RESEARCH ON ECOSYSTEM HEALTH ASSESSMENT INDICES AND THRESHOLDS OF A LARGE YANGTZE-CONNECTED LAKE, POYANG LAKE

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Abstract. Assessing the aquatic ecosystem health status of lakes has been the focus of lake studies for domestic and overseas researchers and water resource managers. Poyang Lake, which is one of the only two remaining large Yangtze-connected lakes in the middle reaches of Yangtze River in China, provides considerable ecosystem service functions, such as flood water storage, water supply for industrial and agricultural production, maintenance of the unique and diverse biota of the entire Yangtze floodplain ecosystem, maintenance of regional ecological balance and so on. However, due to the impact of climate change and human activities, Poyang Lake has experienced drastic hydrological changes, water quality decline and aquatic ecological function degradation in recent years. An assessment of the aquatic ecosystem health of Poyang Lake is of great importance. On the basis of the index system construction principles and a meta-analysis of previous research, this paper puts forward the index system for the ecosystem health assessment of Poyang Lake. The indices contains the three element layers of aquatic organisms, hydrologic characteristics and trophic status and the five indicators of ratio of cyanobacteria biomass to diatom biomass (CB/DB), diversity index of macrozoobenthos, lowest water level anomaly during the dry season, mean water level anomaly during rising season and trophic state index (TLI). Then, the thresholds of indicators are determined using empirical study, frequency analysis, standard specification and so on. Aquatic ecosystem health status is categorised into three groups: 'good', 'moderate' and 'poor'. The study could provide theoretical basis for identifying the causes of the lake aquatic ecosystem health degeneration and protecting the environment of Poyang Lake. This present study provides an attempt to quantify the aquatic ecosystem health in a large floodplain lake with dramatic hydrological variations and will give some impetus for floodplain ecosystem assessment and management worldwide.
Keywords: *aquatic ecosystem health, physical-chemical-biological index, hydrologic indicators, ratio of cyanobacteria biomass to diatom biomass, thresholds, large Yangtze-connected lakes, Poyang Lake*

Introduction

The global ecosystem has become increasingly destroyed since the 1960s, and human society is facing immense challenges concerning survival and development (Zeng et al., 1999). Ecologists have begun to pay attention to the issue of ecosystem health. In 1988, Schaeffer proposed the concept of ecosystem health measurement (Schaeffer et al., 1988), and domestic and foreign scholars have since initiated substantial research on the concept of ecosystem health and related concerns (Costanza et al., 1992; Rapport and Whitford, 1999). Ecosystem health assessments are common in the research fields of forests, rivers, oceans, wetlands and so on (Cui and Yang, 2002; Borja and Dauer, 2008; Davies et al., 2011). Lakes, as a crucial part of the terrestrial

surface system, serve as vital freshwater reservoirs and help conserve species gene pools on earth; they are also known for their ecological functions, including maintaining ecological balance of basins, supplying production and living water, and providing rich aquatic products, and thus have great ecological and economic significance to regional development (Yang et al., 1988). Since the introduction of the ecosystem health concept in the 1980s, the health assessment of lake aquatic ecosystems, as a key part of lake ecosystem management, has gradually become the focus of scholars, resource managers and environment managers at home and abroad (Xu et al., 2001, 2012; Kane et al., 2009). Ecosystem health assessment provides the theoretical basis for analysing the causes of lake ecosystem health degradation and the protection of lake water environment, which is also closely linked with the achievement of the virtuous cycle of lake ecosystems.

Many scholars at home and abroad have performed studies regarding the construction of the assessment index system and the determination of thresholds because they are crucial in the health assessment of lake aquatic ecosystems. The selected assessment indices mainly include two aspects. The first aspect on biological components, e.g. biomass, species, diversity indices, etc. (Xu et al., 2001; Jeppesen et al., 2011; Umi et al., 2018); Phytoplankton and macrozoobenthos are commonly selected for ecosystem health assessment (Lyche-Solheim et al., 2013; Sreeja, 2018). Eutrophication responses are mainly evaluated on phytoplankton, macrozoobenthos and large aquatic plants, whilst pH response is mainly assessed by macrobenthos and fish (Solheim et al., 2008); Large aquatic plants (Mjelde et al., 2013; Keto et al., 2006), macrozoobenthos (Baumgärtner et al., 2008), and fish (Sutela and Vehanen, 2008)) have been used to describe responses to hydromorphological alterations. The second aspect represents the systematic indices, which are constructed from aquatic biological components, such as eco-exergy, structural eco-exergy, ecological buffer capacity, entropy, etc. (Ludovisi, 2006; Ludovisi and Poletti, 2003; Kane et al., 2009). The primary assessment approaches include the comprehensive health indices (Xu, 2005; Shuai and Li, 2014) generated by index system weighting or algorithmic derivation and the water quality model-based method (Xu et al., 2013; Zhang et al., 2010; Banerjee et al., 2017; Qi et al., 2018). Poyang Lake is one of the only two remaining large Yangtze-connected lakes in the middle reaches of Yangtze River in China. Its ecosystem development is affected not only by pollutants and sediments within the lake but also by seasonal hydrological fluctuations, particularly the annual amplitudes of water levels that reach 8 m (Zhao and Tong, 2013), which can significantly affect lake structures and functions (Coops et al., 2003). In recent years, Poyang Lake has also been affected by ecological and environmental issues related to human activities. Water quality has declined and eutrophication has gradually increased, and these phenomena resulted in ecological problems such as potential hazards of cyanobacterial bloom breakout (Yang, 2012; Cheng and Li, 2006; Xu et al., 2012; Li et al., 2017; Zhang et al., 2018). Therefore, constructing a lake aquatic health assessment index system suitable for the hydrological variation characterisation of Poyang Lake and large Yangtze-connected lakes, scientifically determining assessment indicator thresholds, and evaluating lake aquatic ecosystem health are of great theoretical and practical significance. On the basis of the analysis of the ecological system and evolution characteristics of Poyang Lake, this study combines observed and acquired data to construct a preliminary aquatic ecosystem health assessment index for large Yangtze-connected lakes. Then, the aquatic ecosystem health assessment thresholds are determined by adopting the special value

