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Review

An overview of algal monitoring and research in the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program

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Abstract

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey uses algal data together with other physical, chemical, and biological variables to assess the quality of rivers and streams throughout the United States. Pilot NAWQA studies (1987–1990) led to the development of methods for collecting algal samples from various instream habitats and to the publication of protocols for the identification and enumeration of algal samples to ensure nationally consistent data. During the first decade of the Program, more than 7,000 algal samples were analyzed from more than 1,500 river reaches throughout the United States. These data from the NAWQA Program and related studies have been incorporated into more than 70 publications, 50 of which are cited in this paper. Determinations of algal biomass (algal biovolume, chlorophyll *a*, ash-free dry mass), autecological-guild and pollution-tolerance metrics, indicator taxa, physiognomy, and weighted-average optima and tolerance were used in evaluations of stream-water quality, depending on the focus of each study. Relations of the biological data with trophic condition, hydrologic disturbance, geochemistry, and land use were examined. Although species optima and tolerance values for diatoms differ depending on the scale of assessment (national and regional), species optima determined for indicators of alkalinity, water hardness, specific conductance, chloride, and sulfate were consistent with qualitative, autecological classifications for those taxa in western Europe. The ecological studies summarized here are part of nationally guided studies addressing selected water-quality issues, such as the effects of watershed urbanization and agricultural land use on nutrient enrichment and stream ecosystems. The algal data and related physical, chemical, and biological data are released (after quality reviews) and made available to the public online through the NAWQA website http : //water.usgs.gov/nawqa/.

Key index words : algae, autecology, disturbance, eutrophication, land use, water quality

Introduction

The U.S. Geological Survey (USGS) has been investigating algae in rivers, lakes, and reservoirs since the 1960s. These studies led to the publication of methods for collection and analysis of samples (Greeson *et al*. 1977), a key to the phytoplankton of North America (Greeson 1982), and the addition of a biological laboratory for the identification and enumeration of aquatic organisms as part of the National Stream Quality Accounting Network (NASQAN) program. The expertise in collecting and analyzing biological samples during the 1970s and 1980s helped provide the foundation for developing the National Water-Quality Assessment (NAWQA) Program.

The NAWQA program was established by the U.S. Congress in 1986, with the following long-term goals : (1) to provide a nationally consistent description of current water-quality conditions for a large proportion of the Nation's water resources, (2) to define long-term trends (or lack of trends) in water quality, and (3) to identify, describe, and explain the major factors that af-

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fect observed water-quality conditions and trends (Cohen *et al*. 1988; Hirsch *et al*. 1988). More information about the NAWQA Program can be found at http://water.usgs.gov/nawqa/. Pilot studies for this program including algae monitoring (1987–90) were conducted in the Kentucky River Basin (Bradfield & Porter 1990, Stevenson & White 1995, Haag & Porter 1995), the Upper Illinois River Basin (Leland & Porter 2000), and the Yakima River Basin (Leland 1995; Cuffney *et al*. 1997). During the first decade of the fully implemented NAWQA program, studies employing chemical, physical, and biological components were conducted in 51 surface- and ground-water basins throughout the United States.

Design and summary of algae collection, processing, and reports

Algae collection and sample processing

Following the full implementation of the Program in 1991, NAWQA has focused on the collection of periphyton samples from erosional and depositional habitats in streams and rivers of United States (Porter *et al*. 1993, Moulton *et al*. 2002) in order to characterize algal assemblages in representative stream reaches. For NAWQA studies, a reach is defined as a portion of a stream whose length is approximately 20 times the width of the stream channel (Meador *et al*. 1993, Fitzpatrick *et al*. 1998). Quantitative samples from erosional habitats (RTH or richest-targeted habitat samples) were collected principally from epilithic microhabitats in stream riffles and from epidendric microhabitats (submerged woody debris) in stream runs. About 67% of the 2,860 RTH samples collected through 2003 were from epilithic microhabitats and about 28% were from epidendric microhabitats. Quantitative samples (1,885 samples) from depositional habitats (DTH or depositional-targeted habitat samples, *e.g*. silt or sand) were collected from stream pools or margins where water velocities were slow or not measurable (Porter *et al*. 1993, Moulton *et al*. 2002). Algae samples were typically identified to species or variety for diatoms and genus for soft algae. Biovolumes were determined for all algal taxa from morphometric measurements of representative individuals. Results were presented as standing crop (cells per square centimeter, cells/cm^2) and biovolume (cubic micrometers per square centimeter, $\mu m^3/cm^2$) on the basis of laboratory protocols developed for the NAWQA program (Charles *et al*. 2002). Determinations of chlorophyll *a* (Arar & Collins, 1997) and ash-free dry mass data (American Public Health Association *et al*. 1998) also are available for many samples, particularly those collected after 2000 and those from selected synoptic studies prior to 2000 (*e.g*. Sorenson *et al*. 1999, Peterson *et al*. 2001).

