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Office of Research and Development
National Health and Environmental Effects Research Laboratory

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Notice and Disclaimer

The EPA Office of Water's Biological Condition Gradient method was originally developed for application to freshwater streams. This document adapts that approach for use in larger and more complex estuarine and coastal systems. The discussions in this document are intended solely to provide information on advancements in the field of biological assessment. The EPA through its Office of Research and Development, Office of Water, and Region 1 funded and collaborated in the research described here. This document has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. While this manual describes EPA's scientific recommendations regarding biological assessment to help protect aquatic life in coastal and estuarine ecosystems, it does not substitute for CWA or EPA regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, territories, tribes, or the regulated community and might not apply to a particular situation or circumstance. EPA may change this guidance in the future. All environmental data in this document are reported in the published literature and are used here to illustrate the Biological Condition Gradient development process. This is a contribution to the EPA Office of Research and Development's Safe and Sustainable Waters Research Program.

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Cover photos, clockwise from upper left: 1) Entrance to Point Judith Pond, Narragansett, RI. 2) Scientist collecting data, La Parguera reefs, PR. 3) Shipping cranes, San Pedro Harbor, Los Angeles, CA. 4) Kayakers enjoying Caribbean coastal waters. 5) Elkhorn coral, Dominican Republic. 6) Mary Donovan Marsh, Little Compton, RI.

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List of Acronyms

ALU	Aquatic Life Uses
AUV	Autonomous Underwater Vehicle
BCG	Biological Condition Gradient
CMECS	Coastal and Marine Ecological Classification Standard
CMSP	Coastal and Marine Spatial Planning
CPUE	Catch Per Unit Effort
CWA	Clean Water Act
CWA 303(d)	Clean Water Act List of Impaired Waters
DPSIR	Drivers-Pressures-State-Impacts-Responses
EBM	Ecosystem-Based Management
EPA	Environmental Protection Agency
EU	European Union
FGDC	Federal Geographic Data Committee
GSA	Generalized Stress Axis
HICO	Hyperspectral Imager for the Coastal Ocean
IBI	Index of Biological Integrity
LCEP	Lower Columbia Estuary Partnership
MBNEP	Mobile Bay National Estuary Program
NBEP	Narragansett Bay Estuary Program
NCCA	National Coastal Condition Assessment
NEP	National Estuary Program
NERR	National Estuarine Research Reserve
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
RPB	Regional Planning Body
SCCWRP	Southern California Coastal Water Research Project
SDM	Structured Decision Making
SNA	Social Network Analysis
TBEP	Tampa Bay Estuary Program
TALU	Tiered Aquatic Life Uses
TMDL	Total Maximum Daily Load
USCRTF	United States Coral Reef Task Force
WFD	Water Framework Directive
WQS	Water Quality Standards

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This work was inspired by the earlier work of those scientists who developed the foundational concepts of integrity, condition, bioassessment, biocriteria, and related topics. We thank the many scientists who participated in our 2008 and 2009 workshops for their insights and contributions to this effort. We are grateful to Holly Greening of the Tampa Bay Estuary Program for her continued support. We recognize Catherine Corbett of the Lower Columbia Estuary Partnership as well as Tom Herder and Roberta Swann of the Mobile Bay Estuary Program for their BCG work and insightful comments. Marnita Chintala of the U.S. EPA Atlantic Ecology Division promoted these efforts, while Naomi Detenbeck, Dan Campbell, and Elizabeth Watson (also of the Atlantic Ecology Division) provided thoughtful reviews of this document.

Executive Summary

Estuaries and coastal systems are areas of confluence and connection. The river and the land meet the ocean here, resulting in steep gradients of habitat change, a diversity of life, and high biological productivity. People also meet the ocean here and have been attracted to coastlines for many thousands of years. Human populations are expanding rapidly on our coasts; this leads to increased environmental stressors (including excess nutrients, habitat alteration, and toxic pollution) and the need for more effective management of these valuable areas.

Living organisms respond to the cumulative impacts of all stressors, and natural populations of biota have been affected for centuries. These biological changes can be addressed with bioassessments– evaluations of the biological condition of a waterbody using surveys of the structure and function of biotic elements. Bioassessment puts a spotlight on biology and allows managers to address the cumulative impacts that degrade environmental condition. Bioassessment in estuaries and coasts integrates many of the upstream stressors in the larger watershed as well as stressors within the waterbody and is a vital part of managing at the waterbody and watershed levels.

The Biological Condition Gradient (BCG) is a conceptual scientific framework for interpreting biological response to increasing effects of stressors on aquatic ecosystems (U.S. EPA 2016). The framework was developed from common patterns of biological response to stressors observed empirically by aquatic biologists and ecologists in different geographic areas of the United States. The framework describes how attributes of aquatic ecosystems change in response to increasing levels of stressors, from an "as naturally occurs" condition (e.g., undisturbed or minimally disturbed) to a severely altered condition.

The highest level of condition, level 1, represents natural or undisturbed biological communities and anchors the starting point for defining five levels of change or departure from this condition with level 6 representing conditions that have been severely altered due to anthropogenic stress. Each level is defined by a narrative description that can be consistently interpreted regardless of biology, location, or sampling method. These narratives are translated into quantitative decision rules for specific local areas through expert consensus. The BCG end product is a set of well-vetted and transparent decision rules that can be readily interpreted and implemented by state water quality program managers and scientists, and can be easily understood by stakeholders, the public, and higher levels of management.

This process provides the conceptual basis for comparable interpretation of assessments and for clear communication of condition, because the levels have the same basic meaning wherever BCG is applied. Level 4 for fish in a New Jersey estuary describes the same relative biological condition as level 4 for invertebrates in a Maine stream, although in practice the different datasets used in analyses will introduce variability. The BCG provides a tool for effective comparisons of condition across time and among waterbodies, allowing managers to support Clean Water Act (CWA) and Total Maximum Daily Load (TMDL) programs, communicate relative condition, develop thresholds, set goals, and monitor progress towards these goals. The BCG framework was initially developed for application in freshwater streams and has been applied in these environments for years as a management tool to interpret baseline conditions, identify high quality waters, and define attainable goals for improvements in degraded waters.

This document expands the stream BCG framework and proposes guidance for estuarine and coastal BCG implementation as a sequence of actions or steps to assist estuarine and coastal scientists and managers as they plan and implement environmental decisions. The initial Steps (1–7) walk scientists and managers through identifying stakeholders, problems, goals, and relevant biological indicators to develop a descriptive BCG. This phase establishes a common understanding among potential users on the role of a BCG in meeting their specific resource management needs. For example, a descriptive (qualitative) BCG can be used to refine stakeholder visions, improve narrative designated use categories, set broad goals, and communicate biological condition to motivate the public. The last set of actions or Steps (8–11) guide development of a more rigorous quantitative BCG that can help establish numeric thresholds for assessing biological condition, inform CWA decisions, track changes in condition, develop biological criteria, and monitor to evaluate management actions. The approach is flexible–coastal and estuarine managers can choose to develop any of the steps that would best meet their requirements, and in any order. National Estuary Programs (NEPs) were the first groups to adopt this BCG implementation guidance, and the approach is well suited to address many of their needs. Implementation steps of estuarine/coastal BCG development are:

1. Define problems, engage partners and stakeholders
2. Collaborate to define management goals, visions, and objectives
3. Determine the biological components, stressors, measures, and attributes most relevant to management objectives
4. Delineate and classify the waterbody and watershed of interest
5. Organize and analyze existing data for the identified measures, collect new data if needed
6. Define BCG level 1 conditions for the identified attributes
7. Develop narrative descriptions of the biology expected at each BCG level as a narrative BCG model; apply to management needs
8. Convert narrative descriptions to quantitative metrics and thresholds, calibrate the BCG
9. Develop a stressor gradient and stressor-response relationships
10. Organize, interpret, and report results
11. Develop decision support, communication, and monitoring tools; assist management partners.

These BCG implementation steps provide a path for scientists and managers to identify and solve environmental problems. The methods and outputs can be tailored to larger well-funded programs such as state and federal agencies or to smaller programs with fewer resources including NEPs, National Estuarine Research Reserves, town or county governments, and local Non-Governmental Organizations (NGOs) or coalitions.

The estuarine and coastal BCG offers an easily understood method for communicating biological condition in a way that engages the public and other stakeholders. BCG levels can be used at the waterbody scale to define current biological conditions for determining attainment of CWA goals; set non-regulatory goals and targets for attaining a desired biological or ecological condition; and track environmental progress towards achieving targets and goals. NEPs who have used the estuarine and coastal BCG identify the ability to set meaningful targets for habitat protection and restoration, and the ability to positively engage the public and other stakeholders as primary benefits of the approach. At the national scale, consistent interpretation of biological assessments in estuaries and coasts allows for comparisons across waterbodies and better reporting of condition in national surveys, including documentation of successes in restoring or protecting these critical resources. This application of the BCG to estuaries and coasts is adaptable and can be modified for other waterbody types that are studied and managed as individual systems. The process is well underway for estuaries and coral reefs and could also be applied to large rivers, lakes, and other waterbodies.

This document serves as technical guidance for scientists and managers taking on projects that would benefit from use of bioassessment to manage complex coastal systems. BCG methods are described in a logical order of development steps, with recommendations for different uses of BCG in management. Case studies illustrate applications of this approach to waterbodies in a variety of geographic and ecological settings.

1. Introduction

Cumulative impacts and bioassessment

Estuaries and other coastal systems are among the environments most influenced by human activities. These waters are affected by a variety of stressors that act at several scales, including localized point sources of contaminants, anthropogenic inputs from the watershed and the ocean, habitat destruction, widespread or diffuse non-point sources of contaminants, biological harvesting, and larger scale impacts such as sea level rise (Figure 1-1). These valued ecosystems, and their biota, are significantly altered by the cumulative impacts of multiple stressors. Over time, this has led to "severe, long-term degradation of near-shore marine systems worldwide" (Lotze et al. 2006).

Effective management of cumulative impacts on any scale requires coordination among management entities and a variety of tools to quantify degradation, identify causes, address those causes, and track progress. No single approach can address all of these issues, but evaluations of biology are very often used to characterize and communicate the extent of anthropogenic degradation. Biological condition integrates the effects of all the stressors that living organisms are exposed to and can be an effective tool in managing cumulative impacts. Many different methods and indices to quantify biological condition have been developed and applied by scientists, local resource managers, states, and federal agencies. Most bioassessments evaluate changes in quality or quantity of ecologically or economically defined condition or value of habitats, communities, or species, relative to a defined reference state.

Figure 1-1. Docks, roads, commercial fishing vessels, marine transportation, and industry in Point Judith Harbor, RI, an illustration of estuarine uses and stressors.

Consistent bioassessment

These assessments, when applied in different estuaries, often evaluate very different aspects of biology and use different reference conditions, usually for the good reason that biology differs among estuaries. Nonetheless, independent bioassessments do not allow comparisons among estuaries on statewide, regional, or national levels. Estuarine managers have little context for how biological condition in their waterbody compares to that in nearby estuaries, and larger-scale managers cannot easily provide area-wide condition reports or analyses with which to focus priorities for protection or restoration.

One approach to common assessment is to employ an Index of Biological Integrity (IBI), which may be developed for different assemblages (e.g., fishes, invertebrates) in local or regional areas. IBIs tend to be well calibrated and effective for their local area of development, but results are generally not applicable to other areas. The issue of regional comparability has led to development of a nationwide estuarine benthic index using invertebrates (Gillette et al. 2015). However, nationwide indices for other assemblages have not been developed, and local managers may not have the appropriate data or resources to apply these approaches.

Other nationwide approaches, described in the Coastal and Marine Ecological Classification Standard (CMECS), can be based on analyses standardized to infaunal community successional stage (FGDC 2012), or on image-based indices of condition, e.g., sediment profile cameras but these measures may be less sensitive than well-tuned local indices. Further, the widespread use of different bioassessment endpoints leads to reports that are not comparable among waterbodies, states, or federal agencies. A common framework for interpreting data and assessment results and communicating this information to stakeholders would enhance collaboration within and among different agencies and assist in coordination of management actions.

The Clean Water Act

Certain regulatory actions require consistent assessments. Within the U.S. EPA, the vision of the 1972 Clean Water Act (CWA) provides a long-term national objective to “restore and maintain the . . . chemical, physical, and biological integrity of the Nation's waters”. Under the Act, states are responsible for water quality management programs to assess the condition of their waters, set designated uses, establish criteria in their Water Quality Standards (WQS), and then monitor attainment of the uses. The CWA has led to tremendous environmental improvements, largely by regulating point sources and individual chemicals (U.S. EPA 1986). The path to biological integrity, however, has not been as clear cut. Biological integrity has been defined as “the capability 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), but the term is not specifically defined in the CWA itself. Nor does the CWA define the ecological components, or attributes, that constitute biological integrity (Davies and Jackson 2006).

Given this lack of specificity, a way to interpret biological condition consistently and independently of assessment methods would more clearly communicate the current status of aquatic resources and their potential for restoration (Davies and Jackson 2006), allowing scientists and managers to better assess aquatic resources. These gaps in the available management tools led the U.S. EPA Office of Water Biocriteria Program to develop the concept of a BCG. The BCG framework (U.S. EPA 2016) is a scientific model for consistent interpretation of biological response to increasing effects of stressors on aquatic ecosystems. This bioassessment tool supports CWA and other decisions in freshwater streams and is now being applied to coastal and estuarine systems. The BCG anchors biological condition to natural or undisturbed conditions (level 1) and describes five declining levels of condition from that starting point, with level 6 representing severe alteration from undisturbed condition. These level assignments are defined by consistent narratives and methods, allowing comparisons of condition across sampling methods, biological endpoints, waterbodies, and time.

A flexible BCG approach for estuaries and coasts

The objective of this document is to propose an approach for applying the BCG framework to improve management of estuaries and coasts. This is presented as a toolbox of steps or actions that take scientists and managers from identifying environmental problems to applying BCG for solutions. Early steps lead scientists, stakeholders, and managers through the process of defining management needs and goals. Next steps develop a narrative BCG to communicate condition, create visions, and set targets. In the final steps, a more rigorous quantitative BCG is developed to better support management and regulatory actions to protect or improve estuarine and coastal ecosystems. The guidance is not prescriptive, the steps need not be approached in any defined order, and coastal or estuarine scientists and managers can develop any step or steps they deem valuable for their specific needs. This flexible approach can benefit states in regulating water quality, NEPs in developing goals, plans and actions or national and regional managers in comparing condition among estuaries and waterbodies. All steps are consistent with the essential tenets of the BCG framework as developed for freshwater streams by the U.S. EPA's Office of Water Bioassessment Program (U.S. EPA 2016).

Figure 1-2. Charleston Harbor, SC, an important low-lying urban southeastern estuary.
Image: Google Earth, data from SIO, NOAA, U.S. Navy, NGA, GEBCO

Roadmap

This document describes the BCG framework as applied to streams in Chapter 2, then defines and explains the estuarine and coastal BCG guidance in Chapter 3. Chapter 4 provides more detail on the key components of the guidance, Chapter 5 discusses how to apply the guidance, and Chapter 6 presents BCG pilots. A summary and discussion of next directions can be found in Chapter 7. This report is authored by a workgroup of scientists and managers who have been developing and promoting BCG applications in estuaries, coral reefs, and other complex systems since 2008.

2. The BCG in freshwater systems

Figure 2-1. Freshwater stream, Yosemite National Park, CA.

BCG fundamentals

The BCG framework was developed as a conceptual model for consistent interpretation and communication of bioassessment information to improve management of freshwater streams and wadeable rivers (U.S. EPA 2016). The model is based on a scientific understanding of how ecosystems respond to increasing levels of human disturbance or stress. As shown in Figure 2-2, the BCG describes a gradient in biological condition that ranges from a natural or undisturbed condition (level 1) to a severely altered condition (level 6).

These changes in biology are evaluated through attributes, which are measurable and ecologically important characteristics of the ecosystem. These attributes include measures of biological and ecological structure, non-native taxa, organism condition, ecosystem function, spatial and temporal extent, and connectance (U.S. EPA 2016). The BCG provides consistent and comparable interpretation of assessments, because all evaluations are relative to the same fixed starting point (or anchor) of undisturbed conditions, and because consistent narratives define every level for each attribute regardless of waterbody or method. In practice, the BCG approach synthesizes existing data, observations, and expert interpretations to document the response of aquatic biota to increasing levels of anthropogenic stress. This approach helps identify environmental targets and develop biological criteria that support conservation, restoration, monitoring, and management activities.

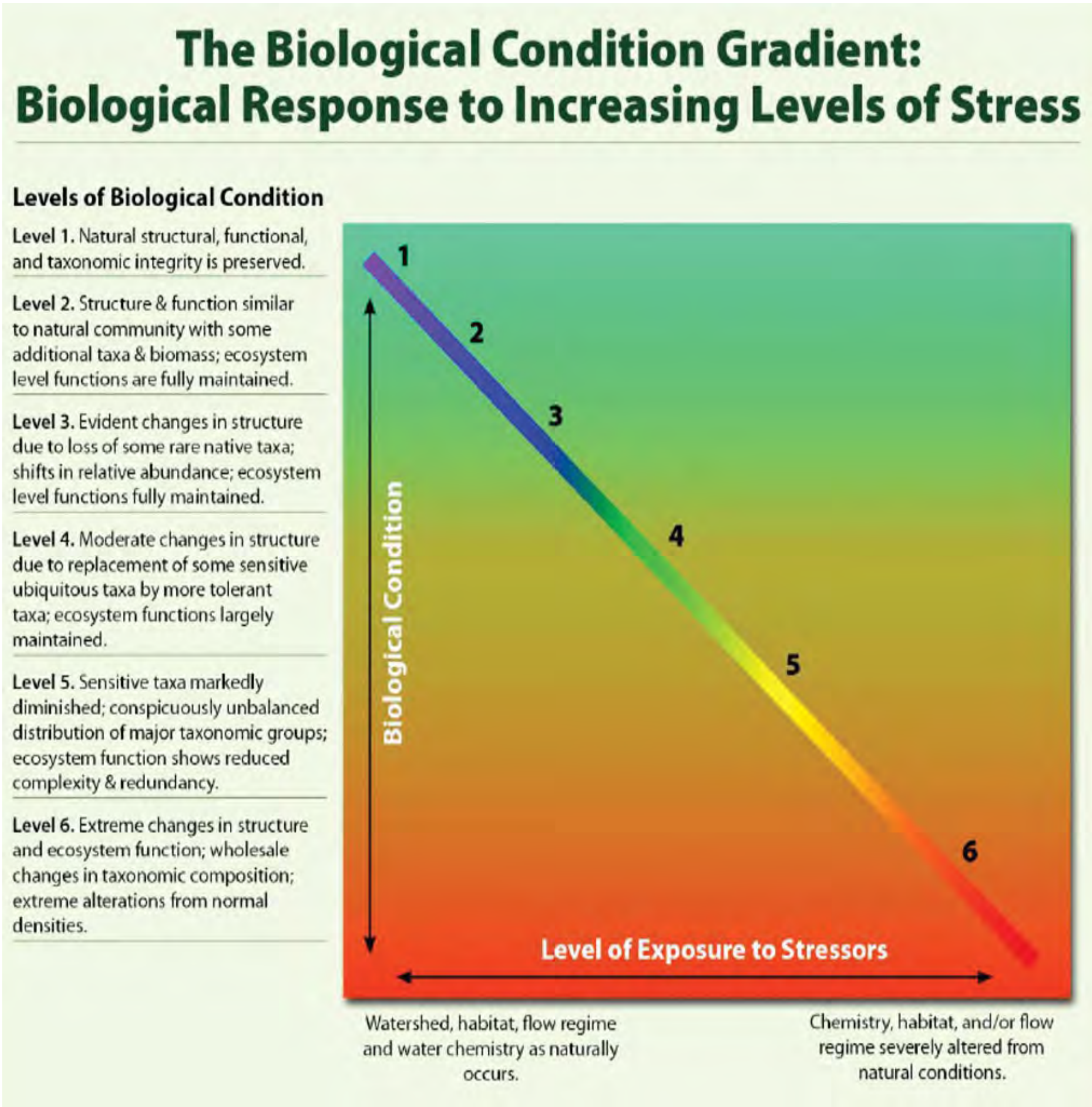

Figure 2-2. Conceptual model of the BCG as developed for streams with narratives for levels 1–6. The actual relationships between multiple stressors and their cumulative impacts on biology are not likely to be linear, although they are presented here as such to better illustrate BCG concepts.
Graphic: U.S. EPA 2016

2.1. Key terms for BCG

Aquatic Life Uses: Beneficial use designations (for state water quality standards) describing how the waterbody should provide suitable habitat for survival and reproduction of native aquatic organisms.

Attributes: Characteristics of structure, non-native taxa, condition, function, landscape, or connectance that reflect biological or ecological condition and represent biological integrity. Used to organize measures and standardize narratives for each of (up to) six levels of biological condition.

Bioassessment: The use of biological indicators to evaluate environmental condition.

Biological Condition Gradient (BCG): A conceptual scientific framework for interpreting biological response to increasing effects of stressors on aquatic ecosystems.

Biological Condition: Levels of biological status defined by narrative or numeric decision rules that are derived from empirically observed patterns of biological response to stressors. The patterns associated with each BCG level are described by ecosystem characteristics or *attributes* (see above).

Ecology: The relationship between living things and their environment. In a BCG, ecology includes the interactions among organisms and with their physical/abiotic environments.

Estuarine and Coastal BCG: A conceptual scientific framework (BCG) for interpreting biological response to increasing effects of stressors on complex, multi-habitat aquatic ecosystems, adapting the freshwater BCG to include larger scale processes. This may also be referred to as the Estuarine/Coastal BCG or the Estuarine BCG.

Estuarine and Coastal BCG Implementation: A set of steps to assist estuarine and coastal scientists and managers from stakeholder engagement and problem formulation (Steps 1–3) through BCG development and application (Steps 4–11).

Metric: As used in this document, a calculated term or enumeration that represents a quantifiable biological feature that changes in a predictable way with increased human influence.

Measure: As used in this document, any quantitative, calculated, qualitative, narrative, or descriptive evaluation of a biological feature that changes in a predictable way with increased human influence. Measures include metrics.

2.2. Overview of BCG

The major components of the BCG framework (U.S. EPA 2016) are as follows:

1. Biological attributes are used to assess biological condition.

2. The BCG defines six levels of biological response to increasing stress (Figure 2-2, page 6).

3. The highest level of condition (level 1) is anchored in undisturbed conditions as naturally occur. BCG level 2 represents minimally disturbed conditions. In many places undisturbed conditions no longer exist and cannot be determined, so BCG levels 1 and 2 are combined and considered comparable to naturally occurring conditions. The poorest condition (level 6) is defined as severely altered and heavily disturbed by high levels of multiple stressors.

4. Expert best professional judgment and consensus in an empirically-based process (U.S. EPA 2016) lead to development of narrative decision rules for assigning sites to BCG levels. Application of independent data sets turns these decision rules into quantitative thresholds using statistically based methods, modeling, or other technical approaches.

5. The BCG process is based on scientific data. Thresholds are calibrated and validated with data, and development steps are documented. This creates a transparent, testable, and defensible assessment method with the clear thresholds needed to determine impairment and likely trajectories of condition.

What does the BCG do, and how?

BCG levels 1–6 provide a 'common language' for assessment because the repeatable scientific process can be applied anywhere that a full range of biological condition can be described with any method of characterizing biology. These levels are used to interpret biological assessments, then apply this information to management decisions in a way that is easily communicated to the public. The BCG identifies both improvements and degradations to biological and ecological condition and can help managers set targets in a transparent way and track environmental progress towards these targets. Further, comparisons among waterbodies allow managers to understand the success of efforts in different systems and to perhaps anticipate the effects on their own systems if stressor levels change to more closely resemble those of other systems.

In practice, expert panels are used in stream BCG development to synthesize biological data, assemble guidelines to define levels for each attribute (e.g., narrative and then numeric decision rules, algorithms and models), and determine level thresholds for designated use assignments. Stream ecosystems across the country have a long history of monitoring for macroinvertebrate, fish, and periphyton communities, although different sampling techniques have been used. Stream ecologists have a good understanding of how these biological communities respond as stressors increase, and in many areas can identify level 1 and 2 sites (Figure 2-2, page 6) as examples of undisturbed or minimally disturbed environments.

The BCG is based on elements of both science and management, with a focus on translating scientific thinking and available data into clear quantitative thresholds for management decision-making. A gap between research and management can occur when the greater understanding of pattern and process sought by scientists does not directly lead to the easily communicated answers that managers need. The BCG bridges this gap through expert scientist workshops and workgroups that distill complex science into six consistent levels of condition that are easily understood and easily communicated to the public.

3. Estuarine and coastal BCG implementation

3.1. How can the BCG be implemented in estuarine and coastal settings?

Applying the BCG to estuarine and coastal areas relies on the concepts described above, but requires a broader ecological approach to address the many different types of coastal waters (Figure 3-1). This adaptation of the freshwater BCG takes a system-level view of the waterbody and modifies attribute descriptions to cover larger scales of assessment. For example, it expands the stream organism condition attribute to include habitat condition, e.g., wetland condition indices which evaluate a variety of plant species, marsh ponding, and other wetland-specific features. The estuarine/coastal BCG provides guidance for management groups to involve stakeholders in defining problems and setting goals and allows a more flexible BCG that can be tailored to the specific problems of an individual waterbody. This BCG can be used to assess condition of coastal waterbodies in the past and present, and can be used to develop visions for desired future conditions. It can assist in a variety of management applications including goal setting by NEPs and regulatory actions by states, and can be applied by small programs with fewer resources.

