

# Eutrophication Control by Physical-Ecological Engineering At the Mouth of the Maixi River in Baihua Reservoir

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# Abstract

From June 2009 to August 2011, an integrated physical and ecological engineering experiment (PEE) for ecological remediation was conducted in the Maixi river estuary in Baihua Reservoir. An experiment site (EXP) inside, and a reference site (REF) outside, the engineering enclosure were selected. Total nitrogen (TN), total phosphorus (TP), Chlorophyll-*a* (Chl-*a*), and chemical oxygen demand (COD) at EXP were significantly lower than at REF; and the greatest differences were 1.00 mg/L, 0.04 mg/L, 23.06  $\mu$ g/L, and 8.40 mg/L, respectively. Transparency at EXP was dramatically higher than at REF. The trophic index state (TSI) was between oligotrophic and mesotrophic at EXP, between mesotrophic and eutrophic at REF. Phytoplankton abundance in June 2011 was 2100×10<sup>4</sup> cells/L at REF, but lower at EXP with 33×10<sup>4</sup> cells/L. Cyanobacteria dominated phytoplankton biomass at both sites, but a higher proportion of diatoms and dinoflagellates was found at EXP. Rotifers were the main estuarine zooplankton. Copepod abundance was significantly different among the sites (*p*<0.01), with greater abundance at EXP. In general, eutrophication was controlled by the PEE, which could be adjusted to improve water quality.

**Keywords:** Physical-ecological engineering; Eutrophication; Phytoplankton; Metazoan zooplankton; Baihua Reservoir

# Introduction

Many lakes and reservoirs in developed, and developing, countries have serious eutrophication problems, and eutrophication has been a serious global environmental and ecological problem since the 1970s [1,2]. There are several aspects to consider when determining the causes of eutrophication [2]. Nitrogen and phosphorus sometimes lead to algal blooms, especially in semi-enclosed areas [3]. Toxic cyanobacteria directly affect drinking water safety in cities and towns, and seriously affect the structure and function of aquatic ecosystems once bloom occurred [4]. In general, estuaries have relatively high number of nonpoint and point sources of pollution, and are the last barrier preventing exogenous pollution of reservoirs [5,6].

After decades of development, scholars have developed a general idea "reduction in number of sources-pollution control-contamination interception-ecological restoration." To control algal blooms, projects in Japan (Terauchi Dam) [7,8] and Germany [9] were undertaken in order to control eutrophication. Ecological engineering programs offer simple, cheap, and energy-efficient wastewater and eutrophic water treatment methods; and thus, are widely used [10-18]. Ecological engineering systems accomplish remediation and pollutant removal, require only space and no equipment, are easy to use and affordable to maintain, and are environmentally friendly [19,20]. However, water quality improvement and ecological restoration engineering measures are different for estuaries as opposed to shallow lakes and other water bodies. At Taihu Lake in China, a single method could not curb eutrophication [21], so a variety of technologies were needed [22]. Recently, there has been an interest in application of floating bed systems to protect vulnerable rivers and reservoirs [19,23], as such physico-ecological engineering methods, integrated with other such methods, are particularly practical.

Baihua Reservoir, located on the Yunnan-Guizhou Plateau in southwest China, had spatially and temporally uneven distribution of water resources in typical karstic topography. There were more than 2000 hydropower reservoirs in Guizhou, designed to regulate water resources. Most reservoirs were 10-100 m deep, and water pollution was the main eutrophication cause. However, to date, most eutrophication studies have focused on either temperate lakes or tropical/subtropical reservoirs, with their being only a limited study of deep karstic reservoirs [24].

Baihua Reservoir, a deep karstic reservoir, was the subject of our study. We applied ecological floating bed technology, water division technology, Zoo benthos increase-expanding technology, artificial medium technology, at the mouth of Maixi River in this reservoir. The study objective was to evaluate integrated physical-ecological engineering effects on ecological remediation and enrich our technical knowledge on improvement of plateau reservoir water quality by analysis of the change in water quality phytoplankton and zooplankton community structure over the two year experiment.

# **Materials and Methods**

# Study area

Baihua Reservoir is located downstream of Hongfeng Reservoir, and both are situated within the catchment of Maotiao River, a branch of the Wujiang tributary to the Changjiang (Yangtze) River in China [25]. The catchment geology consists of carbonate rocks of the karstic Yunnan-Guizhou Plateau. Baihua Reservoir acts as a second cascade of the Maotiao River hydropower station, and is an important drinking water supply for Guiyang City. One of four main tributaries to Baihua Reservoir, the Maixi River, flows through the town of Zhuchang, where

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sewage and industrial wastewater are discharged into the river. These anthropogenic inputs disrupt natural functions, dramatically changing the river and estuary hydrodynamics. The Maixi River trophic state index (TSI) was mid-eutrophication, and algal blooms occurred at the mouth [26,27]. Two sampling sites were established inside and outside the engineering enclosure. Site 1 was the reference location (REF) and Site 2 was the experimental location (EXP) (Figure 1).

