results) that a stream reach fails to attain its assigned water quality goal, the water body segment is listed as impaired on the state's 303(d) list (Table 36). State law requires that water bodies be considered for upgrade to a higher class if they are found to be consistently attaining the standards of that higher classification.

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[32] http://www.maine.gov/dep/water/rules/index.html. Accessed February 2016.

Table 36. Examples of how numeric biological criteria results determine whether or not a water body attains designated ALUs in Maine

Legislative Class	Monitoring Result	Attains Class?	Next Step
A	A	Yes	--
C	B	Yes	Review for upgrade
A	B	No	303(d) list as impaired if confirmed
B	NA	No	303(d) list as impaired if confirmed

MEDEP also conducts biological assessments of stream algal, wetland macroinvertebrate, and wetland phytoplankton and epiphytic algal assemblages (Danielson et al. 2011, 2012). MDEP used Maine's narrative biological criteria and the BCG as the foundation of biological assessment models for stream algae and wetland macroinvertebrates. A first step in model-building was to empirically compute tolerance values for algal and macroinvertebrate species that had been collected in Maine's monitoring program. After computing tolerance values, the species were grouped into the BCG framework's sensitive, intermediate, and tolerant attribute groups. MEDEP then modified the BCG framework for stream macroinvertebrates for stream algae and wetland macroinvertebrates, describing how those assemblages empirically respond to anthropogenic stressor gradients. MEDEP used the BCG and tolerance metrics along with the narrative biological criteria and other metrics to build predictive biological assessment models for the additional assemblages. MEDEP has completed LDM statistical models to predict TALU attainment for both stream algal and wetland macroinvertebrate community data. These models currently are used to help interpret narrative biological criteria. Following adequate testing and standard public review protocols, MEDEP intends to amend the Maine Biological Criteria Rule[33] to include the stream algal and wetland macroinvertebrate models as numeric biological criteria.

In summary, numeric biological assessment models, when codified in the MEDEP biological criteria rule (as for stream macroinvertebrates), or when used as an objective corroboration of expert judgment (as for stream algae and wetlands), provide a transparent and standardized quantitative means for determining attainment of TALUs in Maine WQS. Numeric biological criteria have enabled Maine to use biological information to support multiple water quality management information needs and decision making. Examples of applications follow.

6.5.4 Goal-based Management Planning to Optimize Aquatic Life Conditions

As described in section 6.5.2, the Maine State Legislature revised Maine's WQS and classification law in 1986 (M.R.S.A Title 38 Article 4-A § 464-466) establishing narrative biological criteria for four ALU classes for rivers and streams. This law set in motion a process involving the public, the state environmental agency, and the Maine legislature to assign all Maine waters to an appropriate goal classification. All available monitoring data and information about then-current biological and/or water quality conditions were used to initially propose the statutory classes for stream and river segments for the 1986 law. Many waters that lacked current monitoring data retained their previous water quality goals (generally Class B, except for some urban or industrialized areas, which were Class C) until monitoring data or other evidence was found to recommend a different (and in most cases higher) class.

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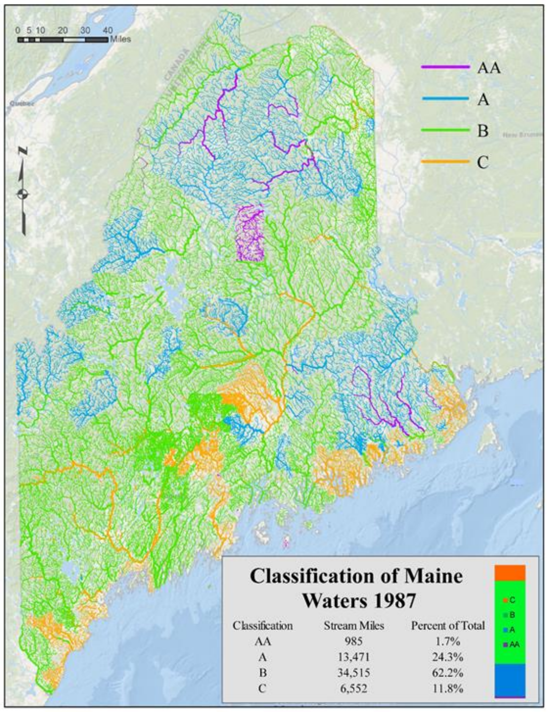
[33] See Code of Maine Rules, MEDEP, Chapter 579, http://www.maine.gov/dep/water/rules/index.html. Accessed February 2016.

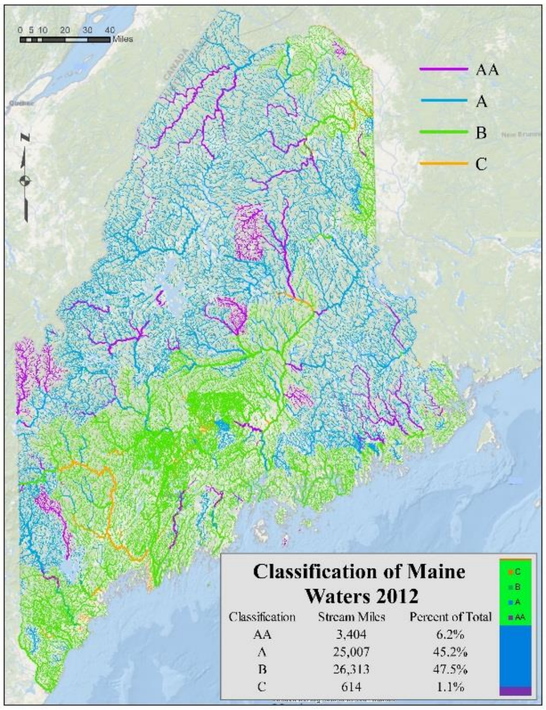
Maps spanning the period between 1987 (Figure 59) and 2012 (Figure 60) show the past and present distribution of water quality classifications. Approximately 99% of Maine's rivers and streams have been designated for classes of protection equal to or higher than Maine's interpretation of the CWA Interim Goal (i.e., Class C). Reclassification upgrades have been implemented with strong public and legislative support. The state has designated water bodies into higher classes to protect waters currently demonstrating high quality and to retain improvements in lower quality waters that had been restored to higher conditions due to wastewater treatment successes. During the nearly three decades since 1987, the Maine State Legislature has assigned 13,955 river and stream miles to a Class A or Class AA management goal, an increase of 25.5%[34]. Numeric biological criteria and articulation of the gradient of aquatic life management classes facilitated the recognition of both the presence of high quality waters and improvements in condition due to remediation. As shown in Figures 21 and 22, these classification upgrades have mostly been drawn from Class B and Class C waters where biological monitoring data demonstrated either the potential, or the actual achievement of the standards of Class A or Class AA. Without their ALU classification approach, TALUs, and criteria, these gains in condition would likely have gone un-detected and unprotected. Additionally, the state's ecologically descriptive condition classes have enhanced public understanding of existing conditions, problems, and restorable target conditions. They provide an important tool in building public and stakeholder support for the often substantial investment that is required to restore aquatic resources.



Classification of Maine Waters 1987

Classification	Stream Miles	Percent of Total
AA	985	1.7%
A	13,471	24.3%
B	34,515	62.2%
C	6,552	11.8%

Figure 59. Distribution of Maine water quality classifications in 1987 prior to WQS revisions.



Classification of Maine Waters 2012

Classification	Stream Miles	Percent of Total
AA	3,404	6.2%
A	25,007	45.2%
B	26,313	47.5%
C	614	1.1%

Figure 60. Distribution of Maine water quality classifications in 2012 following 25 years of water quality improvements and classification upgrades.

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[34] See State of Maine Water Quality Standards Docket, http://www.maine.gov/dep/water/wqs/docket/index.html (Accessed February 2016) and USEPA, State Tribal and Territorial Standards http://www.epa.gov/wqs-tech/water-quality-standards-regulations-maine (Accessed February 2016).

6.5.5 Early Detection and Management of an Emerging Problem

When Maine's Biological Monitoring Program was initiated, a primary concern was management of point source discharges. Implementation of Best Available Technology for point sources eliminated many of these causes of biological impairment with the result that the aquatic life in receiving waters throughout the State rebounded to significantly improved conditions (Davies et al. 1999; Davies et al. 2016). More recently, however, biological assessment of smaller streams has revealed impairment caused by changes in physical stream conditions (e.g., increased impervious surfaces in the watershed, hydrologic and stream channel shape alteration). Chemical assessments in these smaller streams have documented increased nutrients and toxic constituent concentrations, salt runoff, increased temperature, and decreased DO.

In 2006, Maine became one of the first states to issue TMDLs based on the percent of a stream watershed covered by impervious surfaces such as roads and parking lots (% IC) (Meidel and MEDEP 2006a, 2006b). Narrative and numeric biological criteria in Maine's WQS were used as the TMDL end point, goal, and ultimate numeric water quality compliance measure for the impaired portions of the streams in order to address non-attainment of ALUs. The restoration pathway described in the TMDL focused on realistic approaches to minimizing the biological, physical, and chemical *effects* of impervious cover, rather than direct elimination of IC. Expanding on the success of the 2006 % IC TMDL, in 2012, MEDEP completed a statewide % IC TMDL for 30 urban impaired streams and 5 associated wetlands (MEDEP 2012). As in 2006, the 2012 TMDL also included aquatic life restoration targets based on the relationship of % IC in the stream watersheds and target improvements in macroinvertebrate community condition.

In 2015, MEDEP conducted a fine-scale geospatial analysis of % IC in watersheds upstream of algal and macroinvertebrate biological assessment sites and determined attainment of TALU for each assemblage at those sites (Danielson et al. In press). Watershed % IC estimates were computed in ArcMap with 1-meter, high-resolution spatial data from 2004 and 2007. Results, shown in Figure 61, revealed that in general, streams become vulnerable to no longer attaining Class AA/A biological criteria when % IC in upstream watersheds is in the range of 1%–3% IC. The risk of not attaining Class B biological criteria increases in the range of 3%–6% IC. Finally, the transition from low risk to high risk of attaining Class C criteria is in the range of 10%–15% IC.

The % IC study revealed that small streams are at risk of impairment at lower levels of watershed % IC than previously recognized. Recognizing the difficulty, expense, and extended lag times associated with urban stream restoration, environmental managers and urban planners in Maine increasingly realize the importance and cost-effectiveness of *preventing* impairment of urban streams. TALU and BCG concepts, along with rigorous biological assessment data, helped MDEP raise awareness about the vulnerability of biological assemblages to urbanization and other human-caused stressors. This information is used in Maine at both the state and local level to inform water quality management decisions and local land use planning and design of development.