Figure 3-1. Researcher collecting scientific data for a coral reef BCG, La Parguera, PR.

How is managing estuaries different from managing streams?

Estuaries and coastal waterbodies are very different from the stream reaches that are monitored and assessed in many state water quality management programs and so require different assessment and management strategies. Estuaries and coastal systems represent a large diversity of waterbody types, from small lagoons to coral reefs. Many are characterized by rapidly changing natural conditions (e.g., salinity and temperature shifts over a tidal cycle or along the estuarine gradient) and most have a large diversity of habitats, each contributing to overall waterbody function.

Many estuarine species are extremely tolerant of stressors and environmental variability yet recent anthropogenic changes have severely disturbed estuarine organisms, communities, and habitats (Cloern et al. 2016). Worldwide, estuaries and coasts are among the areas most densely settled over long periods of time. Narragansett Bay, for example, has seen over 400 years of post-colonial development and thousands of years of Native American settlement before that (Figure 3-2). Most estuaries show significant degradation from the cumulative effects of anthropogenic stressors, including shoreline development, nutrient inputs, habitat alteration, and overfishing (Lotze et al. 2006, Bricker et al. 2007, Bolster 2012).

Figure 3-2. The Providence River in Narragansett Bay, RI, after 400 years of post-colonial development.

Estuaries and stream reaches also differ from a management perspective. Estuarine and coastal management often involves several different entities at national, state, and local scales, including organizations with different scopes and different mandates. Historic, natural, or undisturbed conditions may be less common in estuaries due to these cumulative historic stresses, and the characteristic variability of estuaries can make assessments difficult. Estuarine programs such as NEPs and National Estuarine Research Reserves (NERRs) often work with limited budgets and staff, so the coastal approach offers guidance for simplified development and use of narrative BCGs, as well as of quantitative BCGs.

Estuaries and coasts are, in general, less intensively monitored than streams and the BCG implementation steps can be used to organize whatever data are available and identify gaps. While many stream reaches can be assessed in aggregate in the context of regional condition, estuaries and coastal systems are usually managed as unique waterbodies requiring individual attention and many different approaches have been used in various estuaries. In order to assess and manage these coastal systems, estuarine/coastal BCG implementation keeps the advantages of the BCG as originally developed for streams but provides management steps and greater flexibility to address the complexity of estuarine and coastal biology (Figure 3-3).

Figure 3-3. Woods Hole, MA, a complex coastal system.

Origins of the estuarine and coastal BCG

The estuarine and coastal approach was proposed and launched at a 2005 estuarine workshop hosted by the U.S. EPA (Office of Water and Region 1) in Providence, RI. Concepts were developed further at workshops in Maine during the winter of 2006 and spring of 2007. The approach was solidified when the EPA Office of Water, Region 1, and Office of Research and Development co-sponsored a November 2008 workshop in Narragansett, RI, inviting many national estuarine experts and managers (Appendix C). The goal of these efforts was to develop and refine a nationally applicable, integrative estuarine BCG approach to enable meaningful comparisons among measures and waterbodies. Another workshop in 2009 gathered Narragansett Bay experts and managers (Appendix D) to begin an estuarine BCG for that area. The work has evolved and been further refined by a standing estuarine/coastal BCG workgroup and by pilot BCG work in Mobile Bay, AL; the Lower Columbia River, OR and WA; Greenwich Bay, RI; and Puerto Rico coral reefs. This document summarizes work to date on development and application of guidance for estuarine and coastal BCG implementation and provides a basis for further work to refine, test and apply the approach.

3.2. Development of estuarine/coastal BCG guidance

Discussions at the Narragansett workshops and afterwards led to a sequence of eleven possible steps or actions as guidance for scientific and management groups developing and applying the BCG to an estuarine system. To address the variety of system types and needs, each group can review the steps and create a path that works for their specific case and may choose to apply one, several, or all of these implementation steps. While these are presented as separate steps, groups can merge these concepts in their actual development process. Collaborative approaches to these steps might range from informal discussions, to expert workgroups, to hosted workshops.

Eleven useful steps - outline

The first implementation steps of the guidance (1–3) do not involve an actual BCG *per se*, but apply management decision tools to involve stakeholders and evaluate environmental problems in preparation for BCG work. In the next steps (4–7) a BCG is built to solve these problems by developing narratives for BCG levels used for communication, engaging stakeholders, and non-regulatory approaches including assessment of condition, goal-setting, evaluating management alternatives, and monitoring to track progress toward goals. In the final stages (8–11) a rigorous and quantitative BCG is developed through expert consensus to define ALU thresholds and baseline conditions, track changes in condition, and assess effectiveness of non-regulatory and regulatory actions. Public/stakeholder engagement and hosted workshops can be critical throughout the process. Steps:

1. Define problems, engage partners and stakeholders
2. Collaborate to define management goals, visions, and objectives
3. Determine the biological components, stressors, measures, and attributes most relevant to management objectives
4. Delineate and classify the waterbody and watershed of interest
5. Organize and analyze existing data for the identified measures, collect new data if needed
6. Define BCG level 1 conditions for the identified attributes
7. Develop narrative descriptions of the biology expected at each BCG level as a narrative BCG model; apply to management needs
8. Convert narrative descriptions to quantitative metrics and thresholds, calibrate the BCG
9. Develop a stressor gradient and stressor-response relationships
10. Organize, interpret, and report results
11. Develop decision support, communication, and monitoring tools; assist management partners.

Eleven useful steps - details

The implementation steps should not be seen as prescriptive, but rather as a series of choices that can be selected to deliver the desired benefits of a BCG for a coastal system or estuary. Some of these steps may already have been accomplished for some systems or may not be necessary for certain objectives. Every coastal group using a BCG approach will have different problems, different goals, and different solutions. The eleven steps can serve as thinking and planning points for BCG development.

Steps 1–3: Initial collaborative management for effective BCG outcomes

1. Define problems, engage partners and stakeholders. Scientists, managers, and stakeholders should first address fundamental questions: What are the problems to be solved? What are the stressors of concern? Who will use or care about the results? Identifying and involving stakeholders (including partners, state and federal agencies, communities, industry, businesses, and the public) early in the process leads to effective application of a developed BCG later on. Well-established management frameworks (Section 5.3, pages 44–48) including Structured Decision Making (SDM) or Drivers-Pressures-State-Impacts-Responses (DPSIR) are effective tools for working with partners to produce a BCG that will be used in environmental decision-making. Social Network Analysis (SNA) is an advanced method of identifying stakeholders, connections among groups, and participation gaps (Figure 3-4). Forming relationships with stakeholders at the start of a project can be critical, as outlined in Steps 1, 2, and 3 of this BCG guidance.

2. Collaborate to define management goals, visions, and objectives. What are the ecological, economic, and social outcomes that should be achieved relative to the management problems? What are stakeholder visions for a desired future estuary? Relative to BCG, what are the environmental objectives? As above, these questions are best addressed in partnerships with stakeholders, and SDM or DPSIR can be very helpful.

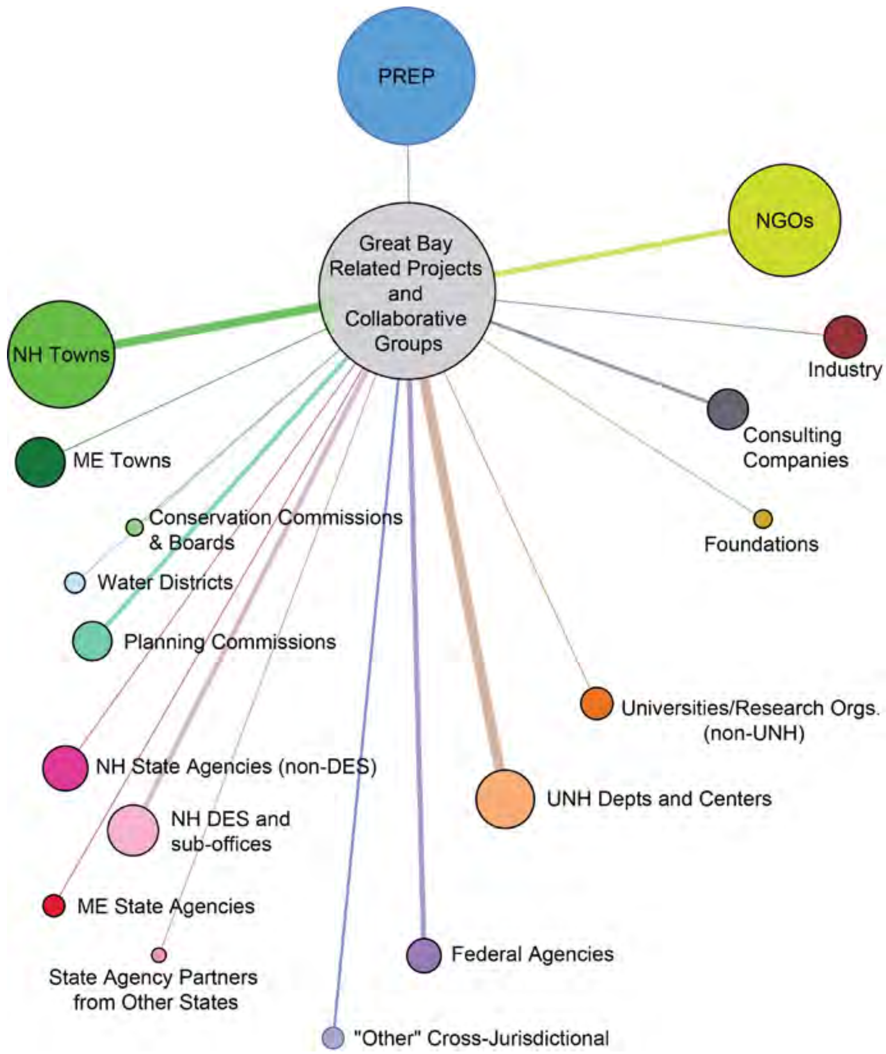

Figure 3-4. SNA map of collaborations within the Piscataqua River Estuary Program (PREP). Partner types are shown with different colors based on participation in past projects and collaborative groups (gray circle). Size of the nodes and thickness of the lines are proportional to the number of organizations and projects represented. Graphic: Kate Mulvaney

3. Determine the biological components, stressors, measures, and attributes most relevant to management objectives. The most effective components of biology, e.g., benthos (Figure 3-5), seagrass, saltmarsh birds, fishes, are: 1) relevant to the management objectives, 2) susceptible to human disturbance and affected by controllable stressors, 3) ecologically important, 4) important to stakeholders, and 5) easily assessed with effective measures (e.g., benthic IBI scores, seagrass acres, bird diversity indices, and fish Catch Per Unit Effort (CPUE) statistics). Evaluating candidate components/measures/attributes and their stressors may require conceptual ecological models, examination of species lists, habitat lists, guild lists, public/stakeholder workshops, information on ecosystem services/values, etc. In many cases, proxies or models may be used to evaluate desired attributes that are difficult to measure; for example, structural measures such as measured depth of bioturbation may be used as proxies for functional attribute processes such as benthic biogeochemical cycling. Any application of proxies or modeled measures should explain the logic behind this use. Final selection of measures and attributes will also depend on the data that are available for each, as described in Step 5 below. Measures are organized into the BCG estuarine/coastal attributes described in Table 4-1 (page 23). This last step is critical because the narrative descriptions used to consistently assign BCG levels are tied to specific attributes.

Figure 3-5. Estuarine benthic invertebrates, often the basis of estuarine assessment. Scale shows one centimeter.

Steps 4–7: A narrative BCG model to identify and communicate condition, develop visions, set goals and targets, and motivate stakeholders

4. Delineate and classify the waterbody and watershed of interest. Bounding the research area will streamline and improve this and later work. The estuary or area of interest should be defined, identifying landward and seaward boundaries. The watershed of the estuary should also be delineated. Areas of heightened interest should be identified, and a variety of spatial tools are available to assist with all these tasks. Classifying the systems into types of estuaries lets managers make comparisons among similar systems, including comparisons of methods to determine undisturbed or minimally disturbed conditions. Classifications can also address specific issues including conservation status or nutrient susceptibility. Within a waterbody, classification by substrate, salinity, habitat, or other factors can reduce apparent natural variability in biological data by grouping analyses within ecologically relevant types. Classification improves the BCG process and clarifies links to stressors. Many established classification schemes exist for various purposes, and this is covered in Section 5.1 (pages 39–42).

5. Organize and analyze existing data for the identified measures, collect new data if needed. Practitioners might consider three actions for each of the measures identified in Step 3 above:

- Identify the spatial and temporal coverages that are required to answer the scientific and management questions, identify existing data, identify data gaps, and determine if new data collection is advisable.

- Develop data acceptance criteria (for existing data) and/or sampling design (for new data). If helpful, texts and resources are available to assist with sampling design, including Gibson et al. (2000) and U.S. EPA (2002).

- As appropriate, if new data are required, define sample collection, sample processing, data management, and Data Quality Objectives (U.S. EPA 2006b).

Different estuarine systems have been studied in various ways, and the types of data that exist in each differ widely. For some estuaries, the type, quantity, quality, and organization of existing and available data on biology and on stressors will be excellent. For many estuaries, some data will be available but a considerable effort will need to be invested in finding, deciphering, and organizing these data. Other estuaries will be relatively unstudied, and basic assessments may need to be conducted. For every estuary, it is important to evaluate the types of data that exist, the resources that are available to collect new data, and the types of new data that would be most useful (Figure 3-6).

Figure 3-6. Scientists collecting the new data required to construct a coral reef BCG, southwestern PR.

6. Define BCG level 1 conditions for the identified attributes. An important element of BCG development is that assessment is consistently linked to natural or undisturbed condition as level 1. This reference is anchored to reduce problems associated with ‘’shifting baselines” (Pauly 1995), where what is perceived as ‘good’ condition declines over decades as humans collectively forget what was ‘good’ 50 years ago. Methods to define this level 1 anchor are discussed in detail in Section 4.2

(pages 29–35). Conceptually, an undisturbed baseline will relate to both biological condition and stressor levels and so can be identified in several ways. An undisturbed coastal or estuarine condition can be defined as a biological state through structural or functional descriptors, as an ecological narrative, as a time period, as a stressor level, or in some other manner. Undisturbed or natural condition should be described as accurately as possible for each assessed waterbody, but methods to determine an undisturbed state will differ among waterbodies depending on the data that are available, on the local history of development, and on other factors. In some cases, level 1 cannot be well defined, and levels 1 and 2 conditions are combined to describe an undisturbed/minimally disturbed baseline. In all cases, baseline conditions can be defined by assembling panels of experts to find consensus on biological conditions that would be expected in a waterbody under undisturbed conditions given the data that are available.

7. Develop narrative descriptions of the biology expected at each BCG level as a narrative BCG model; apply to management needs. Once level 1 is defined, narrative or conceptual descriptions of expected biological structure, condition, and function at levels 2 through 6 can be developed for each of the identified attributes. For consistency among BCG efforts in different areas, BCG narrative for different levels should follow established level descriptions for each attribute. For estuaries and coasts, see Table 4-2 (pages 30–31). These narratives were adapted from those developed and tested in streams (U.S. EPA [2016], Tables A-1 and A-2 of this document). Building on Table 4-2, developing more specific narrative descriptions for each attribute in a particular waterbody better defines the biology characterizing BCG levels. These level descriptions are a narrative BCG model that assigns BCG levels to observed biology. Adding a Generalized Stress Axis (e.g., human population, year for a historical BCG) would add value and context (see step 9 below).

Hosted workshops, panels of invited experts, or expert workgroups have been a successful approach to develop these specific narratives. The basic process is formalized as BCG calibration in Step 8 below. Experts should be well prepared before the workshop, should arrive already familiar with the basic concepts of BCG, and should have a clear vision of workshop expectations. Pre-analysis of data can assist in this process. For example, in streams, biotic assemblage data were analyzed with stressor data to produce empirically derived high stress and low stress indicator taxa; these data were brought to the workshop and compared to expert conception of high and low stress indicator taxa. In developing a BCG for coral reefs, experts were presented with a selection of representative unlabeled photos and videos collected along a condition gradient, which helped facilitate discussion and consensus. The descriptions of coral condition at each level were then used effectively in reef evaluation and goal setting (Bradley et al. 2014). The essential elements of BCG calibration (Step 8 below) were used to develop this BCG model.

In the coral reef example above, a narrative BCG was used for assessment and for setting goals and targets. A narrative BCG is an effective tool for public communication and can support a variety of management needs. For non-regulatory approaches a narrative BCG can take management groups through the entire process of engaging stakeholders, describing past and present conditions, developing a vision for a desired future estuary, defining management goals and targets, evaluating possible actions, and monitoring progress towards targets.

Steps 8–11: A fully developed BCG model to support both regulatory and non-regulatory needs

8. Convert narrative descriptions to quantitative metrics and thresholds, calibrate the BCG. Building on narrative descriptions of the selected measures, numeric metrics (e.g., IBI scores, acres of habitat, density of valued species) can be developed to better define thresholds between levels. This can improve the ability of a narrative BCG to set numeric targets, track progress, prioritize actions, refine stressor-response relationships, or support CWA regulations.

The BCG is calibrated when expert workgroups use consistent BCG level guidelines (Table 4-2) and a consensus process to develop decision rules for assigning thresholds to BCG levels, then test these rules with data and modify as needed. A narrative non-regulatory BCG model can and should be calibrated, but a model intended to support CWA and other regulations must be quantitative, rigorous, based on sufficient data and well-calibrated with the required testing and iteration.

U.S. EPA (2016) provides a detailed, tested, and well-established calibration process for convening experts, using scientific consensus with available data (e.g., stressor-response relationships from monitoring programs), calibrating the BCG, and assigning biological metric scores to BCG levels (U.S. EPA 2016). Figure 3-7 outlines the steps in calibrating a BCG for quantitative or regulatory use by states, tribes, territories, and counties in supporting CWA and other decisions.

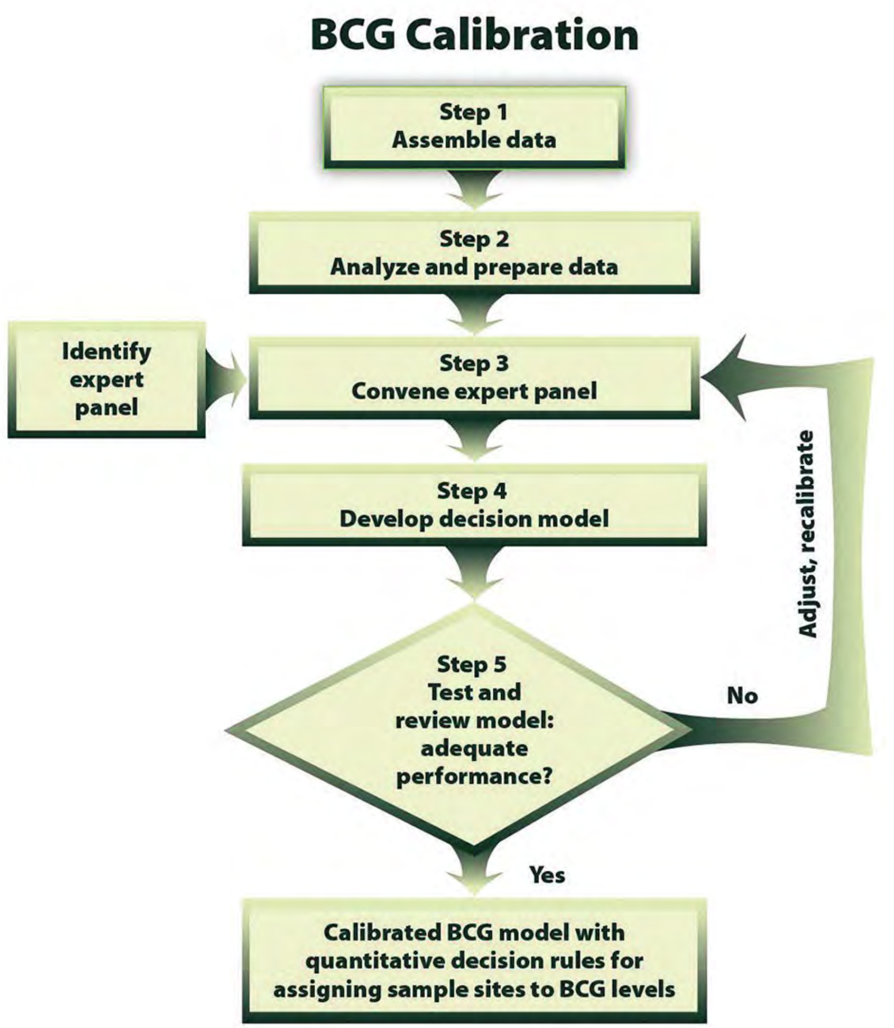

Figure 3-7. Steps for calibration of a quantitative BCG. Graphic: U.S. EPA 2016

In Step 1 of calibration, data are assembled to cover the full range of condition and stress within one or more estuaries or coastal settings. Calibration for regulatory application requires sufficient high-quality data. In Step 2, these data are processed to describe stressor-response relationships, and are put in a format that is useable by workshop participants. Step 3 (identifying and inviting an appropriate range of experts) is critical to the success of the project because in Step 4 these experts will use the data to develop a quantitative BCG, i.e., numeric decision rules for BCG levels in selected attributes. In Step 5, the quantitative model and process are tested against data and recalibrated until the BCG is consistent, scientifically defensible, transparent, well-documented, and ready for use in CWA decision-making or other regulatory and non-regulatory applications. At this point, the decision rules can be applied into the future without further consulting the expert panel.

These calibration steps were designed for development of BCG models for regulatory application under the CWA and rely on quantitative data, but most estuarine or coastal BCG models are developed by non-regulatory programs such as NEPs, and are not intended as a basis for regulation. Further, the sparse data typical of estuaries may not be sufficient to support calibration and testing for CWA decisions. However, the expert workgroup process described above improves any BCG model, even when extensive testing and iteration are not possible. As before, coral reef BCG practitioners used this expert calibration process with narrative descriptions of coral condition to create a much-needed management tool. Expert panels are a central element in developing any BCG model.

9. Develop a stressor gradient and stressor-response relationships. The Generalized Stress Axis (GSA, the BCG x-axis of Figure 2-2, page 6) aggregates stressors on the assumption that biology (the y-axis) responds to the cumulative impacts of all stressors (see U.S. EPA 2016, Chapter 5). Anthropogenic stress to the estuary can be considered in general terms to address many BCG goals, and better characterizations of GSA stressors may include human population numbers, loadings from point sources, ambient pollutant levels, or time, as a surrogate for increasing anthropogenic stress. An analysis of changes in land-use patterns in the estuarine watershed over time (e.g., changes in percent of impervious surface) or use of a landscape development index (Oliver et al. 2011) or other watershed index may be an effective tool for improving a generalized stressor gradient. Many estuarine and coastal impacts are based on stressors within the watershed, e.g., nutrient or sediment loads.

A stress gradient that identifies individual stressors allows development of specific thresholds for these stressors and so leads to a more effective BCG. Diagnostics and control of stressors may involve more detailed stressor characterization and additional analysis using specific stressor-response data sets and diagnostic tools such as stressor identification and causal analysis (www.epa.gov/rps/stressor-indicators, www3.epa.gov/caddis). Specific stressor-response models linking stressor levels to BCG condition are extremely valuable for stressor control.

Oceanic stressors may also play a significant role (Figure 3-8). Temperature changes and rising sea levels are stressors that influence biotic distribution and condition. If these larger-scale stressors are not considered, local restoration (e.g., of saltmarshes) may not be effective. To best relate all biological and stressor measures to a common anchor point, programs can include undisturbed stressor levels in the definition of reference condition. Also, the human-caused component of stressors should be separated from natural stressor variability. In many cases, for the more widely-used indices, basic stressor-response relationships for the assessment measures will already have been developed through established monitoring programs or through the published literature. In other cases, e.g. measures of function and connectance, stressor-response relationships may be estuary-specific and may need more development. In all cases, a stressor gradient that associates biological condition with individual stressors is critical for managing specific stressors.

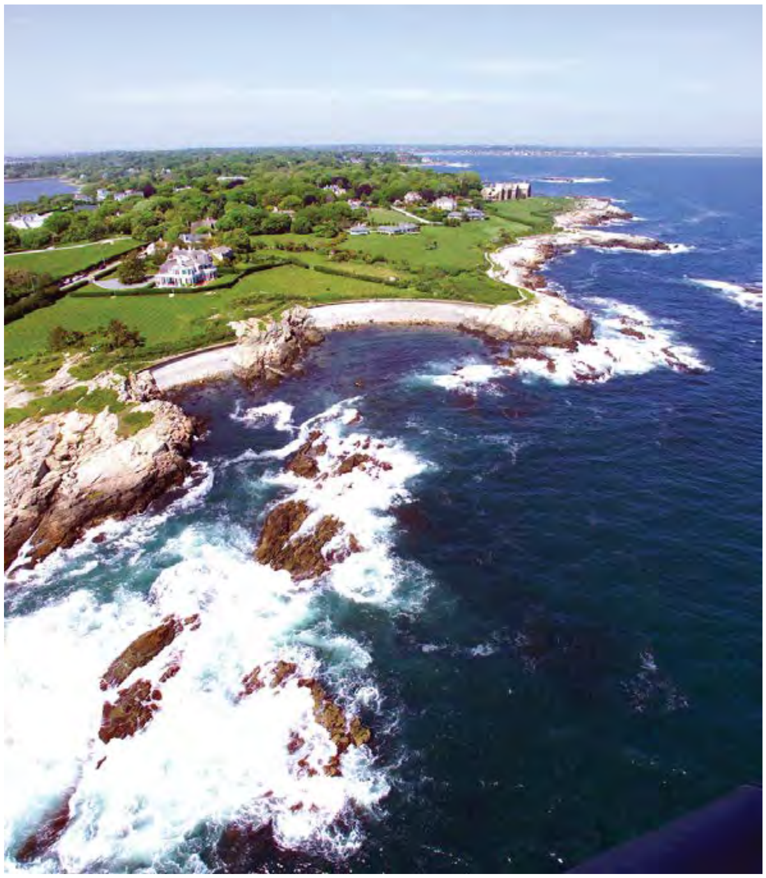

Figure 3-8. Oceanic influence near the mouth of Narragansett Bay, RI.

