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Acceptable nutrient concentrations in agriculturally dominant landscapes: A comparison of nutrient criteria approaches for Nebraska rivers and streams

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ABSTRACT

Developing numeric nutrient criteria for streams has been exceedingly complex due to uncertain background concentrations and uncertain impacts to water quality. In this study, I empirically examine the utility of multiple criteria for total nitrogen (TN) and total phosphorus (TP) criteria for rivers and streams of Nebraska, USA using: (1) whole-population nutrient percentiles; (2) reference stream percentiles; (3) model predicted estimates from relationships between nutrients and anthropogenic land usage; and (4) stressor–response modeling of nutrients and invertebrate and fish assemblages. I predicted that criteria developed for Nebraska would be greater than the criteria recommended by the US Environmental Protection Agency for the associated nutrient ecoregions because the new criteria would be derived from streams only within this agriculturally-dominated state. Also, I predicted that criteria based on responses of biota would be higher than those based on the frequency distribution of nutrient data because biota have been filtered by their ability to endure higher nutrient concentrations. The percentage of rowcrop agriculture was responsible for the vast majority of land usage, and TN and TP were predictable by rowcrop. Nutrient ecoregions did not appear to be particularly useful in Nebraska. EPA recommendations for TP were lower than any of the new criteria we developed (from 113 to 599 μg/l) and those for TN were almost always lower than new criteria (from 552 to 2352 μg/l). Relationships of nutrients to biotic integrity were weak or non-existent; TN was not among the best three predictors of invertebrate or fish metrics and TP was only a good predictor of the pollution tolerance of fish, and this criterion was much higher than EPA recommendations (599 μg/l) and criteria based on percentiles and land usage. I discuss the applicability of criteria to agriculturally-intense streams in Nebraska.

1. Introduction

Section 303(d) of the Clean Water Act of 1972 stipulates that states, territories and tribes are responsible for establishing nutrient criteria to protect current and future water quality (USEPA, 1998, 2010). However, establishing numeric criteria that represent demonstrated thresholds to water quality has proven to be exceedingly complex. Some difficulties include obtaining accurate historical nutrient concentrations in heavily degraded landscapes (Dodds and Oakes, 2004; Stoddard et al., 2006; Dodds, 2007), separating natural versus anthropogenic-driven patterns in nutrient distributions (Herlihy et al., 2013), and the obscuring effects of covarying factors such as light and habitat degradation to aquatic life (Wang et al., 2007). As a result, few states currently have approved nutrient criteria for TN and TP in riverine ecosystems.

The most common approaches to numeric nutrient criteria development (as opposed to narrative criteria such as the presence of harmful algal blooms or hypoxia) include (1) reference condition percentiles; (2) whole-population percentiles; (3) models based on anthropogenic watershed development; and (4) stressor–response modeling of the effects of nutrients on algae and higher trophic levels (USEPA, 2000a, 2000b; Dodds and Oakes, 2004, 2008). Reference and whole-population percentile criteria are based on the frequency distribution of nutrient data. Anthropogenic watershed development models incorporate the influence

Abbreviations: TN, total nitrogen; TP, total phosphorus; TKN, total Kjeldahl nitrogen; AMN, ambient monitoring network; REMAP, regional environmental monitoring and assessment.

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of landscape-level processes over observed local nutrient concentrations, and may provide reasonable estimates of historical nutrient concentrations. However, criteria developed from these approaches may provide values that do not correspond to observed impairment of local water quality (Reckhow et al., 2005). Lastly, stressor–response models are based on measurements of biotic integrity using bioassessments metrics (USEPA, 2010), and thus are strongly grounded in the local quality of the aquatic resources. However, factors such as habitat degradation may constrain biotic integrity more than nutrients and thus make it difficult to determine the impacts of nutrients on organisms (Allan et al., 1997; Miltner and Rankin, 1998; Heatherly et al., 2007; Wang et al., 2007).

In this paper, I directly compare nutrient criteria development approaches for the rivers and streams of Nebraska. The primary foci of these efforts are total nitrogen (TN) and total phosphorus (TP) as with previous research and most state programs (Dodds and Welch, 2000). Ideally, criteria could be developed specifically to predict impairment probability of designated uses of water resources (Reckhow et al., 2005). However, Nebraska's current designated uses are limited to recreational, agricultural, drinking, and aquatic life use designations, and except for the aquatic life use designation, permissible nutrient concentrations would be too high (i.e., TN 5–10 mg/l) to be protective of in-state or downstream water quality. Percentile and watershed development model criteria were derived from a monitoring data set of fixed stations with high temporal sampling resolution. I used a high spatial resolution data set with simultaneous collections of nutrients, water and habitat quality parameters, and invertebrate and fish communities to create criteria based on the relationship of biotic indices to nutrients (stressor–response criteria). Although there can be no single criterion that represents the threshold between impaired and unimpaired water quality, criterion choice may have far reaching consequences for the number of systems identified as impaired. I predicted that criteria based upon the streams within Nebraska would reflect that agricultural nature of this state and thus be higher than the United States Environmental Protection Agency (USEPA) criteria based on the frequency distributions of larger regions within the US that contained fewer impacted streams. In addition, I predicted that criteria based on biotic integrity would be higher than those based on percentiles and land usage because biotic assemblages have been filtered for pollution tolerance and thus high concentrations of nutrients would be necessary to observe further impacts. Research such as this is necessary to understand the consequences of criterion choice and the influence of excess nutrients in the context of the numerous stressors that may be simultaneously impacting aquatic systems.