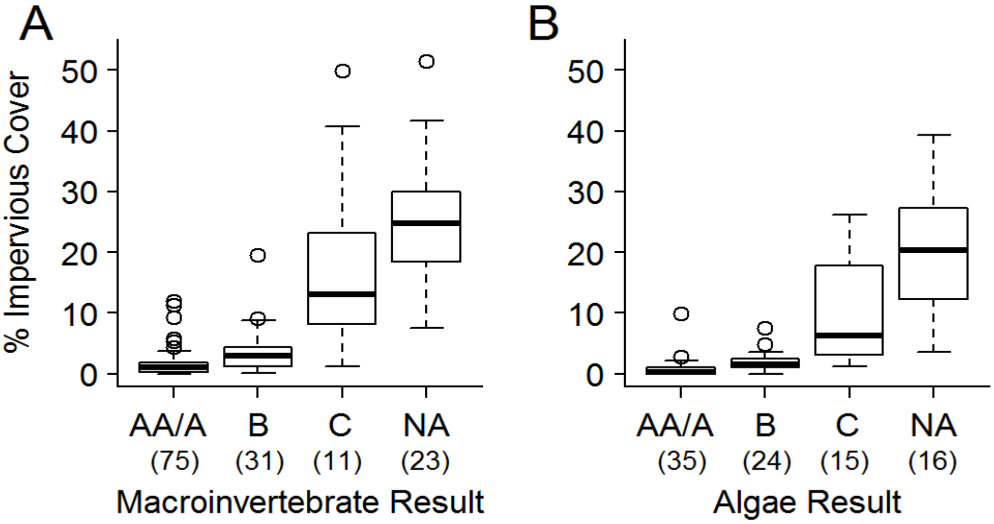
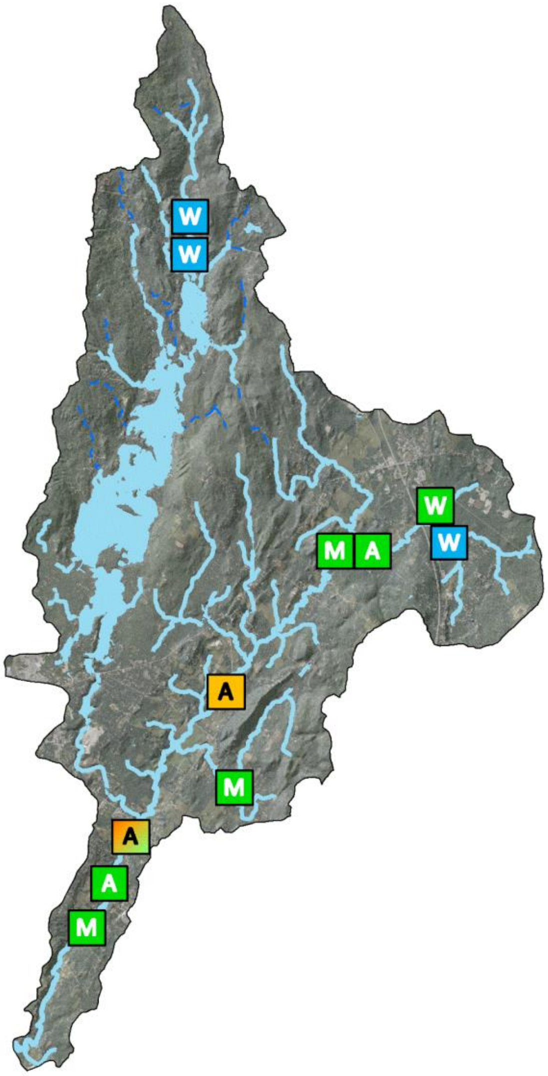


Figure 61. Box-and-whisker plot of % IC of samples grouped by biological assessment results for (A) macroinvertebrates and (B) algae with number of samples in parentheses. The NA group includes samples that do not attain biological criteria for Classes AA/A, B, or C (Source: Danielson et al. In press).

6.5.6 Monitoring and Assessment to Determine Current Condition: Using Biological Condition Gradient Concepts to Integrate Biological Information from Multiple Assemblages and Water Body Types



	WATERBODY	ASSEMBLAGE	CLASS	BCG LEVEL
W	WETLAND	MACROINVERTEBRATE	A	2
W	WETLAND	MACROINVERTEBRATE	B	3
M	STREAM	MACROINVERTEBRATE	B	3
A	STREAM	ALGAE	B	3
A	STREAM	ALGAE	B/C	3/4
A	STREAM	ALGAE	C	4

Figure 62. Pleasant River sites with attained water quality class and BCG level for different assemblages and water body types.

BCG concepts provide Maine with a common assessment framework for comparing biological integrity among different types of water bodies (wetlands, rivers, and streams), regardless of the assemblage assessed or the sampling methods used. This enables MEDEP to evaluate condition and threats to aquatic resources on a watershed basis. The integrated assessment also contributes important information for design of remediation activities, even in the absence of formally promulgated numeric biological criteria. For example, MEDEP evaluated the condition of the Pleasant River watershed using multiple biological assessment models, water quality class attainment, expert judgment, the BCG, and supporting chemical and physical information. Located in southern Maine, the Pleasant River watershed is primarily forested with some agriculture, as well as increasing amounts of urbanization in the downstream portions of the watershed. The Pleasant River has a TALU goal of Class B. MEDEP sampled algae and macroinvertebrates in several locations on the Pleasant River and sampled macroinvertebrates in several headwater wetlands (MEDEP 2006, 2009, 2014; Danielson et al. 2011). Biological assessment showed that the headwater stream and wetland samples attained Class A or B biological criteria using macroinvertebrate data (Figure 62).

However, further downstream, the stream macroinvertebrate samples attained Class B biological criteria, but stream algal samples were mixed, attaining Class B or C. MEDEP used water chemistry data, habitat evaluations, diagnostic algal and macroinvertebrate metrics, expert judgment, and the BCG concept to determine that nutrient pollution was the probable stressor to which the algal community was responding. A watershed survey identified potential sources of nutrients in the lower part of the watershed. The combination of biological assessments for two water body types and taxonomic groups allowed MEDEP to complete a more holistic and meaningful evaluation of the Pleasant River watershed than what could have been accomplished with only one biological assessment method. MEDEP now has a tool to detect early signals of nutrient pollution before the full aquatic community is detrimentally impacted.

Findings from biological assessments of multiple assemblages and water body types have also been used to improve and strengthen Maine's statewide impervious cover TMDL report.[35] For example, in Maine's 2010 Integrated Water Quality Report, Capisic Brook in Portland and Westbrook, Maine was 303(d)-listed for stream benthic macroinvertebrate impairment based on MEDEP's numeric biological criteria rule. Although numeric biological criteria for Maine wetlands had not yet been formally promulgated, Capisic Pond was also listed for wetland macroinvertebrate impairments based on interpretation of quantitative data showing that narrative ALUs were not attained. The state's multivariate biological assessment models for wetland macroinvertebrates and stream algae enabled results to be compared to Maine's TALU classes and macroinvertebrate numeric biological criteria. Stream algal and wetland macroinvertebrate biological assessments helped biologists determine that Capisic Pond and Capisic Brook were not attaining narrative biological criteria, resulting in biological impairment listing for multiple causes.

6.5.7 Using Maine's Tiered Aquatic Life Uses and Biological Assessment Methods to Evaluate Wetland Condition

The MEDEP Biological Monitoring Program assesses the health of inundated emergent and aquatic bed freshwater wetlands. Samples consist of aquatic macroinvertebrates, planktonic and epiphytic algae, and physical and chemical data related to trophic state and habitat condition (MEDEP 2006; MEDEP 2009). Sampling typically occurs in freshwater marshes and fringing wetlands associated with rivers, streams, lakes, and ponds. The biological assessment statistical model for wetlands provides an objective means of assessing condition.

Maine has found that wetland biological assessment provides a complementary approach to assessments of wetland function and value. Under the definitions established by the USEPA *Wetland Core Elements of an Effective State and Tribal Wetlands Program*[36] Maine conducts a "level 3" biological assessment of wetlands. According to EPA, "level 3 or intensive site assessments provide a more thorough and rigorous measure of wetland condition by gathering direct and detailed measurements of biological taxa and/or hydro-geomorphic functions." Maine's wetland macroinvertebrate biological assessment program can detect incremental differences in aquatic resource condition utilizing a locally calibrated statistical model consistent with the BCG concepts (MDEP 2006; MDEP 2009). Additional applications of wetland biological assessments include determining whether wetlands attain designated ALUs, tracking trends over time, and, in conjunction with chemical and physical assessments, diagnosing stressors, and assessing impacts or threats related to land use practices (e.g., point source discharges, toxic contaminants, hydropower, and water withdrawal projects).

In 2013, the MEDEP Biological Monitoring Program evaluated the biological condition of wetland compensatory mitigation projects using wetland biological assessment methods (DiFranco et al. 2013).

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[35] See http://www.maine.gov/dep/water/monitoring/tmdl/tmdl2.html. Accessed February 2016.

[36] See http://www.epa.gov/wetlands/wetlands-funding. Accessed February 2016.

Mitigating adverse environmental impacts of development is an integral part of Maine's Natural Resources Protection Act,[37] a state law regulating land use activities and administered by MEDEP. The State of Maine or federal agencies administering resource protection regulations might require appropriate and practicable compensatory mitigation as a condition of granting a permit to alter or destroy wetlands. Compensation is defined in the NRPA as "replacement of a lost or degraded wetland function with a function of equal or greater value." If ecologically appropriate compensation is not available or otherwise practicable, a permit applicant may request to pay an *in-lieu* compensation fee to be used for the purpose of restoring, enhancing, creating or preserving other resource functions or values that are environmentally equal or preferable to the functions and values being lost. Upon authorization the In-Lieu Fee is placed in a "Natural Resource Mitigation Fund" administered by The Nature Conservancy's (TNC's) Maine office.

For this study, MEDEP wanted to determine whether compensatory mitigation projects supported aquatic life communities comparable to minimally disturbed reference sites. The MEDEP Biological Monitoring Program evaluated quantitative biological data, biological assessment model results, expert judgment, and the BCG, to compare the biological condition of 9 wetland compensation sites to that of 51 minimally disturbed reference sites. The mitigation sites in the study represented a cross section of available Maine "permittee-responsible" compensation projects that used restoration, creation, enhancement, and preservation techniques, and were completed between 1995 and 2007. The compensation projects varied in age and encompassed a range of freshwater wetland types, including forested, scrub-shrub, emergent, wet meadow, aquatic bed, and open water marsh.

Figure 63 illustrates comparisons of reference and mitigation sites for sensitive versus tolerant taxa metrics using box and whisker plots and quantile (cumulative distribution) plots. In general, mitigation sites had fewer numbers and types of sensitive taxa and a higher proportion of eurytopic taxa (i.e., taxa that are adapted to a wide range of environmental conditions). Table 37 shows estimated BCG condition based on data analysis, expert judgment and the provisional wetland biological assessment model (DiFranco et al. 2013). Results of this study indicated that community structure is significantly different between a set of 51 reference wetlands and nine mitigation wetlands based on taxa tolerance metrics and BCG level. This type of information can improve monitoring and assessment of mitigation sites.

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[37] See NRPA, http://www.maine.gov/dep/land/nrpa/index.html (Accessed February 2016), 38 M.R.S.A. § 480 A–BB.