10. Organize, interpret and report results. BCG attribute levels and a GSA can be organized as a BCG model to evaluate environmental data and communicate estuarine condition in a meaningful way. Analyses may focus on specific areas or on the entire waterbody to reveal what the overall condition of the estuary is, which biotic components of the estuary are doing well, what the significant biological problems are, what specific locations within the estuary are doing well (or poorly), and how that estuary is faring in comparison to other estuaries. Stressor-response linkages to biological condition can be reported for the GSA and for specific manageable stressors.

Data should be presented in ways that the public can easily understand and relate to. Although not conducted using a BCG, the Chesapeake Bay Program provides helpful examples of data presentation, having worked with the issues of summarizing multiple assemblages at multiple scales. They report data at the embayment level, whole-bay and watershed level. Various measures are examined separately, and averages are combined into an overall health index. The experiences of Chesapeake Bay (and of other estuaries with long-term data such as Buzzards Bay or Tampa Bay) are useful models for data presentation (See Appendix B, FAQ sheet). Many of these analyses focus on the relationship of the parts to the whole, e.g., evaluating the overall current condition of estuaries relative to the condition of estuarine components, and relative to the conditions of the past.

11. Develop decision support, communication, and monitoring tools; assist management partners. Work in pilot systems provides several excellent examples of applying BCG to management, and Section 6 (pages 61–84) describes these efforts in detail. Different uses of BCG can be explored to meet the objectives of each program:

- Explicitly incorporating biology into estuarine and coastal management for greater public appeal and for better addressing both cumulative impacts and specific stressors.
- Using scientific and stakeholder consensus to improve interpretation of assessment and develop environmental visions, goals, and targets. This can benefit National Estuary Program (NEP) management plans; assist National Estuarine Research Reserve (NERR) programs (Figure 3-9), Non-Governmental Organizations (NGOs) and other self-motivated stakeholders.
- Communicating conditions, goals, progress towards goals, and other aspects of ecology and management. Different forms of communication are usually needed to reach a wide range of audiences and stakeholders. A motivated public can contribute to environmental success in many ways, e.g., reducing inputs from lawns or generating political will.
- Organizing and reporting results from existing monitoring programs; this improves assessments of environmental conditions both nationally and locally.
- Supporting CWA and other regulatory goals for environmental action by states, tribes, territories, counties, and federal agencies. Regulatory goal-setting requires a rigorous calibrated BCG– these goals are usually subject to a higher level of scrutiny than are the non-regulatory goals described above.

Figure 3-9. Taskinas Creek, part of the Chesapeake Bay NERR in Virginia. Photo: April Bahen, CBNERRVA NOAA, courtesy of NOAA

As above, applying the coastal and estuarine BCG guidance can allow better assessment, goal-setting, monitoring, and communication/reporting. It can also contribute to refinement of designated uses so they are directly linked to biological measures. The guidance can be used to improve biological criteria for management of nutrient inputs, assess the overall condition of the waterbody for better communication, prioritize local land-planning decisions, interpret national monitoring programs, communicate a need for protection of nature, or set numeric targets in a way the public can easily understand.

The focus of the BCG approach is on developing the scientific underpinnings needed to assign BCG level numbers to biological conditions. The issues of determining what conditions are or are not acceptable for a specific waterbody are management questions, informed by BCG levels, but decided through a process that considers public and stakeholder interests, environmental regulation, ecological goals, and societal goals. NEPs and similar management groups are well positioned to take BCG through the entire process, from initial stakeholder investment to BCG development to stakeholder involvement in setting and achieving specific goals and targets.

4. Components of the estuarine/coastal BCG

4.1. Attributes and measures

How and Why Do We Group Biological Responses?
Biology responds to stressors in predictable ways that can be divided into types of response. Here we use changes in structure, non-native taxa, condition, function, and connectance as five meaningful groupings of biological response, termed 'attributes' in the BCG approach. This is important because attributes respond differently to stressors; increasing stress may affect species composition (structure) before it affects bioturbation (function). Assigning levels of biological condition within attributes improves resolution and consistency.

This BCG approach organizes important estuarine and coastal biological responses into ecological attributes (Table 4-1). This table serves as a guide for a wide range of applications, is designed to be useful at multiple spatial scales, and incorporates a variety of biological and ecological measures. The stream attributes (see Appendix A, also U.S. EPA 2016) were used as the foundation for the table, but were adapted to include estuarine and coastal features.

Table 4-1. Five attributes and potential measures for application to estuarine and coastal BCGs at different scales, developed through expert consensus at a 2008 BCG workshop. This table provides an ecological organization of measures but does not include all relevant measures and does not provide specific direction on which ones to use in a given waterbody. Attribute and measure selection needs to consider the management questions, the important stressors, and the data that exist or that can realistically be collected.

Attribute	Potential Measures and Description
Structure	Measures of waterbody, community, or habitat structure and complexity, also recognizing 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 or susceptible taxa or biotopes, measures of seagrass or macroalgae
Non-Native Taxa	Measures of non-native species, including intentionally introduced species May include measures of the impact of introduced and non-native species Examples include estimated numbers of species or individuals, biomass measures of natives and non-natives, or replacements of native species
Condition	Measures of the condition ('health') of waterbodies, habitats, or species. Also includes measures of resiliency Examples include harmful algal blooms, disease outbreaks, outbreaks of other harmful taxa, measures of habitat or biotope health such as seagrass condition or wetland condition, fish pathology or shellfish bed condition, measures of reproductive success
Function	Measures of energy flow, trophic linkages, and material cycling, including proxy or snapshot measures that correlate to functional measures Examples include photosynthesis:respiration ratios, benthic:pelagic production rates, chlorophyll *a* concentrations, benthic bioturbation, and form/extent of primary production
Connectance	Measures of exchanges, movements, predation, migrations or recruitment of biota between watersheds, waterbodies or habitats; measures may be strongly affected by factors adjacent to or larger than the immediate study area Proxies may be used as measures, including habitat landscape metrics, biological watershed inputs, anadromous fish data, or hydrological measures

Three basic attributes

The structure, non-native taxa, and condition attributes are often used in building BCG models. These attributes are ecologically important, meaningful to stakeholders, and relatively easy to measure. The structure attribute can be applied to almost all BCGs, and measures of these three attributes can also serve as proxies for function and connectance.

Structure

The estuarine/coastal 'structure' attribute described in Table 4-1 considers structural patterns of biology at several scales including community structure (e.g., IBIs and other measures), habitat structure (e.g., patterns of primary and secondary production within seagrass beds), or waterbody structure (e.g., numeric analyses of the mosaic of living habitats [biotopes] within the waterbody). This attribute may further include biological features at the watershed scale (e.g., landscape measures of terrestrial biology to evaluate the living watershed/waterbody complex).

Figure 4-1. Seagrass is a biotope and a sensitive indicator of condition.
Channel Islands National Marine Sanctuary, CA. Photo: NOAA

Non-native taxa

The coastal/estuarine 'non-native taxa' attribute evaluates the populations of invasive species in a waterbody and their effects on native species. This is essentially identical to the stream non-native taxa attribute, although different species are involved (Figure 4-2).

Figure 4-2. Non-native taxa: dead man's fingers (*Codium fragile),* a branching green seaweed, was first seen in the U.S. in 1957 and has spread extensively since then. *Codium* displaces seagrasses, kelp, and other native flora. *Codium* has washed up on shores in Massachusetts in such large quantities that beaches have had to be closed to the public (Donohue 2006).

Condition

The estuarine 'condition' attribute mirrors the stream condition attribute in evaluating the anatomical or physiological characteristics of an organism through disease, tumors, and deformities, but the estuarine version may also consider ecological condition of a larger habitat or area. Coastal or estuarine condition measures include coral or seagrass disease, multi-metric saltmarsh condition indices, or outbreaks of destructive native taxa (e.g., predatory native urchins or starfish).

Higher-level attributes

In general, measures of biological structure, non-native taxa, and condition (described above) are more available than measures of biological function and connectance as described below (Davies and Jackson 2006). Yet, these higher attributes may better address concepts of sustainability and resilience, and may help identify and predict critical ecosystem shifts and tipping points such as system-level anoxia or coral reef loss. Some effective functional measures have been developed, often based on surrogates or proxies. Structural measures may serve as proxies for function and connectance when logic and assumptions are clearly explained.

Function

The ‘function’ attribute is very similar in both stream and coastal/estuarine BCGs. Both evaluate ecosystem processes including primary production, respiration, and benthic biological exchange, also, both use the evidence of structural proxies as measures of functions. To illustrate, the Southern California Coastal Water Research Project (SCCWRP) and collaborators have developed a macroalgal biomass measure for California coastal lagoons that indicates major shifts in ecological condition and function (Sutula et al. 2014). Macroalgal biomass was linked to bioturbation depth (measured with a sediment profile camera, Figure 4-3) which served as the more direct proxy for evaluating ecological condition and functional shifts.

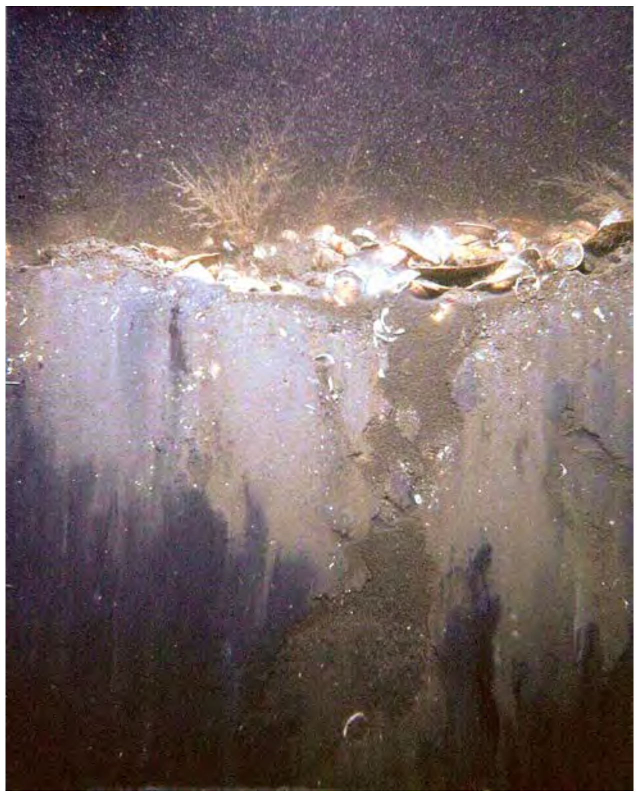

Figure 4-3. Sediment profile image showing shells on the sediment surface and a 15 cm deep section of the sediment below the shelly surface. The light brown or reddish area nearest to the sediment surface has been oxidized by the activities of burrowing animals. The depth of this area is an approximation of benthic bioturbation, which controls many sediment processing rates and is a structural proxy for function. The large brown vertical sediment disturbance just right of center is evidence of tunneling by a larger benthic creature, likely a mantis shrimp (*Squilla empusa*) as they are abundant in this part of the Taunton River (MA).

Other potential measures or proxies of function include system metabolism, form and quantity of primary production, and sediment biogeochemical processing rates. Metrics quantifying changes to the extent, proportion, and distribution of biotopes (living habitats) in an estuary or other area (the biotope mosaic approach, see Section 5.4.1.c on pages 51–53) are structural proxies for function at a larger scale: each biotope provides a unique set of functions, so when the mix of biotopes is changed from the undisturbed condition, so too is the overall function of the waterbody. When high functioning naturally-occurring biotopes (e.g., oyster reefs) are replaced with low functioning biotopes (e.g., shell hash with small tube-building fauna), the overall function and biological condition of the waterbody will be diminished−and this is a concept that engages public sentiment.

Connectance

'Connectance' in estuaries occurs more broadly than in streams: estuaries are not linear, and water movements are multi-directional. Connectance in estuaries, coastal habitats, and coral reefs includes habitat exchanges (Figure 6-18, page 78), linkages within the estuary, and connections to streams, coastal waters, and watersheds or watershed integrity. Proxies may include abundance of anadromous or catadromous fishes (e.g., eels, salmon, and herring) or other taxa known to depend on habitat connections.

Biological watershed inputs (e.g. phytoplankton chlorophyll *a*, prey species, salt-tolerant freshwater taxa) may be used as proxies for watershed connectance. Within-estuary connectance can be evaluated through spatial analyses of biotope mosaics, e.g., measures of landscape structural connectedness, isolation, or fragmentation (Rutledge 2003). Similarly, hydrologic data (e.g., effects of dams, culverts, causeways) when combined with biological data can be used as surrogates for connectance (Figure 4-4).

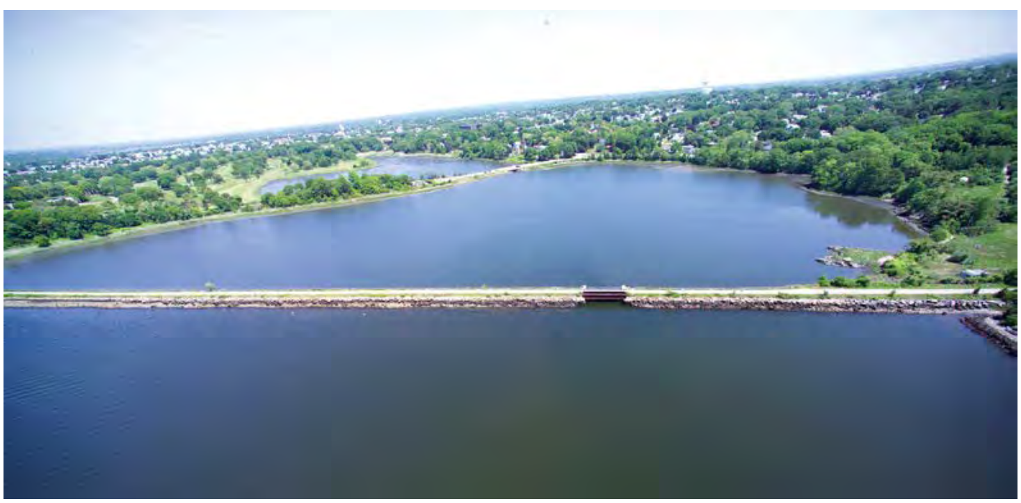

Figure 4-4. Hydrological evidence for poor connectance–Watchemoket Cove, RI, is connected to Narragansett Bay only under a small bridge on an old railroad causeway.

The coastal and estuarine BCG adaptation does not use stream attribute IX (spatial and temporal extent of detrimental effects). Draft narratives for all estuarine attributes follow U.S. EPA (2016) stream narratives (Appendix A) to allow comparability in level assignments among BCG approaches in different types of waterbodies.

New methods

Moving forward, advanced new sampling technologies and analysis tools will lead to new or improved measures to characterize the informative attributes of function and connectance. Evaluating and monitoring coastal and estuarine systems can be difficult due to high levels of complexity and variability. Yet, innovative remote sensing technologies (including acoustic imaging, aerial photography, underwater still and video imagery, autonomous underwater vehicles [AUVs], and satellite imagery) are now available for acquiring large amounts of data.

Satellite ocean color data (such as that previously provided by the Hyperspectral Imager for the Coastal Ocean [HICO] on the International Space Station) offer high quality spectral data at global scales and high spatial resolutions (Figure 4-5). While the HICO hyperspectral sensor with 90 m pixels was damaged in a solar storm, other orbiting sensor platforms are currently providing multispectral data (e.g., Operational Land Imager with 30 m pixels, Ocean and Land Color Instrument with 300 m pixels). Several other hyperspectral sensors are planned for the future with 2020 and later launch dates. Satellite remote sensing presents opportunities to link anthropogenic stressors to biological responses in coastal and inland waters. EPA is developing spectral algorithms that better determine chlorophyll levels, biological productivity (e.g., plankton blooms), and other water quality measures in coastal waters. These could serve as proxies for BCG attributes of function and connectance.

While these developing technologies may enhance our ability to better characterize and manage estuarine and coastal resources, no single sampling method or tool can successfully address all attributes relevant to a waterbody. Incorporating several measures at multiple scales in a BCG leads to a more comprehensive understanding of condition, which should improve the ability to engage the public, to set and track meaningful environmental goals, and to understand the dynamic conditions that exist within coastal waters. BCG is a way to bring different attributes and lines of evidence together with academic and scientific expertise to evaluate large systems, e.g., the managed waterbody and its associated watershed and coastal or oceanic systems.

Figure 4-5. HICO satellite image of the Columbia River, OR and WA. Image: HICO image gallery: http://hico.coas.oregonstate.edu/gallery/gallery-scenes.php, accessed 5-23-2016

4.2. BCG levels

Once attributes and measures have been selected and the necessary data have been acquired, the BCG is assembled by assigning narrative or numeric thresholds and decision rules for levels 1 through 6 for each measure. This will usually occur in separate stages of effort. The key to this process is the consistent guidance of Table 4-2, which provides narrative to define all six levels for each estuarine/ coastal BCG attribute. Table 4-2 was developed through a panel of national estuarine experts at the 2008 BCG workshop (Appendix C), and the first two columns of Table 4-2 ('Attributes' and 'Potential Measures') are identical to those in Table 4-1 (page 23). The six 'Examples of BCG Level Narratives' columns present a flexible set of estuarine and coastal narratives that are closely aligned with stream narratives (U.S. EPA 2016, Appendix A of this document), but have been modified to include estuarine aspects including complexity, biotopes, and estuarine taxa.

The strength of the estuarine and coastal BCG level narratives as shown in Table 4-2 is their consistency with the accepted freshwater level narratives. Level 2 in a Midwest stream should have the same basic ecological meaning as level 2 in a Florida lagoon. BCG levels 1 - 6 provide a common language for assessment because the methods and the narratives can be applied whenever a full range of biological condition can be described using any characteristic of biology. Applications in different estuaries will include different measures; the measure-specific narratives of Table 4-2 are put forth as examples that could be modified for use with different approaches and measures. All measures and narratives of this Table can be adapted as needed. Further, levels can be compressed or eliminated as dictated by the available data or by management needs, e.g., combining levels 1 & 2, 3 & 4, and 5 & 6 as three units of reporting. Each estuarine or coastal BCG program should consider their own uses of Table 4-2, but the basic guidelines provided by the freshwater stream narratives should be followed. The left column of Figure 2-2 (the BCG conceptual model, page 6) shows stream narratives applicable to all attributes, and Appendix A provides stream narratives for each individual attribute. These narratives are discussed in U.S. EPA (2016).

Key table: Consistent narratives to define BCG levels

Table 4-2. Attributes and potential measures developed at the 2008 Estuarine BCG workshop (left two columns) paired with examples of narratives for BCG levels (right 6 columns).

Attribute	Potential Measures and Descriptions	Examples of Estuarine BCG Level Narratives, based on recommendations of a panel of experts and U.S. EPA (2016)					
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Structure	Measures of waterbody, community, or habitat (i.e., biotope) structure and compositional complexity; may also recognize loss of biotopes or species due to human activities. Examples include macroinvertebrate or fish indices, phytoplankton or zooplankton community measures, epifaunal measures, biotope mosaic measures, and presence, quantity, or arrangement of sensitive taxa or biotopes, including large long-lived benthic species, seagrass, coral reefs, macroalgae, or wetland vegetation.	Community or biotope composition is as naturally occurs except for global extinctions; patterns of primary producers, biotope mosaic measures, and communities or areas with large, long-lived and sensitive species or biotopes are as naturally occurs	Minor changes in natural occurrences of biotopes, patterns of primary producers, or other measures; slight changes in abundances of sensitive or tolerant species or biotopes	Evident changes in biological measures; decreases in sensitive species or biotopes and increases in tolerant species or biotopes; evident changes in patterns of primary producers and estuarine biotope mosaics	Significant changes in biological measures; marked decreases in sensitive species, including large or long-lived taxa; increases in tolerant species. Evident changes in patterns of primary producers and estuarine biotope mosaics, which are altered with replacement of natural biotopes by tolerant or non-naturally occurring components	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; patterns of primary producers and estuarine biotope mosaics significantly altered; many sensitive natural biotopes lost with replacement by tolerant or non-naturally occurring components	Sensitive, large and/or long-lived taxa are largely absent with possible extremes in abundance of remaining taxa; marked shifts in diversity, sizes, and densities of remaining species; near complete loss or alteration of estuarine biotope mosaic; marked losses in natural biotope area
Non-Native Taxa	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 densities or biomass measures of natives and non-natives, or replacements 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., benthic invertebrates, crustaceans, algae, bivalves, fishes); some sensitive native taxa may be reduced or replaced by functionally equivalent non-native species	Increased abundance of tolerant non-native species; non-natives prominent in many assemblages	Some assemblages (e.g., benthic invertebrates, algae, bivalves, crustaceans, fishes, epifauna) are dominated by tolerant and/or invasive non-native taxa	Same as level 5
Condition	Measures of the condition of waterbodies, biotopes, communities, populations, or organisms. Some measures may serve as proxies for resiliency. Examples include harmful algal blooms, disease outbreaks, outbreaks of harmful native taxa (e.g., starfish), fish pathology, and measures of specific biotopes or communities, e.g., indices of invertebrate, coral, wetland, or shellfish bed condition.	Diseases, harmful algal blooms, other outbreaks of harmful taxa, and biotope or community measures are consistent with naturally occurring incidents and characteristics	Same as level 1	Incidences of diseases, harmful algal blooms, and other outbreaks may be slightly higher than expected; biotope or community measures may be slightly lower than expected	Incidences of diseases, harmful algal blooms, and other outbreaks are slightly higher than expected (e.g., coral bleaching events occur sporadically and result in slightly elevated mortality), and other indices are slightly lower than expected	Incidences of diseases, blooms, and other outbreaks are increasingly common, particularly affecting long-lived taxa where biomass may also be reduced, e.g., coral bleaching events are frequent and result in mortality. Other indices are significantly lower than expected	Diseases, harmful algal blooms, and other outbreaks are common and serious, biotope or community condition measures are extremely low, Disease, outbreaks, etc. may occur across multiple biotopes, communities, taxa groups, or populations

Table 4-2. (continued)

Attribute	Potential Measures and Description	Examples of BCG Level Narratives, based on recommendations of a panel of experts and U.S. EPA (2016)					
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Function	Measures of energy flow, trophic linkages and material cycling, including proxy or snapshot structural metrics that correlate to functional measures. Examples include production:respiration ratios, benthic:pelagic production ratios, extent of benthic bioturbation, export rates, and form/extent of primary production, e.g., chlorophyll *a* concentrations, macroalgal biomass.	Energy flows, material cycling, and other functions are as naturally occur, typically characterized by complex interactions and trophic 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 trophic 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 (e.g., production, biomass, respiration) may have increased due to organic pollution or low levels of disturbance	Most functions are maintained through operationally redundant system attributes, though evidence shows loss of efficiency or complexity, and some functional rates may shift	Losses of some ecosystem functions are manifested as changed export or import of resources, changes in energy and material processing rates, production: respiration ratios, benthic:pelagic production ratios, or respiration/ decomposition rates	Most functions show extensive and persistent disruption, including shifts in primary production, microbial dominance, fewer and shorter-length trophic links and highly simplified trophic structure, marked shifts in benthic: pelagic production ratios and in energy and material processing rates
Connectance	Measures of exchanges, movements, predation, migrations, or recruitment of biota between watersheds, waterbodies, or habitats. Measures within the area being studied may be strongly affected by factors adjacent to or larger than the immediate study area. Structural measures may be used as proxies, including hydrological metrics, presence of dams or causeways, biotope landscape metrics such as fragmentation or nearest-neighbor analyses, biological watershed inputs, or characteristic migratory species, e.g., anadromous or catadromous fish abundance.	System is naturally connected or disconnected* in space and time - exchanges, movements, predation, migrations, or recruitment between watersheds, waterbodies, or habitats are as naturally occurs *Note that some systems are naturally closed off, and this is the Level 1 state	Same as level 1	Slight loss, or increase, in connectance between watersheds, waterbodies, or habitats, but colonization sources, refugia, and other mechanisms mostly compensate	Some loss, or increase, in connectivity between watersheds, waterbodies, or habitats, but colonization sources, refugia, and other mechanisms prevent complete disconnects or other failures	Significant loss or increase in ecosystem connectance between watersheds, waterbodies, or habitats is evident; alternative pathways and recolonization sources do not exist for some biotopes or taxa; some near-complete disconnects or connects exist; significant reductions in highly connected biotopes	For many groups, a complete loss (or maximum increase) in ecosystem connectance in at least one dimension (either spatially or temporally) lowers reproductive or recruitment success and prevents (or fully allows) exchanges, movements, predation, or migrations between watersheds, waterbodies, or habitats. Disconnects or other failures are frequent. Most naturally occurring biotopes are eliminated

Defining BCG level 1:

The BCG is anchored in level 1 as natural or undisturbed conditions. This ties back to the CWA requirement to protect the biological integrity of waterbodies, and the Frey (1977) definition of biological integrity as grounded in natural condition. Quantitative data representing natural conditions exist in some locations for some measures. In the absence of these data, narrative descriptions from historic records prior to significant human influence (and other methods) may be applied (Table 4-3).