method, frequency analysis method, normative standards and analogies, reference mode method and so on.

Materials and methods

Study area and data

Physical, chemical and biological variables were measured in Poyang Lake from 1984 to 2013. Data from 2007 to 2013 were supplied by the Lake Poyang Laboratory for Wetland Ecosystem Research of the Chinese Ecosystem Research Network, whilst other less and reference data were collected from previous studies (Committee, 1993; Xie et al., 2000). Water level data from 1951 to 2011 were collected from the Changjiang (Yangtze River) Water Resources Commission. The details of these datasets are shown in *Table 1* and *Figure 1*.
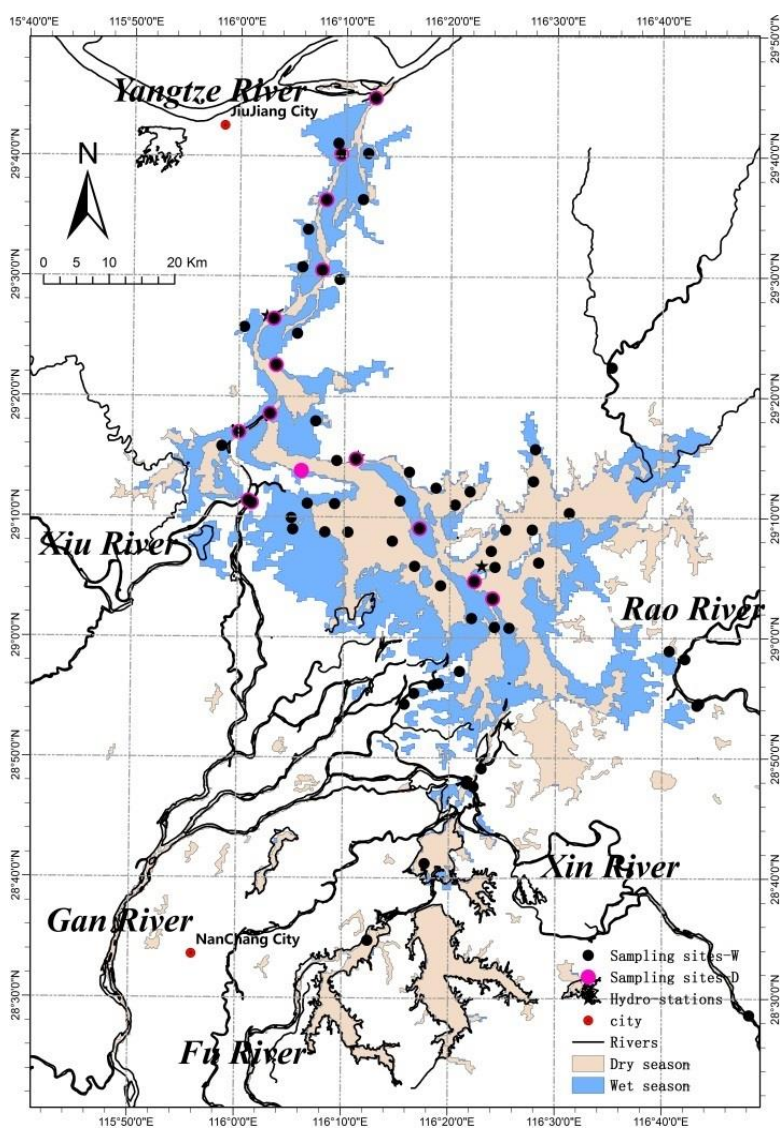
Figure 1. *Location and sampling sites of Poyang Lake*

Notes: Sampling sites-D: sampling sites in dry season, Sampling sites-W: sampling sites in wet season

Table 1. *Summary of variables and number of sites sampled in a given month and year in Poyang Lake*