#### **Physical-ecological Engineering**

An integrated physical-ecological engineering (PEE) experiment was performed at the Maixi River mouth from June 2009 to Augest 2011. The engineering area was a rectangle  $\sim$ 3200 m<sup>2</sup> and the water depth was  $\sim$ 4-8 m. To save on materials, 80 m of the river bank was used as one side of the engineering area. High-density, glue-soaked polyamide fiber cloth was used to trilaterally divide the water into  $\sim$ 40 m,  $\sim$ 80 m, and  $\sim$ 40 m long areas, respectively (Figure 1). Floating beds, artificial medium, aquatic plants, zoobenthos, and other items were added.

#### Sampling and Experimental Methods

Surface water samples were collected monthly, at 0.5 m depth, at the REF and EXP sites from June 2009 to August 2011. Secchi disk depth (SD) was measured in situ. Water samples were collected in polypropylene bottles and immediately analyzed in the laboratory for physical and chemical variables. Total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD) were measured according to standard methods of the State Environmental Protection Administration of China (GB3838-2002). Filters for chlorophyll a (Chl-a) were extracted for 24 h in a 90% acetone solution after being frozen and thawed repeatedly [28], and the Chl-a concentration was determined spectrophotometrically.

Phytoplankton and zooplankton samples were fixed with the concentration of Formalin (3%, buffered, etc.), and species identification and enumeration was carried out using an Olympus microscope. At least 300 specimens (cells, colonies, and filaments) were enumerated in each sample volume [29]. Species-specific biovolume was estimated by multiplying abundance with the mean individual cell volume of each species. Wet weight biomass was based on a geometric approximation, assuming a specific density of phytoplankton cells of 1 g/cm<sup>3</sup> [30,31], and calculated from abundance and species-specific



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biovolume estimates. Zooplankton samples were further concentrated by removing excess water with a pipette covered by plankton netting. Animals were enumerated and identified using  $60-160 \times$  magnification in a 2 mL volume counting chamber.

Page 2 of 7

#### **Data Analyses and Statistics**

Statistical analyses were performed using SPSS18.0 software. Analysis of variance (ANOVA) was used to test for significant differences between the EXP and the REF data, using probability level p<0.05. A corrected Carlson's TSI was used [32]. TSI was calculated according to the following formula.

TS (Chl.a) =10\*(2.46+(ln(Chl.a)/ln2.5)); TSI (SD)=10 \* (2.46+(-1.349 \* ln(SD) + 1.912)/ln(2.5));

$$\label{eq:transform} \begin{split} &TSI\ (TN) = 10\ *\ (2.46 + (0.972*ln(TN) + 1.597)/ln(2.5));\ TSI\ (TP) = 10 \\ *\ (2.46 + (0.654*ln(TP) + 3.497)/ln(2.5)). \end{split}$$

# **Results and Discussion**

#### **Physical and Chemical Variables**

All the variables, except COD, were significantly different after the PEE was applied (p<0.01, n=12). Secchi disk depth varied seasonally, but peaked during January and February; SD of EXP was 1.5 m deeper than REF (Figure 2A). Chlorophyll *a* varied seasonally, with peaks during July and September. In July 2011, Chl-*a* at REF was 23.06 µg/L, much higher than EXP (Figure 2B). Total phosphorus varied seasonally, with peaks during January and February; TP at REF was more than 0.12 mg/L higher than EXP (Figure 2C). Total nitrogen varied seasonally, with the peak during January and February; TN was much lower at EXP than at REF (Figure 2D). COD varied at REF from 6.65 to 36.66 mg/L, and at EXP from 4.63 to 23.95 mg/L (Figure 2E).

The TSI at REF ranged between 38.85 and 54.99 and peaked in July 2009 (Figure 2F). At REF, TSI was eutrophication and mideutrophication, but was oligotrophication and mesotrophication at EXP; especially in July and August 2011, when TSI was 20 points lower at EXP. Elemental N:P ratios in the estuarine study area were generally >16:1 during the experiment, indicating that Maixi River was P-limited following Redfield's ratio.