Figure 4-6. Thicket of *Acropora cervicornis* (staghorn coral) and reef fish indicative of coral reef BCG levels 1 and 2, very good to excellent conditions. Photograph from 1975, Florida Keys, FL.

In practice, four basic methods can be considered for determination of level 1 (or combined level 1 and 2) conditions, based on Gibson et al. (2000): use of historical data, use of current data from 'reference' areas, use of predictive models, and use of expert consensus. Each method has strengths and weaknesses (Table 4-3), and is discussed further below. These methods can also be combined.

Table 4-3. Strengths and weaknesses of various methods used to determine undisturbed or minimally disturbed conditions (Table 4-1 from Gibson et al. 2000).

	Historical Data	Present-Day Biology	Predictive Models	Expert Consensus
Strengths	Yields actual historical information on status. Inexpensive to obtain.	Yields obtainable, best present status. Any assemblages or communities deemed important can be used.	When sufficient data are not available. Work well for water quality.	Relatively inexpensive. Can be better applied to biological assemblages than models. Common sense and experience can be incorporated.
Weaknesses	Data might be limited. Studies likely were designed for different purposes; data might be inappropriate. Human impacts present in historical times were sometimes severe.	Even best sites subject to human impacts. Degraded sites might lower subsequent biocriteria.	Community and ecosystem models not always reliable. Extrapolation beyond known data and relationships is risky. Can be expensive.	May be qualitative descriptions of "ideal" communities. Experts might be biased.

Historical data

Historical data have been used to describe undisturbed or minimally disturbed conditions in a number of U.S. estuaries. The Chesapeake Bay Program set many conservation and restoration goals on historic baselines, using 1994 for oysters and the 1930s for seagrass (CBP 2000). Seagrass is frequently used as an indicator of historic conditions because early charts, records, or photographs often show seagrass and because of its sensitivity and value (Figure 4-7). Historic conditions and subsequent changes over time were also described for Greenwich Bay, Rhode Island (Pesch et al. 2012, Shumchenia et al. 2015). The Buzzards Bay Coalition compared biological data to a historical baseline of pre-colonial conditions. The Lower Columbia Estuary Partnership (LCEP) used historical habitat conditions (the 1870s) as a baseline to set targets for habitat acreage to restore historic habitat diversity (LCEP 2012). Similarly, the Tampa Bay Estuary Program identified 1900 as minimally disturbed conditions for bay habitats, and used historical conditions of 1950 as acreage targets both for restoring seagrass and for restoring the historical balance (proportions) of multiple habitats in the estuary (Greening and Janicki 2006, Cicchetti and Greening 2011). In Puget Sound, historical baselines from the 19th century were incorporated into management of wetlands, bald eagles and resident killer whales (Samhouri et al. 2011). Historical data can correct the misinterpretation of “natural” conditions caused by shifting baselines, and have a solid track record in representing undisturbed conditions for estuarine and coastal management.

Figure 4-7. Seagrass with barracuda.

Current reference data

Present day biology in areas believed to reflect least disturbed reference conditions is also regularly used to develop baselines, especially when applying indices of biological condition to distinguish between unimpaired and impaired condition. Use of reference sites to define reference condition is the preferred technique for setting baseline conditions in the U.S. as well as in areas managed by the European Union (EU) (EC 2002). However, present day best condition may already be significantly degraded from natural, and shifting baselines of human perception can obscure this. Best existing reference may represent a range from undisturbed to minimally or moderately disturbed, so defining the quality and meaning of the reference condition is important (Stoddard 2006), particularly for use in BCG. In severely degraded estuaries, relatively unimpaired areas in a similarly classified estuary may be used as a surrogate measure. Data from existing reference areas have been used extensively in the Chesapeake Bay Program, sometimes supplemented by use of best professional judgment (Weisberg et al. 1997). In BCG developments to date, expert panels have assigned present-day reference sites to BCG levels 2, 3, and 4, reflecting opinions that the reference sites have been exposed to some degree of disturbance. While subject to changes in natural stressors, BCG level 1 is considered anthropogenically unstressed. This is equivalent to the 'Biological Integrity Reference' (Stoddard et al. 2006).

Predictive models

Predictive models have often been used in freshwater systems to approximate biological condition in the absence of environmental impact (Hawkins et al. 2000). These methods, however, have not been widely tested or used to assign minimally disturbed conditions in estuaries and near coastal waters either in Europe (Muxika et al. 2007) or in the United States, although see 'combined approaches' on the next page. This is an area in need of further development and evaluation.

Expert consensus

Expert consensus, panels of experts, or expert workshops can be used together with historical information and/or data to describe the biota expected in undisturbed or minimally disturbed conditions. This combination of methods has been used to narratively describe level 1 in freshwater BCG applications, and is well suited to BCG work in providing an anchored baseline. This approach was used to predict the biological assemblages (fish and macroinvertebrates) expected in undisturbed/minimally disturbed coral reefs in Puerto Rico (Section 6.5, pages 77–82). Expert consensus is also valuable in adjusting best existing condition to more closely match naturally occurring conditions. As a cautionary note, expert consensus may not succeed where data are sparse and conceptual understanding of how the system responds to stress is poor (Thompson et al. 2012).

Combined approaches

Combinations of methods will also be effective. A BCG level 1 condition for fish assemblages has been proposed for the Upper Mississippi River based on historical data combined with a statistical modeling approach (U.S. EPA 2016 Appendix B1). The Upper Mississippi (like many estuaries) is so altered that undisturbed or minimally disturbed conditions no longer exist, yet conditions have more recently been improving under better environmental management. To apply a BCG with a full range of condition, a synthetic historical fish community was developed for level 1. Known ecology and habitat needs of fishes that were abundant early in European colonization were combined with large data sets of modern fish species occurrences linked to a gradient of chemical, physical, and biological stressors. Statistically pairing the living requirements of historically abundant fish to this gradient of stressors led to the synthetic historical fish community, which quantitatively anchored the undisturbed end of the stressor gradient as BCG levels 1 and 2. The full gradient of condition was then used to derive BCG thresholds for existing fish index measures, and these thresholds were used to assess ALU attainment under the CWA. Further, the science-based quantitative descriptions of abundant historical fish species (together with the fact that many of these species are still present) provides context and motivation for restoration in the direction of BCG levels 1 and 2, even if these levels are unattainable. This approach to historic data, while still in development, may be valuable for application to estuarine and coastal aquatic ecosystems—the Upper Mississippi River system is similar to many estuaries in complexity and extent of degradation. Other combinations of the four basic methods to determine reference could also be helpful, and expert consensus contributes to all methods.

Regardless of methods used, development of level 1 (or combined level 1 and 2) undisturbed conditions is a critical part of BCG in setting the anchor point from which other levels will be derived. When BCG levels are distributed over the full range of condition, consistent level narratives allow valid comparisons among measures and attributes at different sites or waterbodies, and at different times from the past, present, and future. This is the foundation for many of the benefits of the BCG approach.

Thresholds and decisions

Level thresholds: After specific attributes and measures have been selected, level 1 has been described, and data from the full range of condition have been prepared for analysis, an expert panel should be convened to develop narrative and then numeric decision rules for assigning sites to BCG levels (U.S. EPA 2016) following attribute guidelines in Table 4-2, pages 30–31. This 'consensus of experts' approach brings different scientific viewpoints together to assign local measures to BCG levels in a well-documented and transparent manner. Expert consensus integrates divergent scientific thinking and imperfect or limited data into numeric thresholds for determining impairments or trajectories of condition. Clear and quantitative threshold values will best determine trajectories of impairment and improvement. Managers gain clear and defensible scientific answers backed by expert consensus, while scientists gain understanding and insight from discussions and consensus-building, and see their work and perspectives incorporated into the management process.

Documentation of process: The BCG focus on transparency and consistent communication of data, methods, expert logic, and assessments has been extremely helpful to managers. Clear documentation of the entire development process includes:

- Defining how undisturbed conditions were identified, including the basis for assuming that these conditions approximate "as naturally occurs"
- Describing how and why biological measures, attributes, and attribute narratives were selected
- Describing the decision rules and numeric thresholds for levels and how these were developed by experts in workgroups or workshops
- Identifying any limitations of the science or of the scientific tools that were used.

This transparency provides the rationale for decision-making, addresses any perception that management decisions are random, and provides rigor for defense in any legal proceedings that may follow.

Decision-making: The BCG provides mechanisms to help translate biology into useful information for management decision-making. The BCG can be used together with societal values and economic considerations to inform management decisions, as in the non-regulatory goals and targets developed by NEPs. In regulation under the CWA, states and territories must establish designated uses for each water body and describe the conditions that are acceptable for these uses, including scientific, social and economic factors. Specific management applications are discussed in Section 5.2 (pages 42–44).

4.3. The Generalized Stress Axis (GSA)

Multiple stressors

Stressors, in the BCG construct, include any or all anthropogenic events, actions, and outcomes that decrease biological integrity. These are addressed on the X axis of the BCG Gradient (Figure 2-2, page 6) as the Generalized Stress Axis (GSA). The GSA is a conceptual description of the full range (or gradient) of all anthropogenic stressors that affect the biology of the waterbody in question. This full range can then be parsed into a set of specific controllable stressors with known stressor-response relationships. The GSA can be quantified using proxies for cumulative human impacts in a watershed, for example human population, land use/land cover metrics, or time in years from undisturbed or less disturbed conditions (e.g., early in European colonization).

A GSA based on more detailed statistical analyses of land use/land cover data leads to a useful understanding of how and where stressors are generated. Further, these data support identification of specific controllable land-based stressors that contribute to cumulative impacts (U.S. EPA 2016). This is valuable for linked watershed-estuary analyses, but since estuaries and coasts are also impacted by oceanic and in-estuary processes, land use analysis alone may not be able to capture all of the important stressors impacting coastal waters.

Natural stressors are not considered in the BCG as causing detrimental effects because they are a part of the natural environments under which biota evolved. As is typical in estuaries, strong natural abiotic gradients (e.g., salinity, flow, abiotic habitat) may be clearly related to the observed biological gradient. Here, classification (Section 5.1, pages 39–42) can remove the influence of the natural gradient by defining undisturbed conditions within each class. For example, an estuary may be classified into mesohaline and polyhaline areas. Some natural stressors may be influenced or exacerbated by anthropogenic actions. In these cases, the change to natural stressor levels is characterized as the anthropogenic component of that stressor.

Stressors in the BCG are considered in aggregate as part of the GSA (U.S. EPA 2016) because biological communities integrate the influence of multiple stressors (Figure 4-8). The GSA is helpful in addressing cumulative impacts and as part of the decision rules used to calibrate the BCG. The GSA also supports state CWA actions and is useful in goal-setting, communication, long-range planning, and other applications in coastal management. The GSA can be evaluated using a variety of methods and at any level of detail.

Figure 4-8. Small cove in Black Rock Harbor, CT, an estuary known for high levels of stressors including toxicity, nutrients, sediment input, and habitat alteration. The GSA (BCG X-axis) represents the synergistic aggregation of all these stressors; the BCG Y-axis evaluates their cumulative impacts on biology.

Individual stressors

Many environmental efforts (such as the TMDL program) identify one or more stressors that should be reduced. Restoration may also focus on a single stressor (e.g., nitrogen) to promote recovery of resources such as seagrass. Specific stressors of concern should be identified when defining waterbody problems, selecting attributes and measures, and characterizing biological response to an overall stressor gradient. The GSA captures the cumulative effects of stressors and serves as an organizing framework for individual controllable stressors. The Greenwich Bay historical BCG (Shumchenia et al. 2015) examined overall change in biological response over time, but also identified the specific stressors impacting the embayment. Identifying the specific causal stressor or stressors can also allow use of the diagnostic decision process (U.S. EPA 2010 [http://www.epa.gov/caddis], Ho et al. 2012) that allows further management and improvement of the waterbody.

More sophisticated use of the stressor gradient has taken place in streams when large data sets are available. Kashuba et al. (2012) used a Bayesian network model to identify the probability of achieving a desired BCG level given a defined management action. For example, if management actions reduced flashiness and specific conductance to certain levels in an urban stream, the probability of receiving a BCG level 3 or better designation would increase from 24% to 70%. Thus, BCG stressor work adds greater scientific understanding of the impacts to biological communities while providing critical information and targets for TMDL work, other load reduction efforts, and restoration. Stressor-response models linked to BCG levels are necessary for management of specific stressors in the BCG framework. The GSA serves as a conceptual basket that holds individual stressor-response models and captures their cumulative effects in a quantifiable way. See U.S. EPA (2016) Chapter 5 and Appendix A for more information and detailed examples.

5. Application of the approach: details and examples

5.1. Classification

Why classify?

Developing a basic understanding of the waterbody (or waterbodies) in question is fundamental to coastal and estuarine management. Coastal systems across the U.S. occur in different sizes and shapes, with varying bathymetry, tidal influence, volume of river inflow, circulation patterns, etc. Within any given system, high spatial and temporal variability support multiple habitats and biological communities. This complexity has led scientists and managers to treat each coastal and estuarine system as a unique entity (Kelly 2008). Yet, these diverse and complex systems can be described and classified through basic sets of geomorphologic, hydrologic, and physical characteristics (Engle et al. 2007). Classification allows coherent groups to be identified so as to inform or simplify a management question (Kurtz et al. 2006). Classification further allows information from one estuary or coastal area to be applied to another, minimizing the need for intensive individual studies of similar coastal systems (Figure 5-1).

Figure 5-1. Two adjacent lagoonal estuaries (Green Pond and Great Pond, Cape Cod, MA).

Classification of estuaries

Many classification schemes have been developed for dividing estuaries into similar groups. Geomorphic classifications (e.g., Pritchard 1967, Dyer 1973) use geologic origin or geology to define estuary classes. Estuaries can be classified as drowned river valleys, fjords, deltas, lagoons, and tectonic estuaries. Hydrodynamic classifications (e.g., Strommel & Farmer 1952, Hansen & Rattray 1966) use circulation and stratification to define estuary classes. Briggs (1974) developed a classification based on zoogeographic regions used by the U.S. EPA's National Coastal Condition Assessment (NCCA). On a smaller within-waterbody scale, habitat classification allows descriptions and inventories of habitats and communities. Classifying data by sediment type, habitat, latitude, salinity, or other influencing factors reduces variability in analysis and is valuable for evaluating changes over time or space. One of the best known habitat classifications is the Cowardin et al. (1979) scheme, which is hierarchical, starting with system (e.g., marine, lacustrine), and then using physical and habitat features along with modifiers to classify habitat type. This model has been further developed into the federally approved Coastal and Marine Ecological Classification Standard or CMECS (FGDC 2012), which has been adopted and is used by many state agencies, several federal agencies, and a number of academic and management groups. This standard assists in classifications of habitats, estuaries, and coastal areas of all types (Figures 5-1, 5-2, and 5-3).

Figure 5-2. An anthropogenic estuary built behind breakwaters (San Pedro Bay and Long Beach, Los Angeles, CA). Image: Google Earth, data from Landsat

Figure 5-3. Entrance to a small riverine estuary (Narrow River, RI).

Classification to meet different needs

More recently, estuarine classification systems have been developed for specific purposes. Edgar et al. (2000) developed a system to identify conservation status. Estuaries were assigned to groups based on geomorphology and hydrology. Fish and benthic invertebrate community structures were used to validate and refine these estuary groupings, which were then ranked based on catchment stressors (e.g., population, land use). Biological data were examined for biodiversity and endangered species, allowing the individual estuaries to be categorized into one of six conservation levels. Bricker et al. (1999) classified estuaries by their susceptibility to nutrient over-enrichment using physical measures of dilution and flushing. In a study in Chesapeake Bay, Boynton and Kemp (2000) suggested that classification may allow normalization of important factors so as to develop stressor-response relationships that could be applied in multiple estuaries.

Classification can be used for many purposes, including "describing and inventorying communities and habitat types, examining differences and similarities between groups, identifying and prioritizing conservation efforts, managing resources, and guiding research" (Engle et al. 2007). The type of classification chosen in a project will be determined by the questions being asked. If the priority is to describe and inventory habitats and communities within an estuary, then geomorphic, hydrodynamic, or habitat classification may be most appropriate. Assessment within groups of similar biological expectation determined by (for example) salinity, depth, or substrate type can improve the quality of assessments by eliminating data from different environmental regimes. Managing resources, especially for TMDL or nutrient reduction work, may require identification of susceptibility (Bricker et al. 1999) and/or normalization (Boynton and Kemp 2000) so that appropriate load-response relationships can be developed. If the differences and similarities between coastal estuaries need to be examined or if conservation efforts need to be prioritized, then further examination of conservation status groups as in Edgar et al. (2000) could be helpful.

For BCG application, the European Water Framework Directive (WFD) may be particularly relevant. Here, estuaries and coastal waters are defined into types or classes based on physical and chemical factors that determine the structure and function of biological communities. Waters are assigned using (primarily) biology into one of five status (condition) categories (equivalent to BCG levels) using a reference condition that is based on high status in other waters as the preferred method (EC 2002). Reference conditions are determined within the same type or class of estuary (U.S. EPA 2011b) so that expectations are appropriate to the physical constraints of the system. For example, reference conditions from an open embayment would not be applied to a lagoon. The extensive work applying the WFD to European estuaries and coasts provides methods and lessons helpful to the application of BCG to U.S. estuaries and coasts. See also the “Six required steps for managing European estuaries” text box on page 83.

Grouping or classification allows better transfer of data, models, and lessons learned from one estuarine or coastal system to another. Although our estuaries and coastal systems are unique resources valued in different ways by their residents and stakeholders, classification creates management opportunities to better protect a specific or unique system through comparisons to other similar systems. Classification within an estuary streamlines and focuses biological assessments. Classification of nature is a well-developed scientific field that can provide benefits to all forms of environmental management.

5.2. How can the BCG improve management of estuaries and coastal waterbodies?

This BCG guidance provides a flexible approach that can be adapted to fit the unique characteristics and management needs of an individual estuarine or coastal waterbody (or a classified set of waterbodies) and then developed to make best use of the resources and data that are available. The ability to make valid comparisons across measures, space, and time provides many benefits. The estuarine and coastal BCG was designed to provide national, regional, state, and local managers with scientific information needed to improve the environmental condition of their waterbodies.

Who can benefit?

National managers (e.g., the U.S. EPA Ocean and Coastal Protection Division) benefit from consistent assessments of estuaries and estuarine biology. This improves communication and allows more comparable national reports on the condition of estuaries and estuarine resources. State managers benefit from the ability of the BCG to help with CWA goals: refine designated uses, develop biocriteria, identify high-quality waters and watersheds, and document biological response to stressors (U.S. EPA 2011a). Consistent assessments guide development of thresholds for Aquatic Life Uses, TMDLs, the management of single or multiple stressors, and the communication of condition to define goals and monitor progress. The BCG provides rigorous and transparent results that can be used in regulation. This has been demonstrated in streams, and the concepts are equally applicable to management of estuaries. Applications of the BCG to state management and regulatory goals are discussed in U.S. EPA (2016).

Local and regional non-regulatory management groups including NEPs, NGOs, Regional Planning Bodies (RPBs), municipal planners, and others are assisted in communicating with stakeholders, determining agreed-upon vision statements for desired future conditions, setting goals and targets, prioritizing actions, and tracking progress towards targets and goals. The estuarine/coastal BCG approach (or any part of it) can also be applied within a larger management program, for example EPA's Healthy Watersheds Initiative, which embraces many of the same principles. Managers will also find other advantages in using the BCG.

How can the BCG help?

The estuarine and coastal BCG implementation approach considers waterbodies at several scales, and extends several uses of the stream BCG approach to the management of larger systems:

1. Assessing (consistently interpreting the environmental conditions that exist). The BCG defines undisturbed conditions, then BCG levels consistently evaluate existing conditions relative to those undisturbed conditions using data from any relevant biological measure at scales ranging from organisms to waterbodies. Consistent assessments are the basis for effective management from goal setting to monitoring to CWA decisions.

2. Developing visions, goals, and targets (providing information to support consensus on desired environmental conditions). Comparing existing conditions of valued biological resources to higher quality (more natural) conditions expected with stressor reductions can help develop a stakeholder vision of what is desirable and attainable for the future. Levels of condition linked to specific attributes and measures can lead to both narrative and quantitative targets towards visions and goals. Ultimately, a compelling vision of a desired future can engage stakeholders to take action and generate the political will to protect and improve their waterbody; for added motivation this vision can also be compared to the 'do nothing different' future (see number 5 below).

3. Informing specific management actions (identifying and prioritizing the stressors most relevant to achievement of goals). Additional development of the GSA and stressor identification (see www3.epa.gov/caddis) can help parse out the stressors (including stressors in the watershed) that most contribute to cumulative impacts. This may also provide information to: identify the specific and generalized stressor values that determine biological condition levels; develop actions to manage those stressors; and evaluate whether environmental targets and goals are realistic.

4. Monitoring progress (providing measures and levels to track progress towards desired conditions). The same measures, attributes, and levels that were used to set targets for an individual waterbody are then used to track progress towards those targets. Direct methods to evaluate improvement or degradation lead to more effective adaptive management.

5. Predicting future scenarios (projecting current or alternative trajectories into the future). In many cases the consequences of a 'do nothing different' management option can be predicted with historic BCGs by extending the existing condition trajectory into the future (Cicchetti and Greening 2011). This may help management groups and communities prevent or prepare for undesirable future conditions.

6. Communicating (translating ecology into terms that are more easily understood and communicated). BCG levels are easily understood as six grades of condition for what we have, what we have lost, and what we can restore, relative to the natural state. The concept of restoring valued resources that once existed can resonate with the public and stakeholders (Cicchetti and Greening 2011). Further, BCG addresses issues specific to an estuary and includes resources that are valued by local stakeholders. BCG levels can easily be converted into another form that may appeal to certain groups (report cards, bar graphs, color codes, etc.). The BCG is a basis for communication with many different audiences.

A goal of an estuarine and coastal BCG is to consider the estuary or coastal area and its stressors in a comprehensive manner by combining consistent assessments at multiple scales. The BCG can serve as a conceptual 'box' that is capable of capturing a wide range of scales and sub-regions from watershed headwaters to the near coastal edge. This provides an ecological foundation for integrating environmental and socioeconomic management.

5.3. The BCG as part of larger social/ecological/economic management approaches

All of the above benefits, however, presume that scientists and managers are well-informed as to the underlying science of how their estuary functions, the human stressors that most alter that function, the environmental, social and economic priorities of the local communities, and the resulting management problems that need to be addressed (i.e., estuarine BCG implementation Step 1). It will be difficult to develop a useful BCG model unless it is clear what needs to be assessed and why. On the other hand, certain aspects of BCG development can assist with this process; for example, an understanding of the historical distributions of biological resources may help clarify goals and objectives.

In situations where objectives are uncertain, initial actions can be taken to apply larger socio-ecological management approaches that better define environmental, social, and economic needs; incorporate stakeholder values; clarify desired objectives; identify stressors; and balance opposing goals. This allows BCG assessments to address those issues most relevant to stakeholders and managers. In some cases, values articulated by stakeholders (e.g., protect charismatic megafauna, figures 5-4 and 5-5) can be addressed through more tractable BCG measures (e.g., habitat quantity and quality). Larger social frameworks used together with BCG can address these and other issues.

Figure 5-4. Large charismatic animals appeal to public sentiment, and are often dependent on high water quality and suitable habitat availability. Manatee calf resting chin on mother's back, Weeki Wachee River, FL. Manatees require abundant aquatic vegetation for food and access to clean fresh water for osmoregulation. Photo: N. Cicchetti

These larger approaches include Structured Decision Making (SDM) (Gregory et al. 2012), Ecosystem-Based Management (EBM) (McLeod and Leslie 2009), Drivers-Pressures-State-Impacts-Responses (DPSIR) (OECD 1994), and Coastal and Marine Spatial Planning (CMSP) (White House Council for Environmental Quality 2010). BCG levels can also be linked to ecosystem service values. Of these, SDM, DPSIR, and EBM have been used directly with BCG (Carriger et al. 2013, Corbett 2013, Yee et al. 2014, Shumchenia et al. 2015). These larger methods are valuable in any decision-making process, and a better understanding of the ecological-social-economic landscape can benefit any BCG effort, even after objectives and assessment goals have been established.

Structured Decision Making

Structured Decision Making is an approach that applies human benefits and stakeholder values to identify clear objectives and evaluate management alternatives. The basic organization of SDM (USFWS 2008, Gregory et al. 2012, Carriger et al. 2013, Yee et al. 2014, Bradley et al. 2015) is as follows:

1. Clarify the decision context – identify the significant problem(s) to be solved, and the stakeholders involved.
2. Define objectives and performance measures – develop environmental, social, and economic objectives (usually in the form of 'more X, and less Y') that reflect stakeholder values. An objectives hierarchy is used to organize this from broad values or 'fundamental objectives',

to specific objectives ('means objectives'), to actions, to performance measures that track progress towards the objectives.

3. Develop alternatives – propose different management approaches, methods, or thresholds through which objectives may be achieved, involving stakeholders in the process.
4. Evaluate alternatives and select management actions; predict likely outcomes and consequences of alternative approaches, in general applying scientific methods. Evaluate tradeoffs with stakeholder input. Select the best approaches and actions as a management decision that is informed by science and stakeholders.
5. Implement, monitor, and review − initiate actions, monitor results using quantitative measures, and review to support adaptive management.