Year	Month and sites	Data
1984, 1987–1993	Details shown in previous studies (Committee, 1993; Xie et al., 2000)	Biological variables (density of phytoplankton, etc.)
2007	October, 24 sites	Physical, chemical and biological variables (SD, TN, TP, COD_{mn}, Chl-a, biomass and density of phytoplankton, macrozoobenthic)
2008	June, 35 sites	
2009–2011	January, April, July and October, 15 sites	
2012	January, April and October, 15 sites July, 97 sites	Physical, chemical and biological variables (SD, TN, TP, COD_{mn}, Chl-a, biomass and density of phytoplankton, macrozoobenthic)
2013	July, 106 sites	
1951–2011	January–December, seven sites (Xingzi, Duchang, Hukou, Kangshan, Wucheng, Tangyin and Boyang)	Water level

SD: Secchi disk depth (water transparency); TN: total nitrogen; TP: total phosphorus; COD_{mn}: chemical oxygen demand; Chl-a: chlorophyll a

Methods

The construction of the aquatic ecosystem health assessment index system for in this study was mainly determined on the basis of literature research and theoretical analysis. The primary approaches for determining the index thresholds can be divided into two categories, namely, through statistical analysis approaches, such as the frequency analysis method and the special value method, direct observation of reference state and the adoption of normative standards. All statistical analyses were performed with the Statistical Program for Social Sciences (SPSS-IBM, New York, NY) 13.0 software.

Results and discussion

Construction of aquatic ecosystem health assessment index system for Poyang Lake

Many studies have demonstrated that the health status of lake aquatic ecosystems of water bodies should be assessed from the perspective of biological elements and supporting hydro-morphological and physico-chemical elements, especially water level-related indices (Mjelde et al., 2013), and not only on the basis of some specific biological, physical or chemical indices (Xie et al., 2013; Xu et al., 2013; Ghosh et al., 2018). Therefore, as a large-scale Yangtze-connected lake, the construction of an aquatic ecosystem health assessment index system for Poyang Lake must also consider the status of biological elements and supporting hydromorphological and physico-chemical elements.

1. Biological indicators

Lake ecosystems mainly include aquatic organisms such as planktons, benthic organisms, large aquatic plants and fish, etc. The indicators most widely used are biomass, quantity, species structure, and so on. On the basis of the response of various aquatic organisms to stress and the aquatic characteristics of Poyang Lake, phytoplankton and macrozoobenthos are selected to characterise the lake's aquatic ecosystem health.

(1) Phytoplankton: Phytoplankton is a critical indicator for the health assessment of lake aquatic ecosystems. Changes in algal species structure can reveal variations in the water environment (eutrophication, etc.) and lake ecosystems (Vanni, 1987; Paerl et al., 2013). The hydrological regime will affect the biomass, species composition, diversity and succession of phytoplankton (Wu and Guo, 2001). Lotic ecosystems are dominated by diatoms, whereas lentic ecosystems are dominated by cyanobacteria (De Emiliani, 2001). Relative to Taihu Lake, the phytoplankton characteristics in Poyang Lake are dominated by diatoms in the aspects of biomass and quantity, not cyanobacteria (Xu, 2013; Wu et al., 2013). But cyanobacteria bloom was also found at the centre part of the lake in 2011 (Xu, 2013). Dam construction in Poyang Lake has become controversial in recent years because of its adverse effects to water level fluctuations, and consequently, to the structure of phytoplankton (Liu et al., 2015). Many scholars have predicted the outbreak of cyanobacteria bloom after dam construction. Algal structural changes, particularly variation tendency in cyanobacteria proportion, are the primary focus of aquatic ecosystem health assessments for Poyang Lake. Constructing the ratio of cyanobacteria biomass (CB) to diatoms biomass (DB) can help determine the water environment of Poyang Lake and its aquatic ecosystem health characteristics.

(2) Macrozoobenthos: Macrozoobenthos are essential indicator organisms for monitoring human disturbance and lake pollution and thus ideal as natural monitors. The diversity index of macrozoobenthos has been widely adopted for the water pollution assessment of lakes and rivers (Shuai and Li, 2014; Xiong et al., 2003; Miler et al., 2013). The EU Water Framework Directive uses macrozoobenthos to monitor and evaluate the ecological health of lakes, as they are sensitive to water level amplitudes (i.e. water levels affect the abundance of macrozoobenthos) (Aroviita and Amalainen, 2008). The density of macrozoobenthos in Poyang Lake has drastically changed in recent years, as evidenced by the obvious decrease of molluscs (Cai et al., 2014), whilst the increased number of large animals have negatively affected the abundance of small marsh and long-horned snails (Ou et al., 2009). Large-scale sand mining and river scouring have also altered the macrozoobenthos habitat and influenced their community structures in recent years. Therefore, macrozoobenthos characterisation has been prioritised in the aquatic ecosystem assessment of Poyang Lake, and the diversity index of macrozoobenthos has been selected as the biological indicator.

Large aquatic plants and fish are also vital indicator species of aquatic ecosystem changes in Poyang Lake. However, large aquatic plants only appear in few branch areas of the lakes during the summer flooding season (Jian et al., 2015), and for the structure of fish species, there are certain similarities between Poyang Lake and Yangtze River Basin and the whole country (Hu, 2009). Hence, in this paper, we will not include large aquatic plant and fish species, considering their representativeness and substantial data availability.

