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Commentary

A case study: Comparison and limitations of biological and chemical assessments of trophic state in four streams of the Genesee River watershed

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ABSTRACT

We evaluated the trophic status of several contrasting wadeable streams with the Nutrient Biotic Index for phosphorus (NBI-P) and the NBI for nitrate (NBI-N) in comparison to trophic status as determined based solely on measured nutrient chemistry. The macroinvertebrate assemblage (NBI-P) and phosphorus assessments agreed well in the designation of the trophic status in three of the four streams. However, total nitrogen (TN)-based predictions of trophic status did not agree well with the biologically derived NBI for nitrate. Although improvements to the NBI-N based on nitrate tolerance scores could be made, a TN-derived trophic status, especially in agriculturally impacted watersheds where nitrate concentrations may be relatively low in comparison to TN, may be preferable. In general, the P short-term and long-term nutrient-derived trophic status provided a similar stream trophic classification. However, this was not always the case. While a short-term average is appropriate for the conditions preceding a macroinvertebrate sample, it may not necessarily be an accurate indicator of a stream's long-term chemistry or trophic state. The widely different results between the short- and long-term TP and TN concentrations suggest that streams with inherently variable nonpoint source agricultural runoff might need a wider time frame to evaluate nutrient concentrations. Although the NBI represents an integrated response to both autochthonous and allochthonous inputs of carbon, invertebrate responses to toxics, as well as nutrients, and the short period of time the NBI may represent, may not adequately reflect impact and nutrient load to downstream systems.

Introduction

Trophic state of an ecosystem is the biological response to forcing functions, such as allochthonous and autochthonous nutrient and organic carbon additions, whose response may be modified by factors such as season, grazing, shading, mixing depth, and hydrology in the case of streams (Carlson and Simpson, 1996). Excessive nutrients and organic carbon from anthropogenic sources often result in the overgrowth of benthic algae and the overabundance of phytoplankton and macrophytes, changing the trophic state of a lake or a stream (Wang et al., 2007). While the determination of trophic status of lakes has been common for several decades (e.g., Carlson, 1977, 1991; Vollenweider, 1979; Wetzel, 2001), the trophic classification of streams has not received the attention or development of lentic systems.

Trophic state of a stream is of interest because it is the adaptive template under which stream organisms have evolved (Dodds, 2007). A change in trophic state will result in modifications of stream assemblages of macroinvertebrates (e.g., Hilsenhoff, 1977, 1982, 1987) and algae (Kelly et al., 1998; Stevenson and Lowe, 1986; Stevenson and Pan, 1999) composition and thus diversity. Several indices based on composition of macroinvertebrates have been developed to evaluate aquatic ecosystems. Macroinvertebrate sensitivity to nutrient and toxic pollution, short life span, low mobility, importance in the food web, and ease of collection make them successful biological indicators of water quality and health of the stream system (Bode et al., 2002; Growns et al., 1997; Smith et al., 2007).

However, indices of species composition do not provide quantitative numerical assessments of nutrient criteria (Smith et al., 2007). Since 1998, USEPA (1998) has required states to determine nutrient criteria for rivers, lakes, wetlands, and estuaries. Both Wang et al. (2007) and Dodds et al. (1998) identify the need for a generally accepted system to define trophic status in streams. A predictive relationship between nutrient concentration and periphyton biomass would be expected. However, the occurrence of a nutrient–algae relationship in wadeable streams is tentative, observed in some locations (e.g., Biggs, 1995; Dodds et al., 1997; Lohman et al., 1992) and not observed in other locations (Jones et al., 1984; Welch et al., 1988); that is, the relationship between primary production and nutrient status is less reliable (Dodds, 2006). Canopy shading (Lowe et al., 1986), frequency of flooding (Lohman et al., 1992),

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and fish and invertebrate grazing are often suggested as causes for this weaker relationship (Wang et al., 2007). Allochthonous sources of carbon (e.g., leaves and associated microflora), independent of an aquatic nutrient-driven food web, also may account for the weaker relationship between nutrients and algal biomass observed in some instances.

Nonetheless, macroinvertebrates with faster individual development, greater body mass, and elevated density have been associated with elevated nutrient levels in streams (e.g., Cross et al., 2006; Deegan et al., 1997; Hart and Robinson, 1990; Mallin et al., 2006). Working with the macroinvertebrate community, Wang et al. (2007) observed strong correlations between most nutrient measures and the macroinvertebrate community that could be used to identify thresholds in nutrient concentration. Beketov (2004) suggested that elevated nutrient levels (ammonia, nitrite, and nitrate) limited the distribution of mayfly species, suggesting that tolerance thresholds existed between species while Smith et al. (2007) suggested that the establishment of biotic indices for nutrients based on macroinvertebrate species tolerances is possible.

Nutrient Biotic Indexes (NBI), one for total phosphorus and one for nitrate, have been developed for benthic macroinvertebrate communities in wadeable streams in the state of New York (Smith et al., 2007). In addition, corresponding nutrient concentrations to NBI scores were established, relating macroinvertebrate community data to trophic status of a stream (e.g., oligotrophic) as commonly used in lake environments. Such macroinvertebrate indices are recognized by the USEPA as secondary response variables that have potentially high value in nutrient criteria development (USEPA, 2000a). Ultimately, a goal of the NBI is to develop a management and enforcement tool to determine a stream's general trophic state and to determine the point at which water quality can be classified as impaired (Smith et al., 2007).

Here we evaluate the trophic status of several contrasting wadeable streams (<1-m depth and watershed area <1296 km^2) with the NBI for phosphorus (NBI-P) and the NBI for nitrate (NBI-N) in comparison to trophic status as determined based solely on measured nutrient chemistry. Sites were selected in advance to include nutrient-impaired and unimpaired streams with varying levels of nitrogen and phosphorus. In this modified paired watershed approach, all sites were in the same catchment and thus the same ecoregion. We also discuss the definition of stream trophic status in relation to time span. In view of our data, we discuss appropriate time spans to consider in the assessment of trophic status of streams.