In Puerto Rico (Section 6.5, pages 77–82), SDM was used prior to development of a coral reef BCG to identify the fundamental objectives of managers and stakeholders, along with potential measures in an objectives hierarchy (Carriger et al. 2013, Bradley et al. 2015). This objectives hierarchy provided a clear list of desired goals and performance measures. For example, a fundamental objective was 'maximize ecological integrity'. A sub-objective was 'living habitat condition (seagrass, mangroves, corals).' Performance measures were 'living habitat condition indices'. Once objectives had been defined, a means-ends network was used to develop those objectives (ends) and link them to proposed actions (means) from a watershed management plan (Carriger et al. 2013). SDM provides a clear understanding of linkages between objectives and management actions, engages stakeholders, helps identify gaps, and facilitates evaluation of alternatives.

DPSIR

As part of SDM in Puerto Rico, the DPSIR framework provided further management context for BCG development (Bradley et al. 2015, 2016). DPSIR is a comprehensive human-focused decision-making framework that integrates humans, management, socioeconomics, and ecology. The DPSIR terms have been defined in slightly different ways, especially with regard to 'Pressures', but in a general form DPSIR includes five stages. 'Drivers' are basic human needs and their influences (e.g., need for sustenance, living space, removal of waste), and 'Pressures' are the human activities and stresses that Drivers place on the environment (additions of nutrients and toxins, destruction of natural habitat). 'State' then describes the resulting environmental conditions (macroalgal biomass, dissolved oxygen levels, seagrass acres, and benthic faunal indices). 'Impacts' describe the resulting losses or changes to ecosystem services (valuable resource losses, fish kills, unsustainable environments, loss of enjoyment of nature). 'Responses' are the actions taken by management to address Impacts and changes in State (regulation of Pressures, restoration of State). DASEES (www.dasees.org), described along with other SDM tools in Bradley et al. (2015, 2016), is an online user-friendly platform to help practitioners use both SDM and DPSIR. For projects exploring environmental links to human health, EPA has expanded the basic ecological version of DPSIR to include human health/social issues on a parallel track. This Eco-Health DPSIR model better integrates the relationships between humans and the environment, and is thoroughly discussed in Bradley and Yee (2015).

The BCG stressor-response approach is embedded in the D-P-S-I portion of the ecological DPSIR framework. Anthropogenic BCG stressors can be DPSIR Drivers (e.g., need for living space and urbanization), Pressures (e.g., nutrient additions, filling of wetlands, increased siltation) or States (e.g., low dissolved oxygen levels, sediment toxicity). Biological BCG responses can be DPSIR States (diversity measurements, benthic condition indices, seagrass abundance) or Impacts (decreased biodiversity, loss of societally valued seagrass), noting that in the BCG approach, 'response' is used in a stressor-response construct, and has a different meaning than does 'Response' in DPSIR, where the term is used to describe management actions. In Puerto Rico, DPSIR was used to organize scientific knowledge, stakeholder values, and conceptual linkages in a transparent way, and to help establish the decision context with which to identify fundamental objectives (Yee et al. 2014, Bradley et al. 2015). Within SDM and DPSIR, the coral reef BCG was valued for its ability to provide the Pressure to State linkages and identify indicators. BCG allows a consistent determination of reef condition that informs management actions across many reefs and reef areas, and plays an important role within both SDM and DPSIR.

In the Greenwich Bay (RI) BCG (see this document Section 6.1 [pages 61–65] and Shumchenia et al. 2015) the DPSIR framework was used to build a conceptual model of the complex pathways among Drivers (human needs), the resulting Pressures (which were BCG stressors), State (which captured the cumulative effects of stressors), and Impacts (which were linked to the biological response indicators used in the BCG). These response indicators were eelgrass loss and replacement, benthic community changes, and primary production/shellfish−which are connected in Greenwich Bay. This combination of indicators addressed shallow substrates, deeper substrates, the water column, and valued species, representing major components of estuarine biology. The DPSIR model organized the ecosystem, included humans, identified BCG stressors, and linked them to meaningful indicators of biological condition. Combining DPSIR and BCG better clarified the workings of the human-ecological system (Shumchenia et al. 2015).

A vision of a desired future state

As a complementary management approach, managers, scientists, and stakeholders can work to develop a consensus-based vision of a desired future state for the waterbody of concern. This is an effective tool for initiating and guiding environmental efforts. The concept of building desired future conditions into management is critical to both SDM and EBM (Carriger et al. 2013). National Ocean Council guidance for regional marine planning (National Ocean Council 2013) also includes a visioning step. Visioning is aligned with the BCG approach, and can take place before, during, and after BCG development. An early or pre-BCG vision can inform selection of the biological condition measures that are most relevant to the desired future state. A developed BCG can be used to derive or refine a stakeholder vision by describing changes to estuarine condition over time. What was our estuary like in the past (levels 1 and 2)? What is our estuary like now? What do we want our estuary to be like in the future? This last leads to the vision, in the context of what we had, what we have, and what we want. If no new actions are taken, forward projections of current environmental trajectories can suggest possible future conditions–perhaps levels 5 or even 6.

A BCG visioning approach can be applied to a specific sub-area or to the overall condition of a coastal waterbody or estuary. Public and stakeholder outreach and workshops can lead to an agreed-upon vision for a desired estuarine condition that resonates with and motivates the public. Objectives, BCG attributes, measures, BCG level targets and actions can be chosen to address the vision. Environmental effects of these actions and progress towards targets, objectives, and the vision can then be monitored and reported using the same measures and consistent BCG levels.

The Tampa Bay Estuary Program (Section 6.2, pages 66–70) used these concepts very effectively, developing a simple and unifying vision to protect and restore certain valued biological attributes to conditions experienced in the 1950s. This vision of a desired future motivated the public and led to specific goals and targets that drove management actions (Cicchetti and Greening 2011). In 2015, the Tampa Bay Estuary Program achieved (and then exceeded) their original goal of restoring seagrass to the historic acreage present in 1950 (TBEP 2015). The vision of moving Tampa Bay ecosystems back towards earlier conditions and to 'restore the balance' of Tampa Bay habitats led to an engaged public, which was a critical element in the success of the program.

Figure 5-5. Charismatic brown pelican in Tampa Bay, FL. Photo: NOAA

Larger decision-making approaches like SDM and DPSIR, visioning, and BCG are valuable tools that can benefit states, NEPs, NGOs and similar organizations in their roles as conveners of different management and stakeholder interests. This work aligns with principles of integrated management (e.g., EBM): evaluating and managing the waterbody and watershed to achieve ecological, societal, and economic goals through involvement of many different groups and partners. This broad participation is an effective way to address the continuing degradations caused by cumulative impacts of multiple stressors.

5.4. Overall estuary or waterbody condition

Why evaluate overall condition?

The public and stakeholders are often very concerned about the overall condition or health of their particular waterbody, whether that is a cove or bay where they live, swim, or fish, or an entire estuary or coastal area. This concern is best addressed with an assessment of the overall condition of that system and the multiple stressors that affect it. The BCG makes the appealing concept of waterbody 'health' meaningful through consistent comparisons to past conditions, and to conditions in other locations. Moreover, evaluating overall condition helps prioritize stressors to best address waterbody-level problems.

Figure 5-6. West Falmouth Harbor, MA, a small lagoonal estuary located down-flow from a groundwater injection sewage treatment facility. Note abundant seagrass in 2002. A good candidate for BCG monitoring of overall condition over time.

How to evaluate overall condition

Overall condition of an estuary (or other waterbody) is difficult to measure. First, overall condition or state derives from the conditions of the major subcomponents, their connections, and their combined functions. Consequently, the waterbody should be considered as a system to include these interactions. Classifying the waterbody (Section 5.1, pages 39–42), then assembling a conceptual ecosystem model or diagram of the physical, chemical, and biological processes that structure the system helps understand overall condition. Estuaries are spatially and temporally variable, with notable differences in structure and function along the axis between head and mouth, and along transects from intertidal to deep waters.

Several methods and proxies have been developed to evaluate overall condition of the estuary or coast, all of which could be included in a coastal and estuarine BCG through comparisons to undisturbed or minimally disturbed conditions. Ideally, the set of biological measures chosen would cover as much of the entire estuarine gradient as possible, and incorporate several components of the estuary (e.g., intertidal and subtidal; primary and secondary production; benthos and nekton). In practice, this will be limited by data availability. Different approaches (which can be combined) to assess overall biological condition are described below.

5.4.1. Structural measures (e.g., number and type of organisms, acreage of habitats). The structure attribute is often used in BCG for practical measurements and repeatable assessments of biological condition.

The waterbody is good if a critical part of it is good

5.4.1.a. Assessment with a single structural measure of condition: in some cases, one well-chosen measure may meet management requirements for evaluating overall condition.

Keystone species, which have large and disproportionate effects on the ecosystem relative to their abundance (Power et al. 1996), may be monitored to assess overall ecosystem condition. An example is the U.S. west coast sea otter. In the absence of otters, sea urchins can completely graze down a kelp forest, leaving a barren seafloor. The otter feeds on the urchins, keeping their population in check, and maintaining the kelp forest (Estes and Palmisano 1974). However, recent work suggests that the influence of keystone species may be context specific (Power et al. 1996), density-dependent, or show lags in response (Dean et al. 2000, Konar 2000). Keystone species should be used cautiously as a sole measure of overall condition.

Individual species or assemblages may also be assessed as indicators of overall condition when they respond predictably to environmental stressors over a range of impact. Seagrass, for example, is very sensitive to water quality (Dennison et al. 1993) and has been used as an indicator in many estuaries. In general, plentiful beds of healthy seagrass in shallow areas of an estuary indicate good overall condition, and the beds further provide important habitat for valued fauna (Figure 5-7). Benthic invertebrates have also been used to assess the overall health of coasts and estuaries. EPA has consistently collected benthic invertebrate data in estuaries since 1990 (U.S. EPA 2001, 2004, 2008, 2012) and summarizes estuarine condition using area-weighted benthic index values (U.S. EPA 2006a). SCCWRP uses benthic invertebrate data and locally developed indices to assess coastal health in southern California (http://www.sccwrp.org/ResearchAreas/RegionalMonitoring). Other common indicator assemblages include wetlands, shellfish reefs, and fishes.

Figure 5-7. Seagrass habitat is important for the settling and development of juvenile conch.

The waterbody is good if several critical parts of it are good

5.4.1.b. Assessment with multiple structural indicators of condition: several species, communities, or habitats may be used together for a more robust overall evaluation that is less prone to annual or seasonal variability.

This approach has been used to evaluate and communicate condition in many estuaries and waterbodies. The Massachusetts Estuaries Project (http://www.oceanscience.net/estuaries/about.htm) uses both seagrass and infaunal invertebrates as indicator species. The Chesapeake Biotic Index (http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2011/indicators/biotic_index) jointly assesses seagrass, benthic invertebrate communities, and phytoplankton communities to provide an overall measure of condition for the entire Chesapeake Bay or for specific spatial areas of the Bay. The health of the living resources of Buzzards Bay is determined by assessing present condition of eelgrass, bay scallops and river herring in comparison to historic (pre-1900) condition (http://www.savebuzzardsbay.org). Similarly, the Greenwich Bay (RI) BCG (Section 6.1, pages 64–65) evaluated seagrass, benthos, and a combined primary production/shellfish measure. Assessment with multiple indicators depends on the availability of data for each indicator and may not be practical in poorly studied waterbodies.

The waterbody is good if its mix of habitats is good

5.4.1.c. Assessment of the extent, composition, or arrangement of living habitats (biotopes): the mix of critical living habitats within a waterbody reflects waterbody-scale changes due to anthropogenic stressors and these habitat mixtures can be evaluated with statistical tools.

Biotopes are repeating combinations of physical features and biological communities, named after the dominant biota (see Appendix B, Question 9). Productive estuaries in a natural state are a mosaic of biotopes (Henningsen 2005), including seagrass beds, oyster reefs, mussel reefs, salt marshes, mangrove forests, clam flats, and specific soft-bottom benthic communities. The biotope mosaic approach is a relatively new structural metric that evaluates the condition of a waterbody through the mix of biotopes it contains (Figure 5-8), just as the condition of a faunal community is evaluated through the mix of species it contains. This method considers biotopes as critical elements of estuarine biology, and quantifies extent (acreages), composition (proportions), or arrangement (spatial distributions) of the important biotopes within an estuary relative to minimally disturbed conditions from a previous or historic state.

Anthropogenic stress to an estuary leads to destruction and alteration of natural biotopes through removal (e.g., filling a wetland) or replacement with other biotopes (e.g., soft sediment fauna replaces a seagrass biotope). A basic tenet of the approach is that restoration towards the mosaic that would naturally occur will provide the greatest benefit for the native communities of organisms that have evolved in that setting over millennia, thereby improving biological integrity. Use of the biotope concept in management is described in Cicchetti and Greening (2011), and biotopes are incorporated into classifications of biology in CMECS, a federal standard (FGDC 2012).

Figure 5-8. Aerial views of heads of two sub-estuaries showing biotopes. Left: a sub-estuary on Martha's Vineyard (MA) showing seagrass, salt marsh, and maritime forest. Right: a sub-estuary in Long Island Sound (CT) with no natural biotopes identifiable in the shallow subtidal, intertidal, or adjacent uplands.

Historical and present-day habitat distribution data are often available for estuaries through early and recent maps, charts, photos, or habitat acreage studies. GIS methods are extremely helpful, and this waterbody-scale evaluation can be very useful in showing major degradations and improvements over long time periods in a BCG. Biotope measures (e.g., extent, relative proportions, diversity, and fragmentation) are inherently quantitative, and loss of certain habitats may identify specific stressors of concern, e.g., loss of seagrass may identify poor water clarity as a stressor while loss of salt marsh may identify filling or sea level rise as stressors.

Perhaps most importantly, the method tells a compelling and intuitive story for public and stakeholder communication. This is described for the Tampa Bay example in Section 6.2 (pages 66–70). While the term 'biotope mosaic' provides a clear link to biological integrity and the BCG, the synonymous term 'habitat mosaic' (or any other language) may be used for more immediate understanding by public audiences.

Structure and function

Many of these structural measures (Sections 5.4.1.a, b, and c above) are assumed to be surrogates for function and condition. Because species (Sections 5.4.1.a and b) occupy specific niches, they have specific functional roles. For example, benthic invertebrates are involved in nutrient cycling, oxygenation of sediments, and building seafloor structures. Structural measures such as species abundance and diversity are often evaluated, but feeding type or pollution sensitivity metrics based on species abundance can also been used to assess condition. An expansion of this approach is biological traits analysis, which uses the life history characteristics of individual species to assess ecosystem function (Bremner et al. 2006). Biodiversity is also related to ecosystem function (Naeem et al. 1999). Here, a decrease in ecosystem function is likely related to the species that become locally extinct (Cardinale et al. 2006), the functional characteristics of those species, and the types of ecosystem and functional pathways within the system (Hooper et al. 2005). A similar structure and function assumption can be made about biotopes (Section 5.4.1.c) in the larger estuary. Since each biotope provides a unique set of species and functional contributions, the overall function of the estuary is expected to change when the extent and relative proportions of the individual biotopes change.

The waterbody is good if it works as it should

5.4.2. Measures of ecosystem function and connectance. Biological measures that quantify processes of ecosystem function include evaluations of energy flows, trophic webs and linkages, carbon or nutrient fluxes, production of diverse biomass, nutrient processing, rates, or resilience to changes. Measures that capture complex interactions in the entire estuary may be particularly valuable. These larger processes are often assessed using proxies that are easier to evaluate, including structural measures as mentioned above.

Measurements and proxies of functional processes include photosynthesis:respiration ratios; benthic-pelagic exchange and production rates; benthic bioturbation and nutrient cycling; chlorophyll *a* concentrations; macroalgal biomass; biodiversity; other comprehensive measures of biological organization; exchange, export, sedimentation, or migration rates; or results from flux chamber work and trophic analyses. Bioturbation is a proxy for benthic ecosystem function (Solan et al. 2004, Teal et al. 2010) and is relatively easy to assess as the depth of the color discontinuity in the upper layers of sediment. Similarly, chlorophyll *a* may serve as a proxy for ecosystem function and is also relatively easy to assess, particularly given new methods of remote sensing. Together, these proxies can cover the vertical profile of an estuary from surface to bottom.

Connectance can refer to the connections of populations among patches, the relationships between habitat patches and the organisms that move between them, or the extent to which the system allows movement of organisms (Kindlmann and Burel 2008). As with ecosystem function, this attribute is more easily measured using proxies, such as landscape ecology metrics from a biotope mosaic approach (when estuarine data allow spatial GIS analyses). These proxies include nearest-neighbor analyses, evaluations of corridors or fragmentation, and other approaches to measure spatial dispersion and arrangement of habitats. Other proxies for connectance may include analyses of metapopulation stability, anadromous fish runs (Figure 5-9), or hydrodynamic and current data (Figure 4-4, page 27) which can be used to help predict isolation or dispersal capacity. As in all cases, the logic behind selection of proxies should be clearly explained.

Figure 5-9. Migrating coho salmon show connectance between oceans, estuaries, and streams. Photo: NOAA

The waterbody is good if biology is good and stressors are low

5.4.3. Combining biological condition and stressors. This is an often used and effective assessment and communication tool that supports the use of stressor-response models in management. Any of the above measures of biology can be combined with a stressor evaluation. The GSA (Section 4.3, pages 36–38) links directly to BCG levels in evaluating the sum of the cumulative stressors to which biota is exposed. The GSA can be characterized with proxies for anthropogenic stress including human population numbers, ambient pollutant levels, combinations of primary individual stressor levels, or time. Analyses of changes in watershed land use over time (e.g., changes in percent of impervious surface or use of a landscape development index) relate to BCG levels and provide information on the nature and distribution of cumulative stressors and their sources (U.S. EPA 2016). These spatial analyses are useful for communicating stressor information and for managing at the watershed level. Further, the GSA can be parsed into the individual stressors that contribute to cumulative impacts and can help to prioritize these stressors.

In one example of this approach, overall health of Chesapeake Bay is calculated by combining the biotic index mentioned above (Section 5.4.1.b, page 51) with a water quality stressor index that includes water clarity, chlorophyll *a*, and dissolved oxygen measures. Overall health can be calculated bay-wide or for individual sections of the bay. Similarly, overall status of Buzzards Bay is determined by combining living resource indicators with indicators of pollution (nitrogen, bacteria, and toxics) and watershed health (forest, streams, and wetlands). In developing the Puerto Rico coral reef BCG, investigators combined measures of the reef and associated biological communities with water clarity to define different levels of condition.

In a BCG for Greenwich Bay RI (Figure 5-10), information from three biological indicators and several attributes was put together with information on a GSA and on specific stressors. This produced an integrated estuary-wide Biological Condition Gradient with an analysis of stressors and their cumulative effects over historical time (Section 6.1, pages 63–65). The approach is valuable in describing the current state of the estuary together with the significant events and processes that have shaped it over time. This provides context and information for scientists and managers working on any question or issue within the estuary, helps prioritize the stressors most important to the waterbody, and reinforces public and management perceptions of a thorough and meaningful research effort.

Figure 5-10. Northeast corner of Greenwich Bay, RI.

More on overall condition

The EU approach (see text box on page 83) uses the overall condition of waterbodies as the primary basis for regulatory decisions. In brief, a set of rules is used to develop status (condition) levels for each of four biological elements: phytoplankton, flora, benthos and fish. Overall waterbody status is determined as the lowest status among the four elements, and regulatory requirements start in with a status below 'Good' for any one element, secondarily considering hydrogeomorphological elements (e.g. dams, dredging) and physico-chemical elements (e.g. toxicants, nutrients). DPSIR is used to evaluate alternative management methods to restore 'Good' status. This somewhat prescriptive approach is used to ensure that Member States are effectively and consistently regulating their waterbodies.

Generally speaking, the public and stakeholders care about the overall condition of their estuary. This is a scale at which people think about waterbodies, and think about waterbody improvement. This scale is also effective for evaluating and managing the biological effects of cumulative impacts, because these effects manifest throughout the entire estuary. For practical application, developing a BCG for the overall condition of an estuary together with a stakeholder vision for a desired overall future estuarine condition is an effective approach to management, and may be of particular benefit to NEPs. Although estuarine and coastal ecosystems are used to illustrate this, these methods can apply to overall assessment of any defined ecosystem. A BCG may be developed to assess and manage areas of high ecological importance within a larger setting, including large rivers, oyster reefs, or rocky outcrops in otherwise soft-sediment areas. Here, the estuarine and coastal BCG may assess overall condition of the ecosystem or area of interest using any of the methods described above, or other more specific approaches.

5.5. Sustainability and the estuarine/coastal BCG

Sustainability

Sustainability has been adopted by the U.S. EPA as a major goal for research, management, and long-range planning. The Agency defines sustainability as "meeting the needs of the current generation while preserving the ability of future generations to meet their own needs" and recognizes the three pillars of sustainability as "economy, environment, and society" (Anastas 2012, see Figures 5-11, 5-12, and 5-13). In the estuarine and coastal BCG, environmental sustainability evaluates the ability of a functioning ecosystem to maintain those functions given past, existing, and future levels of stress and disturbance. The BCG can address the societal pillar of sustainability through stakeholder involvement and stakeholder-driven visions of a desired future estuary−thus exploring the needs of future generations (Section 5.3, pages 47–48). Information on economic sustainability can be provided though an ecosystem services analysis linked to BCG levels. However, the BCG is strongest in characterizing environmental sustainability; other tools can better evaluate economic and societal sustainability.

Figure 5-11. Economy: investment in recreational fishing. Columbia River, OR and WA. Photo: NOAA

Figure 5-12. Environment: seagrass and staghorn coral, both sensitive species, in the Florida Keys Marine Sanctuary. Photo: NOAA

Figure 5-13. Society: public enjoyment of the seashore. Town Beach, Charlestown, RI.

The historical investigations that often accompany an estuarine BCG are useful in evaluating sustainability in coastal systems, because trends over time show trajectories that may or may not lead to support of future needs. Historical evaluations of Tampa Bay habitat mosaics showed that the estuary continuously degraded from 1900 through 2005, and so the environment and associated ecosystem services were not sustained−and would not be sustainable into the future given that trend. In recent years, after concerted public and private efforts that began in the 1970s, trends were reversed, sustainability of valued habitats has improved by way of meeting the needs of future generations, and habitat measures have been trending up (Cicchetti and Greening 2011, TBEP 2015). Yet, continued sustainability of the Tampa Bay estuary is threatened by projections of greatly increased human populations and associated stressors by 2050.

BCG analyses of changes over time can also show year-to-year consistency in ecosystem state, another indicator of stability and sustainability. Ecosystems that are highly variable from one year to the next may be more likely to cross a tipping point that would dramatically alter ecological state. In conditions of high yearly variability in macroalgal bloom biomass, state change may be caused by an inability of the biological system to recover from low dissolved oxygen, sulfides and other macroalgal-related toxins (Sutula et al. 2014) when high algal biomass years occur back-to-back. Incremental changes and feedback loops associated with high macroalgal biomass (Sutula et al. 2014) or other stressors may also lead to state change.

Resilience

Sustainable systems have high resilience and low susceptibility. Resilience is defined as, “the capacity of an ecosystem to absorb disturbance without shifting to an alternative state and losing function and services” (Holling 1973, Côté and Darling 2010). Using BCG terminology, resilience is the ability to maintain biological attribute levels when stressors increase, particularly attributes of function and connectance. Resilient estuaries are characterized by high biodiversity of species and habitats (relative to expectation for that estuary type). In systems with high species diversity, loss of sensitive species is compensated by expansions of other species that fill the same ecological roles, and overall function is retained (Tilman and Downing 1994, Godbold and Solan 2009). High natural connectance within an estuary may enhance recruitment, recolonization, and movement of species from areas of high abundance to areas of low abundance, providing a buffering capacity within the estuary to avoid localized extinctions. The BCG approach offers measures that can serve as proxies for resilience, e.g., species or habitat-level biodiversity and high connectance.

Susceptibility

Susceptibility, when used to describe waterbodies in a BCG approach, is an estimate of the ability of a waterbody to resist stress based upon physical factors such as hydrodynamics and flushing time (Bricker et al. 1999, 2007). Waterbody susceptibility may also be affected by temperature, physical energy, tidal range, depth, or other factors. Some other definitions of susceptibility (often when resilience is not also considered) do include biological factors (Scavia and Liu 2009). However, in the BCG construct biology is included in resilience and so susceptibility is limited to non-biological factors in order to maintain a useful distinction between the two terms. Estuarine BCG levels of condition use a locally-derived reference for minimally disturbed, so level assignments remain comparable among estuaries of different physical susceptibilities. Further, estuarine classification by physical susceptibility (Bricker et al. 1999, 2007) allows BCG comparisons among estuaries of similar susceptibilities (Section 5.1, page 41).

Recovery potential

Recovery potential is a term used to predict the ability of degraded systems to recover, and the probability of success in ecological restoration projects. Indicators of recovery potential consider ecology, stressors, and social factors to evaluate the likelihood that efforts at a specific location will actually lead to an improved environment. The biological and ecological aspects of recovery potential consider current and projected stressor loads, stressor-response relationships, resilience, and susceptibility. Social aspects include political will, community support, funding sources, and existing infrastructure. Information on recovery potential can be found at http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/indicators.cfm.

Summary

Sustainability, resilience, susceptibility and recovery potential are interrelated concepts that can be important to environmental planning and communication. These concepts can be examined through indices or proxies (e.g., biodiversity), or through rates (and variability) of ecosystem change in the past, present, or predicted future. The BCG approach helps by providing consistent measurements of biological and stressor changes over space and time in a waterbody.

6. Results from early pilots

BCG and BCG-like approaches for estuaries and coasts are in use or in development by NEPs on all three marine coasts of the U.S. and in the Caribbean. These NEPs have identified significant benefits of BCG through the ability to set targets for habitat protection and restoration, and the ability to engage stakeholders and managers. This section describes NEP efforts as examples of BCG application and finishes with a sidebar on a very similar approach taken by the European Union.