2. Hydrological indicators

Habitat is commonly characterised on the basis of the following aspects: hydrology, water environment, lake morphology, and human activity or interference. The hydrological elements of Poyang Lake are relatively unique. For instance, water-level fluctuations are significant during the year, which greatly impact the lake's ecological environment. Subsequently, wetland area and distribution are directly affected, whilst the growth of aquatic organisms (e.g. phytoplankton and fish) are either directly or

indirectly affected. Therefore, hydrological element is selected as one of the habitat indicators for the aquatic ecosystem health assessment of Poyang Lake.

Previous studies have proposed that the indices for water level fluctuations include winter water level amplitude and spring flood amplitude (Hellsten, 2001; Keto et al., 2006, 2008; Mjelde et al., 2013), as they affect the species abundance of large aquatic plants (Keto et al., 2006), macrobenthos (Aroviita and Amalainen, 2006) and fish (Sutela and Vehanen, 2006). The communities of *carex–polygonum criopolitanum*, *carex–Phalaris arundinacea* and *Phalaris arundinacea–carex* in Poyang Lake are relatively sensitive to changes in water level conditions and largely affected by water level amplitudes (Zhang et al., 2012), and they have low tolerance to changes in hydrological conditions. The seasonal droughts in spring (rising season) and winter (dry season) over Poyang Lake in recent years have caused serious impacts on the wetlands and aquatic ecosystems of the lake (Yang, 2012). For instance, spring drought is disastrous to fish, as they lay eggs in large quantities due to the simulation of gonads by flowing water and aquatic plants. If the aquatic plants are exposed to non-water areas during April and May, fish reproduction will be seriously affected. The lowest water level during the dry season directly impacts the growth and distribution of wetland plants and the succession of vegetation belts, thus affecting the different ecosystem functions (e.g. wetland ecological function and migratory bird habitat function) of Poyang Lake (Hu et al., 2012). The lowest water level during the dry season will also influence the habitat of migratory birds, and its occurrence is averse to their protection (Qi and Zhang, 2014). Characterising the lowest water level in the spring drought and dry seasons of Poyang Lake is critical in evaluating the aquatic ecosystem health of the lake. Hence, the lowest water level anomalies during the dry season and the mean water level anomalies during the rising season are determined to characterise the lowest water level (dry season) and spring drought (rising season) of Poyang Lake.

Poyang Lake begins to recede in October and rise in April, as the flood season starts in June (Hu et al., 2007) whilst the dry season occurs from December to March the following year. The lowest water level anomaly during the dry season is expressed by the difference between the lowest water level of the dry season (December–March) and the mean value of the lowest water level of the dry season over multiple years. Meanwhile, the rising season anomaly is expressed by the difference between the mean water level of the rising season (April–May) and the mean of mean water level of the rising season over multiple years.

3. Water environment indicators

As discussed in the previous section (2. Hydrological indicators), water environment is one of the four elements of habitat, as its condition can directly impact the growth of aquatic organisms. Therefore, water environment is selected as another indicator of habitat. In the 1980s, Poyang Lake has entered the mesotrophic stage (Cheng and Li, 2006); at present, it is in light eutrophic stage (as reported by Environmental Bulletin in 2013). Water quality has gradually deteriorated because total nitrogen and total phosphorus have both exceeded the standard values. Eutrophication is one of the key issues of Poyang Lake and hence an important aspect of aquatic ecosystem health assessment. Here, the comprehensive nutrition state index (labelled as TLI) is selected as the indicator for the nutrition status in the aquatic ecosystem health assessment index of Poyang Lake.

In summary, the aquatic ecosystem health assessment index system of Poyang Lake is constructed from three perspectives, namely, aquatic organism elements, hydrological elements and water environment elements (*Table 2*).

Table 2. *Aquatic ecosystem assessment index of Poyang Lake*

Objective layer	Element layer	Index layer	Index explanation	Index calculation method	Determination method of index thresholds
Health assessment of Yangtze-connected lake ecosystems	Aquatic organism elements	Ratio of cyanobacteria biomass to diatom biomass (CB/DB)	Characterise the primary productivity status of lakes and ecosystem succession	Measure, calculate	Reference mode method, frequency analysis method
		Diversity index of macrozoobenthos (DI)	Characterise the features of macrozoobenthos and reveal the changes of ecosystem	$DI = \sum_{j=1}^{m} (N_i/N) \log(\frac{N_i}{N}, 2)$	Normative standards and analogies
	Hydrological elements	Lowest water level anomaly during dry season (LWLa-D)	Evaluate the characteristics of lowest water level during dry season	Difference between lowest water level in December–March and mean of lowest water level over multiple years during dry season	Special value method, frequency analysis method
		Mean water level anomaly during rising season (MWLa-R)	Evaluate the characteristics of water level during rainy season (spring drought or not)	Difference between mean water level in April–May and the mean of mean water level over multiple years during rising season	Special value method, frequency analysis method
	Water environment elements	Trophic state index (TLI)	Characterise the state of nutrition of lakes	Reference (Wang et al., 2002)	Normative standards and analogies

TLI: Trophic state index; CB/DB: Ratio of cyanobacteria biomass to diatom biomass; DI: Diversity index of macrozoobenthos; LWLa-D: Lowest water level anomaly during dry season; MWLa-R: Mean water level anomaly during rising season

Determining the aquatic ecosystem health assessment thresholds of Poyang Lake

The threshold proposed by Robert in the 1970s (May, 1997) refers to the set of thresholds and breakpoints of multiple stable states based on the characteristics and functions of the ecosystem. The methods to determine thresholds include normative standards and analogies, special value methods, statistical models, mathematical models, physical models, etc. The threshold determination methods for specific indicators are shown in *Table 2*.