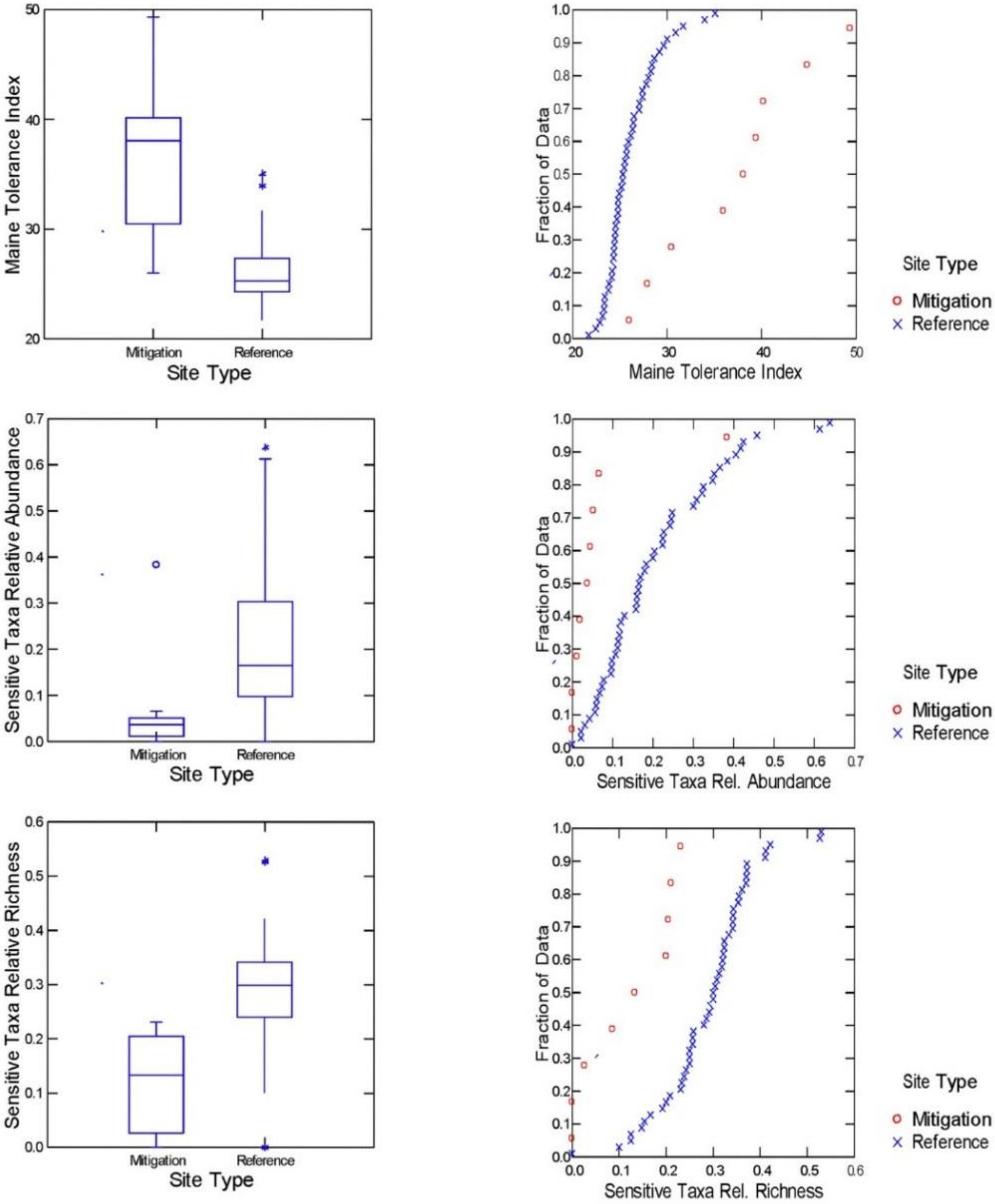


Figure 63. Comparison of reference and mitigation sites for the Maine Tolerance Index and sensitive/tolerant taxa metrics (reference site N=51; mitigation site N=9) (DiFranco et al. 2013).

Table 37. Measured values of chemical and watershed stressors, attained water quality classes, and corresponding BCG levels of reference wetlands and mitigation wetlands (DiFranco et al. 2013)

Mitigation Site Station Number	Specific Conductance µS/cm	Total Phosphorus (mg/L)	MEDEP Human Disturbance Score	% Watershed Alteration	Assigned Legislative Class	BCG Level
Reference site range	**9–95**	**.005–.097**	**1–10**	**0–5.5**		**2.5–4.5**
Reference site mean	**30.6**	**.017**	**5**	**1.9**		**2.8**
W-171	98	0.15	26	24.1	B	5.2[3]
W-173	141	0.22	20	74.7	B	5.5
W-174	57	0.071	10	37.6	C	4.2
W-175	25	0.013	23	16.7	B	4.2
W-179	265	0.051	23	84.0	B	5.5
W-180	76	0.032	22	21.9	B	4.2
W-181	163	0.091	24	39.9	C	4.8
W-182	1120	0.069	40	100	B	4.5
W-184	234	0.027	22	73.3	B	4.5

[1] Reference site classification attainment: Class AA/A or Class B: 78%; Class C: 8%; Non-attainment: 0

[2] Non-attainment of Class C (i.e., lower than the lowest Maine ALU standards)

[3] MEDEP assigns BCG scores utilizing digits to the right of the decimal point to indicate the strength of association, e.g., level 3.2 means "Leans toward level 2"; level 3.5 means "Solid level 3", level 3.8 means "Leans toward level 4".

6.5.8 Conclusion

For Maine, their approach to classifying waters based on current ecological condition provides a direct linkage to CWA biological integrity objectives and ALU goals. This direct linkage facilitates effective communication with stakeholders and water quality management decision makers on current conditions and the likelihood for improvements. As sustained and significant improvements in biological condition were observed based on systematic monitoring of streams, these improvements were documented and class assignments for specific streams were upgraded (e.g., Class C to B; Class B to A as appropriate). As Maine further develops and applies biological assessment tools and data to water bodies other than streams (e.g., wetlands, estuaries, lakes, large rivers), the BCG is included as part of their toolbox.

6.6 Ohio: Use of Biological Gradient to Support Water Quality Management

6.6.1 Key Message

Ohio has used biological assessment information in conjunction with chemical water quality and physical habitat assessments to support water quality management decisions since the late 1970s. While the Ohio ALU classification framework pre-dated the BCG by 25 years, it is based on concepts that are parallel to the BCG, highlighting the relationship between biology, habitat, and the potential for water quality improvements. Ohio's ecological based approach contributed both technical and implementation "lessons learned" to conceptualization of the BCG (Davies and Jackson 2006). The state's biological monitoring and assessment program has provided timely information about the status of individual water bodies and the data to support water quality management program information needs for more than 35 years. This includes when biological conditions improve and when revisions of designated uses are warranted. A systematic process to determine which use(s) is (are) appropriate and attainable for a stream or river has been and remains the key first step in using biological assessment data to support water quality management.

6.6.2 Background

A major aspect of the development of the Ohio biological assessment program and tiered ALU framework is the experience gained through the sustained development of systematic biological assessments beginning in the late 1970s and through the 1980s. This is where the methods, concepts, and theories were tested, applied, and refined, resulting in a tractable system for measuring biological quality at appropriate spatial scales and through time. Qualitative, narrative guidelines were initially used to assess biological status via systematic watershed monitoring and assessment. The data and experiences gained in this early assessment process provided the raw materials for incorporating the concepts of biological integrity that emerged later. Further refinements were also made to the biological assessment tools and the tiered uses including how they are assigned and assessed. Keys to the success of this approach were the initial decisions about indicator assemblages and methods. These have remained stable through time with no major modifications that could have resulted in disconnections within the statewide database that is more than 35 years old.

Ohio EPA formally adopted numeric biological criteria into the Ohio Water Quality Standards (Ohio WQS; Ohio Administrative Code 3745-1) in 1990. The biological criteria have been used to guide and enhance water quality management programs and assess their environmental outcomes. As a result, the state refined definitions of some ALUs, adopted new ones, and added numerical biological criteria to support a tiered approach to water quality management within the Ohio WQS (Table 38). The numeric biological criteria are an outgrowth of an existing framework of TALUs and narrative biological assessment criteria that had been in place since the late 1970s (Table 39 and Table 40). Ohio's approach to biological assessment evolved from an initial reliance on best professional judgment guided by the narrative biological criteria for determining the quality of fish and macroinvertebrate assemblages to a more quantitative and independent approach based on calibrated indices and numeric biological criteria. While the early narrative descriptions of four levels of quality ranging from excellent to poor (Table 39 and Table 40) predated the BCG, the narrative attributes and the rating of multiple levels of condition are consistent with the attributes and scaling of the current BCG. These concepts were retained and further refined with the development of the fish IBI and invertebrate community integrity index (ICI) and the derivation of numeric biological criteria for the current Ohio TALUs (Figure 64) which were initially mapped to the BCG as part of the early BCG development workshops hosted by EPA (Figure 65).

Table 38. Descriptive summary of Ohio's tiered aquatic life use designations

Aquatic Life Use	Key Attributes	Why a Water body Would Be Designated	Practical Impacts (compared to a baseline of WWH)
Warmwater Habitat (WWH)	Balanced assemblages of fish/invertebrates comparable to least impacted *regional* reference condition	Either supports biota consistent with numeric biological criteria for that ecoregion **or** exhibits the habitat potential to support recovery of the aquatic fauna	Baseline regulatory requirements consistent with the CWA "fishable" and "protection & propagation" goals; criteria consistent with EPA guidance with state/regional modifications as appropriate
Exceptional Warmwater Habitat (EWH)	Unique and/or diverse assemblages; comparable to upper quartile of *statewide* reference condition	Attainment of the EWH biological criteria demonstrated by both organism groups	More stringent criteria for DO, temperature, ammonia, and nutrient targets; more stringent restrictions on dissolved metals translators; restrictions on nationwide dredge & fill permits; may result in more stringent wastewater treatment requirements
Coldwater Habitat (CWH)	Sustained presence of Salmonid or non-salmonid coldwater aquatic organisms; bonafide trout fishery	Biological assessment reveals coldwater species as defined by Ohio EPA (2014); put-and-take trout fishery managed by Ohio Department of Natural Resources	Same as above except that common metals criteria are more stringent; may result in more stringent wastewater treatment requirements
Modified Warmwater Habitat (MWH)	Warmwater assemblage dominated by species tolerant of low DO, excessive nutrients, siltation, and/or habitat modifications	Impairment of the WWH biological criteria; existence and/or maintenance of hydrological modifications that cannot or will not be reversed or abated In the foreseeable future so that WWH biological criteria can be attained; a UAA is required	Less stringent criteria for DO, ammonia, and nutrient targets; less restrictive applications of dissolved metals translators; Nationwide permits apply without restrictions or exception; may result in less restrictive wastewater treatment requirements
Limited Resource Waters (LRW)	Highly degraded assemblages dominated exclusively by tolerant species; *should not* reflect acutely toxic conditions	Extensive physical and hydrological modifications that cannot be reversed, are essentially irretrievable and which preclude attainment of higher uses; a UAA is required	Chemical criteria are based on the prevention of acutely lethal conditions; may result in less restrictive wastewater treatment requirements

Table 39. Narrative biological criteria (fish) for determining ALU designations and attainment of CWA goals (November, 1980; after Ohio EPA 1981)

Evaluation Class Category	"Exceptional" Class I (EWH)	"Good" Class II (WWH)	"Fair" Class III	"Poor" Class IV
1.	Exceptional or unusual assemblage of species	Usual association of expected species	Some expected species absent, or in very low abundance	Most expected species absent
2.	Sensitive species abundant	Sensitive species present	Sensitive species absent, or in very low abundance	Sensitive species absent
3.	Exceptionally high diversity	High diversity	Declining diversity	Low diversity
4.	Composite index > 9.0–9.5	Composite index > 7.0–7.5; < 9.0–9.5	Composite index > 4.5–5.0; < 7.0–7.5	Composite index < 4.0–4.5
5.	Outstanding recreational Fishery		Tolerant species increasing, beginning to dominate	Tolerant species dominate
6.	Rare, endangered, or threatened species present			

