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A diatom-based biological condition gradient (BCG) approach for assessing impairment and developing nutrient criteria for streams

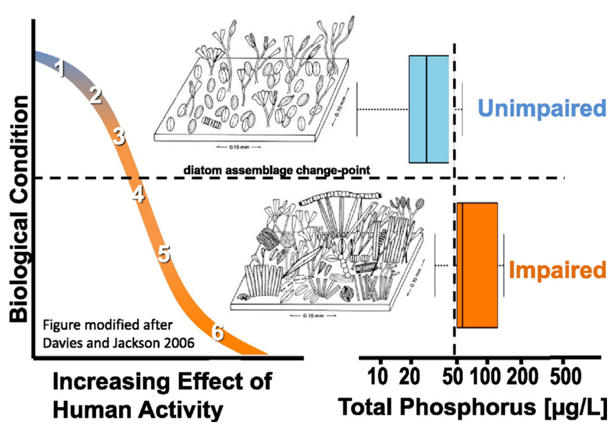
Sonja Hausmann [a,*], Donald F. Charles [a], Jeroen Gerritsen [b], Thomas J. Belton [c]

[a] Phycology Section, Patrick Center for Environmental Research, Academy of Natural Sciences of Drexel University, Philadelphia, PA 19103, USA
[b] Tetra Tech, Inc., Owings Mills, MD 21117, USA
[c] Division of Science, Research, and Environmental Health, New Jersey Department of Environmental Protection, Trenton, NJ 08625, USA

HIGHLIGHTS

- Nutrient criteria are needed to minimize stream impairment due to over enrichment.
- We developed a diatom-based Biological Condition Gradient (BCG) system for streams.
- We used this system to categorize stream sites by level of ecological impairment.
- Nutrient concentrations and land-use correspond with BCG impairment categories.
- The diatom-base BCG is a useful approach to derive potential nutrient criteria.

GRAPHICAL ABSTRACT



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ABSTRACT

Over-enrichment leading to excess algal growth is a major problem in rivers and streams. Regulations to protect streams typically incorporate nutrient criteria, concentrations of phosphorus and nitrogen that should not be exceeded in order to protect biological communities. A major challenge has been to develop an approach for both categorizing streams based on their biological conditions and determining scientifically defensible nutrient criteria to protect the biotic integrity of streams in those categories. To address this challenge, we applied the Biological Condition Gradient (BCG) approach to stream diatom assemblages to develop a system for categorizing sites by level of impairment, and then examined the related nutrient concentrations to identify potential nutrient criteria.

The six levels of the BCG represent a range of ecological conditions from natural (1) to highly disturbed (6). A group of diatom experts developed a set of rules and a model to assign sites to these levels based on their diatom assemblages. To identify potential numeric nutrient criteria, we explored the relation of assigned BCG levels to nutrient concentrations, other anthropogenic stressors, and possible confounding variables using data for stream sites in New Jersey (n = 42) and in surrounding Mid-Atlantic states, USA (n = 1443). In both data sets, BCG levels correlated most strongly with total phosphorus and the percentage of forest in the watershed, but were independent of pH. We applied Threshold Indicator Taxa Analysis (TITAN) to determine change-points in the diatom

* Corresponding author.
E-mail addresses: Sonja.Hausmann@drexel.edu (S. Hausmann), Charles@ansp.org (D.F. Charles), Jeroen.Gerritsen@tetratech.com (J. Gerritsen), Thomas.Belton@dep.nj.gov (T.J. Belton).

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assemblages along the BCG gradient. In both data sets, statistically significant diatom changes occurred between BCG levels 3 and 4. Sites with BCG levels 1 to 3 were dominated by species that grow attached to surfaces, while sites with BCG scores of 4 and above were characterized by motile diatoms. The diatom change-point corresponded with a total phosphorus concentration of about 50 μg/L.

1. Introduction

Excess nutrients are one of most important water quality problems in the United States (Dubrovsky et al., 2010). Eutrophication of rivers and coastal areas is a universal problem (UNEP/RIVM, 1999). Agencies in the US and in Europe have a significant need for science-based nutrient criteria to better protect rivers and streams (USEPA, 2011a, EU Commission, 2015). In the US, nutrient criteria are typically in the form of specific concentrations of phosphorus (P) and nitrogen (N) that should not be exceeded in order to protect water quality under the US Clean Water Act (USEPA, 2011a), which may include meeting nutrient criteria protective of aquatic life. The challenge has been how to set criteria for water body classes in a biologically meaningful way.

