Ecological Engineering 96 (2016) 8–19

Contents lists available at ScienceDirect

Ecological Engineering

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

Performance of macrophyte indicators to eutrophication pressure in ponds

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ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form
25 September 2015
Accepted 9 October 2015
Available online 31 October 2015

Keywords:
Eutrophication pressure
Spatial distribution
Aquatic macrophyte
Relative abundance
Restoration

ABSTRACT

Aquatic macrophytes in ponds are considered as reliable indicators for detecting eutrophication pressure. In this study, the spatial distribution of total phosphorus (TP) and the ratio between transparency and water depth (Z_{SD}/Z_M) were characterized in Lake Baiyangdian, north China. Total P and Z_{SD}/Z_M were adopted to represent eutrophication pressure. The macrophyte indicators including richness of different species, diversity/evenness, biomass, and relative abundance for submerged/emergent ($RA_{sub/eme}$) and sensitive/tolerant submerged species ($RA_{sen/tol}$), were measured for each of the 38 ponds in the study area. Results showed that except richness of emergent and floating-leaved species, other macrophyte indicators were significantly correlated with TP and Z_{SD}/Z_M. Among them, evenness, biomass, $RA_{sub/eme}$ and $RA_{sen/tol}$ were selected to evaluate pond status because of their stronger response to TP. To evaluate the status for each pond, a scoring system was created by integrating TP and the four selected macrophyte indicators. We suggest that, control of external pollution sources and internal pollution sources, especially surface runoff from cropland reclamation and intensive use of fish feed from aquaculture, should be the focus of local managers. Inferred from the response of submerged species abundance to light availability, the value of Z_{SD}/Z_M should be no less than 0.52 to restore submerged species in eutrophic ponds.

1. Introduction

Aquatic macrophytes are considered as reliable indicators for detecting pond status because of their sensitive response to environmental stress, especially to eutrophication pressure (Mahaney et al., 2004; Sass et al., 2010). Under eutrophication pressure, macrophyte community composition shifts from a dominance of meadow-forming submerged species, to canopy-forming submerged, to floating-leaved, and eventually to emergent (Jeppesen et al., 2000; Egertson et al., 2004).

Submerged species are accepted as the most common indicators of eutrophication because they have been proven vulnerable to changes in water quality (Søndergaard et al., 2010). An increase in water turbidity with nutrient enrichment may directly result in changes in abundance, colonization depth limits, and community structure of submerged species (Cheruvelil and Soranno, 2008; Sass et al., 2010). In oligo-mesotrophic ponds, submerged species can stabilize sediments (Madsen et al., 2001), store nutrients (Dai et al., 2012), enhance water clarity (Søndergaard et al., 2010), and act as habitat for other aquatic organisms (e.g., zooplankton, fish, and invertebrates) (Jeppesen et al., 2000). However, an obvious reduction in abundance and richness of submerged species was often observed following water nutrient enrichment (Williams et al., 2004). This change was probably due to light attenuation and poor growth conditions (Gulati and van Donk, 2002), and it could exert substantial and lasting effects on the biodiversity, structure, and function of pond ecosystems (Heino, 2002).

Compared with submerged species, the potential role of emergent ones in detecting eutrophication pressure remains uncertain. One point supported that emergent species are more sensitive to water-level fluctuations, shoreline modifications, and soil characteristics. For instance, Dudley et al. (2013) found that emergent species have significantly weaker relationships with total phosphorus (TP) than submerged species, but are more affected by spring flood-related water-level fluctuations. Differently Alahuhta et al. (2013) and Kolada (2014) found that the percentage of emergent macrophyte in total littoral area is one of the most universal and best performing water quality indicators.

Qualitative indicators are more commonly adopted than quantitative ones for detecting eutrophication pressure. For instance, the presence of "clear/turbid water indicator species" is often used to detect nutrient level (Lauridsen et al., 2003; Jeppesen et al., 2007; Schneider, 2007). However, many species have a broad ecological range, and some that characterized as oligotrophic indicator species

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http://dx.doi.org/10.1016/j.ecoleng.2015.10.019
0925-8574/

