Ecological Indicators 90 (2018) 451–459

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Habitat suitability evaluation of a benthic macroinvertebrate community in a shallow lake

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ARTICLE INFO

Keywords:
Benthic macroinvertebrates
Generalized additive model
Canonical correlation analysis
Habitat suitability evaluation method
Shallow lake
Baiyangdian Lake

ABSTRACT

The relations between benthic macroinvertebrate communities and eco-factors usually are nonlinear and highly complex, and are often difficult to evaluate. In this study, canonical correlation analysis (CCA) and a generalized additive model (GAM) were applied to identify the key eco-factors that influence the community characteristics of benthic macroinvertebrates in a shallow water lake–Baiyangdian Lake. The water depth (H), water transparency (secchi disc depth, SD), concentration of chlorophyll-a (Chl-a), water temperature (T), concentration of dissolved oxygen (DO), oxidation and reduction potential (ORP), ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) in water, median particle diameter (D_{50}), ammonium nitrogen in the substrate (NH_4-N_{soil}), and biomass of macrophytes, are the main eco-factors affecting the spatial distribution and structure of the benthic macroinvertebrate community in the shallow freshwater lake. This study is the first to introduce GAM to habitat suitability evaluation for benthic macroinvertebrates in large shallow lakes, and to use the Margalef index (d_M) instead of individual indicator species to indicate diversity variation. Five factors, including H, T, NH_4-N_{soil}, organic matter (OM) in the substrates, and the biomass of macrophytes, were selected in the optimal model by stepwise regression. The response curves generated by the GAM indicated that the diversity of benthic macroinvertebrates was negatively correlated with H and (NH_3-N_{soil}) and was positively correlated with T and OM. The response curve showing the relation between taxa diversity and the biomass of macrophytes was unimodal. The current study examined the combined influence of multiple eco-factors on benthic macroinvertebrates, and increased understanding of relations between the benthic macroinvertebrate community and eco-factors in a shallow lake system.

1. Introduction

The benthic macroinvertebrate community is an important part of the aquatic food chain and has great significance for the health of freshwater aquatic ecosystems (Butkas et al., 2011). At present, many aquatic ecosystems show symptoms of the loss and degradation of habitat, which cause a decline in biodiversity (Geist, 2011). Benthic macroinvertebrates are vulnerable to changes in habitat conditions (Donohue et al., 2009). Maintaining and protecting the biodiversity of benthic macroinvertebrates is an urgent task in ecosystems management. It is essential to determine the habitat requirements of the benthic macroinvertebrate community and to study the responses of these communities to eco-factors, to prevent a decrease in taxa diversity and deterioration of aquatic ecosystems.

Interpreting relations among benthic macroinvertebrate communities and abiotic factors is very difficult, as benthic macroinvertebrate communities respond to multiple environmental factors and there are many interactions among these factors. Water quality (Clews et al., 2014; Miserendino and Masi, 2010), substrate composition (Schröder et al., 2013), and the distribution and abundance of macrophytes (Declerck et al., 2005) have been reported to influence benthic macroinvertebrate communities. Water quality, hydrodynamic conditions, and substrate conditions are the main abiotic factors that influence benthic macroinvertebrate communities.

Ordination analysis is commonly used to analyze relations among benthic macroinvertebrates and ecological factors (Takamura et al., 2009). Canonical correlation analysis (CCA) is an ordination method based on a unimodal model. Multiple eco-factors can be analyzed simultaneously during the sorting process. In CCA ordination diagrams, arrows indicate eco-factors while symbols indicate taxa or samples. Taxa symbols that are in close proximity in the ordination, often correspond to taxa that occur together. Each quadrant of the ordination indicates a positive or negative correlation between each eco-factor and the axes. The angle between the arrow and the axis represents the

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https://doi.org/10.1016/j.ecolind.2018.03.039
Received 16 October 2017; Received in revised form 14 March 2018; Accepted 16 March 2018

correlation between the eco-factors and the axis. The smaller the angle, the higher the correlation. Taxa symbols can be projected perpendicularly onto the line overlaying the arrow of any particular environmental variable. However, ordination analysis usually focuses on the influence of one or more factors on benthic macroinvertebrate communities. The combined influence of water quality and substrate conditions on the community of benthic macroinvertebrates is difficult to evaluate.

A habitat suitability model is an effective tool for examining the combined influence of eco-factors on taxa. Models can deepen understanding of taxa-habitat relations, and explore the combined effects of multiple eco-factors on taxa (Ahmadi-Nedushan et al., 2006). Habitat suitability modeling has been recognized as a significant tool for use in conservation planning (Austin, 2002; Gevrey et al., 2005). A habitat suitability model is a combination of a habitat suitability evaluation method and a selection of key eco-factors. A variety of habitat suitability evaluation methods have been developed including; habitat suitability indices, multivariate statistical methods such as generalized additive models (GAMs) and generalized linear models (GLMs), fuzzy logic models, artificial neural networks (ANNs), and classification trees (Ahmadi-Nedushan et al., 2006; Yi et al., 2014; Yi et al., 2016a). Many of these methods have been used to predict the suitability of habitat or to quantify habitat requirements for individual taxa or communities of organisms such as endangered fish, important economic fish, or dominant species (Ahmadi-Nedushan et al., 2006; Munoz-Mas et al., 2012; Yi et al., 2016b; Yi et al., 2017). Habitat suitability models have also been developed for benthic macroinvertebrates (Gevrey et al., 2005; Milner et al., 2001). Gevrey et al. (2005) determined functional feeding groups and evaluated species richness for Dutch macroinvertebrates using five modeling techniques (ANN, Regression trees, GAM, Partial Least Squares, and Multiple Linear Regression) and then compared the performance of these five models. The results showed that the ANNs and GAMs performed better with respect to root mean square errors and correlation coefficients compared with the other three methods.