Field sites

Buck Run (Fig. 1) is a relatively small (1751 ha) watershed dominated by agriculture (76.4%) including one large Concentrated Animal Feeding Operation (CAFO, 829.6 ha, 1430 dairy cows) which dominates the catchment. Of the row and cash crops, >50% is as corn. The headwaters are dominated by riparian cover while the rest of the watershed is forested. Flows ranging from 13 to 946,446 m^3/day are typical (Rea et al., 2013b). No wastewater treatment plants (WWTP) or SPDES (State Pollutant Discharge Elimination System) sites are known or registered with New York State (USEPA, 2011). Areal loads of P from the watershed are high (2.4 kg/ha/year) compared to the Stony Brook, Bigelow Creek, and Oatka Creek watersheds.

Bigelow Creek is a small (2616 ha) agricultural (82%) watershed (Fig. 1) classified as impaired due to excess nutrients (NYS DEC, 2003) with annual areal P loads of 1.1 kg/ha/year (Winslow et al., 2013). Of the row and cash crops, >50% is as corn. Seven SPDES sites are located in the watershed but are generally small sanitary effluent discharges (discharge range: ~1 to 14 m^3/day) from home treatment systems as surface water into a ditch or stream (USEPA, 2011). Typically these systems are similar to septic treatment systems with the addition of a sand filter. Nutrients and coliform bacteria are the concern, rather than toxic chemicals. Flows ranging from 6741 to 294,640 m^3/day are typical (Winslow et al., 2013).

Stony Brook (Fig. 1) is a relatively small upland tributary (5491 ha) with flows ranging from 27,173 to 1,012,401 m^3/day. Forest (49.4%) and agriculture (45.5%) are the major land uses and include the Stony Brook State Park. Of the row and cash crops, >50% is as corn. Areal P loading is the lowest of the four watersheds studied (0.2 kg/ha/year) (Rea et al., 2013b). No WWTPs or SPDES sites are registered with New York State.

Oatka Creek is the largest of the four watersheds studied with a drainage area of 55,700 ha (at Garbutt, NY). Land use in Oatka Creek is predominantly agriculture (73.8%), followed by forest (21.6%) and small urban areas (2.7%) (Pettenski et al., 2013). Two main agricultural practices were evident in the watershed: cultivated cropland (25,378 ha) and pastured land (15,580 ha). Of the row and cash crops, >50% is as corn. In 2002, many farms (112), CAFOs (20) and barnyards (90) were located in Oatka Creek with over 23,000 animal units recorded (Takakis, 2002). Four WWTPs and one SPDES site (Caledonia Fish Hatchery) are located in this watershed (Pettenski et al., 2013). Stream flow ranged from 107,649 to 3,914,520 m^3/day (Pettenski et al., 2013).

Besides nutrients, macroinvertebrate assemblages respond to toxic substances, such as pesticides, aromatic hydrocarbons, ammonia, and metals (Miltner and Rankin, 1998). In general, there are no known point source releases of metal contaminants into the study watersheds (USEPA, 2011). Other potential factors, such as pesticides and herbicides, that might impact macroinvertebrates are not found in ground water in the study area in significant concentrations (Whitbeck, 2010). In 2009, 93 different compounds were analyzed from 40 well samples, 32 of which were located on land in corn/cash grain crops and vegetables in Genesee County, which lies in the Genesee River watershed. Well over 99% of the analysis reported non-detectable levels of the 93 compounds. Only two wells had detectable levels of atrazine and metolachlor. Overall results indicated that the well samples did not exceed any ambient groundwater standards or guidance values. Similarly, Reddy (2012) sampled eight production wells and eight private residential wells in 2010 in the Genesee River basin for 147 physiochemical properties and constituents that included major ions, nutrients, volatile organic chemicals, pesticides, trace elements, and radionuclides. None of the pesticides, VOCs, and assortment of metals (e.g., antimony, barium, beryllium, cadmium, lead, mercury) analyzed exceeded existing drinking water standards. There was no evidence of major impacts of toxic compounds in the watersheds studied.

Methods

Study design

Paired catchment studies have been widely used to evaluate the effects of land-use changes on terrestrial inputs to aquatic systems (Hewlett et al., 1969; Watson et al., 2001). In this study, four subwatersheds were selected based on N:P stream concentrations: high P, high N (Buck Run); low P, low N (Stony Brook); low P, high N (Oatka Creek); high P, moderate N (Bigelow Creek) (Table 1, Fig. 1). Buck Run with a high N and P [annual average TP (150.5 μg P/L), total nitrogen (2.03 mg N/L)], and a tributary (Stony Brook) with low N and P [annual average TP (21.0 μg P/L), total nitrogen (1.18 mg N/L)] are in the Canaseraga watershed (Fig. 1). Bigelow Creek at South Byron, NY, is in the Black Creek watershed, and is listed as impaired on the NYS 303(d) list due to high phosphorus from the surrounding agriculture but having a moderate total nitrogen concentration [annual average TP (110.6 μg P/L), total nitrogen (1.44 mg N/L)]. Oatka Creek at Garbutt, NY, had a high nitrogen concentration and lower TP concentration [annual average TP (41.3 μg P/L), total nitrogen (2.52 mg N/L)].

Water chemistry

Weekly water samples were taken at four tributary sites: two sites on Canaseraga Creek (Stony Brook and Buck Run), Bigelow Creek on Black Creek, and Garbutt on Oatka Creek (Fig. 1, Table 2). At each