One of the most relevant and effective approaches for developing nutrient criteria is to base them on relationships between nutrient concentrations and biological indicators of ecological condition (USEPA, 2000). Diatoms have one of the strongest relationships with nutrient concentrations of all aquatic biota and have been used widely as trophic and impairment indicators (Porter et al., 2008, Potapova and Charles, 2007). Relationships developed to date, such as inference models and many metrics (Ponader et al., 2007, Hausmann and Kienast, 2006) can reliably indicate the position of a site along a nutrient gradient. However, it has been difficult to identify points (e.g., response thresholds) along the nutrient gradient that are associated with transition from one level of impairment to another, and to define these levels in terms of diatom assemblage characteristics. The Biological Condition Gradient (BCG) approach provides a way to define such transition points.

The US Environmental Protection Agency (EPA) worked with biologists from across the United States to develop the BCG conceptual model, which describes how measures of structure and function change in response to increasing levels of human disturbance (Davies and Jackson, 2006, USEPA, 2011b, 2016). The measures of structure and function, or attributes, include taxon richness, several groupings of taxon sensitivity to pollution and disturbance, non-native taxa, organism condition, measures of function, and spatial measures including connectivity. The BCG levels represent a range of ecological conditions from natural (1) to highly disturbed (6):

Level 1. Native structural, functional, and taxonomic integrity is preserved; ecosystem functions are within range of natural variability. Water bodies are pristine, or biologically indistinguishable from pristine condition.

Level 2. 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.

Level 3. Some changes in structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa, but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system, but may differ quantitatively.

Level 4. Moderate changes in structure due to replacement of intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; all expected major groups are represented; ecosystem functions largely maintained through redundant attributes.

Level 5. Sensitive taxa are markedly diminished and may be absent; conspicuously unbalanced distribution of major groups from that expected; organism condition may show signs of physiological stress; system function shows reduced complexity and redundancy; increased buildup or export of unused organic materials.

Level 6. Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor (e.g. diseased individuals may be prevalent); ecosystem functions are severely altered.

The six levels of the BCG can serve as endpoints for biological water quality management, and are useful in efforts to meet biological integrity goals of the USA Clean Water Act (CWA). The CWA has as its objective to restore and maintain chemical, physical and biological integrity of waters (USEPA, 2011b). Biological integrity has come to mean “The ability of an aquatic ecosystem to support and maintain a balanced, integrated and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region” (Karr and Dudley, 1981). The six BCG levels are similar in concept to the five ordinal biological condition categories used in the EU Water Framework Directive. These span the range from excellent or nearly pristine to heavily degraded and altered (EU Commission, 2015). “High” status in the WFD is defined as conditions associated with no or very low human pressure — very similar to BCG levels 1 and 2.

BCG development requires professional judgment and development of consensus. Assessing condition of biological communities, using any of the common biotic indexes, involves professional judgment, even though such judgment may be hidden in apparently objective, quantitative approaches. Professional judgment is applied in the development of all assessment frameworks (e.g., Steedman, 1994, Borja et al., 2004, Weisberg et al., 2008). Use of professional consensus has a long pedigree in the medical field, including the National Institutes of Health (NIH) Consensus Development Conferences to recommend best practices for diagnosis and treatment of diseases (NIH http://consensus.nih.gov/). The NIH consensus meetings were a “hybrid of … judicial decision-making, scientific conferences and the town hall meeting” (Nair et al., 2011). In addition to the NIH consensus conferences, other researchers, institutes, and countries develop medical consensus statements, using both the NIH methods and others (Nair et al., 2011).

Development and calibration of a BCG model is a collective exercise among biologists to assign sites to BCG levels, and then to develop rules to make assignments of new sites (USEPA, 2016). This paper describes development of a diatom BCG approach for deriving nutrient criteria for streams and rivers in the state of New Jersey (NJ). It can be broadened for wider applicability in the Mid-Atlantic region of the eastern United States. It is part of a larger effort to develop the basis for scientifically defensible regulatory guidelines to maintain biotic integrity.

Like other states, NJ has embraced the BCG approach for criteria development, and has used it on a macroinvertebrate network developed for assessing the biological integrity of freshwater wadeable streams. Our group expanded this approach to periphytic diatom communities. This was done in part in response to EPAs initiative for states to develop nutrient criteria (US EPA, 2011a). New Jersey promulgated P and N criteria for freshwater streams in the 1980s based on literature values. It is uncertain, however, whether these numbers are protective enough from both a biological and a regional perspective, so investigation of new approaches is necessary.