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A floodplain-scale lake classification based on characteristics of macroinvertebrate assemblages and corresponding environmental properties

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ABSTRACT

Floodplain lakes have been experiencing great pressures by human activities, and ecological functions in different types of lakes show different degrees of degradation. For facilitating conservation and management of different types of floodplain lakes, it is necessary to classify the lakes into similar groups according to certain standards. In this study, on basis of consideration of macroinvertebrate assemblages and corresponding environmental properties, the Yangtze floodplain lakes were classified into three major types grouping five groups of lakes: (1) river-disconnected lakes (algal lakes, macrophytic-algal transition lakes, and macrophytic lakes), (2) semi-connected lakes (oxbow lakes), (3) river-connected lakes. The classification of floodplain lakes mainly reflects the gradients of trophic and hydrological connectivity. The key factors structuring macroinvertebrate assemblages in the Yangtze floodplain lakes were mainly hydrological (connectivity rating, water depth), trophic (total phosphorus, macrophytes biomass) and morphometric (development of lake shoreline). Among the floodplain lakes, ecological status of river-connected lakes, where biodiversity, biomass and production of macroinvertebrates reached maxima, has been confirmed to be the best. From the view of conservation and management of the entire floodplain lakes, it is suggested that protecting the remnants of river-connected lakes, controlling eutrophication and linking disconnected lakes freely with the mainstream are crucial.

Introduction

Floodplain lakes have many functions such as water supply, irrigation, food production, sightseeing, as well as the maintenance of the unique and diverse biota of the entire floodplain ecosystem. In recent decades, the floodplain lakes have been experiencing great pressures by human activities that alter the hydrological, physico-chemical, and biological processes. Therefore, for facilitating conservation and management of these lakes, it is necessary to classify the lakes into similar groups according to certain standards.

Many classifications of lakes have been developed during the past several decades. Some researchers were keen on differences of physical characteristics including location, origin, shape and morphometry (Hutchinson, 1957; Pennak, 1958; Lewis, 1983; Canfield et al., 1984; George and Maitland, 1984). Certainly, chemical characteristics (i.e. total dissolved solids, pH, salinity, and nutrient concentrations related to trophic levels) were also used to differentiate lakes (Stockner and Benson, 1967; Kemp, 1971; Hutchinson, 1973; Schneider, 1975; Pitblado et al., 1980; Chapra and Dobson, 1981; Håkanson and Jansson, 1983). Still other researchers identified differences in lakes on basis of biological characteristics such as macrophytes, plankton, macroinvertebrates, fish and so on (Rawson, 1956; Jensen and Van Der Maarel, 1980; Harvey, 1981; Tonn and Magnuson, 1982). Recently the multi-metric approaches combined with a variety of characteristics have been gaining favor among scientists.

In the process of lake classification based on consideration of multiple factors, selection of good biological indicators is critical. Benthic macroinvertebrates are important components of aquatic ecosystems, and they are often considered as good indicators of long-term changes in environments due to their confinement to the bottom, long life cycles and limited abilities of movement (Hart and Fuller, 1974; Liang and Wang, 1999; Timm and Mõls, 2012; Jiang et al., 2013). Macroinvertebrate quality indices to classify lakes have been developed from indicator values of a few selected species (Wiederholm, 1980; Lafont et al., 1991) and representative

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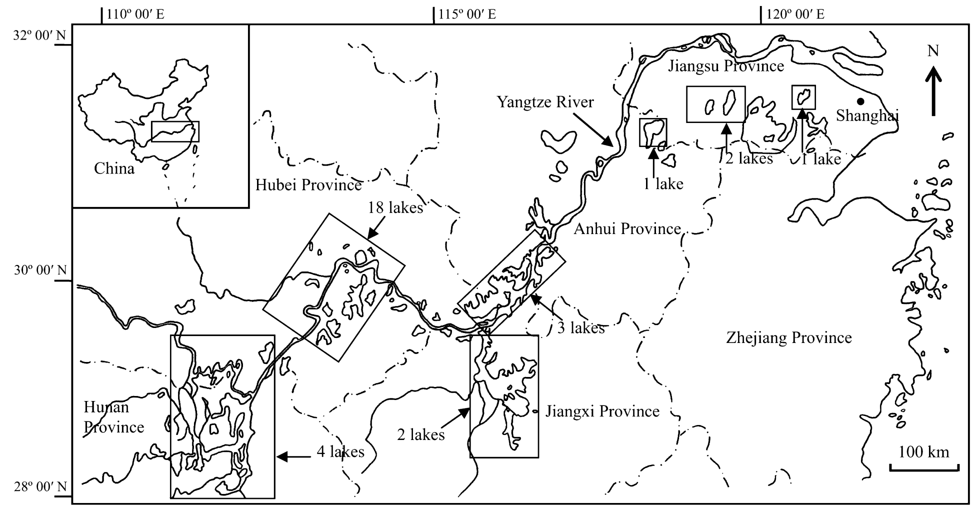

Fig. 1. Distribution of study lakes along the Yangtze River.

taxonomic groups such as chironomids and oligochaetes (Sæther, 1979; Lang, 1990) to species richness and abundance of the entire assemblage (Verneaux et al., 2004). Therefore, it's of significance to differentiate lakes using indication of macroinvertebrate assemblages in combination with other environmental variables.