6.1. Narragansett Bay

Figure 6-1. Narragansett Bay, RI. Note the city of Providence at the northern end of the bay. Image: Google Earth, data from Landsat

Workshops

Narragansett Bay (Figure 6-1) extends almost the full length of RI and is characterized by a strong north-south stressor gradient from high anthropogenic impacts in Providence and the northern bay to less development and significant oceanic influence in the southern Bay. A group of EPA scientists has been working with the Narragansett Bay Estuary Program (NBEP) and other partners on BCG development since 2008. A 2009 workshop was attended by representatives of many scientific and management groups from Rhode Island and Massachusetts including federal and state agencies, NGOs and private groups, NBEP, and academic organizations (Appendix D). The workshop brought out tremendous historical knowledge of Narragansett Bay and explored a number of environmental trends within the Bay. It was a successful starting point by way of gathering information important to a BCG. However, the diversity of opinion at the workshop together with some misunderstandings of BCG principles held back a consensus description of a minimally disturbed Narragansett Bay− which was a workshop goal. A lesson learned from this was that oversight and management of the Narragansett Bay system was somewhat fragmented, with several influential groups arguing for different approaches.

The workgroup concluded that building a Narragansett Bay BCG would need to include discussions to identify common goals of the different user groups. The workgroup also concluded that a next expert workshop to build consensus on BCG issues would benefit from a narrow set of workshop goals, and from better informing participants about BCG approaches before the meeting. The Narragansett Bay workgroup looks at the Puerto Rico Coral Reef workshops as a very successful model, particularly regarding the instructions and materials that were sent to participants ahead of the meeting to frame the discussions (Bradley et al. 2014).

Moving forward from the 2009 workshop, the BCG workgroup expanded into a discussion group and community of practitioners to include EPA scientists working on the coral reef BCG together with more EPA and non-EPA scientists and managers working in Narragansett Bay. These are the authors of this document. Within this larger and more national group, the subset of scientists most interested in Narragansett Bay turned to Greenwich Bay (Figure 6-2, a sub-estuary of Narragansett Bay) to develop an estuarine BCG demonstration and to test the approach described in this document. Greenwich Bay has a rich history of change, a high level of public interest, and relatively abundant social and environmental data.

Greenwich Bay historical timeline

Figure 6-2. Greenwich Bay, RI, located mid-bay on the western shore of Narragansett Bay. Image: Google Earth, data from Landsat

Historical research on Greenwich Bay and the surrounding area led to a historic reconstruction and trajectory of Greenwich Bay that included cultural history, ecological resources, and stressor impacts (Pesch et al. 2012). This instructive story was published as an EPA report for a broad public and scientific audience, and includes guidance for historical research. Figure 6-3 shows a composite of changes and significant events in natural and anthropogenic stressors in Greenwich Bay together with qualitative eelgrass abundance, all on the same historic timeline. This merged the natural and anthropogenic history of the embayment and provided information on a baseline of 'as naturally occurred'. The biological and stressor data uncovered through this effort were used to develop a demonstration BCG for Greenwich Bay.

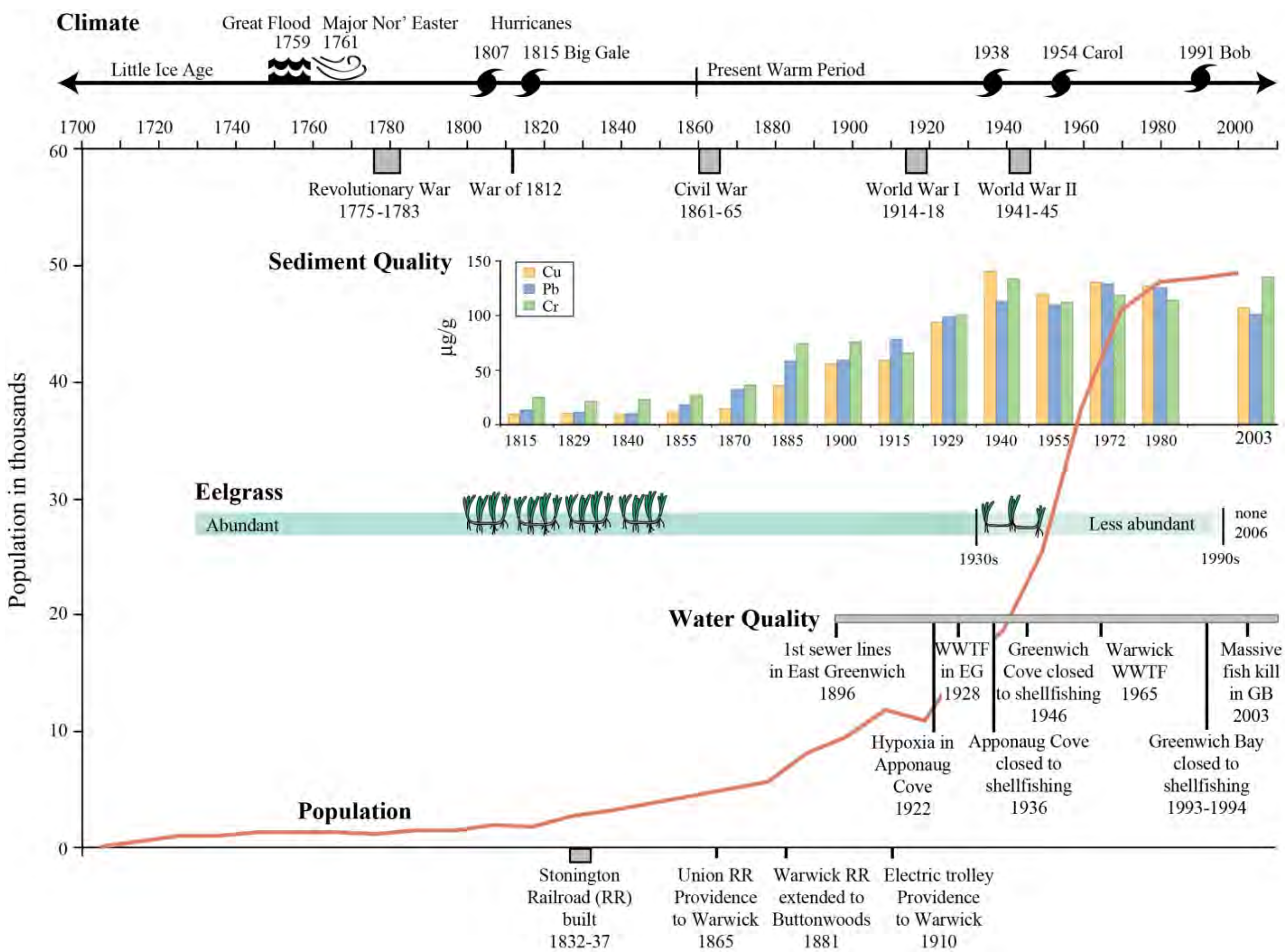

Figure 6-3. The ecological and cultural history of Greenwich Bay, describing the baseline of undisturbed together with historic trajectories of stressors and biological responses. Graphic: Pesch et al. 2012

Greenwich Bay BCG

This BCG demonstration (Shumchenia et al. 2015) is a detailed historical account of stressors and ecological responses over the last two centuries in Greenwich Bay, crafted into a qualitative BCG using stressor changes over time as the GSA (Figure 6-4). BCG development included

1) evaluating and selecting biological measures and attributes
2) defining a minimally disturbed reference condition
3) synthesizing available data to set thresholds for the six levels of biological response to stress for each measure/attribute, and
4) communicating results using the BCG stressor-response diagram (Figure 2-2, page 6).

Consistent narratives for BCG levels (e.g., Appendix A, page 97; Table 4-2, pages 30–31) were used for thresholds. This allows comparability with new efforts to develop a BCG for all of Narragansett Bay.

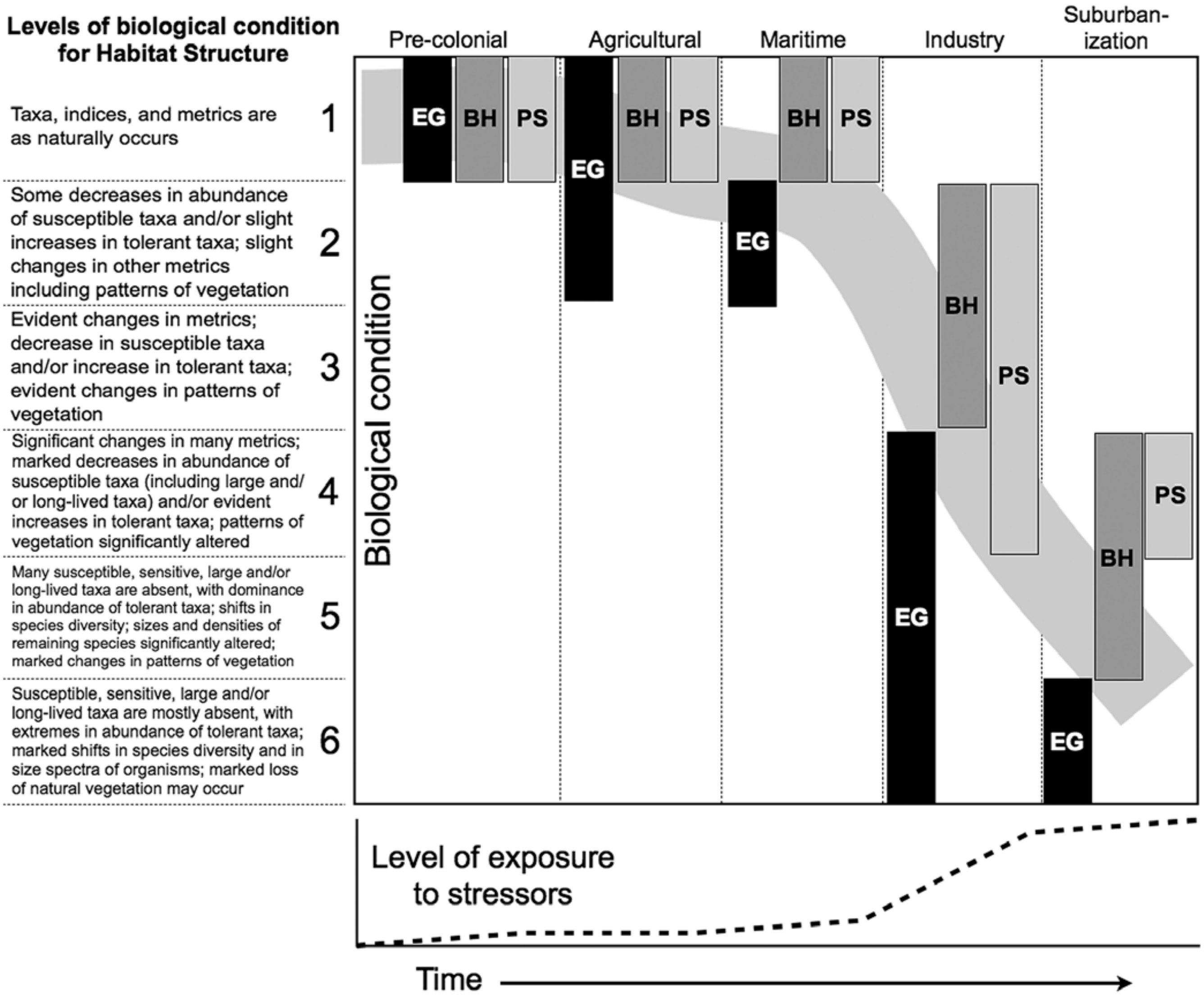

Figure 6-4. Habitat structure BCG model for Greenwich Bay. EG = eelgrass extent; BH = benthic habitat; PS = primary productivity and shellfish, which are linked in Greenwich Bay. The stressor axis is based on time periods (top label) that correspond to stressors in Figure 6-3 (page 64); the response axis shows BCG levels together with narrative threshold guidelines that are consistent with accepted BCG standards. Graphic: Shumchenia et al. 2015

The BCG development process itself also led to ecological insights. Evaluating seagrass, benthic communities, primary production and shellfish showed the benefits of including multiple assemblages. Had the assemblages been examined separately this sub-estuary would have been evaluated at different BCG levels, showing the importance of more holistic large scale approaches. Shumchenia et al. (2015) was written to educate managers on the value of BCG for integrating historical and biological information in setting goals that are supported by the public, and for supporting decisions on how to achieve those goals. It also serves as an example for practitioners applying BCG to other waterbodies. The Narragansett Bay group is using this paper to build management support for a habitat mosaic BCG covering the entire estuary.

6.2. Tampa Bay

Figure 6-5. Tampa Bay, FL. Image: Google Earth, data from SIO, NOAA, U.S. Navy, NGA, GEBCO

Early public involvement and a BCG-like approach

Tampa Bay (Figure 6-5) is Florida's largest open-water estuary. In the late 1970s environmental managers and the public grew concerned about macroalgae covering their beaches, phytoplankton blooms, and loss of marsh, seagrass, birds, fish, and manatees. This led to efforts to better the condition of the Bay. In 1992, the Tampa Bay Estuary Program (TBEP) was formed to build on this previous work and serve as a convener to organize different efforts, providing oversight for improving the Bay. Starting their work before BCG concepts were formalized, TBEP and partners applied a science-based management approach that is very similar to the estuarine and coastal BCG; in fact, this estuarine/coastal BCG implementation document drew from key elements of the Tampa Bay approach, including:

1. Expert consensus and stakeholder outreach to identify biological measures that are important to both estuarine function and the public
2. An overall management approach with a focus on moving the system towards a less disturbed condition that is closer to the ecological settings under which valued native species evolved
3. Use of less disturbed time periods in the past as management restoration goals
4. Expert workshops to assemble data and science for estimating past biological conditions

5. Stakeholder consensus workshops to assist in decision-making, e.g., for setting attainable goals that move the environment closer to a more natural state, while recognizing societal values
6. A strong investment in public outreach and engagement.

Many of these elements involve the public and other stakeholders. TBEP has used a variety of methods to engage, include, educate, and motivate these stakeholders, including hosted meetings, events, public media, informational materials, volunteer opportunities, contests, newsletters (http://archive.constantcontact.com/fs003/1101662914468/archive/1107152227015.html) and economic valuations of the bay area (TBEP and TBRPC 2014).

Biotope mosaics and goals

An important TBEP contribution was the development of the biotope mosaic approach (Section 5.4.1.c, pages 51−53) where bioassessment is based on waterbody-wide changes to quantity (acres) and distributions (relative proportions) of biotopes over time. Establishing 1900 as a minimally disturbed historic condition for habitat acres, ecological priorities for Tampa Bay were to restore the balance of critical biotopes to a less disturbed historic benchmark of 1950, with a specific goal to restore seagrass acreage to that present in 1950 through improvements in water quality. The 1900 minimally disturbed condition and the 1950 goal were developed through consensus of scientists and stakeholders in 1995.

Restoring the balance – a simple unifying vision

Tampa Bay stakeholders and the public were invested in the quantity and diversity of valued habitats, and the concept of 'Restoring the Balance' (Figure 6-6) resonated with this community as a simple unifying vision. The intuitive appeal of this message was effective at communicating estuarine condition and developing stakeholder visions and goals, which led to management actions and environmental results. This method can be used together with other approaches as an important component in the management of estuaries. TBEP has been working with these concepts for many years (Lewis and Robison 1995).

New Habitat Restoration Goals Support a Balanced Approach

The first update of TBEP's Habitat Master Plan in 15 years was completed in 2010, recommending expansion of two key habitats — low-salinity salt marshes and salt barrens — critical to maintaining biodiversity in the bay watershed.

The revised Habitat Master Plan validates the original "Restoring The Balance" approach adopted in 1995, that called for restoring habitats in relative proportion to their historic acreages in 1950.

Under "Restoring The Balance," more than 5,000 acres of coastal wetland and upland habitats have been restored or enhanced in the Tampa Bay watershed since 1995. Some 7,600 acres of seagrasses, the benchmark barometer of the bay's health, have been recovered since 1982. Additionally, 19 of 28 sites priority land acquisition sites have been completely or partially purchased, and eight of those have undergone at least some restoration.

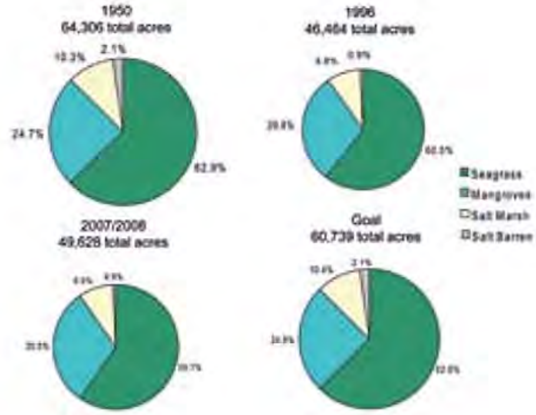

Photo credit: Donna Bollenbach

Mangroves continue to expand faster than other tidal wetland habitats, so more salt marshes and salt barrens need to be created to maintain the historic mosaic of habitats, and ensure that the bay continues to support a diversity of birds, fish and other creatures. Therefore, the new goals call for maintaining the current mangrove coverage of 15,139 acres, while increasing the amount of low-salinity tidal marshes by another 1,918 acres and salt barrens by another 840 acres to keep pace. Having such specific goals helps bay managers focus restoration efforts on priority habitats and track their progress in meeting the goals.

A Tampa Bay Habitat Restoration and Protection Partnership composed of agencies and organizations involved in bay restoration was formed in 2011, to further improve regional coordination and cooperation in identifying and implementing restoration and mitigation.

Figure 6-6. TBEP graphic to describe 'Restoring the Balance'. Graphic: TBEP 2012

A biological gradient

TBEP developed a stressor-response relationship for valued intertidal and subtidal biotopes using 1900 as the minimally disturbed anchor point (Cicchetti and Greening 2011). The stressor gradient was based on time as Tampa Bay became more developed and exploited, while response was characterized as percent change in biological condition metrics relative to 1900. This provided a common language (percent change from minimally disturbed) for comparisons within this estuary in a manner that would allow easy translation into a BCG. Figure 6-7 shows changes in metrics of biological condition (specific habitat areas) since 1900, including the general decline in habitat area up to 1990. This was followed by improvements to the estuary after 1990, following restoration and protection efforts that began in earnest during the 1980s. These data suggest an initial lag in environmental changes after the implementation of management actions, then document subsequent improvements and progress towards goals. In 2015, Tampa Bay achieved their goal (set in 1995) of restoring seagrass to the acreage present in 1950, shown as a red star in Figure 6-7. A historic BCG (or BCG-like approach) offers many insights of value to scientists and managers. Going further, assigning levels 1 through 6 to Tampa Bay metrics would have led to a BCG framework and introduced a common language to improve comparisons among Tampa Bay and other waterbodies.

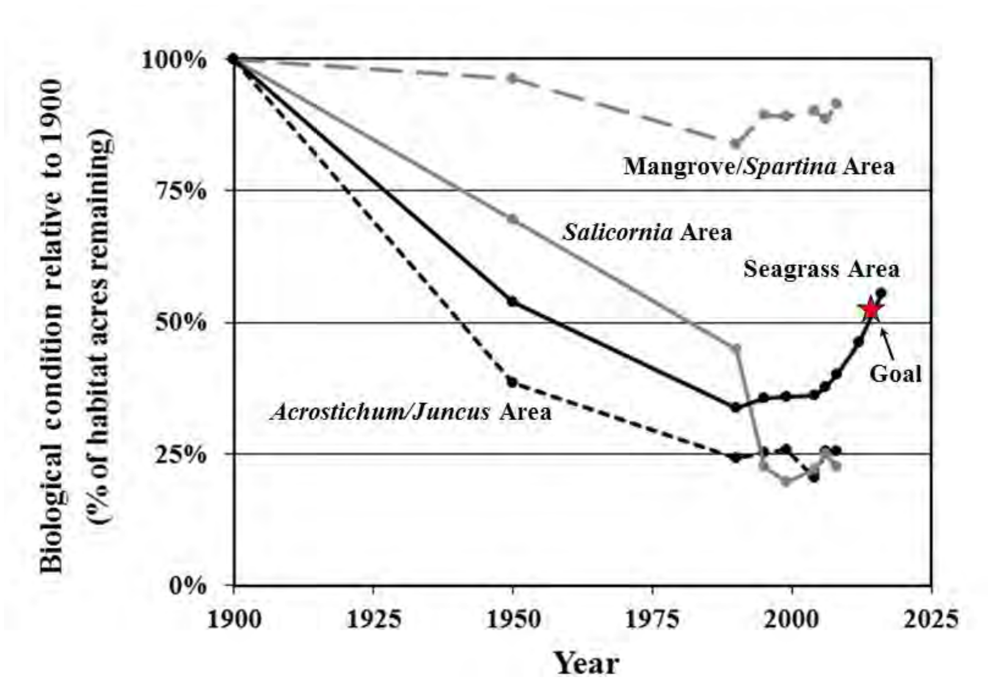

Figure 6-7. Biological gradient for biotopes of Tampa Bay. The 2015 attainment of the 1950 seagrass goal is marked with a star. Graphic: modified from Cicchetti and Greening 2011

Be Floridean

Following water quality and seagrass acreage gains from improved sewage treatment, reduced atmospheric deposition from power plant upgrades, and improved industrial practices, TBEP turned to lawn and landscape fertilization as a significant source of nutrient pollution in urban areas of the Tampa Bay watershed. Reducing these non-point inputs would depend on changing the mindsets and actions of the individuals and communities who own or maintain outdoor spaces. So, the "Be Floridian" campaign (Figure 6-8) was launched to positively engage the public to change their landscaping practices. In "calling on all Southwest Floridians to help protect what makes Florida so fun", the campaign uses billboards, news releases, community outreach, a flock of travelling painted flamingos, even Florida DOT (Department of Transportation) road signs (Figure 6-9) that call for residents to "skip the fertilizer during the summer rainy season", "protect our fun", "Floridify your lawn", and similar. The program has buy-in from a number of cities, counties, organizations and communities, the state DOT, and countless individuals. An expansive website with gardening guides and tips, photo galleries, FAQs, lists of resources, and more can be found at www.befloridian.org.

Figure 6-8. Be Floridian sign: "This summer I will skip fertilizing my lawn and do the responsible thing instead: GO HAVE FUN". Image: TBEP, www.befloridian.org

Figure 6-9. Road sign showing FL DOT support of the Be Floridian campaign. Photo: TBEP, www.befloridian.org

Summary

TBEP efforts, based on a combination of approaches to achieve a simple and unifying vision, have led to habitat gains in Tampa Bay that are widely regarded as a management and restoration success (Cloern 2001; Tomasko et al. 2005; Duarte 2009; Duarte et al. 2015). In 2015, Tampa Bay achieved and exceeded their seagrass restoration target of 1950s acreage (TBEP 2015) in large part due to 20-plus years of active engagement and reach-out to involve and motivate stakeholders including the public, managers, commerce, and other partners (Holly Greening, pers. comm.).

6.3. Mobile Bay

Figure 6-10. Mobile Bay, AL. Image: Google Earth, data from Landsat and NOAA

The Mobile Bay BCG

Mobile Bay (Figure 6-10) is a relatively shallow estuary with a highly variable salinity regime and a major deepwater port at the northern head of the Bay. Building a BCG approach for coastal Alabama is one of the objectives of the Mobile Bay National Estuary Program (MBNEP) in their 2013–2018 Comprehensive Conservation & Management Plan (MBNEP 2013), and the Estuary Program has been working on BCG well before that. The Mobile Bay BCG assesses changes in estuarine condition based on indices of habitat distribution and quality along a continuum of anthropogenic stress (Thibaut et al. 2014). Condition is evaluated and communicated in three levels (good, fair, poor) that are aligned with BCG narrative. The Estuary Program and partners will use the BCG for monitoring status and trends, communicating with the public, developing numeric criteria for condition, tracking management effectiveness, and informing coastal restoration efforts.

Create a clean water future

Along the lines of the TBEP 'Be Floridian' project, MBNEP developed the 'Create a Clean Water Future' outreach program (Figure 6-11). This is a public service campaign to raise awareness of stormwater runoff and its impacts, increase political demand for management actions, clean up trash, and empower individuals and communities with information and tools to reduce polluted runoff from their homes, lawns, and streets. The program promotes the desire for a better future as an inspirational message and provides a number of resources that communities and individuals can use to reach out to others (see www.cleanwaterfuture.com). MBNEP recognized that changing the day-to-day actions of residents is critical for reduction of non-point source pollution and that motivated citizens are a powerful force in environmental improvement (Figures 6-11, 6-12, and 6-13). Public outreach and incorporating the priorities and values of local stakeholders are central tenets of the Estuary Program's work.

Figure 6-11. Create a Clean Water Future campaign−changing public attitudes to protect Mobile Bay. Image: MBNEP

Figure 6-12. Natural beauty of Three Mile Creek, Mobile Bay, AL. Photo: MBNEP

Figure 6-13. Another image from Three Mile Creek, Mobile, AL, illustrating the need to change public actions, and the need for the Clean Water Future campaign. Photo: MBNEP

Habitats, ecosystem services, and restoration

MBNEP, in partnership with The Nature Conservancy and NOAA, used NOAA's Habitat Priority Planner to identify priority habitats throughout coastal Alabama. Through a year-long process of data gathering and evaluation, MBNEP's Coastal Habitats Coordination Team identified 10 priority habitats in need of preservation or restoration. During 2010 planning for the current CCMP, the MBNEP's Science Advisory Committee evaluated the ability of each of these habitats to provide ecosystem services at different levels of impact from a suite of stressors. Freshwater wetlands, streams, rivers and riparian buffers, intertidal marshes, and flats were most stressed, primarily due to habitat conversion. The BCG is used to measure changes in condition of these habitats due to restoration efforts. This BCG also includes ecosystem services analyses to communicate the importance and value of loss or improvement in habitat condition.

