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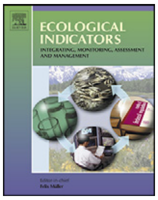

Regional nutrient thresholds in wadeable streams of New York State protective of aquatic life

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ABSTRACT

Human influence on the landscape has caused nutrients in surface waters to increase to the point where their presence has substantially altered biological communities. Because this is a nationally recognized problem, the United States Environmental Protection Agency (USEPA) tasked each state, tribe, and territory to adopt numeric nutrient criteria. Here we integrate the concept of ecological thresholds with the derivation of effects-based numeric nutrient criteria. Acceptable levels of risk exceeding predefined biocriteria were determined using conditional probability and nonparametric changepoint analysis. We show how certain community metrics exhibit threshold responses to nutrients. Using these thresholds, we suggest nutrient values protective of aquatic life and characterize community composition. Nutrient criteria were suggested for two aggregations of USEPA's nutrient ecoregions in New York State an upland pristine forested region (Ecoregions VIII and XI) and a nutrient-enriched lowland region (Ecoregions VII and XIV). Of 11 biological community metrics evaluated, 5 had a strong response to nutrients (NBI-P, NBI-N, HBI, TRI, and DMA). Maximum probabilities of exceeding the biological impairment thresholds established for these metrics ranged from 81% to 100%. Changepoint analysis conducted on probability outcomes of these metrics resulted in nutrient thresholds at or above USEPA nutrient guidance values, depending on ecoregion and nutrient variable (Ecoregion VIII/XI: 15 μg/L TP, 472 μg/L TN, 150 μg/L NO_3-N, Ecoregion VII/XIV: 17 μg/L TP, 1133 μg/L TN, 356 μg/L NO_3-N). Results of taxonomic similarity percentages (SIMPER) and species contributions indicate that several orders of macroinvertebrates and diatoms exhibit significant shifts in their percent of contributions to sample similarity in response to changes in nutrient concentrations.

1. Introduction

Understanding excessive nutrient enrichment and its effects on aquatic ecosystems has recently been the focus of substantial efforts aimed at advancing the derivation of water quality standards for nutrients (Dodds, 2007; Dodds and Welch, 2000; Havens, 2003; King et al., 2009; Martinez, 2002; Palmstrom, 2005; Reckhow et al., 2005; Rohm et al., 2002; Smith et al., 2007; Smith and Tran, 2010; Stevenson et al., 2006; Suplee et al., 2007; Wang et al., 2007; Wickham et al., 2005; Zheng and Paul, 2008). Throughout the United States, human influence on the landscape has exacerbated contributions of nutrients (phosphorus and nitrogen) to surface waters (Smith et al., 2007; Vitousek et al., 1997; Yuan, 2010) to such a degree that nutrients have begun to substantially alter biological community structure in many regions (Justus et al., 2010; Miltner and Rankin, 1998; Smith et al., 2007; Smith and Tran, 2010; Wang et al., 2007; Yuan, 2010). Nutrients are now recognized as one of the most significant determinants of water quality impacts nationally (Carpenter et al., 1998; Ice and Binkley, 2003; Munn et al., 2010; Paulsen et al., 2008; Wang et al., 2007), threatening the biological integrity of surface waters (Miltner and Rankin, 1998; Palmstrom, 2005) and changing their natural trophic status (Dodds, 2007).

Ecological thresholds or breakpoints represented as measurable, sudden change in response to a gradient of disturbance can be useful management tools in development of nutrient criteria (Clements et al., 2010; Dodds et al., 2010; Groffman et al., 2006; Muradian, 2001). They can help explain relationships between stressor and response variables and the transition of systems to different functional states (Clements et al., 2010; Hilderbrand et al., 2010). Most important, identifying thresholds for a response variable related to human disturbance may enable regulation to

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prevent a shift in ecosystem function to an "alternate" or different "stable" state (Dodds et al., 2010; Hilderbrand et al., 2010).

Several recent studies have focused on identifying ecological thresholds relating changes in biological community structure to gradients of nutrient concentrations (Dodds et al., 2010; King and Richardson, 2003; Smith and Tran, 2010; Wang et al., 2007). Methods of threshold detection in these investigations include nonparametric changepoint analysis (King and Richardson, 2003; Smith and Tran, 2010), regression tree analyses, and Kolmogorov–Smirnov techniques (Wang et al., 2007). Dodds et al. (2010) give a more complete account of the possible methods of ecological threshold detection not limited to nutrients.

The identification of thresholds in biological response to disturbance is important but should not be used alone in defining water quality criteria. The use of established biological criteria, previously developed by many states (Davis and Simon, 1995), should be considered to take advantage of extensive knowledge of regional species distributions, tolerances to pollution, and defined levels of acceptable biological impact in regulation. Biocriteria are typically in the form of numeric values of individual or multimetric indices of biotic integrity (Davis and Simon, 1995); for example, species richness, biotic index, observed/expected models, Ephemeroptera–Plecoptera–Trichoptera richness, or some combination (Bode and Novak, 1995). More meaningful numeric water quality criteria result when predefined impairment thresholds for a state's biocriteria are incorporated.

