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Procedia Environmental Sciences 2 (2010) 349–358

Procedia
Environmental Sciences

International Society for Environmental Information Sciences 2010 Annual Conference (ISEIS)

Effects of Water Recharge on Ecosystem Health in Baiyangdian Lake, China

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Abstract

Water recharge has uncertainties in health state improvement for medium-sized lake though it possesses the advantage of quick response in nutrient deduction with low-nutrient water. The observed health states before and after water recharge in seven water areas of Baiyangdian Lake have been compared in order to find out the effects of water recharge on ecosystem health. An index system including phytoplankton biomass, zooplankton biomass, the ratio of macrozooplankton to microzooplankton biomass, trophic state index, eco-exergy and structural eco-exergy has been applied to health state characterization. The results show that Wangjiazhai water area, Nanliuzhuang water area and Zaolinzhuang water area acquire great improvement of ecosystem health following the water recharge. The health states in Duancun water area and Quantou water area have improved to some extent while health states change a little after the water recharge in Shaochedian water area and Caiputai water area. It is concluded that water recharge can realize health state improvement of most water areas in Baiyangdian Lake. The entrance of water recharge is considered as the key factor influencing the effects of water recharge in the medium-sized lake.

Key Words: water recharge; ecosystem health; effect assessment; Baiyangdian Lake; eco-exergy

1. Introduction

Lakes worldwide have encountered the threat of ecosystem health degradation, appearing abnormal state of severe eutrophication, surface area shrink and swampiness. Many approaches such as growing macrophytes for nutrient reduction[1]-[3]and biomanipulation[4]-[5]have been applied to lake ecosystem restoration in order to improve the water quality and organism habitats[6]. However, those methods usually show a slow response in health state improvement and are more suitable to realize partial rehabilitation within a small lake area. Water recharge, expressing a quick response in nutrient deduction when suitable dilution water is available[7], can not only reduce nutrient concentration but also restore hydrologic mechanisms, following the harmonious development of different biological components, which has been considered as an important method for lake restoration[8]-[10]. But since there are some uncertainties in water recharge for medium-sized lake restoration, such as the effects on the health state in

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doi:10.1016/j.proenv.2010.10.040

different water areas, assessing the variation of ecosystem health following water recharge in spatial scales is necessary to find out the restoration effects.

Index system method covering various ecological indicators is an effective way to characterize the health state variation of lake ecosystem[11], especially since Jørgensen applied eco-exergy and structural eco-exergy to measure ecosystem health[12][13], index system including thermodynamic indicators has been successfully used to describe the health state variation of lake ecosystem based on the consideration of ecosystem's integrity, complexity and hierarchy. Xu applied trophic state index, diversity index, eco-exergy, structural eco-exergy and phytoplankton buffer capacity to assess the health state variation of Chao Lake in different seasons[14]and then he successfully used eco-exergy, structural eco-exergy, the ratio of zooplankton to phytoplankton biomass, transparency in Secchi Disc depth to characterize the changes of health state after macrophytes rehabilitation project[15]. Hu et al. used a series of indicators covering biomass of phytoplankton, zooplankton, microzooplankton and macrozooplankton, the ratio of zooplankton to phytoplankton biomass and macrozooplankton to microzooplankton biomass, eco-exergy and structural eco-exergy to assess the health state variation of Qinghai Lake during the period of 1988 to 1989[16]. Lu et al. selected ecological indicators reflecting lake ecosystem structural and system-level aspects consisting of phytoplankton biomass, zooplankton biomass, eco-exergy and structural eco-exergy to make a comparison of the health state in West Lake between winter and summer[17]. Hu et al. and Xu et al. also applied similar index system to assess the spatial variations of health state for Tai Lake's fifteen lake regions in China[18]and 30 lakes in Italy[19], respectively. The previous case studies showed that index system covering thermodynamic indicators is a good candidate to measure the ecosystem development level and reflect the variation of health state under external influence. Specifically, Zhai et al. successfully applied a sequence of indicators including eco-exergy, structural eco-exergy, phytoplankton buffer capacity, the ratio of zooplankton biomass to phytoplankton biomass, diversity index and trophic state index to assess the ecological impacts of water transfers on Tai Lake[20], which further indicated that ecological indicators can better reflect the health state variation following the water recharge.