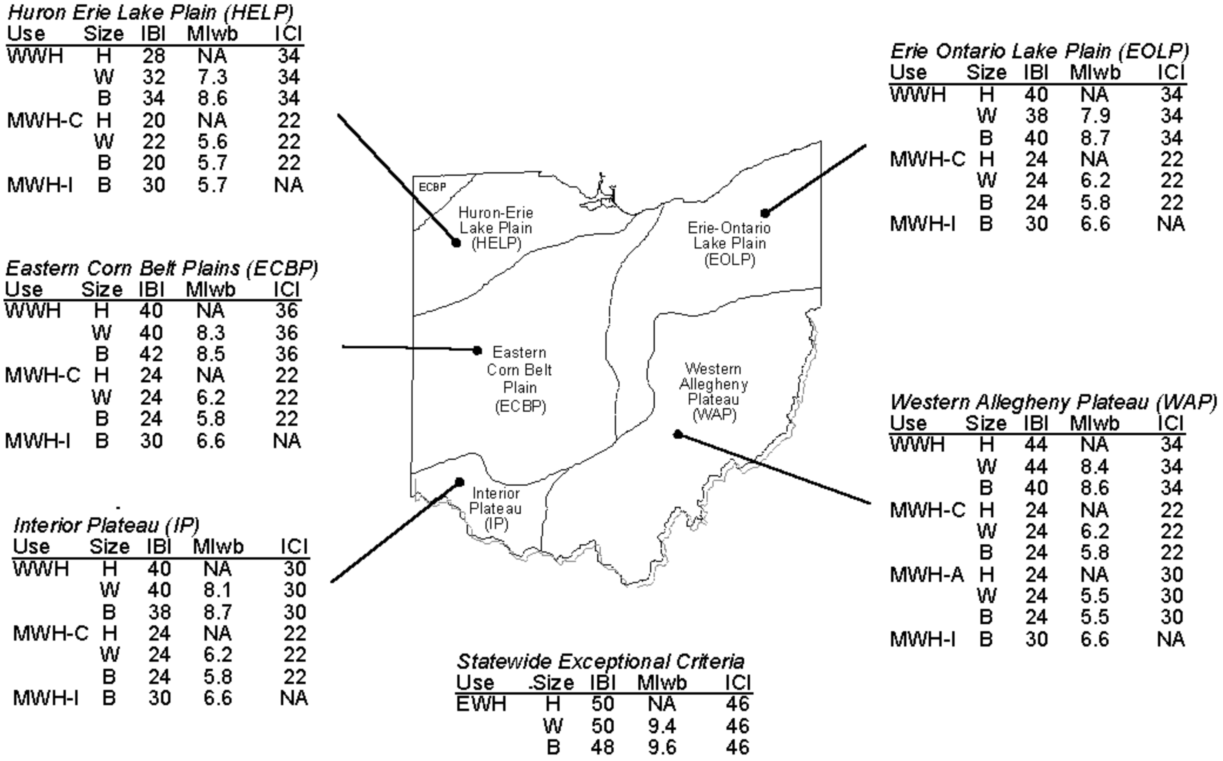
Conditions: Categories 1, 2, 3, and 4 (if data are available) must be met and 5 or 6 must also be met in order to be

Table 40. Narrative biological criteria (macroinvertebrates) for determining ALU designations and attainment of CWA goals (November 1980; after Ohio EPA 1981)

Evaluation Class Category	"Exceptional" Class I (EWH)	"Good" Class II (WWH)	"Fair" Class III	"Poor" Class IV designated in a particular class.
1.	Pollution sensitive species abundant	Pollution sensitive species present in moderate numbers	Pollution sensitive species present in low numbers	Pollution sensitive species absent
2.	Intermediate species present in low numbers	Intermediate species present in moderate numbers	Intermediate species abundant	Intermediate species present in low numbers or absent
3.	Tolerant species present in low numbers	Tolerant species present in low numbers	Tolerant species present in moderate numbers	Tolerant species abundant (all types may be absent if extreme toxic conditions exist)
4.	Number of taxa > 30[1]	Number of taxa 25–30	Number of taxa 20–25	Number of taxa < 20
5.	Exceptional diversity Shannon index < 3.5	High diversity Shannon index 2.9–3.5	Moderate diversity Shannon index 2.3–2.9	Low diversity Shannon index < 2.3

[1] Number of quantitative taxa from artificial substrates.

Ohio Biological Criteria: Adopted May 1990 (OAC 3745-1-07; Table 7-14)



Huron Erie Lake Plain (HELP)

Use	Size	IBI	MIwb	ICI
WWH	H	28	NA	34
	W	32	7.3	34
	B	34	8.6	34
MWH-C	H	20	NA	22
	W	22	5.6	22
	B	20	5.7	22
MWH-I	B	30	5.7	NA

Eastern Corn Belt Plains (ECBP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	36
	W	40	8.3	36
	B	42	8.5	36
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Interior Plateau (IP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	30
	W	40	8.1	30
	B	38	8.7	30
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Erie Ontario Lake Plain (EOLP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	34
	W	38	7.9	34
	B	40	8.7	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Western Allegheny Plateau (WAP)

Use	Size	IBI	MIwb	ICI
WWH	H	44	NA	34
	W	44	8.4	34
	B	40	8.6	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-A	H	24	NA	30
	W	24	5.5	30
	B	24	5.5	30
MWH-I	B	30	6.6	NA

Statewide Exceptional Criteria

Use	Size	IBI	MIwb	ICI
EWH	H	50	NA	46
	W	50	9.4	46
	B	48	9.6	46

Figure 64. Numeric biological criteria adopted by Ohio EPA in 1990, showing stratification of biological criteria by biological assemblage, index, site type, ecoregion for warmwater and modified warmwater habitat (WWH and MWH, respectively), and statewide for the exceptional warmwater habitat (EWH) use designations.

Developed and adopted by Ohio EPA in 1978, the original tiered aquatic life use narratives represented a major revision to a general use framework that was adopted in 1974. Ohio's tiered uses recognized the different types of warmwater aquatic assemblages that corresponded to the mosaic of natural features of the landscape and nearly two centuries of human-induced changes. The eventual development of more refined tiered uses and numeric biological criteria that are in place today was the result of sustained state support to develop a biological monitoring and assessment program with technical capability to discriminate incremental changes in biological condition with increasing stress. The empirical evidence used to develop the initial concepts for tiered uses can be found in comprehensive works on the natural history and zoogeography of the Midwest such as *Fishes of Ohio* (Trautman 1957, 1981). This and other natural history texts documented the natural and human-caused variations in the distribution, composition, and abundance of biological assemblages over space and through time including before and after European settlement. Trautman (1957) not only provides a detailed narrative of Ohio's natural history, but describes the biological evidence that was used to formulate the initial concepts about biological integrity that emerged in the late 1970s and early 1980s and which were later incorporated in the BCG. Such works also described the key features of the landscape that influence and determine the potential aquatic fauna of water bodies and were the forerunners of the regionalization frameworks that appeared soon after. As an alternative to a "one-size-fits-all" approach, these provided an important foundation for the development of Ohio's tiered uses. The articulation of a practical definition of biological integrity by Karr and Dudley (1981) provided a theoretical framework for the development of Ohio's numeric biological criteria (Figure 65). Key components of this framework are: (1) using biological assemblages as a direct measure of ALU attainment status (Herricks and Schaeffer 1985; Karr et al. 1986), (2) the development and use of IBIs as assessment tools (Karr 1981; Karr et al. 1986), (3) derivation of regional reference condition to determine appropriate and attainable ALU goals and assessment endpoints (Hughes et al. 1986), and (4) systematic monitoring and assessment of the state's rivers and streams using a pollution survey design. These represented a major advancement over previous attempts (Ballantine and Guarria 1975) to define and develop a workable framework to address the concept of biological integrity. Embedded in this framework is the recognition that water quality management must be approached from an ecological perspective that is grounded in sound ecological theory *and* which is validated by empirical observation. This means developing monitoring and assessment and WQS to encompass the five factors that determine the integrity of a water resource Figure 22; Karr et al. 1986).

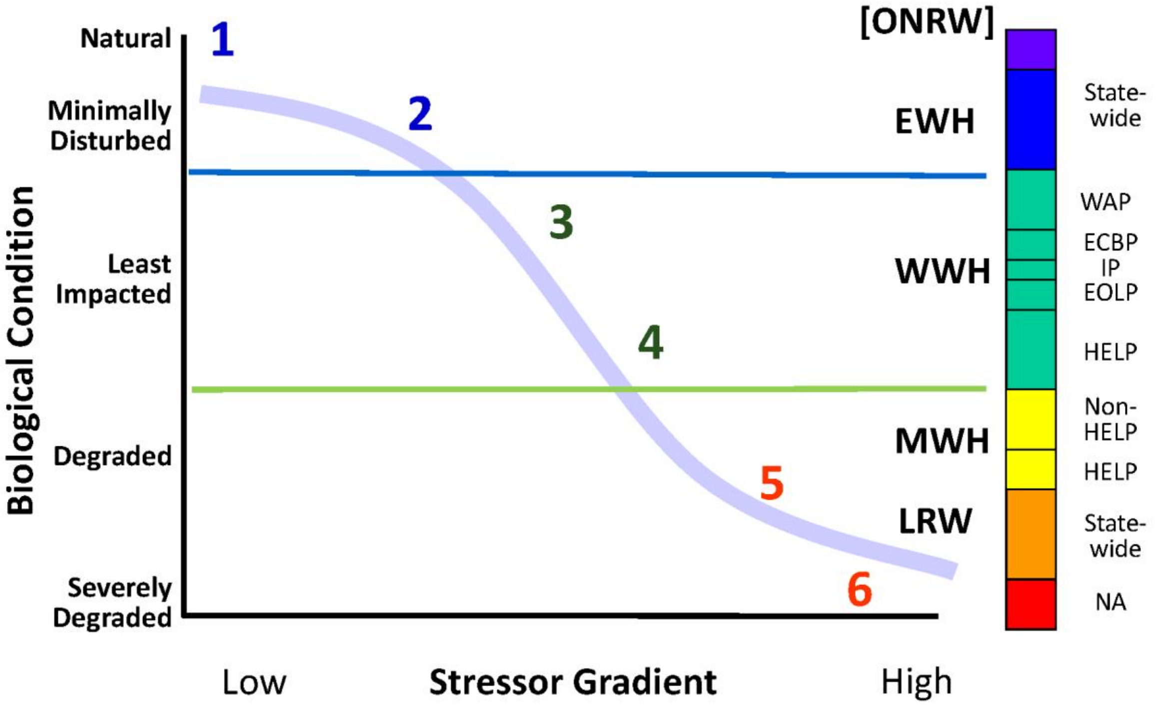
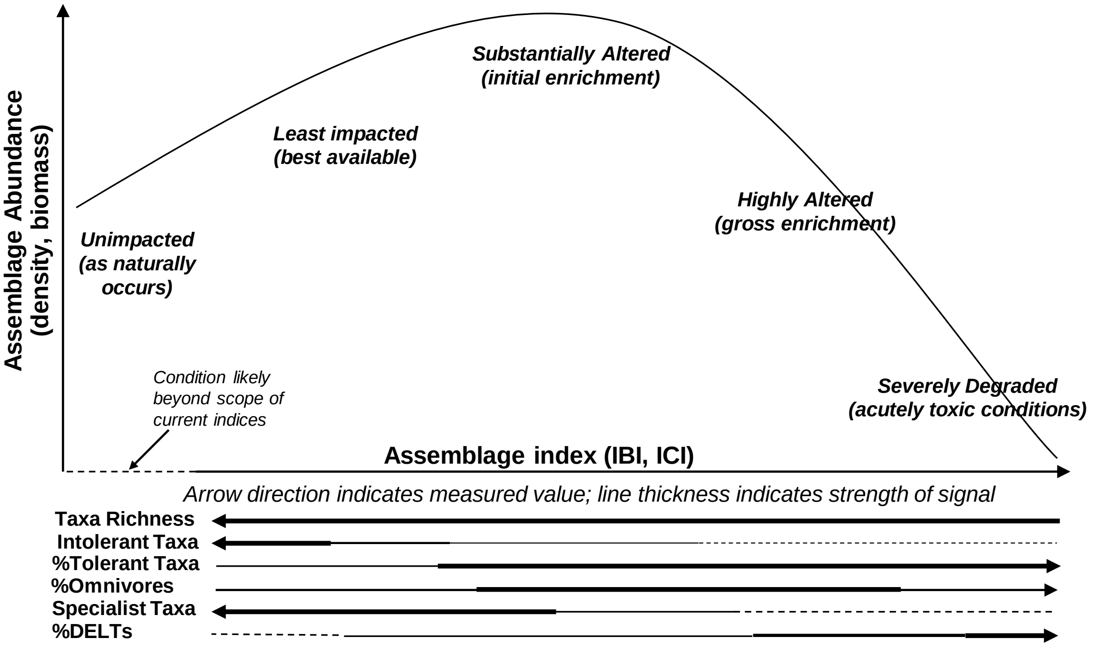