The objective of this study was to integrate the concept of ecological thresholds with identification of nutrient concentrations associated with biological impairment. Results of this integration directly implicate development of regional nutrient criteria. We identify acceptable levels of risk of exceeding predefined biocriteria using conditional probability analysis (Hollister et al., 2008; Paul and McDonald, 2005; Paul et al., 2008). This effectively integrates the legacy knowledge base of long-term biological monitoring programs. We then show how certain community metrics exhibit threshold responses to nutrients. Using these thresholds, we suggest nutrient threshold values protective of aquatic life and characterize benthic community composition at sites below and above these concentrations.

2. Materials and methods

2.1. Study area

For the purpose of developing numeric nutrient criteria throughout the United States, USEPA developed guidance values for phosphorus, nitrogen, chlorophyll *a*, and turbidity within 14 "nutrient ecoregions" (USEPA, 2000a,b,c,d, 2001). These nutrient ecoregions were established largely through the aggregation of USEPA's Level III Ecoregions (USEPA, 2000a,d). Four aggregate nutrient ecoregions are within the borders of New York State and are shared with several other northeastern states. These ecoregions include the mostly glaciated dairy region (Ecoregion VII) (USEPA, 2000a), the nutrient-poor, largely glaciated upper Midwest and Northeast (Ecoregion VIII) (USEPA, 2001), the central and eastern forested uplands (Ecoregion XI) (USEPA, 2000b), and the eastern coastal plain (Ecoregion XIV) (USEPA, 2000c) (Fig. 1).

Although these ecoregions were designed to capture spatial variation in nutrients (Rohm et al., 2002), USEPA's guidance values show little variation among them. We further aggregated the ecoregions based on background nutrient concentrations presented in USEPA's guidance documents and combined the geographical boundary of Ecoregion VII with Ecoregion XIV, and Ecoregion VIII with Ecoregion XI. These new aggregations provided spatial context for evaluation of biological response to nutrients but limited the number of ecoregional nutrient criteria needed. The aggregated regions established two major geographic divisions in NYS: (1) an upland pristine forested region (Ecoregions VIII and XI), and (2) a nutrient-enriched lowland region (Ecoregions VII and XIV) (Fig. 1). This approach provided regional classification and necessary streamlining of the criteria in a regulatory environment.

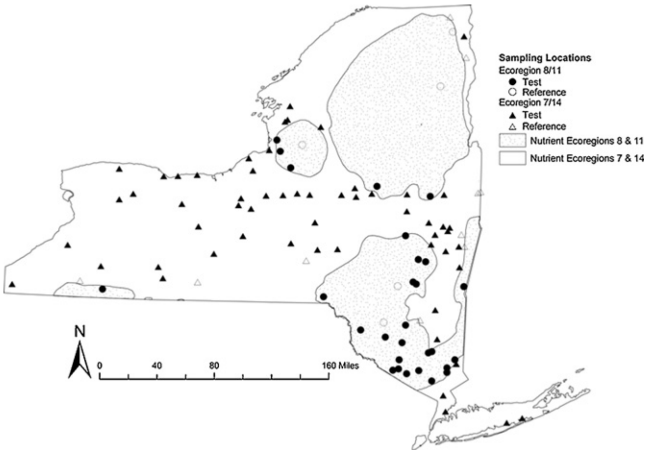

Fig. 1. Map of sampling locations showing the two different aggregate nutrient ecoregions used in this investigation, along with the location of reference and test sites within each region.

Within this aggregation, we evaluated biological community response to nutrients at 100 wadeable streams throughout NYS. Sites were selected to represent both aggregate nutrient ecoregions and a gradient of nutrient conditions. Thirty-three sampling locations were selected in Ecoregion VIII/XI, five of which were considered reference. Sixty-seven locations were selected in Ecoregion VII/XIV, ten of which were considered reference. More sampling locations were allocated to Ecoregion VII/XIV because it is larger than Ecoregion VIII/XI (Fig. 1). Sites were selected using percent land cover data and historical biological community information. Reference sites in each ecoregion were selected for having ≥75% natural cover in their upstream watershed. Nutrient conditions had to be at background levels based on previous water sample collections conducted by the New York State Department of Environmental Conservation's Ambient Water Quality Monitoring Program during 1993–2005. Historical sampling of biological communities had to indicate naturally occurring, unimpacted conditions. These criteria provided a set of reference locations representing the least-disturbed, best-attainable condition in each of the ecoregions (Reynoldson et al., 1997). Test sites were selected to have <75% natural cover in their upstream watershed and represent a gradient of nutrient and biological conditions. Information on chemical and biological conditions was determined from previous sampling records. A similar method was employed in a previous survey of nutrients in large rivers of NYS. The result adequately captured a representative population of rivers with different nutrient and community status (Smith and Tran, 2010).

2.2. Sample collection

We collected biological, physical, and chemical samples once at each site between July and September 2008. Methods followed those outlined in the Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State (Smith et al., 2012). All field work was conducted by staff from the Academy of Natural Sciences, Patrick Center for Environmental Research (PCER) and Watershed Assessment Associates, LLC (WAA).

Benthic macroinvertebrate sampling was conducted using a travelling kick technique. By kicking, the sampler disturbed the