The purpose of the paper is to find out the restoration effects of water recharge by comparing indicators covering phytoplankton biomass, zooplankton biomass, the ratio of macrozooplankton to microzooplankton biomass, trophic state index, eco-exergy and structural eco-exergy for health state characterization of seven water areas in Baiyangdian Lake in order to provide a foundation for lake ecosystem restoration and management.

2. Materials and Methods

2.1. Study area

Baiyangdian Lake, with surface area of 366km^2 (medium-sized lake) and located in Anxin County, city of Baoding in Hebei Province, is a typical plant-dominated shallow freshwater lake divided into about 143 lake parks in North China. Due to the influences of natural and anthropogenic factors, water level has been decreasing year by year. According to statistics, during 1952 to 2002, Baiyangdian Lake even totally dried up for twenty years. At present, Baiyangdian Lake has only one inflow river (Fu River) taking large amount of pollutants from the city of Baoding. In addition, non-point source pollution from life of the residents, aquaculture and farmlands resulted from the villages within the lake caused excessive nutrient-rich pollutants directly discharging into the lake, which make Baiyangdian Lake seriously eutrophied, with severe negative effects in terms of the lake ecosystem health, sustainable development and management. In order to improve the health state of Baiyangdian Lake, during Sep 25th to Oct 15th, 2009, about 6000×10^4m^3 water recharges into the lake from Fu River. The expectations are to reduce nutrient concentration and regular biological component.

2.2. Data sources

The data for indicator calculation are acquired from field monitoring in Sep 23th and Oct 17th, 2009. Seven water areas are selected to compare the health state variation among different water areas following the water recharge. The distribution of seven water areas and their corresponding sampling sites are shown in Fig.1.

Physical and chemical indices including secchi disk depth (SD), chlorophyll-a (chla), total nitrogen (TN), total phosphorus (TP) and biological indices containing biomass of macrozooplankton, microzooplankton and detritus content are measured according to [21]. Phytoplankton biomass is converted from chlorophyll-a concentration by the equation proposed by [22].