1. Ratio of cyanobacteria biomass to diatom biomass

Few related researches on the indicator exist at present. In this study, health assessment thresholds are determined by performing the time reference mode method and the frequency method. *Figure 2* shows the CB/DB ratio from 1984 to 2013. The values have increased year by year, and the ratio in 2013 is larger than that in 2012. By taking the state of Poyang Lake in 1984 as the reference state of 'good' (maximum value 1.22, minimum value 0.004, average value 0.16, median value 0.04), and combined with the histogram of the CB/DB ratio in the past 30 years (*Fig. 3*), the thresholds are determined to be as follows: 'poor' (> 0.6), 'moderate' (0.4–0.6) and 'good' (< 0.4).
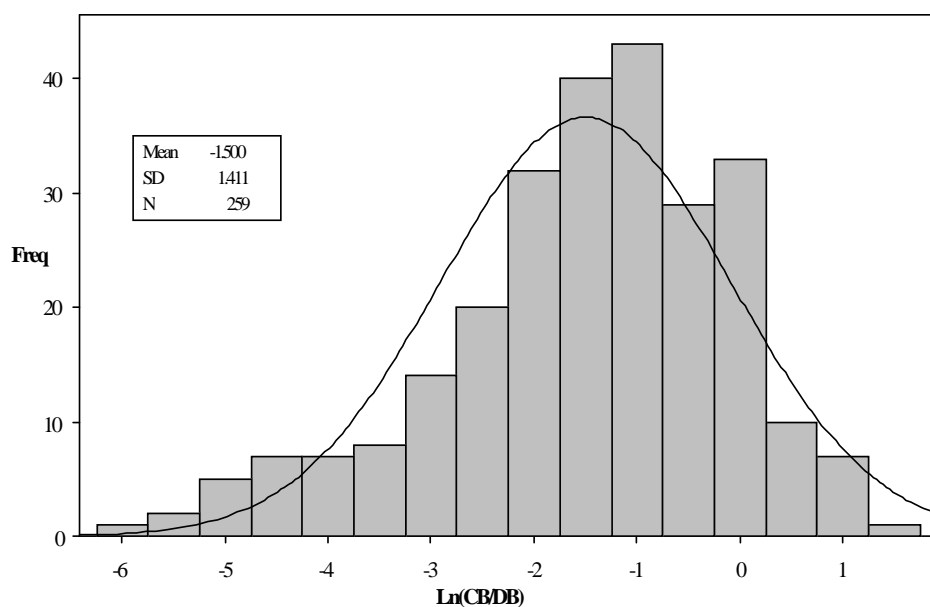
2. Diversity index of macrozoobenthos

The diversity index of macrozoobenthos has been widely used in water quality assessments (Lu, 1985; Lv et al., 2009; Miler et al., 2013; Xiong et al., 2003).