Figure 65. An initial mapping of the Ohio TALUs to the BCG relating descriptions of condition along the y1-axis and ranges of condition encompassed by the numerical biological criteria for each of four tiered use subcategories and the highest antidegradation tier (ONRW) along the y2-axis. ONRW – Outstanding National Resource Waters; EWH – Exceptional Warmwater Habitat; WWH – Warmwater Habitat; MWH – Modified Warmwater Habitat; LRW – Limited Resource Waters.

The understanding of fish and macroinvertebrate assemblage responses to stressor gradients ranging from minimally disturbed to severely altered conditions was affirmed by repeated empirical observations of assemblage responses which are depicted in Figure 66. This graphic represents measured assemblage abundance (y-axis) against assemblage indices (fish IBI, macroinvertebrate ICI; x-axis) with the response of selected metrics and other assemblage attributes at increments along what



Biological and Stressor Gradient Descriptors

"As Naturally Occurs" *(Pristine)*	"Least Impacted" *(Exceptional)*	"Initial Enrichment" *(Good)*	"Moderate Enrichment" *(Fair)*	"Gross Enrichment" *(Poor)*	"Severely Degraded" *(Very Poor)*
Assemblage Characteristics					
Native assemblages; no symptoms of stress	"Best of what's left" assemblages; high richness; intolerants, specialists predominate	"Typical" assemblages; good richness; emerging symptoms of stress in selected metrics	"Impaired" assemblages; tolerants & generalists predominate numbers/biomass; loss of intolerants	"Degraded"; highly tolerant taxa predominate; reduced abundance; anomalies increasing	"Severely degraded"; very low numbers; few taxa; very high % anomalies; toxic signatures
Chemical Water Quality Conditions					
As natural; no human-made compounds present	"Best reference" quality; toxics < detection; high D.O., low nutrients	"Background reference" quality; toxics < chronic; adequate D.O., nutrients = reference	"Enriched" quality; toxics < chronic; marginal D.O. regime, nutrients > reference	"Degraded" quality; toxics > chronic; low D.O., nutrients >> reference	"Extremely poor" quality; toxics ≥ acute; very low D.O., nutrients >> reference; contaminated sediments
Physical Habitat & Flow Regime					
Natural habitat and flow regime; no human-made modifications	Excellent quality habitat & flow regime; recovered from human-made modifications	Good quality habitat & flow regime; *de minimis* human modifications	Fair quality habitat & flow regime; active human modifications; incomplete recovery	Poor quality habitat & flow regime; active human modifications; no recovery	Severe modifications; ephemeral flows; active human modifications; no recovery potential
Examples of Sources and Activities					
No effects of human activity are evident	Point sources present, do not dominate flows; NPS impacts buffered by extensive riparian system	Point sources may dominate flows; NPS impacts buffered by good riparian zones	PS/NPS enrichment impacts; NPS unbuffered; channel modifications; impoundments	Gross PS/NPS enrichment impacts inc. CSOs; NPS unbufferd; channel modifications; urbanization	Severe PS/NPS toxic impacts; extreme channel modifications; urbanization; acid mine drainage, severe thermal

Figure 66. Descriptive model of the response of fish and macroinvertebrate assemblage metrics and characteristics to a quality gradient and different levels of impact from stressors in Midwestern U.S. warmwater rivers and streams (modified from Ohio EPA 1987 and Yoder and Rankin 1995b).

is in reality a continuum. Biological descriptions correspond to the six levels of the then emerging BCG model and include descriptions of key assemblage characteristics, chemical water quality conditions, physical habitat and flow regime, and sources of stress that are typically associated with each. This was modified from the original conceptual model of Ohio EPA (1987a) and Yoder and Rankin (1995b), and it includes the probable upper limits of Ohio's fish and macroinvertebrate indices. It demonstrates that understanding the relationship between assemblage responses and stressors is a fundamental aspect of using biological assessments to support condition assessments *and* water quality management programs. It also demonstrates the pre-BCG concepts that eventually merged in the formal development and description of the current BCG.

6.6.3 Determining Appropriate Levels of Protection

By merging the ALU framework with systematic monitoring and assessment, Ohio has been able to determine attainable levels of condition for streams and rivers and also to set protection levels for high quality waters. This framework is consistently applied within a rotating basin sequence of "biological surveys" that address the following questions:

1) Is the current designated ALU appropriate and attainable and if not, what is the appropriate use for a water body?
2) Are the biological criteria for the most appropriate and attainable use tier attained?
3) Have there been any changes through time and what do they portend for water quality management?

The scale of monitoring and assessment is sufficiently detailed so that designations of individual water bodies or segments of a water body can be made based on scientific information and data. Getting this task done correctly affects everything that follows including assessments of condition and which WQS will guide water quality management actions such as permitting and TMDLs. The data gathered by a biological survey is processed, evaluated, and synthesized in a biological and water quality report. The report serves as the rationale for justifying recommended changes to a currently assigned ALU. The report also identifies sources of pollutants and/or pollution contributing to impairment(s) of the recommended designated uses. The recommendations for use designation revisions are a direct output of the biological and water quality assessment. Recommended revisions to the WQS are based on a UAA framework that emphasizes the demonstrated *potential* to attain a particular use tier based on the following information (and in order of importance):

1) Attainment of the numeric biological criteria for WWH[38] or EWH results in designation of that use; or,
2) If the WWH biological criteria are not attained, the habitat determined by the Qualitative Habitat Evaluation Index (QHEI; Rankin 1995) based on an assessment of habitat attributes is used to determine the *potential* to attain WWH.

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[38] WWH – Warmwater Habitat is the minimum condition that meets the 101[a][2] goal of the Clean Water Act under the Ohio WQS. A UAA is required to designate a river or stream to a lower use (e.g., MWH or LRW).

For uses below WWH (i.e., MWH or LRW), a UAA is performed and includes consideration of the restorability of the water body and of the factors that may preclude WWH attainment. This process requires the following information:

1) The current attainment status of the water body based on a biological assessment performed in accordance with the requirements of the biological criteria, the Ohio WQS, and the Five-Year Monitoring Strategy;
2) A habitat assessment to evaluate the potential to attain WWH; and,
3) A reasonable relationship between the impaired status and the precluding human-caused activities based on an assessment of multiple indicators used in their most appropriate indicator roles and a demonstration consistent with 40 CFR Part 131.10[g].

Since 1978 Ohio EPA has used a consistent process to validate and, if necessary, revise uses in the Ohio WQS. The codified uses for approximately 2,000 streams and rivers have been revised using this process (Figure 67) and information from a biological and water quality assessment. This became a routine practice once the assessment criteria and decision making process for UAAs were established in the mid-1980s. It required the parallel development of reliable tools, particularly for determining status, assessing habitat, and determining causal associations, all of which is part of the developmental process described in several documents and publications (Ohio EPA 1987; 2006; Rankin 1989; 1995; Yoder 1995). The terms "upgrade" and "downgrade" are used only as descriptions of the direction of change from the current codified use to that derived from systematic monitoring and assessment. The vast majority of these changes are from the baseline of original designations that were made in 1978 without the benefit of systematic monitoring and assessment data, numerical biological criteria, and refinements in the process that occurred in the mid-1980s. Hence, these original designations are merely being replaced by the most appropriate use designation based on consistently applied criteria and assessments. Undesignated streams are almost always smaller watersheds of < 5–10 mi^2 drainage area that were missed by the default stream naming format that was employed when stream and river specific designations were originally adopted in 1985. Prior to that time, smaller tributaries were "automatically" assigned the use tier of the parent mainstem river or stream, a practice that resulted in numerous erroneous use designations. The more frequent monitoring of these smaller streams and watersheds in the 1990s and 2000s was partially the result of a shift in emphasis to watershed based TMDLs which resulted in numerous undesignated streams being monitored and hence designated for the first time. A detailed fact sheet is prepared for each use designation rulemaking to communicate the types of proposed changes to the WQS, the rationale for the changes, and which rivers and streams are affected by the proposed changes. When use designation rulemakings are underway, fact sheets specific to affected river basins can be found on Ohio EPA's website.[39]

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[39] See http://epa.ohio.gov/dsw/dswrules.aspx#120473212-early-stakeholder-outreach. Accessed February 2016.