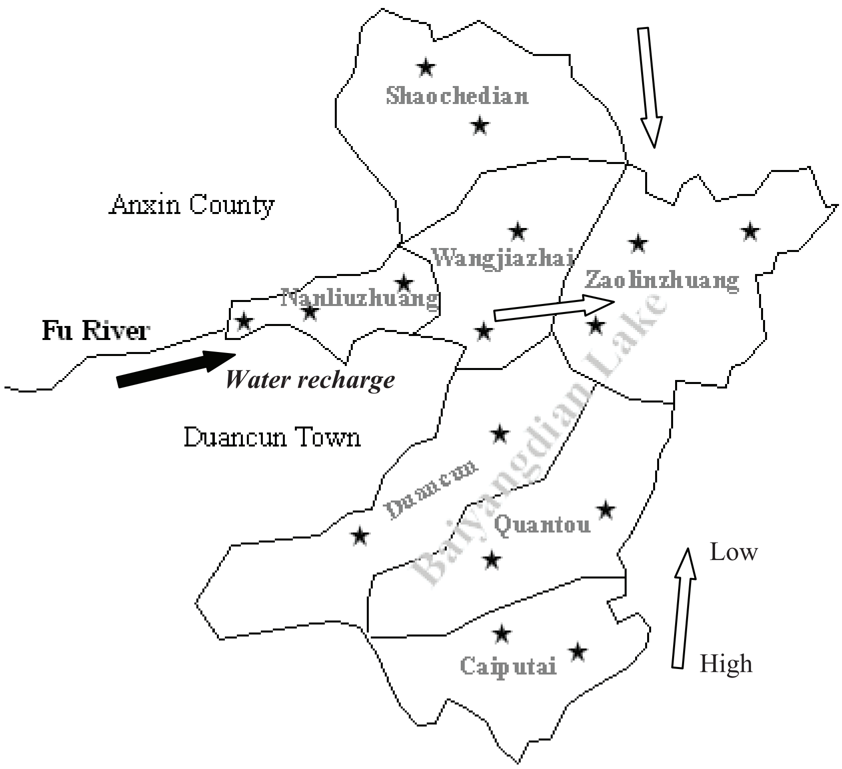

Fig. 1. The schematic diagram of distribution of seven water areas (Shaochedian; Wangjiazhai; Nanliuzhuang; Zaolinzhuang; Duancun; Quantou; Caiputai) and sampling sites (stars). The black arrow shows the entrance of water recharge and direction of white arrows expresses terrain changes from high to low.

2.3. Indicators for ecosystem health characterization

Phytoplankton biomass (BA), zooplankton biomass (BZ), the ratio of macrozooplankton to microzooplankton biomass (BZmac/BZmic), trophic state index (TSI), eco-exergy (Ex), structural eco-exergy (Ex_{st}) are selected for ecosystem health characterization of Baiyangdian Lake according to [14] and [23]. Chla, SD, TN and TP are chose to establish TSI based on the method of relation-weighting synthetic trophic state index[24][25]. Eco-exergy (Ex) is defined as the maximum amount of work a system can perform when it is brought to equilibrium with the surrounding environment[26]and can better express the development degree of an ecosystem[27].For eco-exergy calculation of an ecosystem, the chemical energy stored in biomass and the information embodied in genes are considered[28]and the general equation proposed in [12] and [13] is:

$$Ex = \sum_{i=1}^{n} \beta_i C_i \qquad (1)$$

where β_i is the weighting factor of the *i* th component and can be determined according to [29]; C_i is the biomass of the *i* th component or the concentration of the *i* th component; *n* is the total number of components selected. Phytoplankton, microzooplankton (protozoa and rotifera) and macrozooplankton have been selected for eco-exergy calculation and β values are 20, 39, 163 and 232, respectively.

Structural eco-exergy (Ex_{st}), defined as eco-exergy divided by the total biomass, characterizes the ability of an ecosystem to utilize available resources[30]and can be calculated by the following equation[12][13]:

$$Ex_{st} = \sum_{i=1}^{n} \beta_i C_i \Big/ C_t \qquad (2)$$

where C_t is the total biomass, which is the sum of all the C_i.

2.4. Method to determine the effects of water recharge on ecosystem health

According to [12] and [23], a healthy lake ecosystem should have relative high Ex, Ex_{st}, BZmac/BZmic and meanwhile possess relative low BA, BZ and TSI. If the water area has at least four indicators becoming better after water recharge, which means water recharge has influenced a lot on the ecosystem health of the water area, we mark this type of water area with "++"; if the water area has two or three indicators becoming better after water recharge, we mark this type of water area with "+"; If the water area has less than two indicators becoming better after water recharge, we mark this type of water area with "-" to express that water recharge has little or doesn't have influence on ecosystem health.

3. Results and Discussion

3.1. Spatial variations of health state following water recharge in Baiyangdian lake

TSI, Ex, Ex_{st} have been calculated based on the measured data. Spatial variations of the six indicators following water recharge are shown in Figs.2-7, respectively. The effects of water recharge on ecosystem health in seven water areas are expressed in Table 1.