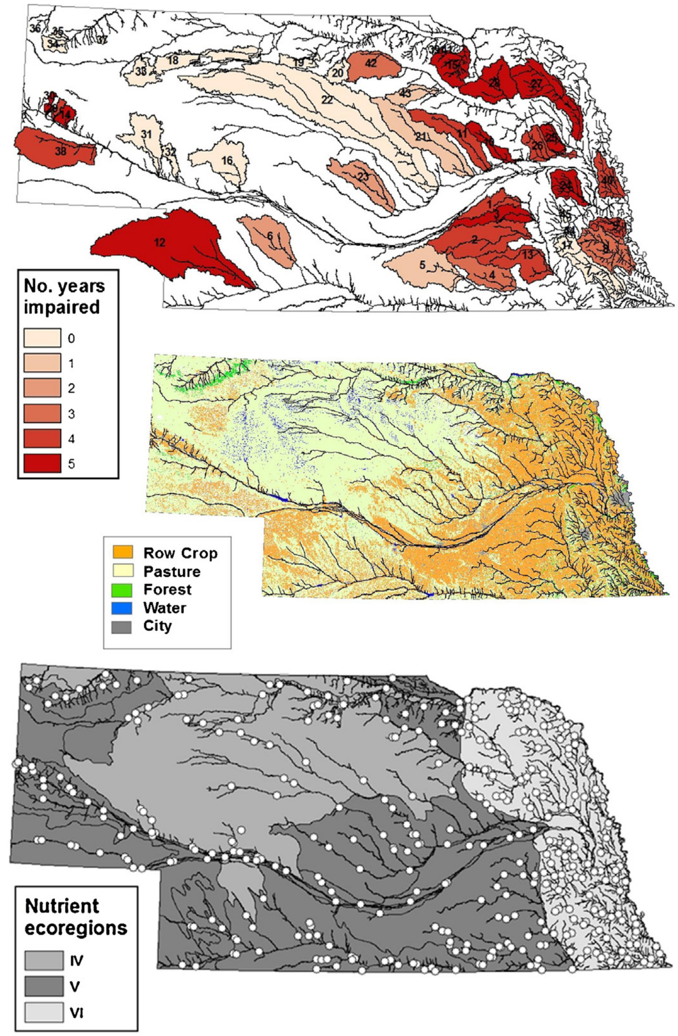

Fig. 1. Top: the 45 watersheds from the Nebraska Department of Environmental Quality Ambient Monitoring Network (AMN). Deepness of red signifies the number of years of the 5 tested that the stream exceeded moderate watershed development total nitrogen criteria. Middle: the primary land usage types across Nebraska. Bottom: stream reaches from the Nebraska Department of Environmental Quality's Regional Environmental Monitoring and Assessment Program with shading representing USEPA nutrient ecoregions. Watersheds of the AMN are listed in A1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

2. Methods

2.1. Data sets

I performed exploratory data analyses on both data sets following the protocols of Zuur et al. (2010) to search for outliers and data entry errors, understand variable distributions and examine covariance among parameters. The first data set was from the Ambient Monitoring Network (AMN), which had weekly sampling of nutrients and other water quality parameters for 97 streams and rivers from fixed locations (NDEQ, 2012a). I reduced the data set to 45 streams by requiring watersheds to be non-overlapping and to have at least 5 full years of growing-season data (Fig. 1). Watersheds were spread throughout the state and ranged in size from 1033 hectares to nearly 1.1 million hectares (A1), with an average size of ~144,000 hectares. This subset of the AMN accounts for ~6.5 million total hectares, which is approximately 32% of Nebraska's 20 million hectares. Land cover for the 45 watersheds was obtained through the USDA's National Agricultural Statistics Service 2009 Nebraska Cropland Data Layer (http://nassgeodata.gmu.edu/CropScape/).

The second data set was collected as part of the Regional Environmental Monitoring and Assessment Program (REMAP) (NDEQ, 2012b). This data set had one-time simultaneous collections of water quality, habitat quality, and invertebrate and fish assemblages from 390 randomly-selected stream and river stations from 1997 to 2009 (Fig. 1). All data were collected from May to September to represent summer baseflow conditions.

2.2. Sampling protocols

Detailed collection protocols may be found in Bazata (2011). Water quality parameters collected for both the AMN and REMAP networks included temperature, pH, turbidity and conductivity. Discharge was measured by multiplying the cross-sectional area of the stream by water velocity. Water for nutrients and total suspended solid analysis was collected the day of sampling in