Going further

MBNEP is initiating a program for high resolution mapping of habitats to establish present-day baselines for acreage and distribution of critical habitats (including seagrasses), with continued monitoring for change. A later action would be to develop numeric criteria for habitat condition. Also, an existing restoration effort in Mobile Bay's D'Olive watershed is being used as a pilot to develop and test a conceptual model to measure levels of ecosystem services as related to changes in stressor levels. Restoration success here may guide the re-establishment of once-present seagrass beds downstream. The BCG would be used to quantify this and other changes as well as to communicate results in a way that resonates with stakeholders and informs further restoration actions. MBNEP is building a comprehensive approach that effectively incorporates BCG into management of Mobile Bay, and is developing these tools for transferability to other areas on the Alabama coast.

6.4. Lower Columbia River

Figure 6-14. The Lower Columbia River, which forms much of the border between Oregon and Washington. Image: Google Earth, data from Landsat

The Lower Columbia River Estuary (Figure 6-14) is the 146 mile tidally-influenced reach of the Columbia River from the Bonneville Dam (which is about 100 river miles east of Figure 6-14) to the Pacific Ocean. The Lower Columbia Estuary Partnership (LCEP) uses the BCG to evaluate ecosystem condition and to develop quantitative environmental targets for different areas of the river, thus improving management of this system.

Engaging stakeholders and developing a vision

LCEP actively engaged and involved communities and stakeholders throughout the process of articulating a holistic vision, determining objectives, and setting quantitative management targets. Communicating and implementing the resulting plan was then a collaborative effort with these initial partners. LCEP now practices adaptive management by monitoring to ensure that environmental goals are met and reports results back to the involved communities and stakeholders. This approach adopts the principles of both EBM and SDM (Section 5.3, pages 45-46).

Through this process, biological integrity and habitat loss/modification were identified as management issues significant to the region, and were addressed in the Estuary Partnership's Management Plan. A vision and goals (LCEP 2012) were developed as:

- Integrated, resilient, and diverse biological communities are restored and maintained in the Lower Columbia River and estuary.

- Habitat in the Lower Columbia River and estuary supports self-sustaining populations of plants, fish, and wildlife.

Moving to deliver on this vision, the Partnership has devoted significant time and resources to address biological integrity and habitats using a BCG approach.

LCEP BCG

LCEP organized a two-day workshop in April 2012 with EPA support to define 'minimally disturbed' and identify attributes specific to the estuary (Corbett 2012). Workshop participants specified attributes including 1) natural habitat diversity, 2) focal species (e.g., Pacific salmon and steelhead), 3) water quality, and 4) ecosystem processes. While LCEP did not name their attributes in the terminology of BCG (e.g., Table 4-2, pages 30–31), they identify stakeholder management priorities which could easily be translated into specific BCG attributes. To address LCEP attribute 1 (natural habitat diversity) the Partnership has identified priority habitats (including several classes of wetlands and vegetation-based shore habitats) for protection and restoration based on past habitat coverage; this is the BCG 'Structure' attribute and serves as a proxy for the 'Function' attribute.

Figure 6-15. Prairie Channel (WA) and the natural beauty of the Lower Columbia Estuary. Photo: LCEP

Quantitative targets

This group completed an extensive habitat change analysis comparing 1870 to 2009 land cover and developed quantitative habitat coverage targets for native habitats based on past habitat extent using species-area curves (MacArthur and Wilson 1967). The targets include 1) no net loss of native habitats as of the 2009 baseline, 2) recover 30% of the historic coverage of priority habitats by 2030, and 3) recover 40% of the historic coverage of priority habitats by 2050. By meeting these targets the Lower Columbia River will have regained between 46–88% of its historic habitat coverage by 2050, depending on river reach, with an average of 60% historic habitat coverage. The Partnership's next task is to identify "anchor areas" for larger protected reserves, a minimum number of reserves, and important locations for filling habitat gaps and migratory corridors (i.e., connectance).

The Estuary Partnership is in the process of developing numeric and spatially explicit targets for the other three attributes. Focal species (LCEP attribute 2) were identified in the 2012 workshop, and the Partnership has been developing draft targets for this attribute, particularly for juvenile salmonids, a group of primary importance to the region (Corbett 2013).

Consensus and communication

The Partnership recognizes that quantitative targets, though they require a significant development effort, are very effective tools for environmental improvement. Further, quantitative targets promote Partnership goals within the larger competitive political landscape, and are an important communication tool both for managers and the public (Corbett 2013). The Estuary Partnership has made important strides in advancing BCG implementation, and continues to develop their plan, emphasizing consensus and communication among stakeholders so that science-driven targets are well-received and supported (Figure 6-16).

Figure 6-16. Stakeholder investment: paddlers on the Lower Columbia Estuary. Photo: LCEP

6.5. Puerto Rico coral reefs

Figure 6-17. The stretch of reefs from La Parguera to Guánica Bay, southwestern PR, the area of data collection for the coral reef BCG. Note the heavily agricultural landscape. Image: Google Earth, data from SIO, NOAA, U.S. Navy, NGA, GEBCO

Coral reefs are unique ecosystems in decline

The southwestern Puerto Rico coast (Figure 6-17) is a patchy assortment of cays, coral reefs, mangroves, seagrasses, and beaches known for snorkeling, scuba diving, and nature tourism. Coral reefs, like estuaries, are complex coastal ecosystems made up of many closely linked habitats that interact with other adjacent habitats. Connectance is high in functioning coral reef systems. Mangroves and seagrasses, for example, strongly influence the community structure of fish on neighboring coral reefs (Figure 6-18, Mumby et al. 2004). These adjacent vegetated habitats also improve water quality on nearby reefs by trapping sediments, nutrients and pollutants (Grimsditch and Salm 2006). Coral reefs are the most biologically diverse marine ecosystems on earth and rely on the interaction of many species including hard and soft corals, marine invertebrates, and fishes (Sebens 1994, Odum 1997, Bradley et al. 2010).

Sadly, coral reef ecosystems are rapidly declining, in large part due to human activities including agriculture and land use practices that lead to polluted runoff, overfishing, temperature change, ship groundings and coastal development. Recognizing the importance and fragility of coral reefs, the United States Coral Reef Task Force (USCRTF) was established by Presidential Executive Order in 1998 to conserve coral reefs, and includes 12 Federal agencies, a number of states and territories, and many other partners. The Task Force selected Guánica Bay, Puerto Rico, as the first pilot of their Watershed Initiative.

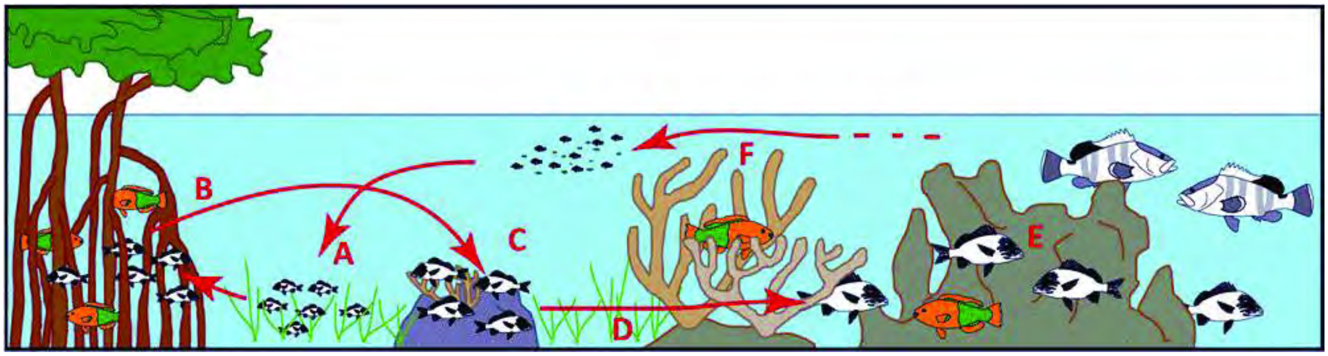

Figure 6-18. Diagram showing ecosystem connectance between mangroves, seagrasses, and coral reefs for different life history stages of a species of grunt. Label (A) shows juvenile grunts in a seagrass bed. Upon reaching a certain size the fish move to mangroves (B). The mangroves serve as a nursery habitat as fish further increase in size and migrate to patch reefs (C), then shallow fore reefs (D), and finally high relief reefs (E). As adult grunts spawn on these high relief reefs their larvae (shown above in the upper water column) grow into juveniles that move into seagrasses (A). If mangroves (B) are not present, grunts on patch reefs (C) are smaller and significantly less abundant. Other species (F) including some parrotfishes (shown in orange and green here) are more dependent on mangroves, and are not seen when mangroves are absent. This connectance could be evaluated using a habitat mosaic approach. Graphic: Mumby et al. (2004), reprinted with permission from Nature.

Workshop: Decision support, SDM, and DPSIR

Working with the USCRTF prior to developing a coral reef BCG for Guánica Bay, the EPA Office of Research and Development and colleagues co-hosted a decision support workshop in 2010, inviting decision makers, scientists, and stakeholders (Bradley et al. 2015). Goals were to facilitate participants to:

- Look at the watershed as a system
- Share a collaborative vision for sustainable coral reefs
- Initiate a systematic, deliberative process to analyze coastal and watershed decisions that impact coral reefs and other ecosystems that provide services to humans
- Advance an integrative framework to incorporate the ecological, social, economic and legal consequences of alternative decisions.

This workshop used SDM and DPSIR to build consensus for management of the Guánica Bay watershed, using SDM tools including an objectives hierarchy (Section 5.3, pages 45–46) and a Social Network Analysis (Section 3.2, page 14) to better understand and improve stakeholder communications, and an advanced online SDM/DPSIR tool (DASEES, www.dasees.org) to organize the process. This work set the stage for development of a BCG. Bradley et al. (2015) present a detailed report on the process and outcomes of the workshop.

Coral reef BCG

Moving forward from this foundation, EPA developed a conceptual narrative model and BCG approach to describe how biological attributes of coral reefs change along a gradient of increasing anthropogenic stress. The approach also identifies the critical attributes of coral reefs and evaluates how each attribute changes in response to stress. This BCG assists decision-makers in understanding the current conditions of Puerto Rico coral reefs relative to natural, undisturbed conditions. Decision makers can then set realistic goals for their coral reefs, and establish monitoring (measurement) endpoints based on attributes identified by the scientific community (Bradley et al. 2014).

Workshop: Biological integrity and levels of condition

To develop this BCG, EPA hosted an expert consensus workshop in 2012 (Bradley et al. 2014). Invited scientists evaluated photos and videos collected by EPA and partners at 12 stations from Puerto Rico coral reefs exhibiting a wide range of conditions. The experts individually rated each station for observed condition ('good', 'fair' or 'poor') and documented their rationale for the assignment (Figure 6-19).

Figure 6-19. EPA coral reef sites reflect a range of coral reef conditions, from good (left) to fair (middle), to poor (right).

The group further identified the attributes that characterize high biological integrity (or natural condition) for Puerto Rico's coral reefs. A BCG based on hard corals, fishes, gorgonians, sponges, and other critical biota was developed for shallow-water linear reefs of southwestern Puerto Rico (Bradley et al. 2014). The experts were able to identify and develop narratives for four distinct levels of condition: very good-excellent, good, fair, and poor as shown in Table 4-2 (pages 30–31), a qualitative but very useful approach. Going further, a quantitative BCG was later developed for fish species based on decisions of a BCG panel using analyses of numeric fish data.

Table 6-1. Summary descriptions of four coral reef condition categories (very good/excellent to poor) based on expert assessments of individual stations. The description of 'very good/excellent' condition is based on panelist determination of features expected in very good stations (Bradley et al. 2014).

Condition Level	Attribute descriptions
VERY GOOD – EXCELLENT (Approximate BCG level 1-2)	**Physical structure:** High rugosity or 3D structure, substantial reef built above bedrock, many irregular surfaces provide habitat for fish, very clear water, no sediment, flocs or films
	Corals: High species diversity including rare; large old colonies (*Orbicella*) with high tissue coverage; balanced population structure (old and middle-aged colonies, recruits); *Acropora* thickets present
	Sponges: Large autotrophic and highly sensitive sponges abundant
	Gorgonians: Gorgonians present but subdominant to corals
	Condition: Low prevalence disease, tumors, mostly live tissue on colonies
	Fish: Populations have balanced species abundance, sizes and trophic interactions
	Vertebrates: Large, long-lived species present and diverse (turtles, eels, sharks)
	Other invertebrates: *Diadema,* lobster, small crustaceans and polychaetes abundant, some large sensitive anemone species
	Algae/plants: Crustose coralline algae abundant, turf algae present but cropped and grazed by *Diadema* and other herbivores, low abundance fleshy algae
GOOD (Approximate BCG level 3)	**Physical structure:** Moderate to high rugosity, moderate reef built above bedrock, some irregular cover for fish habitat, water slightly turbid, low sediment, flocs or films on substrate
	Corals: Moderate coral diversity; large old colonies (*Orbicella*) with some tissue loss; varied population structure (usually old colonies, few middle aged, and some recruits); *Acropora* thickets may be present; rare species absent
	Sponges: Autotrophic species present but highly sensitive species missing
	Gorgonians: Gorgonians more abundant than level 1-2
	Condition: Disease and tumor presence slightly above background level, more colonies have irregular tissue loss
	Fish: Decline of large apex predators (e.g. groupers, snappers) noticeable; small reef fish more abundant
	Vertebrates: Large, long-lived species locally extirpated (turtles, eels)
	Other invertebrates: *Diadema,* lobster, small crustaceans and polychaetes less abundant than level 1-2; large sensitive anemones species absent
	Algae/plants: Crustose coralline algae present but less than level 1-2, turf algae present and longer, fleshier algae present than level 1-2
FAIR (Approximate BCG level 4)	**Physical structure:** Low rugosity, limited reef built above bedrock, erosion of reef structure obvious, water turbid, more sediment accumulation, flocs and films; *Acropora* usually gone, present as rubble for recruitment substrate
	Corals: Reduced coral diversity; emergence of tolerant species, few or no large old colonies (*Orbicella*), mostly dead; *Acropora* thickets gone, large remnants mostly dead with long uncropped turf algae
	Sponges: Mostly heterotrophic tolerant species and clionids
	Gorgonians: More abundant than Levels 1-3; replace sensitive coral and sponge species

Table 6-1 (continued)

Condition Level	Attribute descriptions
	Condition: High evidence of diseased coral, sponges, gorgonians; evidence of high mortality, usually less tissue than dead portions on colonies
	Fish: Absence of small reef fish (mostly damselfish remain)
	Vertebrates: Large, long-lived species locally extirpated (turtles, eels)
	Other invertebrates: *Diadema* absent; *Palythoa* overgrowing corals; crustaceans, polychaetes and sensitive anemones conspicuously absent
	Algae/plants: Some coralline algae present but no crustose coralline algae; turf is uncropped, covered in sediment; abundant fleshy algae (e.g., *Dictyota*) with high diversity
POOR (Approximate BCG level 5-6)	**Physical structure:** Very low rugosity, no or little reef built above bedrock; no or low relief for fish habitat; very turbid water; thick sediment film and flocs covering bottom; no substrate for recruits
	Corals: Absence of colonies, those present are small; only highly tolerant species, little or no tissue
	Sponges: Heterotrophic sponges buried deep in sediment, highly tolerant species
	Gorgonians: Small and sparse colonies, mostly small sea fans, often diseased
	Condition: High incidence of disease on small colonies of corals, sponges and gorgonians, if present
	Fish: No large fish, few tolerant species, lack of multiple trophic levels
	Vertebrates: Usually devoid of other vertebrates other than fishes
	Other invertebrates: Few or no reef invertebrates, high abundance of sediment dwelling organisms such as mud-dwelling polychaetes and holothurians
	Algae/plants: High cover of fleshy algae (*Dictyota)*; complete absence of crustose coralline algae and rarely calcareous algae

Lessons from this coral reef workshop that apply to other BCG workshops are:

1. The heightened contributions of motivated participants who care deeply about the resource and who are committed to bioassessment as a management tool.
2. The value of easily communicated measures of biology, e.g., visual assessment methods that can be distributed as images for participant review before the workshop.
3. The importance of thorough workshop pre-planning.

This workshop is described and discussed in Bradley et al. (2014).

Public Values Forum: Involving stakeholders in management decisions

The EPA group positioned this BCG in the USCRTF pilot effort in Guánica Bay to communicate biological condition as part of a larger management effort. EPA further hosted a Public Values Forum for stakeholders in Guánica Bay during the summer of 2013. Goals of this forum were to identify stakeholder values, objectives, and performance measures, then prioritize management actions to address stakeholder and public values. Anonymous electronic voting tools were used to gather immediate, individual, and inclusive feedback. Stakeholders also developed a preliminary consequence table–a matrix of management alternatives vs. effects on values or concerns (Bradley et al. 2016). This allowed EPA and partners to frame the issues, understand citizen values and perceptions, engage stakeholders, clarify the decision landscape, and develop stakeholder objectives. Together with BCG and previous SDM work, this led to effective management decisions important to, and supported by, stakeholders. The forum is reported in Bradley et al. (2016) along with a section on decision support tools.

Summary – Puerto Rico

These efforts in Puerto Rico followed a clear logic path through a series of stakeholder workshops: first, the 2010 Decision Support workshop identified stakeholder objectives and measures using SDM, an objectives hierarchy, and DPSIR; next, a workshop in 2012 developed a BCG as the scientific basis for reef management; then, the Public Values Forum in 2013 elicited stakeholder values to further inform the decision process. This path closely parallels the BCG implementation steps we present here, but moves the process further into stakeholder-based management at a regional and watershed scale. These efforts are well documented in a number of U.S. EPA reports and publications which serve as detailed examples for estuarine and coastal BCG practitioners. The EPA played a very significant role in shaping decision-making in the Guánica Bay watershed as part of the large interagency USCRTF effort. This work takes implementation of the BCG to a high level in supporting management decision-making in coastal areas. While smaller management programs may not have the equivalent funding to replicate these efforts, the sequence of activities taken in Puerto Rico could be successfully enacted on a smaller scale with fewer resources.

Another example - waterbody management in the European Union

The twenty-eight countries in the European Union (EU) have been using a BCG-like approach to manage their waters since the 2010 enactment of the EU Water Framework Directive (WFD), and this body of work is relevant and instructive to estuarine and coastal BCG development in the United States. EU Member States (countries) use the agreed-upon WFD to assess their coastal and estuarine waters. The Directive applies core BCG concepts in a series of steps.

Six required steps for managing European estuaries

1) The DPSIR framework with a 'pressures and impacts assessment' is used to evaluate environmental problems.

2) Waterbodies are classified into one of six 'categories' (rivers, lakes, estuaries, coasts, artificial waterbodies, and heavily modified waterbodies), then each category is further classified into 'types' of similar systems to improve comparability. Types are determined using a hierarchy of classification factors.

Obligatory Factors:

- Ecoregion
- Tidal Range
- Salinity

Optional Factors for estuaries, in the following order if possible:

- Mixing
- Intertidal Area (%)
- Residence Time
- Other Factors (Depth, Current Velocity, Wave Exposure, etc.)

3) Biological elements (a bit more prescriptive than BCG attributes) can be evaluated using any method suited to the situation. All elements must be assessed.

Biological elements for estuaries:

- Composition, abundance, and biomass of phytoplankton
- Composition and abundance of other aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition and abundance of fish fauna

4) Type-specific reference conditions for biological elements are defined using a hierarchy of methods, identical to those used in U.S. bioassessments (Gibson et al. 2000):

- Comparison to an existing undisturbed site or one with only very minor disturbance (preferred)
- Use of historical data or information
- Models
- Expert Judgement

5) Assignment of ecological status classes (High, Good, Moderate, Poor and Bad) to biological elements is anchored in the type-specific reference condition and is based on consistently defined narratives. This is analogous to the BCG approach, although the WFD formalizes intermediate steps and applies an intercalibration process to assure that status class thresholds have consistent meaning among Member States.

6) The status classes are used with the DPSIR analyses (Step 1) in planning and decision-making. Overall ecological status of the waterbody is defined as the lowest status of any of the four biological elements, considering also (but to a lesser degree) status of hydromorphological and physico-chemical elements. Waterbody thresholds between Good and Moderate (also between High and Good) lead to sets of actions that must be taken by Member States to protect and improve their waters.

The WFD allows flexibility in methods for assessing condition and determining reference, but is designed for comparable assessment and regulation across Member States and so is significantly more prescriptive than the BCG we present here. The document (EC 2002) at http://www.eutro.org/documents/wfd%20cis2.4%20(coast)%20guidance%20on%20tcw.pdf is an excellent guidance report for the European approach, with many lessons for applying the BCG to estuaries and coasts on our side of the Atlantic. If you go to this document, take note of terminological differences, particularly with 'typology' and 'classification'. Other WFD guidance documents describing every stage of the process in detail can also be accessed as pdfs on the internet.

The coastal and estuarine BCG and similar approaches have been used to manage a number of waterbodies. Each case study is different, to address a variety of research and management needs. Together, they provide a tremendous resource of ideas and insight for those considering or implementing BCG methods.

7. Summary and next steps

Figure 7-1. Photo montage of public/stakeholder interest in estuaries and coasts. Clockwise from top left: 1) Manatees are a boon to tourism, Weeki Wachee River, FL. Photo: N. Cicchetti 2) Shallow water coral reef scenes attract snorkelers, Florida Keys National Marine Sanctuary. Photo: NOAA 3) Recreational boating and fishing are popular activities, Everglades City, FL. Photo: NOAA 4) Young beachgoers and a swimmer enjoying the water, Charlestown, RI.

Biological tools for managing estuaries and coasts

The BCG is the U.S. EPA approach to bioassessment and positions biology as a central element in environmental management and decision making. BCG levels provide a 'common language' that allows consistent biological assessment of waterbodies at different times, scales or locations. The BCG stressor axis helps identify and address degradations due to cumulative impacts of many stressors or due to specific impacts of individual stressors. This guidance document provides a toolbox of actions to address management needs and build a BCG to solve environmental problems in coasts and estuaries.

Core aspects of developing an estuarine and coastal BCG for any system or area are to:

1. Build public and stakeholder consensus, evaluate environmental problems, important stressors, management needs, stakeholder needs, and available data to define the biological measures and attributes that will best assess biological condition for the problems at hand.
2. Apply expert consensus to define undisturbed and minimally disturbed conditions. Develop narratives for BCG levels and use the narratives to support non-regulatory management needs, including stakeholder engagement, visioning, target setting, assessments, and monitoring.
3. Use expert best professional judgment to develop numeric decision rules and thresholds for each level. Apply the BCG to management needs, both non-regulatory (e.g., increased impact of all the above actions) and regulatory (e.g., state CWA actions or TMDLs). Use specific stressor-response models, further stakeholder input, adaptive management, and other tools as applicable.

Future development of estuarine and coastal BCG

New and continued use of BCG by management programs is by far the most effective way to improve and expand this approach. Current adopters (Section 6 above) have shown many different ways to use these methods, and will continue to innovate. The estuarine and coastal BCG is intended as a flexible set of concepts and tools; new programs will select and develop those aspects best suited to their particular situations and needs. This adds to the experiences of a community of users and the approach will grow through a better understanding of what works in a variety of ecological, social, and political settings.

Moving forward, a workgroup of scientists and managers (including the authors of this document) continues to develop and promote BCG in estuaries, coral reefs and other complex systems. This group has been active and growing since 2008. BCG projects for managing specific coastal and estuarine waterbodies are underway in many areas across the country. Each application addresses a different set of problems and explores a different approach to environmental management but the goal for all projects is to improve decision-making by bringing biology and BCG methods into direct use by managers. The workgroup is also addressing priorities identified as important for further development of the estuarine and coastal BCG and its implementation.

One priority is to better develop the GSA (the BCG X axis). A detailed stressor gradient can improve links between specific stressors and the resulting biological responses. When these relationships are quantitative, BCG can inform target setting for reduction of specific stressor levels and guide related management actions. Integrating these individual stressors-response measures into a well-developed quantitative GSA (with its own measures and proxies that evaluate cumulative impacts) would better define the entire stressor field to which biota is exposed and so improve both management and communication.

On the biological condition axis (the BCG Y axis) the workgroup continues to explore the use of higher attributes such as function and connectance to provide more comprehensive assessments of waterbody condition. Developing more effective and easily attained measures of these attributes would allow EPA and others to better address questions of waterbody sustainability and resilience. This would be particularly applicable in degraded parts of estuaries where structure and composition are so severely altered that improving function becomes the priority for restoration and management. This information may in turn help human communities adapt to the effects of global change (Figure 7-2).

Biotope mosaics are being explored as a way to evaluate function and connectance, and interest in this approach has been growing. New stressors leading to biotope losses, including sea level rise, are of growing concern. Mosaic measures are inherently quantitative, and work to consistently assign values of measures to BCG levels would be a valuable contribution to application of the method. This would require input from national experts working in different types of systems at different stages of degradation.

Figure 7-2. Eroding marsh edge, which can be a cause of marsh loss due to sea level rise. Lower Chesapeake Bay, VA.

Another interest is in improving tools that engage stakeholders in developing visions for desired future estuarine conditions and in setting environmental goals. Proven tools such as facilitated workshops and public fora may be supported by new tools such as electronic polling, Social Network Analyses (SNA), and outreach through electronic or visual media. Other priorities include exploration of more efficient sampling technologies including remote sensing of biology, which has potential to change the scale at which we assess our coasts and estuaries. Further, better approaches to estuarine classification−that specifically integrate the stressor field and biological response−could improve transfer of knowledge and practice among estuaries and estuarine managers.