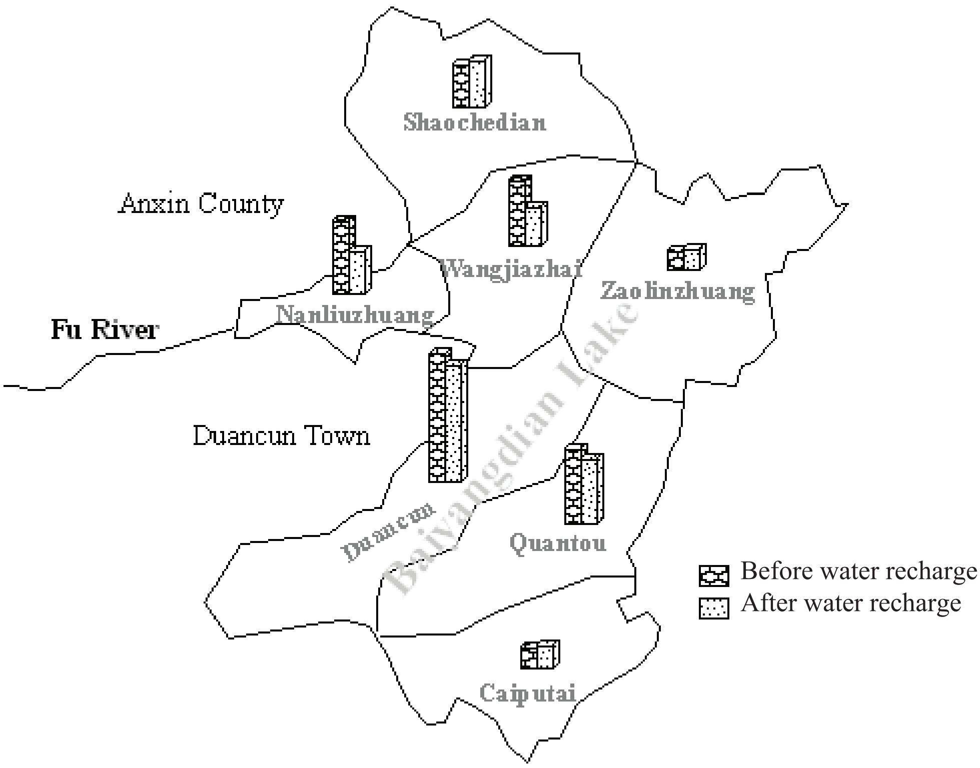

Fig. 2. Spatial variations of BA following water recharge in Baiyangdian Lake

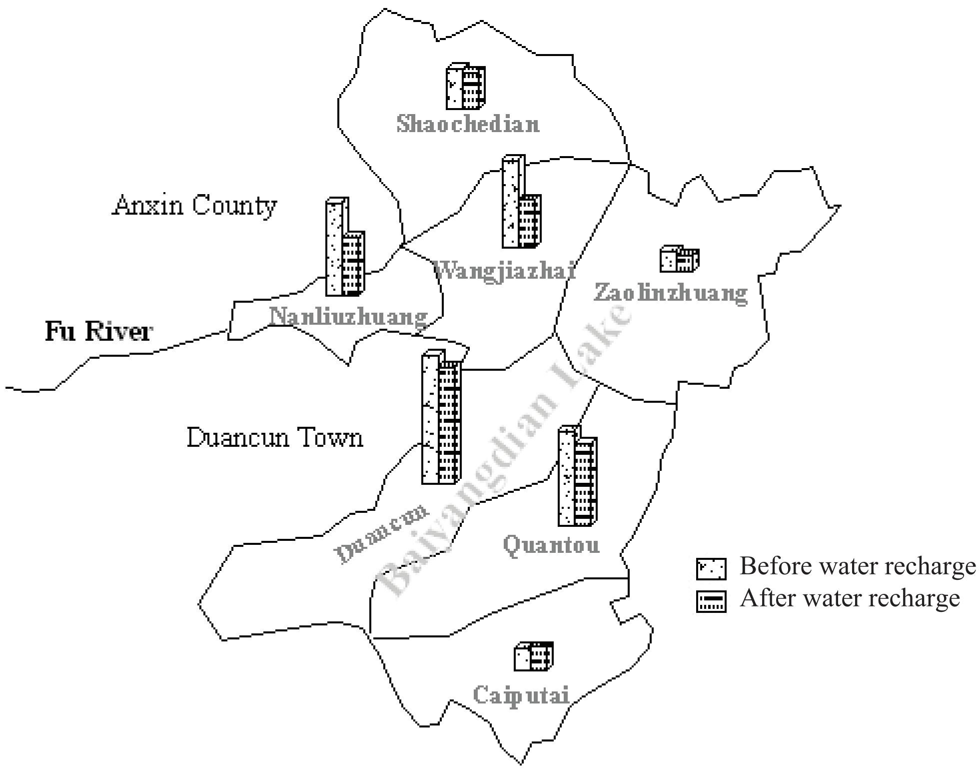