According to the Aquatic Biomonitoring Manual (State Environmental Protection Agency, 1993), the relationship between ecosystem health status and the macrozoobenthos Shannon diversity index can be divided into four pollution categories: H = 0 for 'severe pollution', 0 < H < 1 for 'heavy pollution', H = 1–2 for 'medium pollution' , H = 2–3 for 'light pollution' and H > 3 represents 'clean'. As shown in *Figure 4,* the diversity index of macrozoobenthos has a normal distribution, and the index with relatively high frequency is 0.8–2. The aquatic ecosystem health thresholds, which are determined on the basis of existing evaluation criteria and frequency methods, are as follows: 'poor' (0–1), 'moderate' (1–2) and 'good' (> 2).
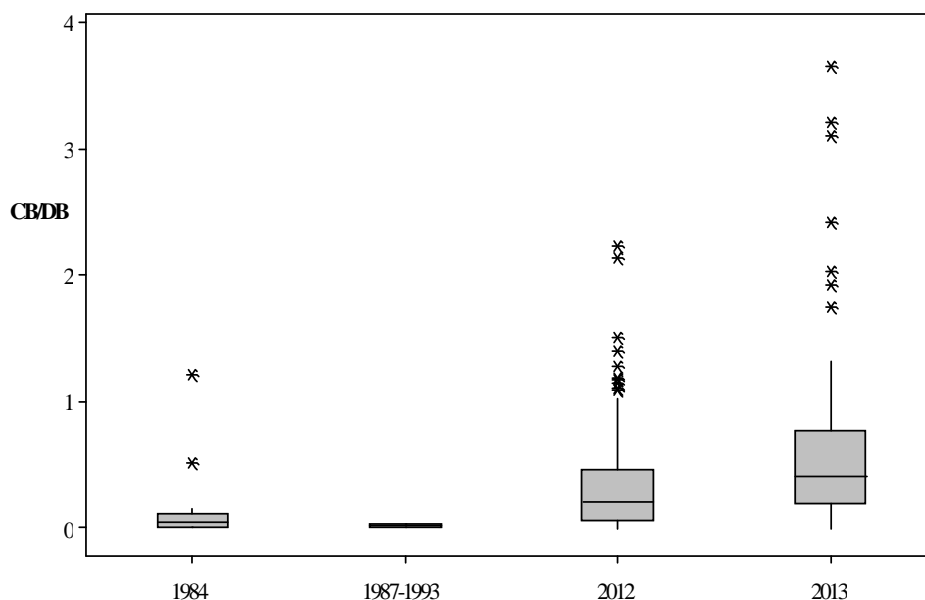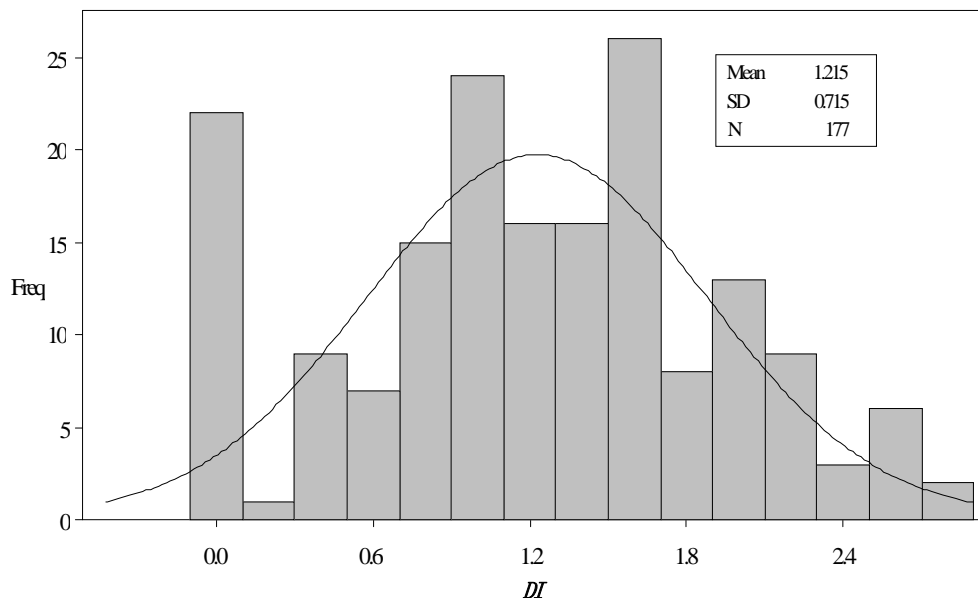

Figure 2. Box-plot of CB/DB ratios of Poyang Lake in the recent 30 years (some data from previous studies (Committee, 1993; Xie et al., 2000))

Figure 3. Histogram of CB/DB ratios of Poyang Lake in the recent 30 years

Figure 4. Histogram of diversity index of macrozoobenthos of Poyang Lake in 2012–2013

3. Lowest water level anomaly during the dry season

A statistical analysis of water level amplitudes during the dry season of Hukou, Xingzi, Duchang, Wucheng, Tangyin, Kangshan and Boyang stations for Poyang Lake from 1950 to 2011 was conducted. The amplitude variations of the seven stations are not significant, which is in accordance with the normal distribution. The average value is 0, the standard deviation is 0.7644 m, and the 5% and 95% tantiles are 1.34 m and −1.18 m, respectively (*Fig. 5*). In actual situations, the extremes of lowest water level during the dry season affect exposure time and area of wetlands. Exposure time directly affects the development of vegetation on the beach; it may be conducive to vegetative growth and may even result in the growth of new species of wetland ecological vegetation, but wetland degradation may occur if exposure time is too long (Ge et al., 2010). However, an extremely short exposure time over a small exposure area is unfavourable to the growth of wetland plants (Hu et al., 2010) and this will cause a series of ecological problems. Therefore, the extremes of lowest water level anomalies during the dry season signify an unhealthy state. In addition, the water level in Xingzi Station in 2008 was low with amplitude of −0.95 m during the dry season. The water levels in Duchang Station in 2008 and 2009 were low (e.g. 7.99 m in 2009, the lowest in history) with amplitudes of −1.49 m and −1.55 m during the dry season, respectively. In summary, the range of 1× standard deviation is determined to be from −0.5 to 0.5 m ('good'). The 5% and 95% tantiles (i.e. based on short plate effect, taking the minimum of absolute value) of 1× standard deviation is from 0.5 to 1.18 m and from −0.5 to −1.18 m ('moderate') and 'poor' if the value is less than −1.18 m or greater than 1.18 m, respectively.