Local or national expert workshops can refine implementation of the BCG to best meet management needs and will contribute to addressing the issues listed above. The coastal/estuarine BCG work-group has started to evaluate the need for national workshops to assist all BCG practitioners and improve management applications. In fact, well-organized workshops have been indispensable in advancing local and national efforts from the very beginning of the Office of Water BCG program.

Conclusion

The estuarine and coastal BCG approach has an intuitive appeal to the public and other stakeholders. The focus on living things has a clear connection to the human experience, as does the concept of looking at changes over time. Linking stressor increases over historic time to losses of valued species, habitats, and functions leads to collaborative goal-setting as 'what did we have, what do we have, and what do we want', an approach that can resonate with people. Comparing existing condition to natural condition makes intuitive sense, and people like to see evaluations of an entire waterbody rather than just a part of it. This human appeal can engage citizens to participate in discussions to identify biological measures they value and set targets for improving the condition of those measures. A motivated public is a powerful driver of environmental change through their actions, communications, volunteerism, and ability to increase political will. Engaging the public and other stakeholders is a primary focus of the estuarine and coastal BCG.

Applicable at any scale or at multiple scales using one or several attributes, BCG is an effective and flexible approach to bioassessment and environmental management. The ability to consistently compare biology over time and location offers many advantages. The BCG is firmly entrenched and supported within the U.S. EPA Office of Water and can be used in combination with other management frameworks. A number of management groups have successfully applied the BCG (or similar methods) to address the problems facing their waterbodies.

Increased use of the BCG in programs around the nation has inspired other groups to look into the approach. This document proposes guidance for estuarine and coastal BCG implementation as a logical set of actions to engage stakeholders, scientists, and managers in solving problems and managing complex systems. NEPs, NGOs, states, and other interested parties are urged to contact current users, the authors of this report, or the Office of Water bioassessment program for further discussions and assistance.

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Appendix A. Attributes and narratives to assign BCG levels in streams

Table A-1. Ecological attributes and possible measures (first three columns) paired with example narratives for BCG levels (last 6 columns), from U.S. EPA (2016).

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
STRUCTURE	**Structure and Compositional Complexity (Attributes I-V)** **See Table AI-2 for detailed descriptions of 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

Table A-1 (continued)

	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

Table A-1 (continued)

	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

Table A-1 (continued)

	Attribute Grouping	Description	Examples of BCG					
			1	2	3	4	5	6
CONNECTANCE	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 A-2. Detailed matrix of Taxonomic Composition and Structure Attributes I–V for streams (compressed into 'Structure' in Table A-1), from U.S. EPA (2016).

	BCG Levels					
Ecological Attributes	1 Natural or native condition	2 Minimal changes in the structure of the biotic community and minimal changes in ecosystem function	3 Evident changes in structure of the biotic community and minimal changes in ecosystem function	4 Moderate changes in structure of the biotic community and minimal changes in ecosystem function	5 Major changes in structure of the biotic community and moderate changes in ecosystem function	6 Severe changes in structure of the biotic community and major loss of ecosystem function
	Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability	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	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	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	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	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)

Appendix B. The BCG for estuaries and coasts: Frequently Asked Questions

1 - Why bioassessment?

Bioassessment (the use of biological indicators to evaluate environmental condition) allows biology to be included in management. Living organisms respond to the cumulative impacts of many anthropogenic stressors, and this can be parsed into the impacts of individual stressors as well. Bioassessment allows managers to address these impacts through approaches ranging from public engagement to Clean Water Act regulations. Bioassessment in estuaries integrates many of the upstream stressors in the larger watershed and is a vital part of managing at the waterbody and watershed level.

2 - What exactly is the Biological Condition Gradient or BCG?

The BCG is a conceptual scientific framework for interpreting biological response to increasing effects of stressors on aquatic ecosystems (U.S. EPA 2016). This method was developed by EPA's Office of Water (Office of Science and Technology) to evaluate the extent of biological impairment relative to a baseline condition of 'as naturally occurs' or 'minimally disturbed.' The BCG model defines up to six levels of biological condition along a trajectory of degradation in response to increasing anthropogenic stress (Figure B-1). The consistent narratives of condition on this trajectory can be used for comparable interpretation of biological assessment, support of Clean Water Act objectives, meaningful goal-setting, and coordinated management decision-making (Davies and Jackson 2006, U.S. EPA 2016).

3 - How does the BCG provide a common language for different biological measures?

The levels of biological condition on the response axis of the BCG serve as a common language for assessment in comparing different biological measures such as benthic IBIs, seagrass acres, chlorophyll concentrations, etc. Levels of the BCG have the same inherent definitions for any biological measure in any setting, so that level 3 carries the same basic meaning e.g. for phytoplankton in a Vermont stream, benthos in a California lake, and fish communities in a Georgia estuary.

The descriptive gradient of biological response to stressors (Figure B-1) is the scientific underpinning behind a coastal and estuarine BCG. The gradient represents the full range of condition from the natural or undisturbed anchor (level 1) to most severely disturbed (level 6). Panels of experts bin the gradient into 6 levels using consistent descriptions of each level (left column of Figure B-1). This process can be applied to any biological setting because the entire range of biological condition can be defined anywhere and consistently divided into bins (levels).

In practice, U.S. EPA (2016) provides a detailed process for using expert consensus and available data (e.g., stressor-response relationships from comprehensive monitoring programs) to define the full range of condition, calibrate the BCG, and consistently assign biological metric scores to BCG levels. BCG levels 1–6 provide a common language for assessment because the repeatable scientific process can be applied anywhere that a full range of biological condition can be described with any method of characterizing biology.

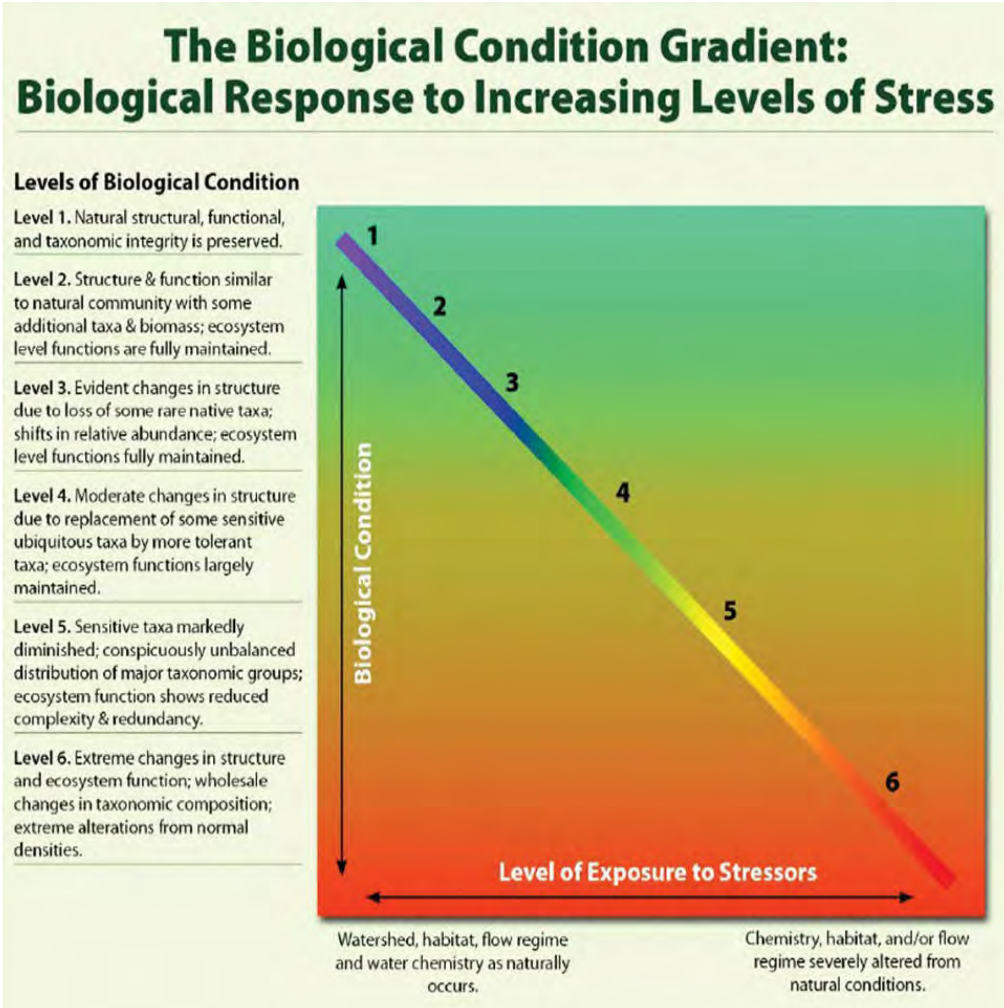

Figure B-1. Conceptual model of the BCG as used in freshwater. Graphic: U.S. EPA 2016

4 - What are the ecological attributes and how do they relate to the BCG concept?

Attributes are ecological characteristics used to organize biological response. In streams, the following ten attributes were tested and shown to be useful in environmental management:

Attribute I: Historically documented, sensitive, long-lived or regionally endemic taxa
Attribute II: Sensitive-rare taxa
Attribute III: Sensitive ubiquitous taxa
Attribute IV: Taxa of intermediate tolerance
Attribute V: Tolerant taxa
Attribute VI: Non-native or intentionally introduced taxa
Attribute VII: Organism condition
Attribute VIII: Ecosystem function
Attribute IX: Spatial and temporal extent of stressor effects
Attribute X: Ecosystem connectance

In estuaries, the Estuarine BCG Workgroup proposes five attributes to be evaluated at multiple scales, bundling Attributes I through V above into 'Structural and Compositional Complexity':

- Structural and Compositional Complexity
- Non-Native Taxa
- Condition
- Function
- Connectance

Identifying and focusing on one, a few, or all attributes simplifies and improves BCG development. Going beyond the more general definitions of levels in Figure B-1, each attribute provides more precise definitions of each BCG level, tailored to the specific ecology of that attribute (Table A-1).

5 – What is the estuarine and coastal BCG implementation approach?

BCG implementation is proposed as a set of eleven actions or steps to assist coastal and estuarine scientists and managers in framing environmental problems and applying BCG methods towards solving those problems. The steps can be divided into three stages of development.

Steps 1–3. Initial collaborative management for effective BCG outcomes

1. Define problems, engage partners and stakeholders
2. Collaborate to define management goals, visions, and objectives
3. Determine the biological components, stressors, measures, and attributes most relevant to management objectives

Steps 4–7. A narrative BCG model to identify and communicate condition, develop visions, set goals and targets, and motivate stakeholders

4. Delineate and classify the waterbody and watershed of interest
5. Organize and analyze existing data for the identified measures, collect new data if needed
6. Define BCG level 1 conditions for the identified attributes
7. Develop narrative descriptions of the biology expected at each BCG level as a narrative BCG model; apply to management needs

Steps 8–11. A fully developed BCG model to support both regulatory and non-regulatory needs

8. Convert narrative descriptions to quantitative metrics and thresholds, calibrate the BCG
9. Develop a stressor gradient and stressor-response relationships
10. Organize, interpret, and report results
11. Develop decision support, communication, and monitoring tools; assist management partners

Taken together, these steps can provide a full path for managing coastal waterbodies. However, the guidance and the steps are flexible, and managers should use any steps in any order and at the level of rigor that best meets their management needs.

6 - Why is moving "up" BCG levels and closer to natural conditions a valuable environmental goal?

1. From an EPA point of view, the Agency's mandate under the Clean Water Act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters", with integrity often defined in the sense of 'as naturally occurs'.
2. A natural state, its beauty, and its associated biodiversity confer significant human well-being.
3. History has shown that deviations from the natural condition can lead to catastrophic unforeseen consequences (building levees along the Mississippi, introducing rabbits to Australia, building groins and jetties on beaches, etc.).
4. A historic benchmark of 'as naturally occurs' can be anchored at a defined point in the past, which avoids problems associated with 'shifting baselines' where expectations of "good" condition become lower over time.
5. For large-scale measures such as the biotope mosaic, natural biological condition describes the relatively stable environments under which native biota evolved prior to rapid human population growth. Restoring towards these conditions should favor the survival of valued native organisms.

7 - How can this complement the ecosystem services/benefits work being done in many estuaries?

This BCG work can easily move forward in tandem with efforts to quantify ecosystem services and benefits. By assessing the values associated with BCG levels, ecosystem service analyses can demonstrate the importance and benefits of protecting or restoring an ecological state, and the costs of not doing so. Ecosystem benefits information helps decision-makers address stakeholder needs when setting goals and evaluating trade-offs between different management scenarios.

8 - What is the biotope mosaic method for bioassessment?

This bioassessment approach quantifies estuary-wide changes to living habitats (biotopes) and to mosaics of these biotopes over time. Scientists at the Tampa Bay Estuary program (TBEP) posited that the cumulative impacts of stressors manifest through destruction and conversion of biotopes, and that returning the proportions or balance of biotopes to a previous and less-disturbed state would benefit the estuary as a whole by moving the estuary closer to the mosaic of biotopes under which native organisms evolved. Several quantitative metrics can be applied to evaluate the estuary-wide mosaic of biotopes. Tampa Bay stakeholders and the public valued quantity and diversity of habitats, and this method proved effective at communicating estuarine condition and developing stakeholder visions and goals that led to management actions and environmental results. This approach was written into a paper (Cicchetti and Greening 2011) that informs scientists and managers of a successful management program that has many parallels to the coastal/estuarine BCG framework.

9 - How is biotope defined?

A *biotope* is an area that is relatively uniform in physical structure, and that can be identified by the dominant biota (Davies et al. 2004). A biotope is defined through the repeatable combination of an abiotic habitat and a strongly associated biological species or group, and the biotope is named after that species or group. *Biotope* can be used interchangeably with *habitat* when habitats specifically include biology: a sand bar is a habitat but not a biotope while seagrass is both a habitat and a biotope. A more informative biotope name would include both the taxon and the abiotic setting, e.g., '*Zostera marina* on subtidal sandy mud'. Bioassessment includes biotopes, but not physical habitats. However, the term 'habitat' is more familiar to a public audience and may be used in that context for better communication to stakeholders: 'the habitat mosaic'. Biological classifications in the Coastal and Marine Ecological Classification Standard (CMECS) document (www.csc.noaa.gov/cmecs) have a strong focus on the biotope concept, and CMECS is a federally approved national classification standard.

10 - Where have BCG or similar approaches been applied to estuaries and coasts?

BCG approaches have been applied in Narragansett Bay, Mobile Bay, Lower Columbia River, Puerto Rico Coral Reefs, and Tampa Bay (essentially a BCG approach). Work in these estuaries is described in Section 6 of the EPA document "Implementing the Biological Condition Gradient Framework for Management of Estuaries and Coasts".

Other estuaries have been evaluated and managed with bioassessments and other methods using elements in common with the BCG approach. Two examples are described below:

Example 1:

Buzzards Bay (MA) and its side estuaries have suffered from losses and alterations to natural species, communities, and habitats. The Buzzards Bay Coalition compared biological data to a historical baseline, in this case pre-colonial conditions. While Buzzards Bay has not developed a BCG, many of the critical elements exist – use of biology for assessment, determination of conditions 'as historically occurred', and use of expert consensus and best professional judgement to evaluate data (Figure B-2).

LIVING RESOURCES

Eelgrass | 23 | no change

If you want to track the spread of nitrogen pollution in your own corner of Buzzards Bay, watch the eelgrass. This rooted underwater plant grows in meadows along the bottom of harbors, coves, and tidal rivers that have clear, shallow waters.

But when nitrogen pollution increases, it fuels the growth of algae that reduces water clarity. Without enough sunlight reaching the bottom, eelgrass dies. And those species that depend on eelgrass – young fish, blue crabs, and bay scallops – begin to vanish, too.

In 2015, the eelgrass score did not change from its 2011 score of *23*. This score is based on the extent of eelgrass meadows in the Bay in 2015 compared with the Bay's maximum historical potential eelgrass coverage (estimated by the Buzzards Bay National Estuary Program).

Along with inputs of nitrogen pollution, eelgrass losses in Buzzards Bay have leveled off as a whole. The good news is that when we reduce nitrogen pollution and water clarity improves, eelgrass can recover on its own. For instance, in the Wareham River and outer New Bedford Harbor, recent wastewater and stormwater upgrades have led to increases in eelgrass acreage.

Bay Scallops | 2 | Down 1 from 2011

Bay scallops were to Buzzards Bay what oysters historically were to Long Island and the Chesapeake Bay. But today, our once-abundant and highly-valuable bay scallops have all but disappeared from most parts of Buzzards Bay.

The bay scallop score fell to *2* in 2015, down one point from 2011. The Massachusetts Division of Marine Fisheries reported an average catch of roughly 1,500 bushels per year between 2011-2015. It's a stunning decline from 1985, when nearly 70,000 bushels of bay scallops were harvested in Buzzards Bay.

This drop in bay scallop harvest is linked to the effects of nitrogen pollution. Bay scallops live and grow among the shelter of eelgrass; as these underwater meadows have disappeared, so have bay scallops. The graph below shows the relationship between these two independent, but closely related, indicators. As we reduce nitrogen pollution and restore clean water, the Bay's signature shellfish can begin to return to health.

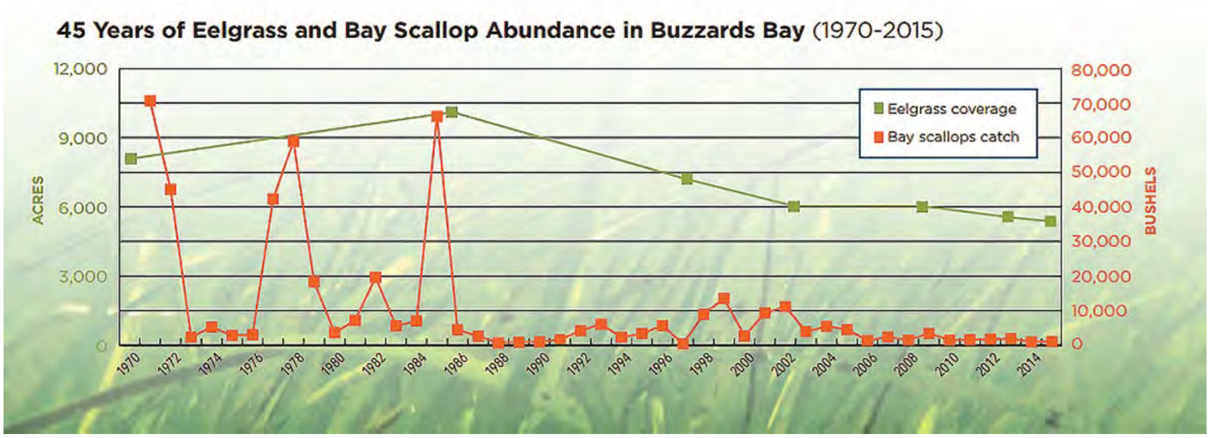

Figure B-2. Excerpt from Buzzards Bay Report Card output. Trends of various measures are shown, as well as resource improvements or declines. Numbers represent the comparative value of the resource relative to historic reference value−a BCG concept. Graphic: Buzzards Bay Coalition 2015

Example 2:
The Chesapeake Bay Program is a well-funded effort that has monitored biological condition for decades in several states. Many of their restoration targets are based on historic baselines (CBP 2000). A variety of biological endpoints are monitored on a routine basis, and biological condition is assessed by summarizing the data into indices based on information from reference sites. These indices are reported separately, for the entire Bay and for each sub-embayment, and can be compared to previous monitoring data for examination of trends. These indicators are also combined into an overall Bay Health Index (Figure B-3).

Figure B-3. 2012 Chesapeake Bay Report Card output. Graphic: CBP 2000

Although work in the Chesapeake was not done for BCG development, many of the important elements of BCG are included. Biological data are used for assessment; reference conditions are defined; multiple levels of condition are identified (in some cases only good/fair/poor); and multiple assemblages are evaluated alone and in concert, at multiple scales, to determine estuary health.

While these programs successfully used BCG concepts to manage estuaries, the development of an actual BCG would allow unification of the indices used into a common language, better management of CWA goals related to “as naturally occurs”, comparability to sub-estuaries and to other estuaries, more consistent prioritization, management, and monitoring, and a more effective way to communicate condition to the public and other stakeholders in a meaningful way.

11 - How have NEPs most benefited from the estuarine and coastal BCG?

NEPs that are using a BCG approach identify significant benefits in 1) setting meaningful targets for habitat protection and restoration and 2) engaging and motivating the public and other stakeholders to participate in waterbody management and to improve the environment by changing behaviors and actions.

Appendix C. Attendees at the 2008 workshop: A proposed organizing framework for bioassessment of estuaries

The goal of this effort was to develop and refine an integrative framework to provide a common language and enable meaningful comparisons among measures and waterbodies, thus allowing better management of entire estuaries and watersheds.

Attendees:

Walter Berry[1]
Curtis Bohlen[2]
Claire Buchanan[3]
Lilian Busse[4]
Marty Chintala[1]
Giancarlo Cicchetti[1]
Bob Connell[5]
Susan Davies[6]
Chris Deacutis[7]
Naomi Detenbeck[1]
Ed Dettmann[1]
Jerry Diamond[8]
Walt Galloway[1]
Tim Gleason[1]
Diane Gould[9]
Holly Greening[10]
Susan Jackson[11]
Danielle Kreeger[12]
Chris Madden[13]
Tim O'Higgins[14]
Angela Padeletti[12]
Peg Pelletier[1]
Margherita Pryor[9]
Richard Ribb[7]
Ed Sherwood[10]
Hilary Snook[15]
Martha Sutula[16]

[1] U.S. EPA, Atlantic Ecology Division, Narragansett, RI
[2] Casco Bay Estuary Partnership, Portland, ME
[3] Interstate Commission on the Potomac River Basin, Rockville, MD
[4] San Diego Water Board, San Diego, CA
[5] New Jersey Department of Environmental Protection, Leeds Point, NJ
[6] Maine Department of Environmental Protection, Augusta, ME
[7] Narragansett Bay Estuary Program, Narragansett, RI
[8] Tetra Tech Corporation, Owings Mills, MD
[9] U.S. EPA, Region 1, Boston, MA
[10] Tampa Bay Estuary Program, St. Petersburg, FL
[11] U.S. EPA, Office of Water, Washington, DC
[12] Partnership for the Delaware Estuary, Wilmington, DE
[13] South Florida Water Management District, West Palm Beach, FL
[14] U.S. EPA, Western Ecology Division, Newport, OR
[15] U.S. EPA, Region 1, North Chelmsford, MA
[16] Southern California Coastal Water Research Project, Costa Mesa, CA

Appendix D. Attendees at the 2009 workshop: A biological condition gradient for Narragansett Bay

The goals of this workshop were to develop a concept and qualitative description of 'minimally disturbed' in the Narragansett Bay estuarine system, identify key indicators, and identify the existing historical and current data that are available for these key indicators.

Attendees:

Andrew Altieri[1]
Tom Ardito[2]
Walter Berry[3]
David Borkman[4]
Keryn Bromberg Gedan[1]
Carrie Byron[5]
Christopher Calabretta[4]
Rachel Calabro[6]
Dan Campbell[3]
Marty Chintala[3]
Giancarlo Cicchetti[3]
Earl Davey[3]
Susan Davies[7]
Chris Deacutis[2]
Ed Dettmann[3]
Walt Galloway[3]
Jonathan Garber[3]
Jeroen Gerritsen[8]
Susan Jackson[11]
David Gregg[9]
Alana Hanson[3]
Carl Hershner[10]
Susan Jackson[11]
Roxanne Johnson[3]
Q Kellogg[12]
Sue Kiernan[13]
Chris Krahforst[14]
Lesley Lambert[2]
Chris Melrose[15]
Dave Murray[1]
Candace Oviatt[4]
Peg Pelletier[3]
Carol Pesch[3]
Chris Powell[16]
Sheldon Pratt[4]
Warren Prell[1]
Margherita Pryor[17]
Paul Rees[18]
Richard Ribb[2]
Ken Rocha[3]
Rodney Roundtree[19]
Liz Scott[13]
Emily Shumchenia[4]
Ted Smayda[4]
Charlie Strobel[3]
Diane Switzer[20]
Glen Thursby[3]
Sue Tuxbury[21]
Cathy Wigand[3]

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[2] Narragansett Bay Estuary Program, Narragansett, RI
[3] U.S. EPA, Atlantic Ecology Division, Narragansett, RI
[4] University of Rhode Island, Graduate School of Oceanography, Narragansett, RI
[5] University of Rhode Island, Coastal Institute, Narragansett, RI
[6] Save the Bay, Providence, RI
[7] Maine Department of Environmental Protection, Augusta, ME
[8] Tetra Tech Corporation, Owings Mills, MD
[9] Rhode Island Natural History Survey, Kingston, RI
[10] College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA
[11] U.S. EPA, Office of Water, Washington, DC
[12] University of Rhode Island, Kingston, RI
[13] Rhode Island Department of Environmental Management, Providence, RI
[14] Massachusetts Bays Program, Boston, MA
[15] NOAA, National Marine Fisheries Service, Narragansett, RI
[16] Rhode Island Department of Environmental Management, Providence, RI (retired)
[17] U.S. EPA, Region 1, Boston, MA
[18] University of Massachusetts, Water Resources Research Center, Amherst, MA
[19] Marine Ecology and Technology Applications, Inc., Waquoit, MA
[20] U.S. EPA, Region 1, North Chelmsford, MA
[21] NOAA, National Marine Fisheries Service, Gloucester, MA

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