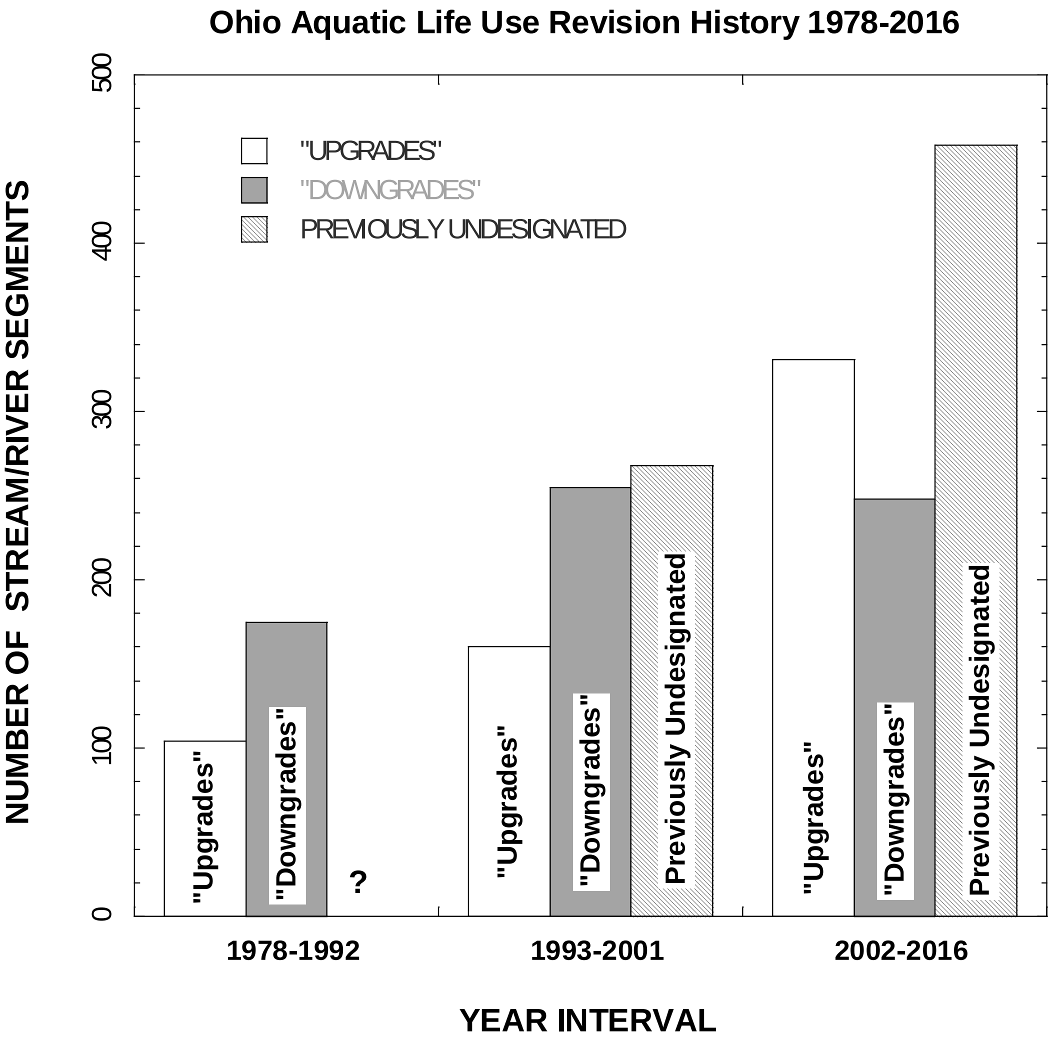

Figure 67. The number of individual stream and river segments in which ALU designations were revised during 1978–1992, 1993–2001, and 2002–2016. Cases where the use was revised to a higher use are termed "upgrades" and cases where a lower use was assigned are termed "downgrades." Previously undesignated refers to streams that were not listed in the 1985 WQS, but which were added as each was designated as a result of systematic monitoring and assessment. The number of waters previously undesignated in the first interval is unknown.

The Ohio tiered use and biological criteria framework and their application to Ohio rivers and streams were first tested in the Ohio court system in 1989 and were validated by a lower court and upheld in appeals up to, and including, the Ohio Supreme Court (NEORSD vs. Shank No. 89-1554, Supreme Court of Ohio, Feb. 27, 1991). The application of the biological criteria to justify additional pollution controls in response to a biological impairment was likewise validated by a lower court and upheld in subsequent appeals (City of Salem vs. Korleski No. 09AP-620, Tenth District Court of Appeals, March 23, 2010; Ohio Supreme Court 2010-0818; appeal not accepted, August 25, 2010).

6.6.4 *Setting Attainable Goals for Improvements*

Ecologically-based tiered uses, a systematic approach to monitoring and assessment, and a tractable UAA process can provide substantial benefits for water quality management programs related to guiding efforts to improve conditions and assessing the effectiveness of those efforts in protecting and restoring an ALU. The identification of the recovery potential for aquatic life in a water body using a systematic approach can help set attainable goals for improvements and support evaluation of environmental risks. The Ohio case example illustrates the role of tiered ALUs using a BCG approach for interpretation of conditions, systematic monitoring and assessment, and a consistent process for conducting UAAs in support of TMDLs. The UAA process is routinely applied as a result of the systematic monitoring and assessment of Ohio rivers and streams (Figure 68). The data are used to support recommendations for revisions to the Ohio WQS on an annual basis.

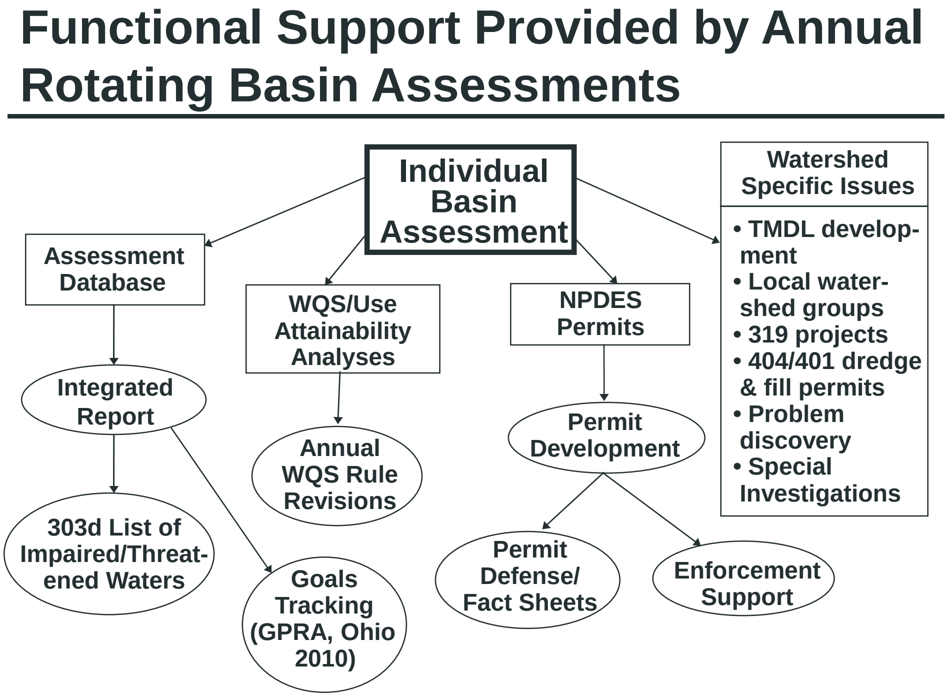

Figure 68. The flow of information from biological and water quality assessments to support for major water quality management programs in Ohio.

Ohio's tiered ALU designation procedures were incorporated into the TMDL process beginning in 1999 (Figure 69; Ohio EPA 1999). Figure 69 illustrates the steps for validating the most appropriate tiered ALU and then basing a TMDL on the criteria embodied by that use tier and the attendant assessment of the receiving streams and rivers. It also illustrates the delineation of the severity and extent of impairments, the most probable causes of the impairments, and follow-up assessments to validate TMDL effectiveness. Because the Ohio EPA monitoring and assessment strategy includes chemical, physical, and biological indicators which are used in their most appropriate roles as indicators of stress, exposure, and response (Yoder and Rankin 1998), support for the development of TMDLs can go beyond addressing singular pollutants to addressing the combination of pollution and pollutants that impair an ALU.

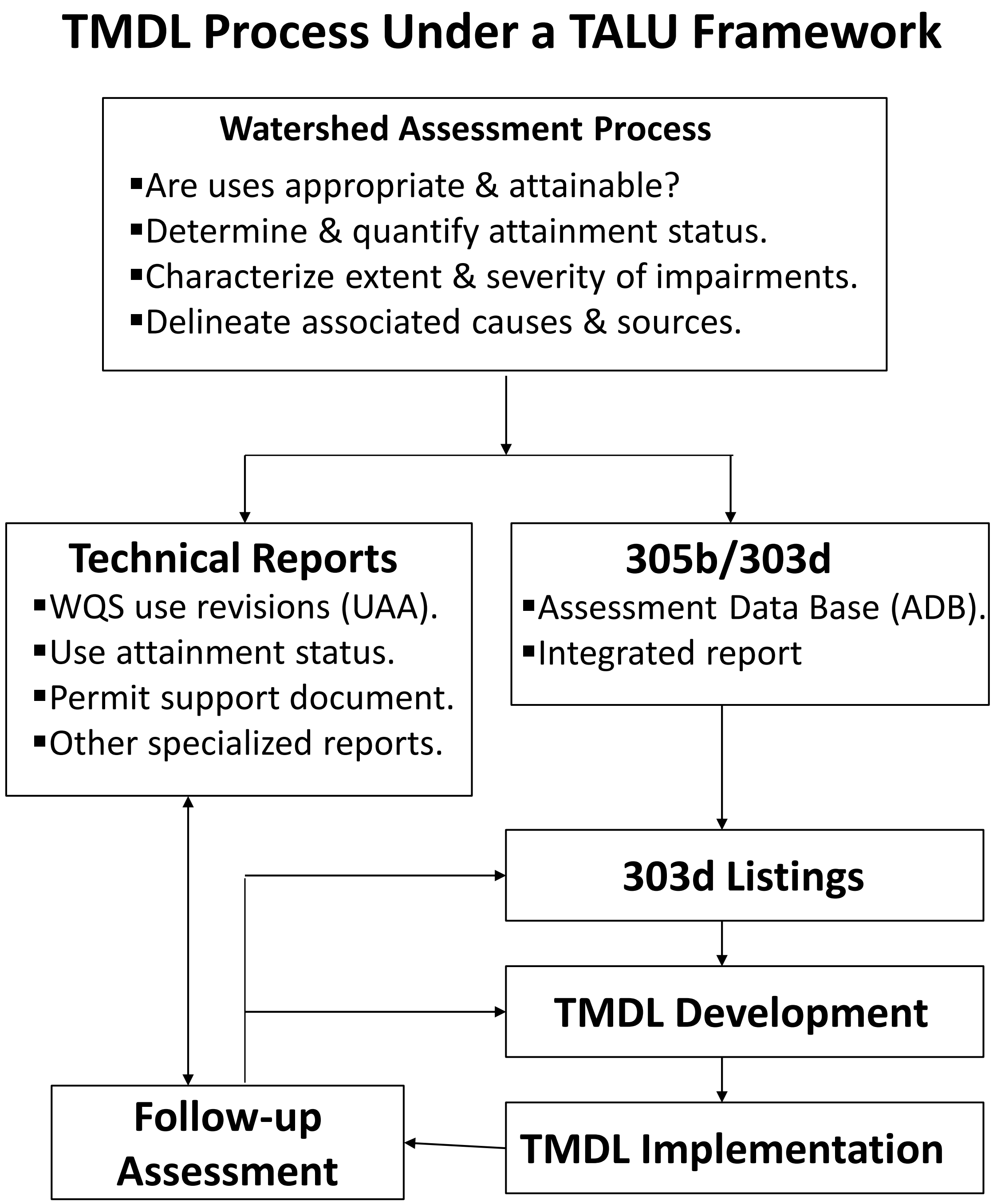

Figure 69. Key steps showing how a TALU based framework can be used to organize and guide a TMDL development and implementation process.