Qualitative multi-habitat (QMH) algae samples were collected at monitoring sites during the first cycle of the NAWQA Program (1991–2001). More than 2,000 QMH samples were obtained by collecting from each microhabitat (epilithic, epidendric, epiphytic, epipsammic, and epipelic) prevalent in the stream reach and compositing equal amounts of biomass from each microhabitat. The preservative was 3 to 5% buffered formalin (Porter *et al*. 1993, Moulton *et al*. 2002 http://water.usgs.gov/nawqa/protocols/OFR02-150/index.html). Algal taxa identified from RTH, DTH, and (or) QMH samples from each site and date were combined into a master list of species for each site.

More than 500 phytoplankton samples (PHY) were collected from reservoirs (Bauch & Malick 2003), large rivers (Kroening *et al*. 2003, Leland & Frey *in review* 2004), and (or) small streams (Stevenson & White 1995, Sorenson *et al*. 1999, Leland *et al*. 2001). These samples were taken from the same depth- and (or) width-integrated samples collected for water chemistry. Subsamples were processed for chlorophyll *a* determinations and (or) species identification and enumeration.

Twelve workshops on harmonization of taxonomy of diatoms (10) and soft algae (2) were held to resolve differences in nomenclature and regional variations. During the first workshop a list of 500 names and authorities, representing all diatom taxa at >1% abundance in NAWQA samples, were examined in detail to facilitate data consistency among taxonomists and institutions (ANSP 1999, http://www.acnatsci.org/research/pcer/research.html). Successive workshops focused on reducing "unknown taxa", creating a master list of 1,131 taxa initially (>5,000 in 2004) with identification numbers and specific image citations, establishing criteria for adopting

new names, incorporating the changes to the database (ANSP 2000a & b), and identifying the problematic taxa within *Navicula* and *Gomphonema* (ANSP 2001). At present (2004), one new genus and nine new diatom species have been described on the basis of NAWQA collections (Kociolek & Kingston 1999, Morales, 2002, Potapova *et al*. 2003, Potapova & Ponader 2004).

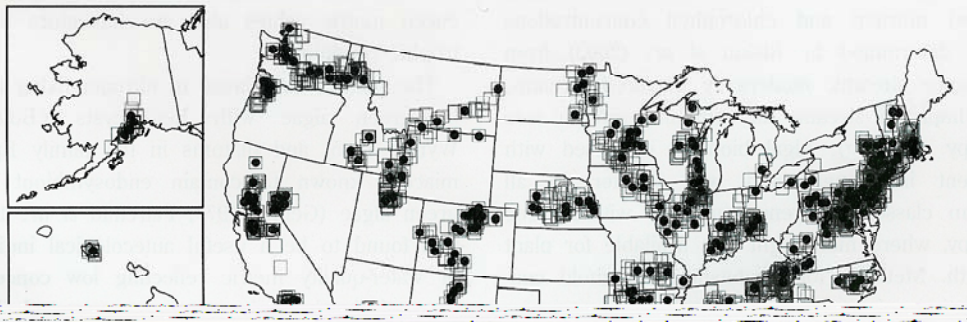
Reports

Algae samples collected and analyzed by the U.S. Geological Survey scientists and associates have resulted in more than 70 publications since 1990. These publications are largely funded by the NAWQA Program but some represent related projects using methods developed in the Program. These publications range from data summaries to interpretative reports, including discussions of community responses to land use (from forest to agriculture and urban), physical habitat (*e.g.*, as riparian shading, width, slope, current velocity), and water-quality (*e.g.*, nutrients, salts, metals, pesticides, and organic matter).

The periphyton was the principal subject of most of the reports (85%), but sixteen included information on the phytoplankton. Seven of these reports focused on large rivers, lakes, or reservoirs, where phytoplankton was the primary component of plant production. Publications on phytoplankton range from data reports (Averett *et al.* 1993) to seasonal and spatial analyses of species / environment relations (Stevenson & White 1995). Nine studies included phytoplankton as well as the benthic algae in order to account for whole stream production in response to gains and losses in nutrients. Analysis of algal biomass as chlorophyll *a*, ash-free dry mass, or biovolume, and the resultant metabolic rate of the community as estimated by diurnal dissolved oxygen was used to evaluate varying land use and riparian cover conditions (Sorenson *et al*. 1999, Peterson & Porter 2002). In addition, two papers on diatoms from reservoir sediment cores evaluated changes in environmental conditions and land-use practices over recent decades (Bradbury & Van Metre 1997, Juracek 2003).

Results and Discussion

During the first decade of the NAWQA program, more than 7,000 algae samples were analyzed from more than 1,500 river reaches throughout the United States (Fig. 1). The algal data from the NAWQA Program and related studies have been incorporated into more than 70 publications, 50 of which are cited in this paper. Estimates of algal biomass (total algal biovolume, chlorophyll *a*, ash-free dry mass), autecological-guild and pollution-tolerance metrics, indicator taxa, physiognomy, and weighted-average optima and tolerance calculations were all used to evaluate the condition of streams and rivers.



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