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Q1 Development of methods for establishing nutrient criteria in lakes and reservoirs: A review

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ABSTRACT

Nutrient criteria provide a scientific foundation for the comprehensive evaluation, prevention, control and management of water eutrophication. In this review, the literature was examined to systematically evaluate the benefits, drawbacks, and applications of statistical analysis, paleolimnological reconstruction, stressor-response model, and model inference approaches for nutrient criteria determination. The developments and challenges in the determination of nutrient criteria in lakes and reservoirs are presented. Reference lakes can reflect the original states of lakes, but reference sites are often unavailable. Using the paleolimnological reconstruction method, it is often difficult to reconstruct the historical nutrient conditions of shallow lakes in which the sediments are easily disturbed. The model inference approach requires sufficient data to identify the appropriate equations and characterize a waterbody or group of waterbodies, thereby increasing the difficulty of establishing nutrient criteria. The stressor-response model is a potential development direction for nutrient criteria determination, and the mechanisms of stressor-response models should be studied further. Based on studies of the relationships among water ecological criteria, eutrophication, nutrient criteria and plankton, methods for determining nutrient criteria should be closely integrated with water management requirements.

Contents

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Introduction

The majority of freshwater resources worldwide have suffered from eutrophication caused by excessive inputs of nitrogen and phosphorus (Huo et al., 2013a, 2013b啊; Janssen et al., 2017). The determination of numeric nutrient criteria is considered important for controlling cultural eutrophication and protecting water quality in lakes and reservoirs (Hawkins et al., 2010; Kelly et al., 2015; Ma et al., 2016). Nutrient criteria are the maximum acceptable concentrations that cause ecological effects in water without threatening the function of the waterbody; thus, they represent the trophic state of surface waters in the absence of significant human disturbance (Bouleau and Pont, 2015). Due to geographical differences in catchments (*e.g.*, species biogeography, geology, and elevation) and lake factors (*e.g.*, depth, area, and water color), regional nutrient criteria must be developed to better protect water quality (Cardoso et al., 2007; Carvalho et al., 2008). Many countries have derived ecoregions to establish regional nutrient criteria and prevent eutrophication-related designated use impairments (Huo et al., 2014a, 2014b, 2014c, 2014d啊; Solheim, 2005).

Nitrogen and phosphorus are not toxic to aquatic organisms and humans at low concentrations and generally do not interfere with designated uses (Lamon and Qian, 2008; Stow et al., 2014). However, excessive nutrient levels can lead to the overgrowth of phytoplankton and aquatic plants, resulting in the depletion of dissolved oxygen, fluctuations in the water pH, changes in the taxonomic composition and structure of aquatic communities, the release of toxins from phytoplankton, and disinfectant byproducts in treated drinking water (Huo et al., 2013a, 2013b啊). Nutrient criteria are ecological criteria, not toxicological criteria, and are not derived by simple dose–response relationships in laboratory studies (US EPA, 2010). Hence, a statistical method based on large amounts of monitoring data would provide the theory and a foundational approach for the establishment of nutrient criteria. The objectives of this paper are as follows: (1) to review the research progress in nutrient criteria determination, (2) to summarize and evaluate the established methods of nutrient criteria determination, and (3) to describe the future developments and challenges for improving nutrient criteria determination in lakes and reservoirs.

1. Research on nutrient criteria determination in lakes and reservoirs

The United States (US) was the first country to develop nutrient criteria. The National Nutrient Strategy for the Development of Regional Nutrient Criteria was established by the US Environmental Protection Agency (US EPA) in 1998 (US EPA, 1998). Based on waterbody characteristics, a series of technical guidance documents was released for developing nutrient criteria for different waterbodies, such as lakes and reservoirs, rivers and streams, estuarine and coastal marine waters, and wetlands (US EPA, 2000a, 2000b, 2001a, 2008). Similarly, the Water Framework Directive issued by the European Union tasked member nations with developing nutrient criteria strategies for controlling water eutrophication (Solheim, 2005). In recent years, researchers have initiated studies of nutrient criteria determination in China, and a Regional Nutrient Criteria Research Plan was created in 2008 to develop region-specific nutrient criteria (Huo et al., 2014a).

The earliest approaches used by the US EPA to establish nutrient criteria were statistical analysis methods, model prediction or extrapolation, paleolimnological reconstruction of past conditions and expert judgments (US EPA, 2000a). In 2010, three types of approaches were recommended for scientifically determining numeric criteria: the reference condition approach, mechanistic modeling, and stressor-response analysis (US EPA, 2010; Hausmann et al., 2016). The continental US was divided into 14 separate lake ecoregions with similar geographical characteristics based on perceived patterns of causal and integrative factors, including land use, land surface form, potential natural vegetation, and soils. The US EPA suggested an ecoregion-based national strategy for establishing nutrient criteria, and a statistical analysis approach was applied to determine the nutrient criteria in 14 ecoregions (US EPA, 2001b; Omernik, 1987). In Europe, waterbodies have been divided into classes based on geographical differences in catchments and lake factors, and type-specific nutrient criteria were derived to reach the appropriate ecological quality (Cardoso et al., 2007; Carvalho et al., 2008; Poikāne et al., 2010). Based on a spatial cluster analysis that considered the boundaries of water resources and provincial administration boundaries, China has been divided into eight lake ecoregions to develop ecoregional nutrient criteria (Huo et al., 2014a).

2. Methods of establishing nutrient criteria in lakes and reservoirs

2.1. Statistical analysis approach

Three methods are proposed as statistical analysis approaches for the determination of numeric criteria to address nitrogen/phosphorus pollution: the reference lake method, the lake population distribution method, and the trisection method. The reference lake method is suitable for watersheds with little human disturbance, and reference lakes in the upper 25th percentile are commonly used to develop nutrient criteria (Fig. 1). This method fails when reference lakes or sites are not available, as in some agriculturally dominated regions

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