In the Yangtze basin of China, belonging in the monsoon region of East Asia subtropical zone, floodplain lakes are numerous, with a total area over 16,600 km^2. Historically, most lakes were connected freely with the main river course of the Yangtze, where floods occur periodically. To prevent villages and cultivated lands along lakeshore from being flooded, embankments and sluice gates were constructed during the 1950s–1970s and eventually isolated most lakes from the river (Pan et al., 2011). Thus, some lakes freely connected with river mainstream can maintain natural ecological health, however, these river-disconnected lakes may lose water self-purification ability due to reduced hydrological connectivity degree, and they also have been facing the threat of eutrophication, so their service functions are severely damaged. In view of this, to conserve and manage the floodplain lakes, it's necessary to classify the lakes into several similar groups.

This paper deals with systematic limnological investigations in the Yangtze floodplain quarterly during 2004–2005. The purpose of this study is threefold: to differentiate Yangtze floodplain lakes based on macroinvertebrate assemblages and environmental variations; to analyze the potential factors structuring macroinvertebrate assemblages in the Yangtze floodplain lakes; to put forward some implications for lake conservation and management.

Study area and methods

All these 31 river-disconnected lakes are situated in the mid-lower Yangtze Basin, in other words, located in the monsoon region of East Asia subtropical zone. The locations of study lakes are given in Fig. 1.

Field investigations were quarterly conducted in April–May 2004 (spring), June–August 2004 (summer), September–November 2004 (autumn) and December 2004–Janurary 2005 (winter). Average values from the seasonal investigations were used for analyses. Water depth (Z) and Secchi depth (Z_{SD}) were measured with a sounding lead and a Secchi Disc, respectively. Water samples were taken near the surface and at the bottom, and combined for laboratory analyses. Total nitrogen (TN) was analyzed by the alkaline potassium persulfate digestion-UV spectrophotometric method. Total phosphorus (TP) was analyzed by the ammonium molybdate method. Phytoplankton chlorophyll a concentration (Chl a) was measured after acetone extractions by reading absorbance at 665 nm and 750 nm using spectrophotometer (Unico UV-2000, Shanghai, China). All variables were analyzed according to Standard Methods for the Examination of Water and Wastewater (2002). In the same habitat adjacent to benthic sampling site, macrophytes were sampled with a scythe (0.2 m^2), 2–4 times at each site, then cleaned, removed superfluous water and weighed for wet weight (B_{Mac}). Principal component analysis (PCA) was used to assess environmental differences between floodplain lakes.

Benthic animals dwelling in the sediment were taken with a weighted Petersen grab (0.0625 m^2) and then sieved with a 420-μm sieve. The collected animals were preserved in 10% formalin. Benthic animals were identified to the lowest feasible taxonomic level according to relevant references (Morse et al., 1994; Wiggins, 1996; Dudgeon, 1999; Wang, 2002; Zhou et al., 2003). Wet weight of animals was determined with an electronic balance after being blotted, and then dry mass (mollusks without shells) was calculated according to the ratios of dry-wet weight and tissue-shell weight reported by Yan and Liang (1999). In the study of Yan and Liang (1999), the data were collected from mid-lower Yangtze lakes, and mollusk samples were treated according to Banse and Mosher (1980) (the shells were removed and then shell and tissue were dried separately). All taxa were assigned to functional feeding groups (shredders, collector–gatherers, collector–filterers, scrapers, and predators) according to Morse et al. (1994) and Liang and Wang (1999). When a taxon had several possible feeding activities, its functional designations were equally proportioned, e.g. that if a taxon can be both collector–gatherer and scraper, the abundance of it is divided 50:50 into these groups. Two-way indicator species analysis (TWINSPAN) was performed to explore differences between macroinvertebrate assemblages in these floodplain lakes.

PC-ORD 4.0 (MjM Software Design, Gleneden Beach, Oregon) was used for two-way indicator species analysis (TWINSPAN), a divisive clustering method widely used to determine significant differences between assemblages (Hill, 1979). STATISTICA 8.0 (StatSoft, Inc., Tulsa, Oklahoma) was used for principal component analysis (PCA). CANOCO 4.53 (Microcomputer Power, Ithaca, New York) was used for detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA). DCA indicated that a normal model (gradient lengths >2.0 standard units) would best fit the data, and CCA was used to analyze the relation between animal assemblages and environments. In CCA, analyses of forward selection and Monte Carlo permutation test were used to yield important environmental factors influencing abundance and distribution of macroinvertebrates. Altogether 11 environmental