#### Phytoplankton

Cyanobacteria, chlorophyta, and bacillariophyta were important phytoplankton based upon species number. After the PEE was applied at June 2009, thirty one phytoplankton taxa were identified at REF and forty three taxa at EXP. More bacillariophyta and chlorophyta were found at EXP. *Dinobryon divergens* was found at EXP, but not at REF. Dominant algal species were *Pseudanabaena limnetica* in summer, and *Synedra ulna* in winter, while *Limnothrix* sp. was always co-dominant. At the beginning of the PEE area, *Pseudanabaena limnetica* was the dominant algal species at EXP. Bacillariophyta were the dominant algal group for a much longer period at EXP than that at REF. Cyanobacteria were the dominant algal group at REF, but cyanobacteria, bacillariophyta, pyrrophyta, and euglenophyta comprised the phytoplankton community.

Phytoplankton biomass varied from 0.01 to 4.74 mg/L at REF, and from 0.002 to 0.973 mg/L at EXP. The lowest phytoplankton biomass was at EXP in May 2011, and the maximum was at REF in June 2011. At the beginning of the PEE, there was no difference in phytoplankton biomass between REF and EXP, and the biomass trend was consistent. In summer 2011 (6-8 months), phytoplankton biomass



rapidly increased at REF, but remained low at EXP (Figure 3). After the PEE was operating a year, phytoplankton community structure changed greatly. At REF, cyanobacteria were dominant in biomass, but bacillariophyta and pyrrophyta dominated biomass at EXP (Figure 4).

# Zooplankton

**Zooplankton species composition:** As shown in Table 1, rotifers were the main metazoan zooplankton during from June 2009 to August 2011 at the Maixi river estuary in Baihua Reservoir. Dominant species were *Keratella cochlearis, Brachionus calyciflorus, Brachionus diversicornis, Asplanchna priodonta Gosse*, and *Polyarthra* 

*vulgaris. Bosmina longirostris* was relatively numerous at EXP, as was *Bosminopsis deitersi Richard* at REF.

**Zooplankton abundance:** Copepod abundance range was 0.63-121.95 ind./L at EXP, and 0.99-42.62 ind./L at REF. Figure 5A shows maximum copepod abundance occurred in November 2010 and August 2011 at EXP. Copepods were more abundant at EXP and significant differences in abundance were found between the sites (p 01, n=14).

Rotifer abundance range was 3.30-258.58 ind./L at EXP and 1.72-1309.75 ind./L at REF, but there was no significant difference in abundance between sites (p>0.05, n=14). Figure 5B shows the maximum

J Environ Anal Toxicol ISSN: 2161-0525 JEAT, an open access journal

Page 3 of 7

#### Page 4 of 7

rotifer abundance was in November 2010, and *Asplanchna priodonta* Gosse was the dominant species. Minimum rotifer abundance was in June 2011 at REF.

Cladoceran abundance range was 0-9.24 ind./L at EXP, and 0 - 24.8 ind./L at REF. Figure 5C shows the maximum cladoceran abundance occurred in November 2010 at REF, and in October 2010 at EXP. No significant difference in cladoceran abundance between REF and EXP was found (p>0.05, n=14).





Species	EXP	REF	Species	EXP	REF
Copepoda			Brachionus calycifloru	++	++
Nauplii	++	++	Brachionus angularis	+	+
Mesocyclops thermocyclopoides	+	+	Brachionus caudatus	+	+
Copepodites	+	+	Brachionus diversicornis	++	++
Harpacticella sp.	+	+	Brachionus quadridentatus	+	+
Cladocera			Brachionus forficula	+	+
Bosmina longirostris	++	+	Trichocerca pusilla	+	+
Bosminopsis deitersi	+	++	Richocerca stylata	+	+
Alonella exigua	+	+	Trichocerca capucina	+	+
Diaphanosoma brachyurum	+	+	Trichocerca cylindrica	+	+
Pleuroxus aduncus	+	+	Asplachna priodonta	++	++
Moina micrura	+	+	Polyarthra vulgaris	++	+
Daphnia pulex Leydig	+	+	Conochilus dossuarius	+	+
Daphnia cucullata	+	+	Lecane luna	+	+
Diaphanosoma orghidani	+	+	Lecane bulla	+	+
Rotifera			Filinia longisela	+	+
Keratella cochlearis	+	++	Hexartra mira	+	-
Keratella tropica	+	+	Gastropus hyptopus	-	+
Filinia sp.	+	+			

1. Note: - absent, + present, ++ abundant

 Table 1: Composite list of metazoan zooplankton at the Maixi River Estuary in the Baihua Reservoir.