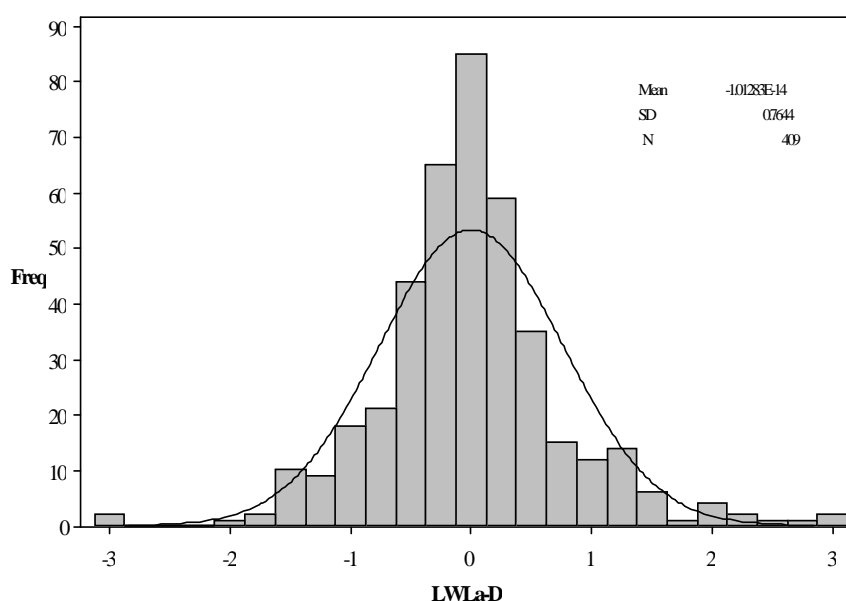### 4. Mean water level anomaly during the rising season

A statistical analysis on mean water level anomaly during the rising season of Xingzi, Duchang, Hukou, Kangshan, Tangyin, Wucheng and Boyang Stations was conducted. The findings, which accord with normal distribution, show a mean value

of 0.014 m and a standard deviation of 1.042 m (*Fig. 6*). The 5% and 95% tantiles are 1.80 m and −1.50 m, respectively. In actual situations, spring drought will affect fish breeding and wetland vegetation. The larger the MWLa-R is, the unhealthier the state will be. In the past 60 years, spring drought occurred five times since 2000, particularly in 2004, 2005, 2008, 2009 and 2011. The mean water level anomalies during the rising season in Xingzi Station for the abovementioned years are −1.44, −1.08, −1.53, −0.95 and −4.2 m. In Hukou Station, the corresponding anomalies are −1.35, −1.02, −1.34, −0.67 and −3.94 m. In Duchang Station, the corresponding values are −1.21, −0.80, −1.62, −1.15 and −3.24 m. In Wucheng Station, the corresponding values are −1.01, −1.25, −1.43, −1.12 and −3.73 m. In summary, the range of 1× standard deviation is determined to be from −1.03 to 1.06 m ('good'). The 5% and 95% tantiles (i.e. based on short plate effect, taking the minimum of absolute value) of 1× standard deviation is from 1.06 to 1.5 m and from −1.50 to −1.03 m ('moderate') and 'poor' if the value is less than −1.5 m or greater than 1.5 m, respectively.

5. Comprehensive nutrition state index

The comprehensive nutrition index is used to evaluate the nutritional status of water bodies, and it includes the five variables of Chl-a, TN, TP, COD$_{mn}$ and SD. According to the literature (Wang et al., 2002), a TLI of < 30 means 'oligotrophic', 30–50 means 'medium nutrition', and > 50 means 'eutrophication'. The thresholds are determined on the basis of the histogram of the comprehensive nutritional status of Poyang Lake in the past six years (*Fig. 7*). The thresholds can be determined as follows: 'poor' (> 50), 'moderate' (40–50) and 'good' (< 40).

In summary, the evaluation thresholds for the aquatic ecosystem health assessment index system of Poyang Lake can be divided into the following three levels: 'good', 'moderate' (sub-healthy) and 'poor' (*Table 3*).