Fig. 3. Spatial variations of BZ following water recharge in Baiyangdian Lake

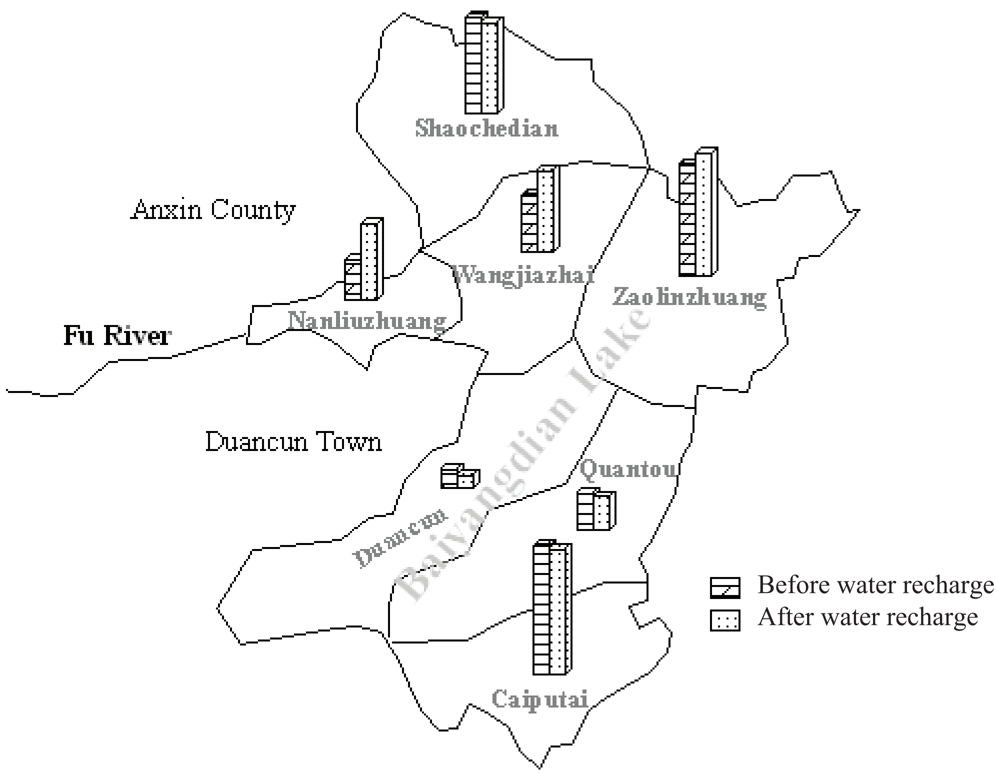

Fig. 4. Spatial variations of BZmac/BZmic following water recharge in Baiyangdian Lake