6.6.5 Protecting High Quality Water Bodies

Ohio's antidegradation rule (Ohio Administrative Code 3745-1-05) incorporates levels of protection between the minimum required under the CWA and the maximum protection afforded by federal regulations. The most stringent application of antidegradation is to disallow any lowering of water quality in waters listed as ONRWs. The minimum requirement allows for a lowering of water quality to the minimum WQS applicable to the water body if a determination is made that lowering water quality is necessary to accommodate important social and economic development. However, lowering of water quality below that which is necessary to protect an existing use is prohibited. Ohio has two intermediate levels of protection for certain ecologically important water bodies that permanently reserve a portion of the unused pollutant assimilative capacity, thereby assuring maintenance of a water quality that is better than that prescribed by the prevailing designated use tier. The two intermediate levels are: (1) Outstanding State Water (OSW; Figure 70), and (2) Superior High Quality Water (SHQW) which fall in between ONRW and General High Quality Waters (GHQWs; Figure 71). High quality water bodies are valued public resources because of their ecological and human benefits. Their biological components act as an early warning system that can indicate potential threats to human health, degradation of aesthetic values, reductions in the quality and quantity of recreational opportunities, and other ecosystem

Figure 70. The Mohican River in northeastern Ohio—a candidate for OSW classification because of its high quality ecological and recreational attributes.

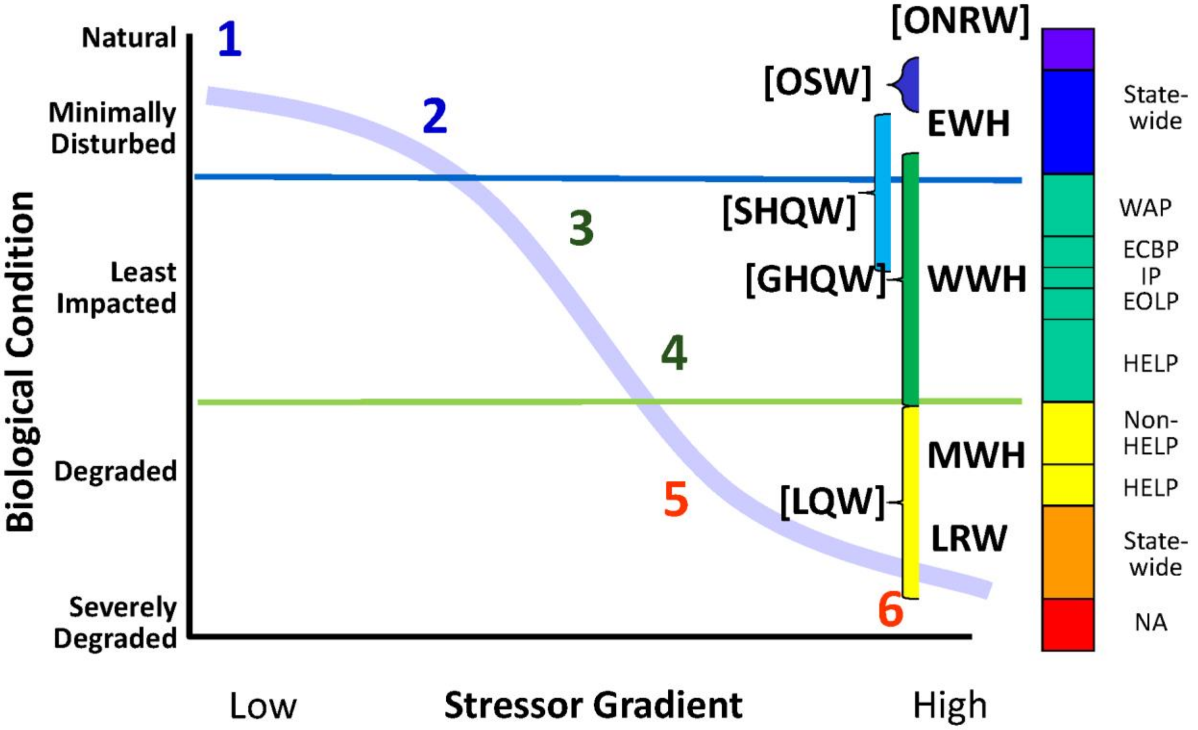

Figure 71. Mapping the Ohio antidegradation tiers to the BCG relating descriptions of condition along the y1-axis and ranges of condition encompassed by the numerical biological criteria for each of four tiered use subcategories and the four antidegradation tiers along the y2-axis. ONRW – Outstanding National Resource Waters; OSW – Outstanding State Waters; SHQW – Superior High Quality Waters; GHQW – Generally High Quality Waters; LQW – Low Quality Waters; EWH – Exceptional Warmwater Habitat; WWH – Warmwater Habitat; MWH – Modified Warmwater Habitat; LRW – Limited Resource Waters.

benefits, or services. The ability of streams and rivers to provide these beneficial services and to act as environmental sentinels is reduced whenever their integrity is degraded. Under the Ohio antidegradation rule, a portion of the remaining assimilative capacity is reserved for water bodies classified as OSW or SHQW in order to preserve an already existing high quality.

Ohio uses a number of biological and physical attributes to place river and stream segments into the OSW, SHQW, and GHQW antidegradation tiers (Table 41). Included are the presence of state or federally listed endangered and threatened species, declining fish species (as defined in the antidegradation rules), the fish and macroinvertebrate assemblage indices (IBI and ICI), the QHEI, the vulnerability of the river or stream to increased stressors, the relative abundance of fish species sensitive to pollution and habitat destruction, and the accumulation of multiple attributes. Adjustments are also made for the Lake Erie drainage to account for the fewer endemic fish and mussel species. Additional considerations include other designations, such as state and national scenic river status, outstanding biodiversity among all aquatic assemblages, exceptionally high quality habitat, and the presence of unique landforms along geological and geomorphological boundaries.

Table 41. General guidelines for nominating OSW, SHQW, and GHQW categories in Ohio. Attributes are considered both singly and in the aggregate

Attribute	OSW	SHQW	GHQW

Attribute	OSW	SHQW	GHQW
Endangered & Threatened Species	Multiple species; large populations; include the most vulnerable species	Present, smaller populations; may include less vulnerable species	Absent or, if present, small populations or of low vulnerability
Declining Fish Species	> 4 declining fish species/segment; large populations	2–4 declining fish species/segment; moderate populations	< 2 declining fish species/segment; typically small populations
IBI and ICI	High mean scores; very high max scores (> 56)	Lower mean scores; fewer high max scores or, if more high scores, few other attributes	Lower mean scores; few or no very high max scores
QHEI	High percentage of QHEI scores ≥ 80	Fewer QHEI scores ≥ 80, many above 70	Few or no QHEI scores ≥ 80, fewer above 70
Vulnerability	Little wastewater effluent; high vulnerability	May be more wastewater effluent; moderate vulnerability	Lower vulnerability; for vulnerable components, antidegradation application may still be denied
Relative Abundance of Fish Species Sensitive to Pollution and Habitat Destruction	Relative abundance is ≥ 3 standard deviations compared to statewide collections of similar sized streams	Relative abundance is ≥ 2 standard deviations compared to statewide collections of similar sized streams	Relative abundance is < 2 standard deviations compared to statewide collections of similar sized streams
Multiple Attributes	High co-occurrence of above attributes	Lower co-occurrence of above attributes or individual attributes more marginal	Little co-occurrence of above attributes, individual attributes often marginal if present

6.6.6 Conclusion

The Ohio approach to classifying waters based on current ecological condition and potential for improvement provides a direct linkage to the CWA biological Integrity objective and ALU goals. This direct linkage enables more effective communication with stakeholders and water quality management decision makers on current conditions and likelihood for improvements. The BCG-like approach enables Ohio EPA to account for biological expectations relative to ecoregion and drainage area and provides a numeric value that synthesizes everything that is being experienced by the biota that can be tracked, monitored, and compared over time to determine if conditions are improving, stabilizing, or deteriorating. As chemical, physical, and biological monitoring has been coordinated and the database expanded, critical information for investigating cause and source of biological impairments has been built and has enabled water quality managers to target sources of stressors and their mechanism of action on the aquatic ecosystem. Because of this database, the state has been able to develop water quality goals for some parameters less well-suited to the classic dose-response relationship for DO and many toxicants. Ohio's ecologically-based approach to classifying waters combined with a robust monitoring program has provided a scientifically defensible method to categorize waters into designated uses and antidegradation tiers. The process has generated UAAs and justification documents as an accepted and routine rulemaking process, primarily resulting in incremental upgrades as controls and BMPs were implemented and improvements observed.

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Glossary

aquatic assemblage	An association of interacting populations of organisms in a given water body; for example, fish assemblage or a benthic macroinvertebrate assemblage.
aquatic community	An association of interacting assemblages in a water body, the biotic component of an ecosystem.
aquatic life use	A beneficial use designation in which the water body provides, for example, suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms.
attribute	The measurable part or process of a biological system.
benthic macroinvertebrates or benthos	Animals without backbones, living in or on the sediments, of a size large enough to be seen by the unaided eye and which can be retained by a U.S. Standard no. 30 sieve (28 meshes per inch, 0.595-mm openings); also referred to as benthos, infauna, or macrobenthos.
best management practice	An engineered structure or management activity, or combination of those, that eliminates or reduces an adverse environmental effect of a pollutant.
biological assessment or bioassessment	An evaluation of the biological condition of a water body using surveys of the structure and function of a community of resident biota.
biological criteria or biocriteria	Narrative expressions or numeric values of the biological characteristics of aquatic communities based on appropriate reference conditions; as such, biological criteria serve as an index of aquatic community health.
biological indicator or bioindicator	An organism, species, assemblage, or community characteristic of a particular habitat, or indicative of a particular set of environmental conditions.
biological integrity	The ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats in a region.
biological monitoring or biomonitoring	Use of a biological entity as a detector and its response as a measure to determine environmental conditions; ambient biological surveys and toxicity tests are common biological monitoring methods.
biological survey or biosurvey	Collecting, processing, and analyzing a representative portion of the resident aquatic community to determine its structural and/or functional characteristics.

biotope	An area that is relatively uniform in physical structure and that is identified by a dominant biota.
catchment	An incremental watershed that drains directly into a stream reach and excludes upstream areas.
Clean Water Act	The act passed by the U.S. Congress to control water pollution (formally referred to as the Federal Water Pollution Control Act of 1972). Public Law 92-500, as amended. 33 U.S.C. 1251 *et seq*.
Clean Water Act section 303(d)	This section of the act requires states, territories, and authorized tribes to develop lists of impaired waters for which applicable WQS are not being met, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that the jurisdictions establish priority rankings for waters on the lists and develop TMDLs for the waters. States, territories, and authorized tribes are to submit their lists of waters on April 1 in every even-numbered year.
Clean Water Act section 305(b)	Biennial reporting requires description of the quality of the nation's surface waters, evaluation of progress made in maintaining and restoring water quality, and description of the extent of remaining problems.
Clean Water Act section 304(a) criteria	EPA-published, recommended water quality criteria that consist of scientific information regarding concentrations of specific chemicals or levels of parameters in water that protect aquatic life and human health. The States may use these contents as the basis for developing enforceable water quality standards.
criteria	Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.
designated uses	Those uses specified in WQS for each water body or segment whether or not they are being attained.
disturbance	Human activity that alters the natural state and can occur at or across many spatial and temporal scales.
ecological integrity	The condition of an unimpaired ecosystem as measured by combined chemical, physical (including physical habitat), and biological attributes. Ecosystems have integrity when they have their native components (plants, animals and other organisms) and processes (such as growth and reproduction) intact.