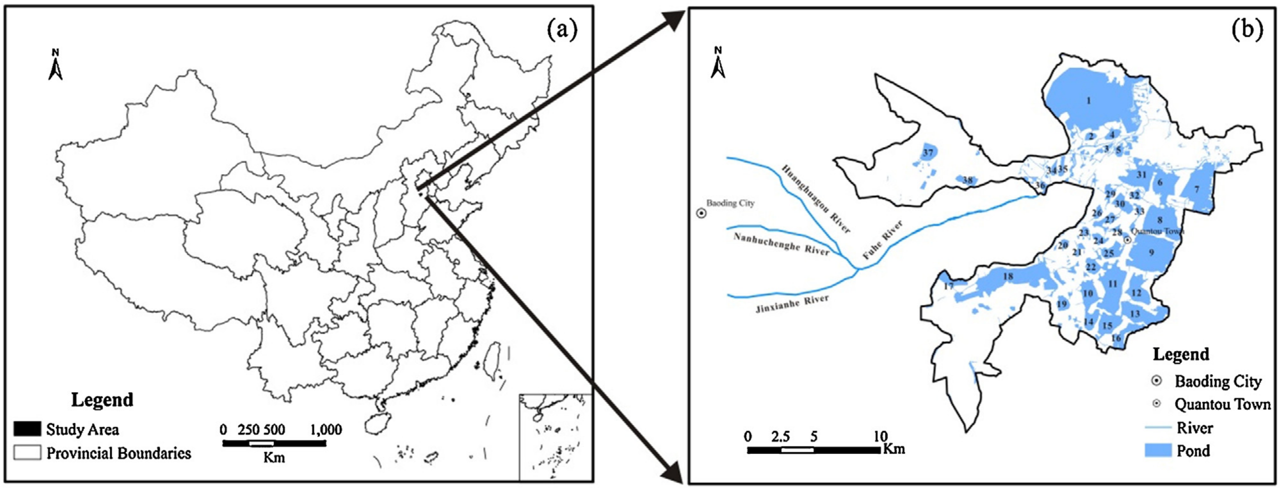

Fig. 1. Study area within Baoding City, China (a), and location of the study ponds (b).

may also be present in meso-eutrophic water (Schneider, 2007), and species may also be differently classified when empirical relations are analyzed (Penning et al., 2008a). In addition, although a change from sensitive submerged species to tolerant ones is conceptually expected with increased eutrophication pressure, species occurrence is also likely determined by hydro-morphological variables and stochastic factors rather than eutrophication pressure, especially in shallow freshwater ecosystems (Moss, 2007). Compared with qualitative indicators, although quantitative indicators are being more well defined and more objective (e.g., percentage coverage of whole lake area, biomass, and frequency), they have been given less attention and are less commonly used for detecting eutrophication pressure (Cheruvelil and Soranno, 2008). In addition, many previous studies have focused on performance of individual indicator to eutrophication pressure (Egertson et al., 2004; del Pozo et al., 2011), however, using multiple macrophyte indicators instead of individual indicator seems to be more objective for detecting “pressure-response” relationship (Kolada, 2010).

The present study used Lake Baiyangdian as a case study, and the main objectives were to: (1) investigate spatial changes of eutrophication pressure indicators, (2) detect the performance of individual macrophyte indicator responding to eutrophication pressure, (3) evaluate pond status through applicable macrophyte indicators, and (4) summarize some implications for pond restoration.

2. Materials and methods

2.1. Study area

Lake Baiyangdian (38°38′N, 115°54′E) is the largest macrophyte-dominated shallow lake in Baoding City, North China (Fig. 1a). Before 1990s, the water level of Lake Baiyangdian was above 8.5 m, and the lake was made up of 140 ponds that were interconnected through water channels. Nowadays, there are only less than 40 ponds exist due to continuously decreasing water input in the past few decades, and most of these ponds are isolated. Meanwhile, substantial species losses due to eutrophication result in different community compositions between study ponds (Fig. 1b). With increasing awareness on pond restoration, eutrophication relief has been adopted as the main strategy by local managers. Therefore, objectively evaluating the status of different ponds is very necessary to ensure the efficiency of strategies for restoration.

2.2. Data collection

2.2.1. Environmental variables

We measured 10 water physicochemical variables monthly from June to September in 2012 in 38 ponds (Table 1). Water depth and Secchi depth transparency were measured within each ponds. We determined pH and dissolved oxygen (DO) using a portable multi-meter (YSI Pro Plus; YSI Incorporated, U.S.A.). Water samples at the depth of 0.5 m were taken into 2-L polypropylene bottles, and preserved with ice in the field, and then kept at 4 °C in the refrigerator when back to the lab. Total nitrogen (TN) and total phosphorus (TP) were measured using the cadmium reduction method and ascorbic acid method, respectively, after persulphate digestion in disposable polycarbonate bottles in an autoclave at 120 °C for 45 min (APHA, 1998). Suspend solids (SS) were collected with glass fiber filters (Whatman GF/F; Whatman Incorporated, U.S.A.) under a low vacuum and dried before weighing. Chlorophyll a (Chl a) was determined spectrophotometrically after filtration on Whatman GF-C glass filters and 24 h extraction in 90% acetone (Lorenzen, 1967).

We used digital land-use maps and a geographical information system (ArcGIS9.1; ESRI, Redlands, CA, U.S.A.) to obtain pond surface area, and the geographical coordinates (x, y) of each pond center. The coordinates ‘x’ and ‘y’ were considered as spatial variables affecting eutrophication pressure, respectively. Spatial variables were rescaled from 0 to 1 using a max–min rescaling equation as follows:

$$X'_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}$$

Table 1
Mean, standard deviation (SD) and range for variables characterizing the pond physico-chemical status ($n = 38$).

Variable	Mean ± SD	Range
Surface area (ha)	65 ± 4.6	23–172
Mean depth (m)	1.21 ± 0.35	0.72–1.53
pH	8.24 ± 0.18	7.38–8.39
Dissolved oxygen (mg/L)	3.39 ± 1.03	3.21–12.6
Conductivity (μs/cm)	480 ± 231	45–1187
Total nitrogen (mg/L)	5.78 ± 7.78	0.96–21.7
Total phosphorus (mg/L)	0.16 ± 0.14	0.012–0.5266
Transparency (cm)	76 ± 15	37–146
Chlorophyll a (μg/L)	35 ± 58	4.21–169.3
Suspend solids (mg/L)	17.4 ± 10.5	5.7–135