Percent Composition of Zooplankton: Rotifers, copepods, and cladocerans were the primary metazoan zooplankton found in the Maixi River estuary. At EXP, the percent composition of copepods ranged from 10.85-94.91%, rotifers ranged from 5.10-86.84%, and cladocerans ranged from 0-5.93%. At REF, the percent composition of copepods ranged from 3.10-89.21%, rotifers ranged from 5.04-93.90%, and cladocerans ranged from 0-5.76%. Metazoan zooplankton abundance was not significantly different between June and December 2010 at the beginning of engineering, but it was significantly different in 2011. Percent composition of copepods exceeded rotifers and cladocerans at EXP and REF. As to metazoan zooplankton abundance with PEE, the percent abundance of copepods and cladocerans increased, but rotifers decreased. The percentage of copepods and cladocerans was greater at EXP than REF. Rotifers became less important and copepods increased. A stable metazoan zooplankton community structure reflected better water quality (Figure 6).

# Relationships between Zooplankton Abundance, TSI, and Phytoplankton Abundance

There was a strong negative correlation between copepod abundance and TSI ( $R^{2}$ =-0.581, p<0.01, n=28) (Figure 7A), but no significant correlation with TSI in both cladoceran abundance ( $R^{2}$ =0.290, p>0.05, n=28) and rotifer abundance ( $R^{2}$ =0.079, p>0.05, n=28) (Figures 7B and 7C). A strong negative correlation between copepod abundance and total phosphorus was found ( $R^{2}$ =-0.747, p>0.01, n=28), and a positive correlation was found with cladoceran abundance and transparency ( $R^{2}$ =0.618, p>0.05, n=28) and cladoceran abundance and nitrate nitrogen ( $R^{2}$ =0.570, p>0.05, n=28).

# Discussion

Ecological floating bed technology was a kind of biological treatment widely used to improve eutrophic water [21-23]. Pollutant absorption by floating plant roots was an important way of purifying contaminated water. Roots and rhizome holes (aerenchyma) provide good adsorption conversion interfaces and microorganism habitat

### Page 5 of 7



[19]. Plant roots increased in conjunction with microorganism species number and abundance, effectively improving eutrophic water and making ecological restoration of water possible by harvesting floating plant beds [20,21]. There is competition for mineral nutrients between aquatic plants and algae. On the other hand, aquatic plants release allelochemicals (secondary metabolites from the growth process) that could effectively promote, or inhibit, algal growth [33]. Artificial medium with more surface area, and volume as biological carrier, could efficiently enrich indigenous aquatic microorganisms using microbial nitrification and denitrification to remove dissolved nitrogen and phosphorus. Microbial degradation could remove organic pollutants in water, and improve water quality. The use of artificial medium in eutrophic water enriched microorganisms that removed algae from the water [34,35]. Zoobenthos were able to eliminate suspended substances in water, rapidly causing flocculation to agglomerate and subside. Zoobenthos intake and excretion of suspended solids varied with temperature and time, feeding less at high temperature. The zoobenthos metabolism was more robust in summer, therefore removing more pollutants in water. Zoobenthos were significant for ecosystem stability, promoting circulation of materials and improving water quality [36,37]. After the engineering, the beneficial reduction in phosphorus caused copepods to increase. The proportion of copepods increased and rotifers decreased, which might reflect better water quality. From the correlation between zooplankton and TSI, change in copepod abundance better reflected water quality conditions and trophic state, while change in rotifer and cladoceran abundance could not discern the eutrophication level. Zooplankton community structure and the relationship between environmental factors indicated water quality improved after the engineering, and eutrophication was restrained.

# Conclusion

Aquatic plants, zoobenthos and artificial medium could reduce the nutrient concentration in water and effectively inhibit algal growth, especially cyanobacteria, improving water quality, and therefore achieving good experimental effect. By using EFBT, WDT, ZBT, and



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140 А 120 Copepods abundance(ind./L -5.1839x + 275.88 100  $R^2 = 0.3382$ n=28, p<0.01 80 60 40 20 0 40 45 50 35 55 Trophic state index(TSI) 30 В Cladocera abundance(ind./L) 25 y = -0.3812x + 20.8 $R^2 = 0.0844$ 20 n=28,p=0.131 15 10 5 0 35 40 45 50 55 Trophic state index(TSI) С 1400 = -4.7746x + 344.89 $R^2 = 0.0062$ n=28,p=0.690 200 0 35 40 45 50 55 Trophic state index(TSI) Figure 7: Correlation between zooplankton abundance and TSI.

AMT in the PEE area, diatom abundance increased and cyanobacterial growth was inhibited. Integration of physical and ecological technologies proved beneficial to Guizhou Plateau Baihua Reservoir water quality and results validate the use of PEE. Algal blooms were controlled and the trend toward eutrophication was restrained.

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Page 6 of 7

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Page 7 of 7

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