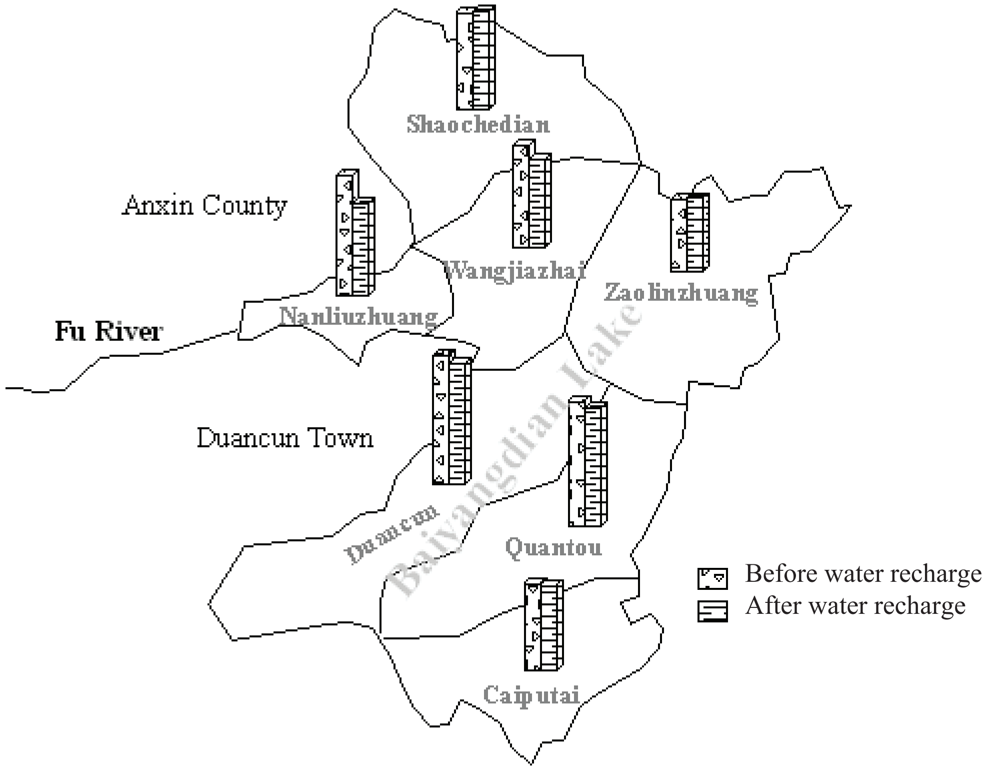

Fig. 5. Spatial variations of TSI following water recharge in Baiyangdian Lake

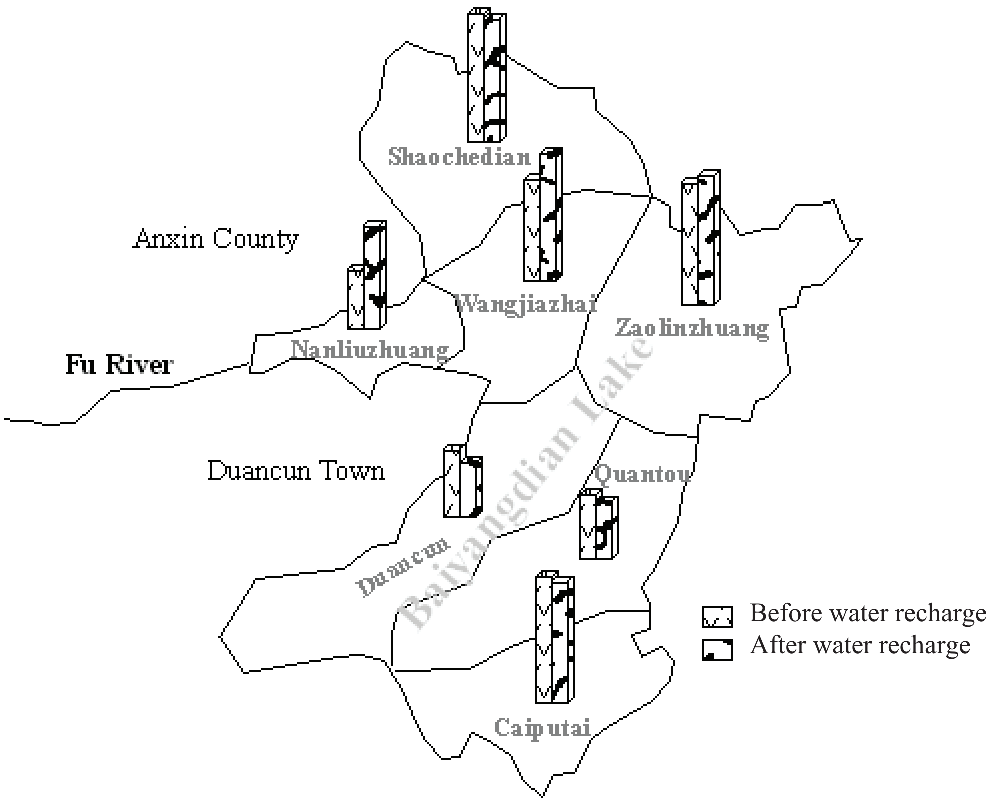

Fig. 6. Spatial variations of Ex following water recharge in Baiyangdian Lake

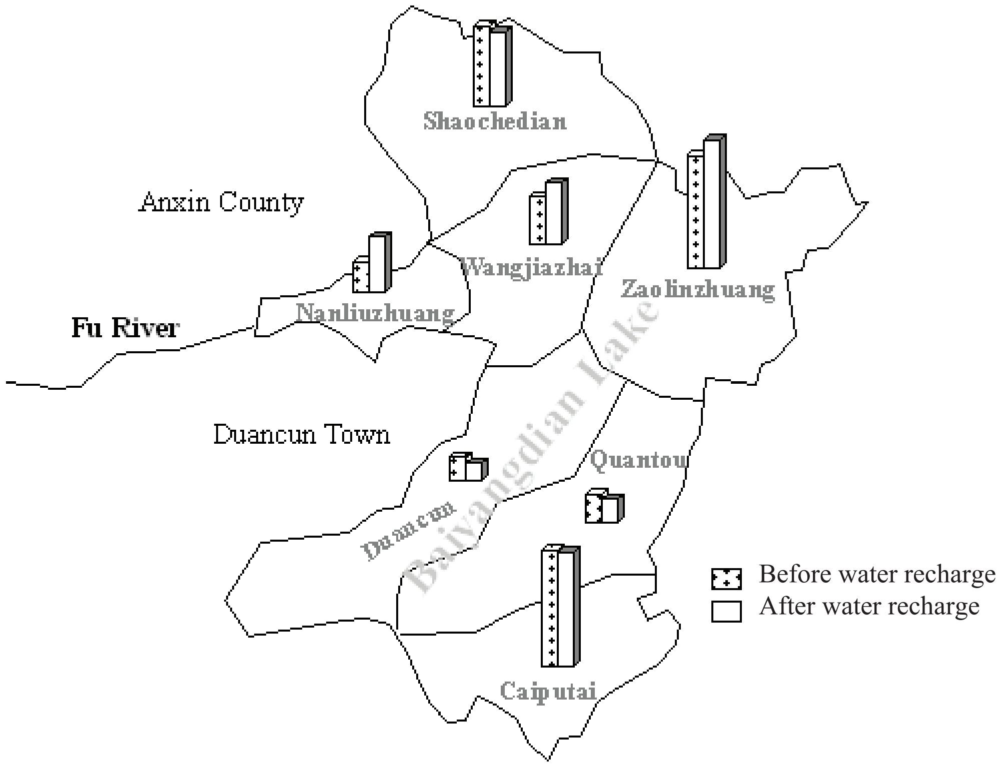

Fig. 7. Spatial variations of Ex_{st} following water recharge in Baiyangdian Lake

Table 1. The effects of water recharge on ecosystem health in seven water areas[1]

Water area	BA	BZ	BZmac/BZmic	TSI	Ex	Ex_{st}	Overall effect
Shaochedian	↑	↓	↓	↑	↓	↓	-
Wangjiazhai	↓	↓	↑	↓	↑	↑	++
Nanliuzhuang	↓	↓	↑	↓	↑	↑	++
Zaolinzhuang	↑	↓	↑	↑	↑	↑	++
Duancun	↓	↓	↓	↓	↓	↓	+
Quantou	↓	↓	↓	↓	↓	↓	+
Caiputai	↑	↑	↓	↓	↓	↓	-

[1] "↓" and "↑" express indicator value decreases or increases following the water recharge, respectively. The table cell with shadow represents the indicator with positive change after water recharge.