Most studies focus on one taxa or a group of dominant taxa in river systems. Little is known about the responses of benthic macroinvertebrate communities to eco-factors in lake systems. Compared with river systems, lake systems are more vulnerable. Although dominant taxa are important, it is also important to evaluate habitat suitability for communities of organisms. Using a habitat evaluation method to analyze the responses of the benthic macroinvertebrate community to eco-factors in lake systems is critical to increasing understanding of these systems.

The responses of the benthic macroinvertebrate community to eco-factors in Baiyangdian Lake were analyzed using the habitat suitability evaluation method. Baiyangdian Lake is a shallow lake in the North China Plain. Habitat within the lake is degenerating and biodiversity is decreasing. The relations among taxa and eco-factors are usually nonlinear and highly complex, and it is often difficult to express these relations using traditional mathematical equations. A GAM was used to analyze the relations among the benthic macroinvertebrate community and eco-factors. This technique is well suited to highly nonlinear and nonmonotonic relations, and requires only a minimum of data. The community characteristics of benthic macroinvertebrates were described using the Margalef diversity index (d_M), which typically is used to estimate the abundance of a taxa within a region. The Margalef diversity index performs well in distinguishing differences among communities (Margalef, 1958). The combined influence of multiple eco-factors on the community of benthic macroinvertebrates was examined in Baiyangdian Lake.

2. Study area and methods

2.1. Study area

Baiyangdian Lake, with an area of about 366 km^2, is located in the North China Plain. The lake consists of more than 100 small, shallow lakes, linked to each other by hundreds of ditches. The water depth is generally about 2–3 m. About 39 villages are distributed sporadically around the lake (Yang and Yang, 2013). Baiyangdian Lake is the largest shallow lake in northern China and it plays an important role in providing habitat for native plant and animal species, in water purification, and in protection against floods. Prior to the 1960s, Baiyangdian Lake was known as "The Pearl of North China" due to its favorable weather conditions, scenic beauty, convenient transportation facilities, and abundance of aquatic products (Xu et al., 1998). Since the 1960s, there has been an increase in water pollution and a reduction in water levels, due to intense anthropogenic pressure and climate change. This has resulted in obvious changes to the ecology of the lake. Five consecutive years of drought (1983–1988) had a major impact on water levels in the lake and biodiversity decreased during this period. Benthic macroinvertebrate species in Baiyangdian Lake decreased from 38 in 1975 to 28 in 1989. The dominant phyla changed from mollusks to arthropods. The numbers of different bivalve species were greatly reduced, while the number of oligochaete species increased (Yang, 2013). A total of 14 sampling sites representing a range of different habitats were selected for the sampling of benthic macroinvertebrates and ecological variables in Baiyangdian Lake (Fig. 1).

2.2. Data collection

Sampling was done in April, June, and September of 2016. A team of 4–6 persons visited to the field sites of study for about 3–4 days every season to properly collect samples from all sites. Water quality parameters including and physical features were measured: water depth (H), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), ammonium (NH_4-N), nitrate-nitrogen (NO_3-N), phosphate (PO_4^{3-}), oxidation–reduction potential (ORP), water transparency (Secchi disc depth, SD), chlorophyll-a (Chl-a), pH, water temperature (T) and dissolved oxygen (DO) were measured. Variables associated with the lake substrate including; the amount of organic matter (OM), total nitrogen (TN_{soil}), total phosphorus (TP_{soil}), ammonium nitrogen (NH_4-N_{soil}), nitrate nitrogen (NO_3-N_{soil}), median particle diameter (D_{50}), and the biomass of macrophytes. Some parameters including T, DO, pH, ORP, and Chl-a were measured in the field using a multiparameter water quality analyzer (YSI 6600). A secchi disc (SD) was used as a surrogate for water transparency. Water depth (H) was measured using a plumb-line. Median particle diameter (D_{50}) was examined by a laser particle sizer (Microtrac S3500). Water samples and sediment samples were collected and returned to the laboratory to measure all other factors using methods corresponding to national standards.

Benthic macroinvertebrates were collected using a Peterson grab sampler with an open area of 0.0625 m^2, following the general protocol by Chiasson and Williams (1999). At each site, three random subsamples were collected at comparable locations given the fine-scale habitat heterogeneity. Subsamples were pooled to represent each site. Areas that were greatly impacted by human activities (such as dredged channels) were avoided as much as possible during sampling. Sampled sediments were washed through a metal sieve with a 0.5 mm mesh. Material that was retained on the sieve was placed in a white enamel tray with some water and the benthic macroinvertebrates were picked from the sample using thin-tipped tweezers and a magnifying glass. Macroinvertebrates were preserved in plastic bottles with a 75% alcohol solution. In the laboratory, all benthic macroinvertebrate individuals were sorted and identified using a stereoscopic microscope to at least family level according to appropriate identification guides (e.g., Epler, 1977; Liu et al., 1979; Morse et al., 1984).

2.3. Methods

The Margalef diversity index (d_M) (Margalef, 1958) was used to describe the diversity of benthic macroinvertebrates in the study area.