Figure 5. *Histogram of lowest water level anomaly during dry season in Hukou, Xingzi, Duchang, Tangyin, Wucheng, Kangshan and Boyang Stations*
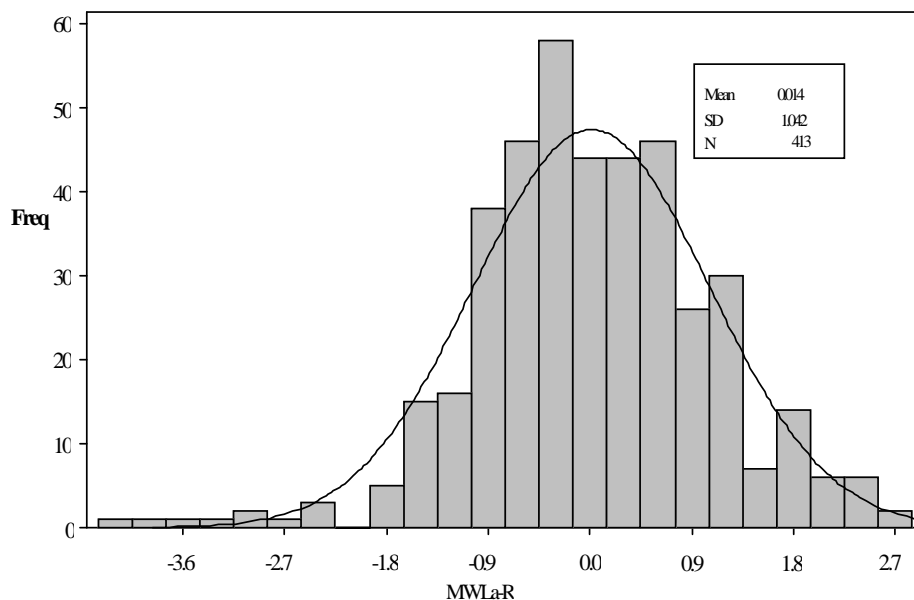
Figure 6. *Histogram of mean water level anomaly during rising season in Hukou, Xingzi, Duchang, Tangyin, Wucheng, Kangshan and Boyang Stations*
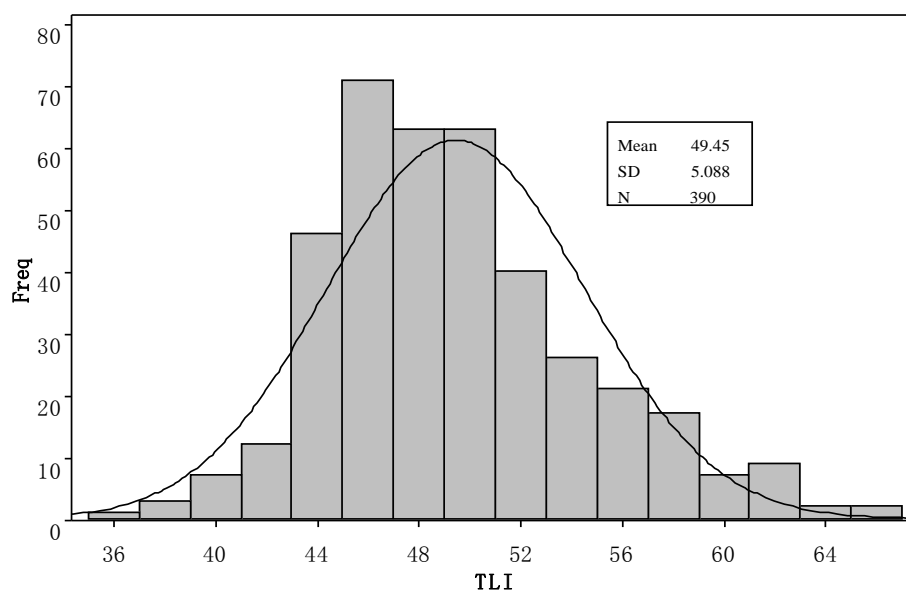
Figure 7. *Histogram of TLI of Poyang Lake in 2007–2012*

Table 3. *Threshold of indicators for Poyang Lake*

Indicators/health status	Good	Moderate (sub-healthy)	Poor
CB/DB	≤ 0.4	0.4 to 0.6	≥ 0.6
DI	≥ 2	1 to 2	0 to 1
LWLa-D (m)	-0.76 to 0.76	0.76 to 1.18, -0.76 to -1.18	$<-1.18, > 1.18$
MWLa-R (m)	-1.03 to 1.05	1.05 to 1.52, -1.50 to -1.03	$<-1.50, > 1.52$
TLI	≤ 40	40 to 50	≥ 50

Conclusions and prospects

The assessment index system for Poyang Lake presented in this paper comprises the following elements: CB/DB ratio and diversity index of macrozoobenthos for the aquatic organism index; lowest water level anomaly during the dry season and mean water level anomaly during the rising season; and the comprehensive nutrition state index with three habitat indicators. The frequency analysis method was conducted, normative standards and analogies were considered, and the special value method was performed to initially determine the thresholds for the health assessment of Poyang Lake's aquatic ecosystem. The three grades ('good', 'moderate' and 'poor') can help provide the research basis for further evaluating the aquatic ecosystem health of the large Yangtze-connected lakes, such as Poyang Lake.

This work is a preliminary study on the index system and the thresholds for the aquatic ecosystem health assessment of large-scale Yangtze-connected lakes. Thus, optimisation and adjustment are still needed. Only the indicators of phytoplankton, macrozoobenthos, and habitat (hydrology and water environment) were considered. In the future, ecological indicators (e.g. migratory fish) and thermodynamic oriented ecological indicators (e.g. ecological energy and structural ecological energy) shall also be covered. Considering that large proportions of fish in these lakes have similar ecological compositions, excluded; however, this approach may have affected the comprehensive assessment of aquatic ecosystem health of Poyang Lake in this study. Moreover, due to the hydrological rhythm ('ample flow, short water') in Poyang Lake, and large aquatic plants mainly appear in few branch area of the lake during the rising season, they are not easily accessible. That is to say, the related data are hardly got. Thus, this study did not consider aquatic plants for the time being, but future research will be conducted to improve this limitation. The indicators on hydrologic elements were determined on the basis of existing data, and further in-depth research and screening can be performed to construct more appropriate indicators. The thresholds of indices were determined on the basis of available data, but some of the important information, especially biological data, was limited. Having access to a wealth of information can help optimise this aspect of the research. In addition, the values of the indicators for Poyang Lake vary greatly with the seasons. Thus, this study only determined the mean threshold value. A further deepening of the research scope is needed for the large Yangtze-connected lakes, such as Poyang Lake, considering their obvious seasonal differences.

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