It could be seen from Figs. 2-7 and Table 1 that health states of seven water areas show various responses to the water recharge. For Shaochedian water area and Caiputai water area, indicators for ecosystem health characterization don't vary too much after the water recharge due to their higher terrain (only a little recharging water can reach these two water areas). BZ, BZmac/BZmic, Ex and Ex_{st} decrease a little while BA and TSI increase slightly in Shaochedian water area, which is mainly because a litter higher TSI leads to declining macrozooplankton biomass that makes great contributions to Ex and Ex_{st}. In Caiputai water area, though TSI show a little decrease, other indicators all become worse than that before water recharge, which primarily results from the relative quick and sensitive response of water quality indicator to water recharge in comparison with the indicators reflecting biological status. Duancun water area and Quantou water area express the same variation trend of the six indicators. Although BZmac/BZmic, Ex and Ex_{st} decline slightly and don't show positive changes following the water recharge, the reduced TSI, BA and BZ are also indications of health state improvement to a certain degree. Zaolinzhuang water area has relative low terrain to acquire enough recharging water but at the same time some pollutants can also reach this water area from the upper water areas, which causes TSI and BA show a little increase. Nevertheless, this condition can't influence a lot on the positive changes of other indicators after the water recharge. Under the influence of water recharge, both Wangjiazhai water area and Nanliuzhuang water area show remarkable deceasing BA, BZ, TSI and inceasing BZmac/BZmic, Ex, Ex_{st}, but their changes differ in degree due to the various distances from the entrance of water recharge.

Combining the above analysis, Wangjiazhai water area, Nanliuzhuang water area and Zaolinzhuang water area acquire great improvement of ecosystem health following the water recharge. The health state in Duancun water area and Quantou water area have improved to some extent while health state changes a little after the water recharge in Shaochedian water area and Caiputai water area.

3.2. Method to effect assessment

Comparison of the health state before and after the treatment is an common method to find out the effects of lake ecosystem restoration. Especially for short-term water recharge (such as the water recharge in Baiyangdian Lake we have studied), the effects can be observed quickly and both natural and anthropogenic factors such as water temperature, solar radiation, effluent discharge with a little changes can be considered to have less influence on the variation of indicators for health state characterization. However, if short-term water recharge is carried out during the period of seasonal change such as autumn to winter, these external factors need to be taken into account. That is because usually phytoplankton and zooplankton will decrease notably in winter, declining BA and BZ don't totally indicate health state improvement resulting from water recharge. For long-term water recharge, the external factors especially affecting organism growth should be considered in the effect assessment. In the case study of ecological impact assessment of water transfers on Tai Lake[20], when ecological indicators have been compared before and after water recharge, the relationship between environmental factors and ecological indicators are also analyzed by regression analysis in order to exclude the influences of natural and anthropogenic factors, which can provide a reference for similar case studies.

3.3. The effects of water recharge on ecosystem health in medium-sized lake

Results in this research indicate that water recharge can realize health state improvement of most water areas in Baiyangdian Lake (only Shaochedian water area and Caiputai water area have not acquire health state improvement). The entrance of water recharge is considered as the key factor influencing on the effects of water recharge in Baiyangdian Lake. Water recharges from the Nanliuzhuang water area, resulting in notable health state improvement in this water area and health state in the water areas where recharging water can't reach will change a little. In general, acquiring the health state improvement of all the water areas from water recharge is more difficult in this type of medium-sized lake than in small lake. Adjusting the entrance of water recharge such as arranging not only one entrance can be tried to resolve this problem.

4. Conclusions

The effects of water recharge on ecosystem health of seven water areas in Baiyangdian Lake have been successfully assessed by comparing the indicators including phytoplankton biomass, zooplankton biomass, the ratio of macrozooplankton to microzooplankton biomass, trophic state index, eco-exergy and structural eco-exergy. The results reveal that health state improvement can be acquired following water recharge in most water areas of Baiyangdian Lake, especially in Wangjiazhai water area and Nanliuzhuang water area near to the entrance of water recharge. Comparison of the indicators for health state characterization directly can be considered as a suitable method for effect assessment of short-term water recharge conducted without during the period of seasonal change.

For medium-sized lake, water recharge can still acquire better effects in health state improvement, although it is not an easy thing to obtain health state improvement of all the water areas with one entrance of water recharge.

Acknowledgements

The special thanks are to the National Natural Science Foundation of China (Grant No. 50979006 and Grant No. 50939001) and Key Research Program on Water Pollution Control and Remediation, P.R. China (Grant No. 2008ZX07209-009) for the financial support.

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