ecoregion	A relatively homogeneous ecological area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.
function	Processes required for normal performance of a biological system (may be applied to any level of biological organization).
guild	A group of organisms that exhibit similar habitat requirements and that respond in a similar way to changes in their environment.
historical data	Data sets from previous studies, which can range from handwritten field notes to published journal articles.
index of biological/biotic integrity	An integrative expression of site condition across multiple metrics; an IBI is often composed of at least seven metrics.
invasive species	A species whose presence in the environment causes economic or environmental harm or harm to human health. Native species or nonnative species can show invasive traits, although that is rare for native species and relatively common for nonnative species. (Note that this term is not included in the biological condition gradient [BCG].)
least disturbed condition	The best available existing conditions with regard to physical, chemical, and biological characteristics or attributes of a water body within a class or region. Such waters have the least amount of human disturbance in comparison to others in the water body class, region, or basin. Least disturbed conditions can be readily found but can depart significantly from natural, undisturbed conditions or minimally disturbed conditions. Least disturbed condition can change significantly over time as human disturbances change.
maintenance of populations	Sustained population persistence; associated with locally successful reproduction and growth.
metric	A calculated term or enumeration that represents some aspect of biological assemblage, function, or other measurable aspect and is a characteristic of the biota that changes in some predictable way with increased human influence.
minimally disturbed condition	The physical, chemical, and biological conditions of a water body with very limited, or minimal, human disturbance.
multimetric index	An index that combines indicators, or metrics, into a single index value. Each metric is tested and calibrated to a scale and transformed into a unitless score before being aggregated into a multimetric index. Both the index and metrics are useful in assessing and diagnosing ecological condition. See **index of biological/biotic integrity (IBI).**

narrative biological criteria	Written statements describing the structure and function of aquatic communities in a water body that support a designated aquatic life use.
native	An original or indigenous inhabitant of a region; naturally present.
nonnative or intentionally introduced species	With respect to an ecosystem, any species that is not found in that ecosystem; species introduced or spread from one region of the United States to another outside their normal range are nonnative or non-indigenous, as are species introduced from other continents.
numeric biological criteria	Specific quantitative measures of the structure and function of aquatic communities in a water body necessary to protect a designated aquatic life use.
periphyton	A broad organismal assemblage composed of attached algae, bacteria, their secretions, associated detritus, and various species of microinvertebrates.
rapid bioassessment protocols	Cost-effective techniques used to survey and evaluate the aquatic community to detect aquatic life impairments and their relative severity.
rebuttable presumption	In the context of water quality standards, the concept that the CWA 101(a)(2) uses are attainable and therefore must be assigned to a water body, unless a State or Tribe affirmatively demonstrates, with appropriate documentation, that such uses are not attainable.
recovery potential	In the context of water quality management, the likelihood that an impaired water body can be restored so that it ultimately meets water quality standards. Consideration of ecological, stressor, and social factors are involved in the consideration of recovery potential.

reference condition (biological integrity)	The condition that approximates natural, unaffected conditions (biological, chemical, physical, and such) for a water body. Reference condition (biological integrity) is best determined by collecting measurements at a number of sites in a similar water body class or region undisturbed by human activity, if they exist. Because undisturbed conditions can be difficult or impossible to find, minimally or least disturbed conditions, combined with historical information, models, or other methods can be used to approximate reference condition as long as the departure from natural or ideal is understood. Reference condition is used as a benchmark to determine how much other water bodies depart from this condition because of human disturbance. See definitions for minimally and least disturbed condition
reference site	A site selected for comparison with sites being assessed. The type of site selected and the types of comparative measures used will vary with the purpose of the comparisons. For the purposes of assessing the ecological condition of sites, a reference site is a specific locality on a water body that is undisturbed or minimally disturbed and is representative of the expected ecological integrity of other localities on the same water body or nearby water bodies.
refugia	Accessible microhabitats or regions in a stream reach or watershed where adequate conditions for organism survival are maintained during circumstances that threaten survival; for example, drought, flood, temperature extremes, increased chemical stressors, habitat disturbance.
sensitive taxa	Taxa intolerant to a given anthropogenic stress; first species affected by the specific stressor to which they are *sensitive* and the last to recover following restoration.
sensitive or regionally endemic taxa	Taxa with restricted, geographically isolated distribution patterns (occurring only in a locale as opposed to a region), often because of unique life history requirements. Can be long-lived, late-maturing, low-fecundity, limited-mobility, or require mutualist relation with other species. Can be among listed endangered/threatened or special concern species. Predictability of occurrence often low; therefore, requires documented observation. Recorded occurrence can be highly dependent on sample methods, site selection, and level of effort.

sensitive-rare taxa	Taxa that naturally occur in low numbers relative to total population density but can make up large relative proportion of richness. Can be ubiquitous in occurrence or can be restricted to certain micro-habitats, but because of low density, recorded occurrence is dependent on sample effort. Often stenothermic (having a narrow range of thermal tolerance) or coldwater obligates; commonly K-strategists (populations maintained at a fairly constant level; slower development; longer life span). Can have specialized food resource needs or feeding strategies. Generally intolerant to significant alteration of the physical or chemical environment; are often the first taxa observed to be lost from a community.
sensitive-ubiquitous taxa	Taxa ordinarily common and abundant in natural communities when conventional sample methods are used. Often having a broader range of thermal tolerance than sensitive or rare taxa. These are taxa that constitute a substantial portion of natural communities and that often exhibit negative response (loss of population, richness) at mild pollution loads or habitat alteration.
stressors	Physical, chemical, and biological factors that adversely affect aquatic organisms.
structure	Taxonomic and quantitative attributes of an assemblage or community, including species richness and relative abundance structurally and functionally redundant attributes of the system and characteristics, qualities, or processes that are represented or performed by more than one entity in a biological system.
taxa	A grouping of organisms given a formal taxonomic name such as species, genus, family, and the like.
taxa of intermediate tolerance	Taxa that compose a substantial portion of natural communities; can be r-strategists (early colonizers with rapid turnover times; boom/bust population characteristics). Can be eurythermal (having a broad thermal tolerance range). Can have generalist or facultative feeding strategies enabling utilization of relatively more diversified food types. Readily collected with conventional sample methods. Can increase in number in waters with moderately increased organic resources and reduced competition but are intolerant of excessive pollution loads or habitat alteration.

tolerant taxa	Taxa that compose a small proportion of natural communities. They are often tolerant of a broader range of environmental conditions and are thus resistant to a variety of pollution- or habitat-induced stresses. They can increase in number (sometimes greatly) in the absence of competition. Commonly r-strategists (early colonizers with rapid turnover times; boom/bust population characteristics), able to capitalize when stress conditions occur; last survivors.
total maximum daily load	The sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources; the calculated maximum amount of a pollutant a water body can receive and still meet WQS and an allocation of that amount to the pollutant's source.
water quality management (nonregulatory)	Decisions on management activities relevant to a water resource, such as problem identification, need for and placement of best management practices, pollution abatement actions, and effectiveness of program activity.
water quality standard	A law or regulation that consists of the designated use or uses of a water body, the narrative or numerical water quality criteria (including biological criteria) that are necessary to protect the use or uses of that water body, and antidegradation requirements.
whole effluent toxicity	The aggregate toxic effect of an aqueous sample (e.g., whole effluent wastewater discharge) as measured by an organism's response after exposure to the sample (e.g., lethality, impaired growth or reproduction); WET tests replicate the total effect and actual environmental exposure of aquatic life to toxic pollutants in an effluent without requiring the identification of the specific pollutants.

Abbreviations and Acronyms

ADEM	Alabama Department of Environmental Management
AIS	aquatic invasive species
ALAWADR	Alabama Water-Quality Assessment and Monitoring Data Repository
ALU	aquatic life use
ANOVA	univariate analysis of variance
aRPD	apparent redox potential discontinuity
ATtiLA	Analytical Tools Interface for Landscape Assessments
AUSRIVAS	AUStralian RIVer Assessment System
BCG	biological condition gradient
BEAST	BEnthic Assessment of SedimenT
BMP	best management practice
BT	brook trout
CADDIS	Causal Analysis/Diagnosis Decision Information System
CART	classification and regression tree (statistical analysis)
CBP	Chesapeake Bay Program
CCA	Canonical Correspondence Analysis
CFR	*Code of Federal Regulations*
CIBI	Continuous Index of Biological Integrity
CNMI	Commonwealth of the Northern Mariana Islands
CRW	Coral Reef Watch, NOAA
CT DEEP	Connecticut Department of Energy and Environmental Protection
Cu	copper
CWA	Clean Water Act
CWH	coldwater habitat
DELT	deformities, erosion, lesions, and tumors
D-IBI	diadromous index of biotic integrity
DO	dissolved oxygen
EDAS	Environmental Data Acquisition System
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
EPT	ephemeroptera, plecoptera, trichoptera taxa
ESD	environmental site design
E/T	endangered/threatened
EV	exceptional value
FACI	Fish Assessment Community Index
F-IBI	fish index of biological/biotic integrity
GAM	general additive model
GHQW	General High Quality Water

GLEI	Great Lakes Environmental Indicators
GRE	Great Rivers Evaluation
GRFIn	Great River Fish Index
GSA	generalized stress axis
HDG	human disturbance gradient
HDS	human disturbance score
HQ	high-quality
HUC	hydrologic unit code
HWI	Healthy Watershed Index
IBI	index of biological/biotic integrity
IC	impervious cover
ICI	invertebrate community integrity index
LDI	landscape development intensity index
LDM	linear discriminant model
LRBOI	Little River Band of Ottawa Indians
LRW	limited resource water
LWD	large, woody debris
MANOVA	multivariate analysis of variance
MCDEP	Montgomery County Department of Environmental Protection
MEDEP	Maine Department of Environmental Protection
M-IBI	macroinvertebrate index of biological/biotic integrity
mIBI	modified index of biological integrity
MIwb	modified index of well-being
MMI	multimetric index
M-NCPPC	Maryland-National Capital Park and Planning Commission
MPCA	Minnesota Pollution Control Agency
MWH	modified warmwater habitat
NA	non-attainment
NBEP	Narragansett Bay Estuary Program
NCRMP	National Coral Reef Monitoring Program
NELP	New England large rivers
NHD	National Hydrography Dataset
NIH	National Institutes of Health
NJ DEP	New Jersey Department of Environmental Protection
NLCD	National Land Cover Database
NMDS	non-metric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
O/E	observed over expected
OM	organic matter

ONRW	Outstanding National Resource Water
OSI	Organism-Sediment Index
OSW	Outstanding State Water
PA DEP	Pennsylvania Department of Environmental Protection
PAR	photosynthetic active radiation
PCA	Principal Component Analysis
QHEI	qualitative habitat evaluation index
POM	particulate organic matter
REMAP	Regional Environmental Monitoring and Assessment Program
RIDEM	Rhode Island Department of Environmental Management
RIVPACS	River Invertebrate Prediction and Classification System
RM	river mile
RPS	Recovery Potential Screening
SHQW	Superior High Quality Water
SPI	sediment profile imagery
SST	sea surface temperature
STORET	STOrage and RETrieval
TALU	tiered aquatic life use
TBEP	Tampa Bay Estuary Program
TITAN	Threshold Indicator Taxa ANalysis
TIV	Tolerance Indicator Value
TMC	Ten Mile Creek
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
UAA	use attainability analysis
UMRBA	Upper Mississippi River Basin Association
UMR	Upper Mississippi River
USVI	U.S. Virgin Islands
WDG	watershed disturbance gradient
WSIO	Watershed Index Online
WQS	water quality standards
WQTF	Water Quality Task Force
WQV	Weighted Stressor Value
WWH	warmwater habitat
WWTF	wastewater treatment facility

EPA 842-R-16-001

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